NORTHERN LANCASTER COUNTY GROUNDWATER STUDY: A RESOURCE EVALUATION OF THE MANHEIM–LITITZ AND EPHRATA AREA GROUNDWATER BASINS

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SUSQUEHANNA RIVER BASIN COMMISSION

Paul O. Swartz, Executive Director

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to coordinate the planning, conservation, management, utilization, development and control of basin water resources among the public and private sectors.

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ACKNOWLEDGMENTS

The authors acknowledge those who made significant contributions to the completion of this project. Local municipal representatives and citizens of the Water Budget Advisory Committee (WBAC) who live in the study area provided guidance and recognized the need for managing the resource. Matt Kofroth, Lancaster County Conservation District, provided helpful insight and leadership on the WBAC. Kelly Gutshall, LandStudies, Inc., provided insight into the local issues and tied together local initiatives, plans, ordinances, and municipal input into recommendations and management strategies. Additional thanks go to the Pennsylvania Department of Environmental Protection (PADEP), which provided funding for this project, and Jineen Boyle, PADEP's project advisor, who provided helpful comments and assistance.

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EXECUTIVE SUMMARY

Achieving a balance among environmental, human, and economic needs in the management of the basin's water resources is a critical mission of the Susquehanna River Basin Commission (Commission), as described in the 1971 Susquehanna River Basin Compact (Compact). The Commission carries out its water resource management responsibilities in a number of ways through its regulatory program, public education and information, and resource evaluation. In areas of intense water resource utilization, the Commission may conduct special studies, water budget analyses, and identify critical aquifer recharge areas (CARAs).

The Commission, in partnership with the Lancaster County Conservation District (LCCD), performed a groundwater resources evaluation of a carbonate valley located in northern Lancaster County, Pennsylvania. The project was funded by the Pennsylvania Department of Environmental Protection (PADEP) through its Growing Greener Grant Program. The study area includes an isolated carbonate aquifer of 50 square miles and a surrounding siliciclastic contributing area of 20 square miles. Parts of 13 municipalities, including the Boroughs of Manheim, Lititz, Akron, Ephrata, and Denver, are located in the study area.

Groundwater is the primary source of water for municipal, domestic, industrial, and agricultural uses. As groundwater withdrawals increase to meet growing demands, stakeholders need information on the location and quantity of water resources available, and how to best develop, conserve, and protect them. Removal of groundwater resources faster than the sustainable rate could lead to a growing water deficit, the gradual failure of water supplies, diminishing stream and spring flows, and degraded aquatic and riparian habitat.

Project participants involved the local public during the course of the study through a Water Budget Advisory Committee (WBAC) and educational workshops. Important resource areas are identified, and management recommendations for these areas are provided in this report.

The study area has experienced rapid growth. From 1990 to 2000, several municipalities in the study area exceeded Lancaster County's growth rate of 11.3 percent. Warwick Township, located in the Manheim–Lititz groundwater basin, experienced the highest growth rate of 33.2 percent. Anticipated growth and development in the study area are expected to result in increased water demand. Population projections from 2000 through 2025 represent a 26 percent increase.

Historic changes in land use have led to increased impervious areas, increased stormwater runoff, and reduced infiltration. Impervious cover was 9 percent of the 70-square-mile study area. This potentially reduces average annual recharge by 1,575 million gallons in the study area. When one considers the carbonate areas of the Manheim-Lititz and Ephrata area groundwater basins, 12.6 percent and 8 percent of these areas are impervious, respectively.

The focus of the study is a valley approximately 50 square miles in area, underlain by a highly productive carbonate aquifer, and herein informally termed the “carbonate valley.” The carbonate valley is surrounded almost entirely by hills underlain by aquifers of much lower permeability (Figure 2). The carbonate valley includes parts of the Chiques Creek, Cocalico Creek, and Lititz Run watersheds. Streams generally flow from north to south across the study area, with the exception of the largest stream, Cocalico Creek, which flows from northeast to southwest.

The study area includes parts of 8 townships and 5 boroughs, and had a population of approximately 61,000 in the year 2000. Water supply needs are met almost entirely by groundwater. The valley was once largely agricultural, but is rapidly changing to a mosaic of urban, suburban, and agricultural areas. The population in the carbonate valley is rapidly growing, as is the need for water. However, the amount of water available is limited. Most of the groundwater is derived from the carbonate aquifer that underlies the valley.

The presence of sinkholes, abundant closed depressions, large springs, and lack of streams in many areas suggests that dissolution of the carbonate bedrock, a condition known as karst, has substantially enhanced the ability of the aquifer to store and transmit water. Karst aquifers are known for their abundant water resources and extremely high well yields, as well as their hard water, enigmatic flow patterns, sinkholes, and high susceptibility to contamination.

Findings

From June 2003 to June 2005, the Commission evaluated the groundwater resources to address water quantity issues in a 70-square-mile area underlying parts of Chiques Creek, Cocalico Creek, and Lititz Run watersheds. Normal annual precipitation was 43.5 inches, of which 14.4 inches was estimated to be groundwater recharge.

Two groundwater basins were delineated (Figure 10) based on water table mapping, and two sets of water level measurements were made during this study.

The Manheim-Lititz groundwater basin is 21.8 square miles and contains the upper Lititz Run watershed and part of Chiques Creek watershed. The groundwater basin is in the area westward from Manheim to within a few thousand feet of the Cocalico Creek water gap, and includes parts of Rapho, Penn, Warwick, and Elizabeth Townships, and the Boroughs of Manheim and Lititz. Groundwater level measurements taken during the study indicate a water table that gradually declines from 400 to 340 feet in elevation.

East of the Manheim-Lititz groundwater basin, the water table rapidly falls 40 to 60 feet. This area is called the Ephrata area groundwater basin, and has a water table graded to the lower reaches of Cocalico Creek, where it crosses the Cocalico Formation through the Cocalico Creek water gap at an elevation of approximately 300 feet. The 48.4-square-mile Ephrata area groundwater basin contains parts of Elizabeth, Warwick, Clay, Ephrata, West Cocalico, and East Cocalico Townships, and parts of Akron, Ephrata, and Denver Boroughs within the Cocalico Creek drainage area.

The annual recharge for each groundwater basin, for the 2-, 10-, and 25-year recurrence intervals, was based on previous regional studies that employed extensive base flow separations, water table mapping, and groundwater modeling. The annual recharge of the Manheim-Lititz groundwater basin, for the 2-, 10-, and 25-year recurrence intervals, was estimated to be 5,822 million gallons, 3,531 million gallons, and 2,449 million gallons, respectively. The annual recharge of the Ephrata area groundwater basin, for the 2-, 10-, and 25-year recurrence intervals, was estimated to be 11,676 million gallons, 7,077 million gallons, and 4,917 million gallons, respectively.

Annual Recharge in Million Gallons for the Study Area and Groundwater Basins

	1-in-2	**1-in-10**	**1-in-25**	**Area (sqmi)**
Manheim-Lititz	5,822	3,531	2,449	21.8
Ephrata Area	11,676	7,077	4,917	48.4
Study Area	17,498	10,608	7,366	70.2

The Commission uses the 1-in-10-year recharge as the sustainable limit of groundwater development. This limit attempts to balance the amount of groundwater available for development, instream flow needs, and required reservoir or tank storage capacity. This would suggest a maximum sustainable limit for groundwater withdrawals of 3,531 million gallons per year (mgy) for the Manheim-Lititz basin and 7,077 mgy for the Ephrata area basin. However, passby flows can place further restrictions on availability.

The Commission, in coordination with the Commonwealth of Pennsylvania, requires that regulated withdrawals negatively impacting streamflows must cease or streamflows be augmented when the flow in a stream classified as a warm water fishery falls below 20 percent of the average daily flow. Discharge of an equal amount of wastewater immediately upgradient or adjacent to the impacted stream reach would largely mitigate this impact.

Groundwater withdrawals in the Ephrata area groundwater basin have not exceeded 10 percent of the lowest flow for 7 consecutive days in 10 years (Q7-10) for Cocalico Creek as it leaves the carbonate valley (Figure 12). However, most of the existing groundwater withdrawals are located in the southern half of the basin, and are compensated for by the discharge from the Ephrata area wastewater treatment plant. However, future withdrawals could trigger the passby requirement in one of the subbasins. This can be avoided by locating wells in downstream areas where the Q7-10 flow is higher.

Streamflows in the study area will be below 20 percent of their average daily flow approximately 30 days per year. Groundwater withdrawals in the Manheim-Lititz groundwater basin have exceeded the Q7-10 for the surface water flow (combined flow from Chiques Creek and Lititz Run) as it leaves the carbonate valley (Figure 13). However, most of the existing groundwater withdrawals are located in the southern half of the basin, and are compensated for by the discharge from the Manheim and Lititz wastewater treatment plants. Future withdrawals located in the northern half of the basin could trigger the passby requirement. The passby requirement can be avoided by locating wells in downstream areas where the Q7-10 flow is higher.

Existing conditions

Groundwater withdrawals were evaluated to determine the total amount of water currently approved for withdrawal (i.e., allocated withdrawals) and the portion of such allocations currently being withdrawn to meet present demands (i.e., existing withdrawals). The total allocated groundwater withdrawals in each basin includes both existing withdrawal amounts plus approved but unused amounts. Existing (actual, current) water withdrawals, plus currently allocated but unused quantities, were identified and totaled for each groundwater basin. These total allocated groundwater withdrawals were compared to the Commission's criterion for allocated withdrawals in potentially stressed areas (PSAs), which is 50 percent of the 1-in-10-year recharge.

Actual, current (year 2000) withdrawals for the Manheim-Lititz groundwater basin, the Ephrata area groundwater basin, and the entire study area do not exceed 50 percent of the 1-in-10-year recharge.

Allocated and Existing (Current Year 2000) Groundwater Withdrawals and Comparison to the 1-in-10-Year Recharge

	Allocated Withdrawal (mgy)	**Existing Withdrawal (mgy)**	**Percent Allocated to the 1-in-10**	**Percent Existing to the 1-in-10**
Manheim-Lititz	2,478	1,493	70	42
Ephrata Area	2,418	1,497	34	21
Study Area	4,896	2,990	46	28

The total groundwater withdrawal in the Ephrata area groundwater basin of 1,497 mgy is approximately equal to that of the Manheim-Lititz groundwater basin (1,493 mgy). However, the area of the Manheim-Lititz groundwater basin (21.8 square miles) is less than half the area of the Ephrata area groundwater basin (48.4 square miles) that results in a groundwater yield of approximately 188,000 gallons per day (gpd) per square mile versus 85,000 gpd per square mile, respectively. The size of a groundwater basin (recharge catchment area) relative to the volume of total withdrawals is an important consideration in determining groundwater sustainability in a given area.

For the entire study area, allocated groundwater withdrawals were 46 percent of the 1-in-10-year recharge. For the Manheim-Lititz groundwater basin, allocated groundwater withdrawals were 70 percent of the 1-in-10-year recharge, which exceeds the Commission's PSA standard. Allocated groundwater withdrawals from the Ephrata area groundwater basin are 34 percent of the 1-in-10-year recharge.

Projected conditions

Groundwater withdrawal for the study area has been projected for 2010 and 2025. The water demand projection is based on census data showing a population of 61,085 in 2000 and a per-capita water use of 116 gpd. Using data provided by Lancaster County Planning Commission, the projected population in 2010 and 2025 will be 67,400 and 76,905, respectively. Utilization in 2010 (3,753 mgy) is estimated to be 35 percent of the 1-in-10-year recharge and 51 percent of the 1-in-25-year recharge. Utilization in 2025 (4,337 mgy) is estimated to be 41 percent of the 1-in-10-year recharge and 59 percent of the 1-in-25-year recharge.

Existing and Projected Total Use and Percent Utilization of 1-in-10 and 1-in-25-Year Recharge for the Study Area

Study Area	2000	2010	2025
Total Population	61,085	67,400	76,905
Total Use mgy*	3,382*	3,753	4,337
Percent Utilization of 1-in-10	28	35	41
Percent Utilization of 1-in-25	41	51	59

*Includes surface withdrawals at Ephrata and Denver.

For the Ephrata area groundwater basin, water use in 2010 (2,070 mgy) is estimated to be 29 percent of the 1-in-10-year recharge and 42 percent of the 1-in-25-year recharge. Water use in 2025 (2,357 mgy) is estimated to be 33 percent of the 1-in-10-year recharge and 48 percent of the 1-in-25-year recharge. The projected population in 2010 and 2025 will be 41,329 and 47,174, respectively.

Existing and Projected Total Use and Percent Utilization of 1-in-10 and 1-in-25-Year Recharge for the Ephrata Area Groundwater Basin

Ephrata Area	2000	2010	2025
Total Population	37,449	41,329	47,174
Total Use mgy*	1,889	2,070	2,357
Percent Utilization of 1-in-10	27	29	33
Percent Utilization of 1-in-25	38	42	48

*Includes surface withdrawals at Ephrata and Denver.

The projected population in the Manheim-Lititz groundwater basin in 2010 and 2025 will be 26,071 and 29,732, respectively. Water use in 2010 (1,677 mgy) is estimated to be 47 percent of the 1-in-10-year recharge and 68 percent of the 1-in-25-year recharge. Water use in 2025 (2,007 mgy) is estimated to be 57 percent of the 1-in-10-year recharge and 82 percent of the 1-in-25-year recharge.

Existing and Projected Total Use and Percent Utilization of 1-in-10 and 1-in-25-Year Recharge for the Manheim-Lititz Groundwater Basin

Manheim-Lititz Area	2000	2010	2025
Total Population	23,636	26,071	29,732
Total Use mgy	1,493	1,677	2,007
Percent Utilization of 1-in-10	42	47	57
Percent Utilization of 1-in-25	61	68	82

The existing allocations for groundwater withdrawal are sufficient to meet these projected demands, assuming that the new demand is located on the systems with existing excess capacity or can be served through interconnections with water systems that have excess capacity.

Recommendations

The Commission developed a series of recommendations to address water resource problems in the study area, after consideration of the following: (1) a review of existing ordinances and regulations that impact water resources; (2) a review of related plans and water resource initiatives; (3) community input on issues and concerns through the WBAC and at a June 2004, workshop; and (4) the findings of this study. The *Water Resource Management Recommendations* section provides a detailed explanation of the issues, problems, and recommendations and description of the existing management tools available to the Commission, PADEP, and municipalities.

The recommendations address four major issues. Recommendations 1 through 5 address overall reduction of infiltration and groundwater recharge. Recommendations 6 and 7 address excess withdrawal of groundwater in PSAs. Recommendations 8 through 11 address overall increase in water use, and recommendation 12 addresses consistency among municipal ordinances.

1. ***Problem:*** *Loss of critical aquifer recharge areas (CARAs) from future growth and development is a concern.*

   Recommendation: Municipalities should maintain or enhance the unique hydraulic characteristics of CARAs to maximize the amount of groundwater available for utilization within a groundwater basin. Mapping of these important water resource areas provides information that municipal governments can use to make informed decisions on planning for future growth (Plate 1).

2. ***Problem:*** *Increased areas of impervious cover will reduce the potential for recharge.*

   Recommendation: Municipalities should encourage developers to reduce the effect of impervious cover by implementing technologies that increase the infiltration capability of that cover. Developers should consider using designs such as porous pavement in areas where natural recharge rates are higher than other land areas. Where the infiltration capability of the land cover cannot be increased, such as rooftops, the stormwater runoff can be directed to other areas and enhance groundwater recharge through distributed infiltration best management practices.

3. ***Problem:*** *Floodplain systems that were once areas of natural recharge are now filled with fine sediment and less permeable, thereby reducing recharge.*

   Recommendation: Municipalities should consider floodplain restoration in a limited number of areas that historically contained meandering stream channels, thereby improving groundwater recharge along those reaches.

4. ***Problem:*** *Lack of stormwater plans in the study areas misses opportunities to address infiltration and recharge of stormwater runoff.*

   Recommendation*:* County and local governments should complete Act 167 stormwater management plans for the remaining areas. They also should implement the PADEP's new comprehensive stormwater policy, which promotes the use of distributed infiltration best management practices to increase groundwater recharge.

5. ***Problem:*** *Certain carbonate areas, such as those identified as karst modified uplands, may not be suitable for on-site stormwater management best management practices.*

   Recommendation: County and local governments should consider distribution of stormwater runoff to regional stormwater management facilities in restored floodplains and CARAs. They also should explore transfer of stormwater requirements to receiving areas (i.e., CARAs or stormwater management facilities) for the expansion of development rights in sending areas (i.e., areas in a development that would normally be set aside for stormwater best management practices).

6. ***Problem:*** *Water use in the Manheim-Lititz and Ephrata area groundwater basins is 70 percent and 34 percent, respectively, of the sustainable limit.*

   Recommendation: The Commission should continue to require groundwater availability analyses for new water withdrawal projects and detailed water budgets in PSAs.

   Regional and local planning agencies should evaluate the impacts of different post build-out scenarios on recharge and water demand.

7. ***Problem:*** *Intensive groundwater withdrawals in localized areas will diminish groundwater yields, base flows, and perennial streamflow.*

   Recommendation: Project sponsors applying for new or increased withdrawals should utilize groundwater models in localized areas to evaluate the withdrawal impact and address sustainability. For localized areas where the sustainable yields have been exceeded, new wells should not be installed and additional withdrawals should be discouraged.

   Since existing allocations for groundwater withdrawal are sufficient to meet projected demands, the Commission should encourage municipalities and water authorities to consider addressing new demand with systems with existing excess capacity or through interconnections with water systems that have excess capacity.

8. ***Problem:*** *The public is not well educated about the limits of groundwater resources.*

   Recommendation: Water resource management agencies should partner with schools to introduce material on water and the environment into the curricula for grades K through 12.

   Water resource management agencies should continue to conduct basinwide or regional workshops to acquaint citizens with water management issues, problems, and solutions. The Commission should present the findings and recommendations of this study to watershed groups, civic organizations, and legislative leaders.

9. ***Problem:*** *Insufficient or incomplete beneficial reuse of process water or wastewater results in increased water demand.*

   Recommendation: Industrial and commercial users should identify opportunities to reclaim water from one application for use in another application. Within the context of appropriate water quality limitations, agricultural sites near urban areas may provide opportunities to recycle industrial and commercial water for irrigation.

   Reuse water is a sustainable water supply. Municipalities should be evaluating ways to take advantage of their wastewater plant effluent for reuse, thus lessening the demand on their potable water supplies. Municipalities can perform "Reuse Master Plans" that focus on reuse opportunities as a water resource for their community and surrounding area.

10. ***Problem:*** *Inefficient water use or lack of conservation measures wastes water.*

    Recommendation: Water authorities and purveyors, in partnership with municipalities, should offer residential water surveys. Water surveyors check for leaking plumbing, provide water conservation tips, offer advice on retrofitting with water-efficient fixtures, and may distribute water-efficiency kits (containing, for example, faucet aerators and low flow showerheads).

    When businesses apply for new or increased withdrawals in PSAs, water resource management agencies should encourage them to consult with qualified engineering firms that specialize in on-site water use evaluations and assist in replacement of water-inefficient equipment.

    Watershed organizations should organize and conduct public information programs consisting of conservation brochures, displays, and classes dealing with outdoor use practices, such as landscaping alternatives and changing wasteful practices, to conserve water.

11. ***Problem:*** *Water discharged from mining operations is underutilized as a resource.*

    Recommendation: The Commission should encourage cooperative efforts to promote alternative water supplies such as mining operations for public drinking water, commercial operations, and industrial supplies.

12. ***Problem:*** *Municipal ordinances that influence water supply availability are inconsistent across municipal boundaries.*

    Recommendation: Local governments should continue to utilize the opportunities presented in the Pennsylvania Municipalities Planning Code to develop comprehensive land management ordinances that address groundwater resource protection and enhancement.

INTRODUCTION

Purpose and Scope

The Susquehanna River Basin Commission (Commission), in partnership with the Lancaster County Conservation District (LCCD), performed a groundwater resources evaluation of a carbonate valley located in northern Lancaster County, Pennsylvania. The purpose of this study is to evaluate the groundwater resources available for development and to provide guidance on how best to develop and conserve them. The study was prompted by a concern about groundwater sustainability, due to the combination of rapid growth and increasing water needs. The study area has an unusual hydrogeological setting, being a carbonate valley that is encircled by hills underlain by aquifers with relatively low permeability. The study was conducted over a two-year period from June 2003 to June 2005.

Location and Geographic Setting

The study area is located in northern Lancaster County in south-central Pennsylvania, approximately 30 miles southeast of Harrisburg, the state capital, and 10 miles north of the City of Lancaster (Figure 1). This area includes a regional groundwater basin and the surrounding contributing area.

The focus of the study is a valley approximately 50 square miles in area, underlain by a highly productive carbonate aquifer, and herein informally termed the “carbonate valley.” The carbonate valley is surrounded almost entirely by hills underlain by aquifers of much lower permeability (Figure 2). The carbonate valley includes parts of the Chiques Creek, Cocalico Creek, and Lititz Run watersheds. Streams generally flow from north to south across the study area, with the exception of the largest stream, Cocalico Creek, which flows from northeast to southwest.

The study area includes parts of 8 townships and 5 boroughs, and had a population of approximately 61,000 in the year 2000. Water supply needs are met almost entirely by groundwater. The valley was once largely agricultural, but is rapidly changing to a mosaic of urban, suburban, and agricultural areas. The population in the carbonate valley is rapidly growing, as is the need for water. However, the amount of water available is limited. Most of the groundwater is derived from the carbonate aquifer that underlies the valley.

The presence of sinkholes, abundant closed depressions, large springs, and lack of streams in many areas suggests that dissolution of the carbonate bedrock, a condition known as karst, has substantially enhanced the ability of the aquifer to store and transmit water. Karst aquifers are known for their abundant water resources and extremely high well yields, as well as their hard water, enigmatic flow patterns, sinkholes, and high susceptibility to contamination.

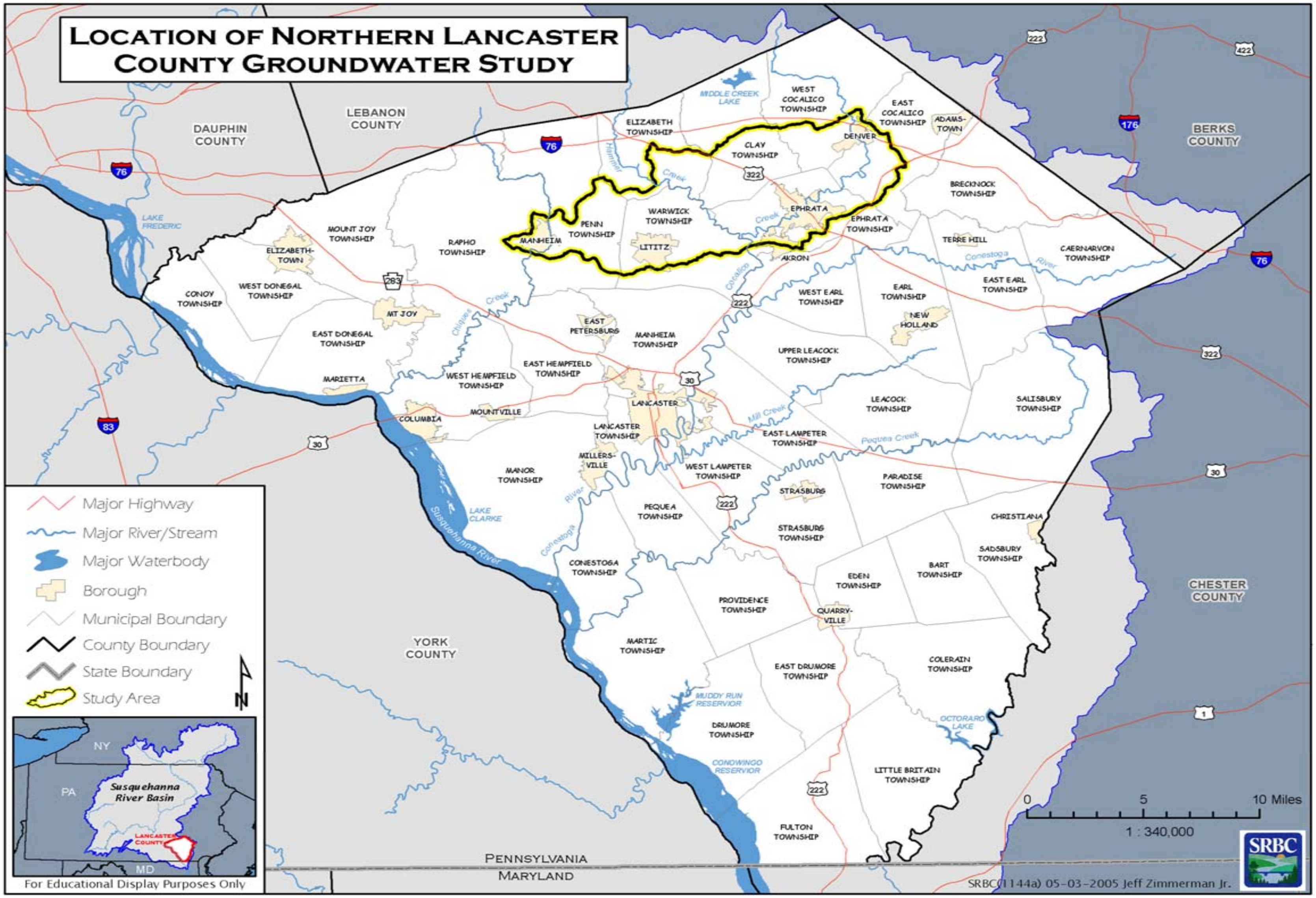

Figure 1. Location of Study Area, Lancaster County

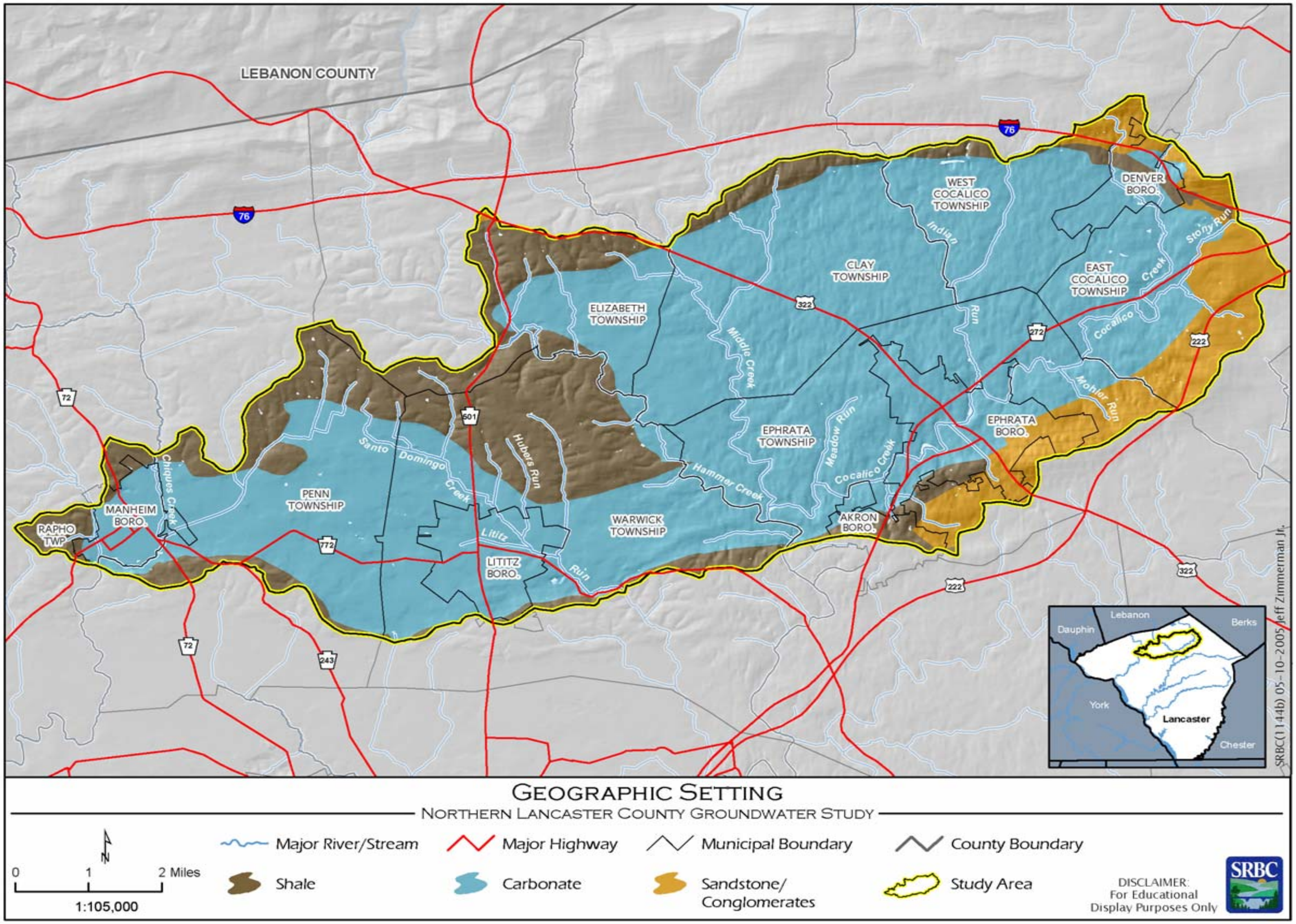

Figure 2. ***Geographic Setting of the Study Area, Lancaster County***

GROUNDWATER BASICS

What is groundwater? Groundwater is any water beneath the earth's surface that supplies wells and springs, and replenishes streamflow. For the purposes of this study, groundwater is the water that has reached the water table and the saturated zone, where all interconnected voids in unconsolidated (loose) sediments, and fractures and openings between layers in consolidated (hard) rock are filled.

Where can groundwater be found? Groundwater occurs virtually everywhere beneath the land surface. Aquifers are the rocks and sediments that contain significant quantities of groundwater and have sufficient permeability to allow groundwater to flow to wells.

What kind of aquifers are in the study area? Groundwater in the study area occurs, with few exceptions, in unconfined, water table aquifers. When a well in an unconfined aquifer is pumped, a region of drawdown and dewatering develops around the well.

The aquifers are primarily composed of consolidated bedrock. The water occurs within interconnected fractures and openings between layers, as well as voids within the bedrock. The density and width of fractures and openings generally decrease with increasing depth. In noncarbonate rocks (sandstones, siltstones, and shales; also termed siliciclastics), most of the fractures are located within 100-300 feet of the ground surface. In carbonate bedrock (limestone or dolostone), some of the fractures have been enlarged where acidic water has dissolved the rock. Fractures may be solutionally enlarged up to depths of several hundred feet, but most occur within 250 feet of the ground surface (Meisler, 1963).

Locally, the saturated zone within weathered bedrock and overlying soils functions as a porous media type aquifer. These porous media aquifers may provide a substantial amount of groundwater storage.

What is karst? Karst refers to a distinctive landscape and underlying soluble bedrock that are characterized by features formed by or resulting from the dissolution of bedrock by acidic water. Some of the karst features typical of the study area include sinkholes, losing streams, dry valleys, large springs, and conduits (natural pipes).

Where does the water found in aquifers come from? Water in aquifers primarily comes from precipitation—mostly rain. Replenishment or "recharge" occurs on most of the land surface, wherever water can soak into the ground. Exceptions include areas covered by impermeable materials like rooftops and paved areas, and areas where groundwater is upwelling, such as most perennial stream valleys.

Precipitation landing on the ground surface must be absorbed by the soil in order to become recharge. If the soil is frozen or precipitation is delivered at a rate that exceeds the ability of the soil to absorb it, then some of the precipitation is "rejected" and becomes surface runoff to streams and wetlands. Surface runoff moves downslope and becomes channelized flow.

Some of the precipitation absorbed by the ground is taken up by plant roots and transpired; the remaining water filters downward through the pores and fractures in the soil in the unsaturated zone. Eventually, this water reaches the water table, the boundary below which all of the spaces and cracks in the soil or rock are filled with water. Water that filters through the ground to the water table recharges the aquifer.

Some water becomes "stranded" in depressions or as drops on leaf (and other) surfaces. Most of this water evaporates and is returned to the atmosphere. The water returned to the atmosphere by plants (transpiration) or by evaporation is grouped under the single term evapotranspiration.

How much groundwater is there in a given area? Although this is difficult to generalize due to differences in recharge rate and geologic controls, the catchment area is an important factor. The groundwater equivalent of a watershed is the recharge area of a groundwater basin. For water table aquifers like those in the study area, the recharge area includes the land surface overlying the aquifer plus that for groundwater flowing into the aquifer from neighboring aquifers.

Where does all the groundwater go? With precipitation and recharge occurring year after year, and a limited amount of interconnected pore space available, aquifers eventually fill up and overflow. When the water table rises to the land surface, the overflow is termed groundwater discharge. Groundwater discharge to streams is termed base flow. For small watersheds, such as those in the study area, the groundwater component of streamflow (base flow) constitutes nearly all of the day-to-day streamflow with the exception of periods of precipitation and a few days afterward, when surface water runoff provides much higher peak flows.

How does groundwater flow? Groundwater flows from areas of higher "head" to areas of lower "head." In the study area, "head" is predominantly the force of gravity and the resulting pressure. Said another way, the water table is a subdued reflection of the topography, being higher beneath hills than it is in valleys. Groundwater flows under the influence of gravity and pressure, from the hills, downward and laterally toward the stream valleys, where it discharges to streams.

What is an underdrained carbonate terrain? A carbonate terrain is said to be "underdrained" when the water table is below most of the stream channels. Underdrained carbonate terrains are underlain by aquifers having extensive karst conduit development. The high permeability results in a water table with a low gradient (slope) and low relief beneath hills. Such areas typically have few flowing tributaries, and extensive areas "drained" by dry valleys, the terrain being effectively drained by the karst conduits. Most of the flowing streams in an underdrained carbonate terrain are through-flowing; that is, they originate outside the carbonate terrain, enter at a lower elevation than smaller streams, flow across it, and leave.

What is the safe yield of a groundwater basin? The safe yield of a groundwater basin is equal to the amount of natural replenishment that the aquifer receives annually. In water budget terms, water withdrawals cannot exceed the average annual water income received by a groundwater basin. The use of the safe yield as a maximum limit for groundwater development will result in a substantial reduction of stream and spring flow during extended periods (several months or longer) with below average precipitation. Stream base flow represents aquifer overflow, which on a long-term basis is equal to the amount of recharge the aquifer receives. During a year with average recharge, the safe yield is equal to the total recharge received. When withdrawals equal the safe yield, the result is the loss of base flow during a year with average (or less) recharge. On a long-term basis, management of groundwater withdrawals using the safe yield as a limit results in a stable average water table elevation, but a substantial reduction in streamflow during years with below average recharge.

What is the sustainable yield of a groundwater basin? The sustainable yield of a groundwater basin is equal to the amount of natural replenishment that the aquifer receives during a year with average recharge (i.e., the safe yield) minus the amount of water required to maintain groundwater discharge sufficient to support the existing aquatic and riparian habitat.

PREVIOUS INVESTIGATIONS

The study area and hydrologically similar neighboring areas have been the subject of several water resource reports. The Pennsylvania Geologic and Topographic Survey has produced a number of reports (Hall, 1934; Meisler, 1963; Johnston, 1966; Meisler, and Becher, 1971; Poth, 1977; Wood, 1980; Royer, 1983; Taylor and Werkheiser, 1984) on this area. These reports focus on county-size areas or the outcrop area of geologic formations of a particular age or rock type, and provide valuable information on the general geology, existing wells, well yields, well performance, well construction, depth to water-bearing fractures, and water quality. More recently, this and additional information have been summarized in a report titled "Geohydrology of Southeastern Pennsylvania" (Low and others, 2002). A statistical summary and searchable database of the hydrogeologic and well construction characteristics of the formations in Pennsylvania were made available on CD (Fleeger and others, 2004).

A quantitative evaluation of the groundwater resources of the lower Susquehanna River Basin was performed by Gerhart and Lazorchick (1984a, 1984b, 1988). They employed extensive water table mapping, base flow separations for 26 watersheds, and groundwater modeling to estimate average annual groundwater availability, and break down the base flow contribution by specific rock types and geologic formations.

Chichester (1991, 1996) studied the hydrogeologic characteristics of the carbonate aquifer in the Cumberland Valley, Pennsylvania. Water level mapping and streamflow measurements were used in conjunction with existing geologic and topographic mapping to develop a hydrogeologic framework. Hydraulic parameters were calculated from specific capacity data. Recharge values were derived from base flow separations of two watersheds in the study area. These were used to develop a groundwater flow model.

The study area is known as a highly productive agricultural region, and one with water quality problems related to agricultural activities. Recently, these problems and the effectiveness of "best management practices" in addressing them has been summarized in several United

States Geological Survey (USGS) publications (Lietman and others, 1996; Hall and others, 1997; Hainly and Loper, 1997; Lietman, 1997; Koerkle and others, 1997; Hainly and others, 2001).

HYDROGEOLOGIC SETTING

Physiography

The study area is located within the Piedmont Lowland Section of the Piedmont Physiographic Province. The Piedmont Lowland Section is underlain by carbonate and siliciclastic rocks of Cambrian, Ordovician, and Triassic Age. These are relatively nonresistant to weathering and erosion, and have developed a landscape that is characterized by relatively low relief and gentle slopes. A noteworthy exception is the resistant Hammer Creek Formation of Triassic Age (Figure 3), which is composed of well-cemented sandstone and conglomerate, and forms a range of rugged hills with up to 550 feet of local relief adjacent to the study area.

The focus of this study is a gently rolling terrain of Cambro-Ordovician carbonates that is almost completely surrounded by hills underlain by Ordovician and Triassic Age siliciclastics (Figure 3). The hills underlain by the Ordovician Age siliciclastic rocks are typically 100 feet higher than the carbonate valley. The hills underlain by the Triassic Age siliciclastic rocks are up to 400 feet higher than the adjacent carbonate valley.

Three streams and their tributaries drain the study area. Surface water drainage is generally from north to south across the width of the carbonate valley. The extreme western portion of the carbonate valley is crossed by Chiques Creek. The topography on the floor of the carbonate valley in the vicinity of Chiques Creek is a gently rolling plain with 10 to 30 feet of local relief. Lititz Run, a tributary of Cocalico Creek, crosses the carbonate valley near Lititz and heads into the Cocalico Formation hills on the north side of the valley. The topography consists of broad, low hills with 40 to 60 feet of local relief. Cocalico Creek and its tributaries drain the eastern two-thirds of the carbonate valley. Cocalico Creek flows along the southeastern edge of the carbonate valley. Major tributaries include, from east to west, Middle Creek, Indian Run, and Hammer Creek. The topography of this portion of the carbonate valley is hilly, with 80 to 120 feet of local relief.

Stratigraphy

Table 1 is a summary of the stratigraphy of formations in the study area arranged in order of increasing geologic age. Formation names and map symbols follow the Geologic Map of Pennsylvania (Berg and others, 1980). The lithologic information presented is from Meisler and Becher (1971).

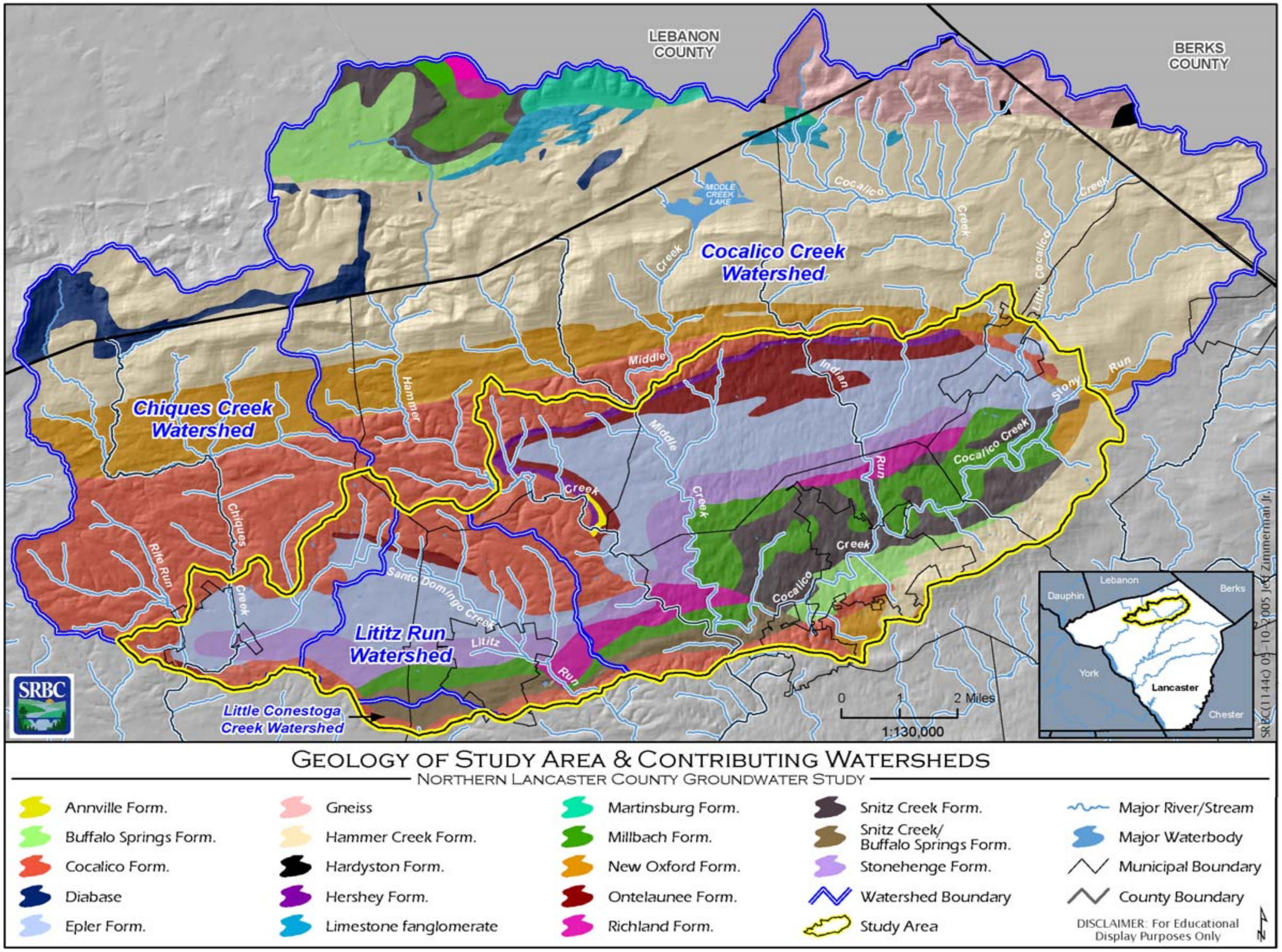

Figure 3. Topography and Geology of the Study Area and Upgradient Watersheds

Table 1. Stratigraphy and Lithologic Characteristics of Formations in the Study Area

Formation	Map Symbol	Description
Hammer Creek; and Conglomerate	Trh; Trhc	Interbedded red shales, red, brown, gray sandstones, and fine to coarse quartz conglomerates.
New Oxford; and Conglomerate	Tnh; Tnhc	Interbedded red shale, siltstone, fine-grained and arkosic sandstones, some with carbonate cement and conglomerate.
Cocalico	Oco	Bluish-black to dark gray fissile shale; purple and green shale with thin quartzite bed near base.
Hershey	Oh	Dark gray, thin bedded, argillaceous limestone; shaly near top of bed.
Myerstown	Omy	Medium gray, thin bed limestone grading to black at base.
Annville	Oa	Light gray, massive bed limestone.
Ontelaunee	Oo	Medium to dark gray, thick-bedded crystalline dolomite with minor limestone.
Epler	Oe	Medium-light gray, thick-bedded limestone and dolomite.
Stonehenge	Os	Medium-gray, crystalline, cherty limestone and gray shaly calcarenite.
Richland	Cr	Gray, thick-bedded, finely crystalline dolomite.
Millbach	Cs	Pinkish-gray and medium gray, laminated limestone with thin sandstones.
Snitz Creek	Csc	Light to medium gray, thick-bedded, oolitic dolomite with medium gray interbeds.
Buffalo Springs	Cbs	Light gray to pinkish-gray crystalline limestone with alternating light gray crystalline dolomite.

The Cambrian and Ordovician carbonates in the study area are similar to those exposed in the Lebanon Valley Subsection of the Great Valley Section of the Valley and Ridge Physiographic Province. They differ in being more strongly deformed and recrystallized, in having more sand and interbedded sandstone, and in their carbonate mineralogy (limestone vs. dolomite). Recrystallization has all but erased the primary rock fabric and fossils. These changes, along with additional sand content and changes in carbonate mineralogy, have made subdivision and detailed correlation with the Cambro-Ordovician Formations of the Great Valley somewhat uncertain. Therefore, a new stratigraphic subdivision for these rocks has gradually developed. Those interested in the detailed stratigraphy of the study area are encouraged to review works by Jonas and Stose (1930); Gray, Geyer and McLaughlin (1958); Hobson (1963); MacLachlan (1967); and Meiser and Becher (1971).

The Ordovician Cocalico Formation is a lightly metamorphosed shale (phyllite) with some interbedded sandstone and siltstone. Lithologic subdivisions within the Cocalico Formation were mapped and described by Jonas and Stose (1930). The Cocalico Formation underlies the low hills that partially encircle the carbonate valley.

The Triassic Age rocks in and near the study area are a part of the northeastern portion of the Gettysburg Basin and are classified as such. They are well described in Glaeser (1966). The basal rock unit, the New Oxford Formation, consists of a discontinuous basal conglomerate zone overlain by light-colored arkosic sandstones, siltstones, and shales. The New Oxford Formation is relatively nonresistant and forms a belt of lowlands.

The New Oxford Formation is overlain by the Gettysburg Formation, which consists of red shale, siltstone, and sandstone. In the study area, the typical Gettysburg is largely replaced by the Hammer Creek member, which is characterized by a dominance of hard sandstone and conglomerate. The Hammer Creek member is relatively resistant to erosion and forms high, rugged hills to the north and east of the study area.

Recent high resolution, infrared air photography of the study area indicates that the structure and stratigraphy locally diverge, sometimes significantly, from the published mapping. However, a comparison of the more recent published mapping (Meiser and Becher, 1971; Berg and Dodge, 1981) suggests that the published mapping is generally correct and is useful for large area hydrogeologic studies such as this one.

Geologic Structure

The geologic structure essentially divides the study area into two geologic terrains. The terrain underlain by Cambro-Ordovician rocks is characterized by complex, recumbent folding and imbricate thrust faulting (Meiser and Becher, 1971). The strike of the beds is generally east-west. Bedding generally dips to the south at 10 to 70 degrees, and is locally overturned. Older beds cover successively younger beds from north to south across the width of the carbonate valley.

The terrain underlain by Triassic Age rocks is characterized by monoclinal structure and normal faulting (Root and MacLachlan, 1999). The strike of the beds is generally east-west. Beds generally dip to the northwest at 20 to 40 degrees. Locally, the structure is often more complex, with open folds and block faulting.

Both the Triassic siliciclastic rocks and the Cambro-Ordovician rocks have well-developed joints. Three sets are usually discernable: strike parallel, strike perpendicular, and strike oblique. The Cambro-Ordovician carbonates and siliciclastics also display well-developed cleavage that is generally strike parallel (axial plane cleavage), although a variety of orientations may be locally present.

Groundwater Flow Types

In the saturated zone, groundwater flows through interconnected openings of three types in the study area: intergranular pores, fractures, and karst openings. While all three types may be present in a given area, one of them is usually dominant.

Porous media

Groundwater flow through the space between individual rock and mineral particles (i.e., intergranular pores) is called porous media flow (Figure 4). Within the study area, porous media flow occurs in the saturated weathered bedrock residuum, saturated soil and colluvium, alluvium in stream valleys, and silt and clay that fills some karst conduits.

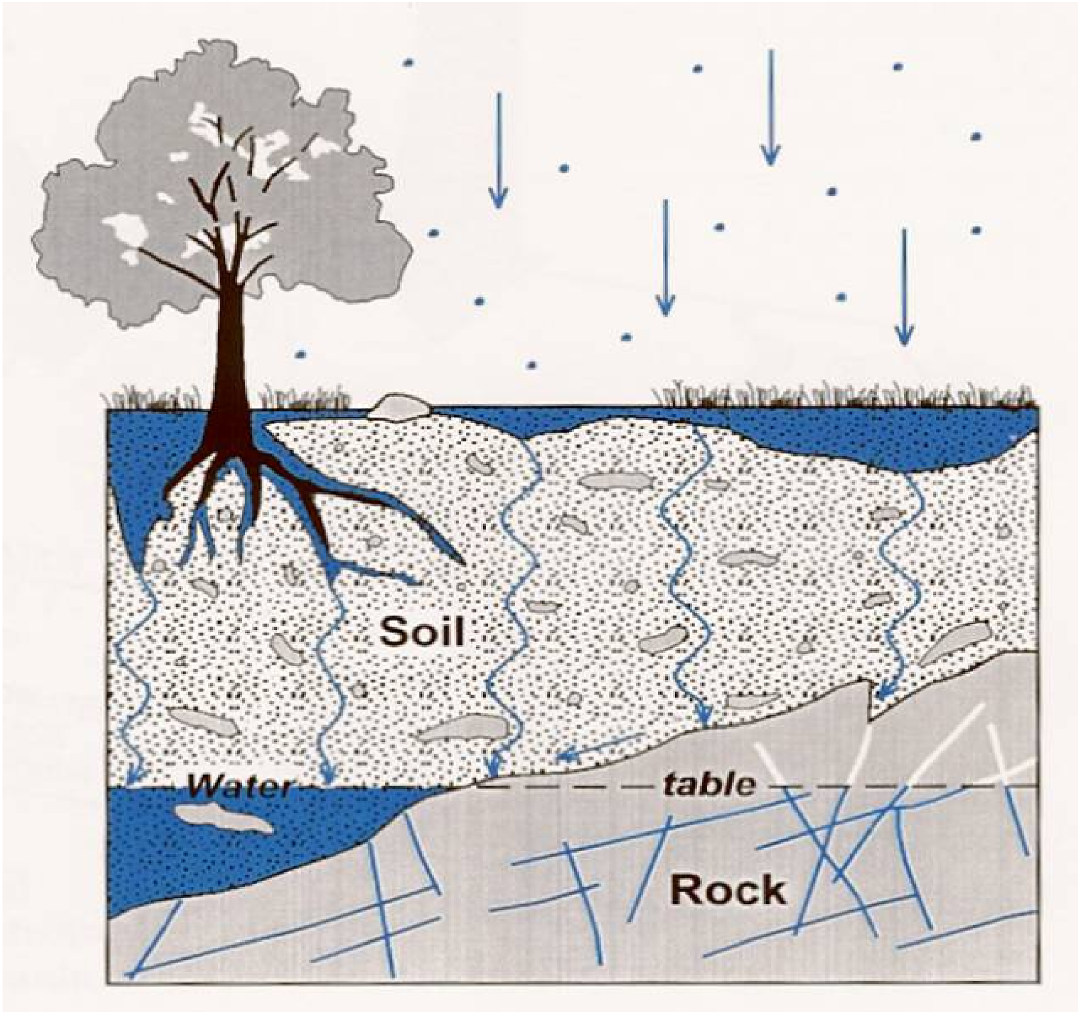

Figure 4. Diagram of Flow through Porous Media (Fleeger, 1999)

Fractures

In fracture flow, water is stored and moves through various fractures in the bedrock (Figure 5). Types of fractures that are important to groundwater flow include bedding partings, cleavage, joints, and fracture traces.

Bedding partings are naturally occurring fractures developed along the boundaries between beds or laminae of sedimentary rock. They are generally more open at shallow depths due to unloading of lithostatic pressure. Some are relatively open at considerable depths due to breakage along rock beds of contrasting strength. Bedding partings are commonly more laterally continuous than other fracture types. They often impart a strong preferential flow direction to the groundwater flow system.

Joints are fractures resulting primarily from the relief of stress within the rock mass, such as the unloading of lithostatic pressure due to erosional removal of the overlying rocks. They typically are widest near the top of rock and gradually close up with depth.

Cleavage planes are fracture surfaces along which the platy and elongate minerals are parallel. They are formed during the folding of the rocks and are oriented perpendicular to the compressive force. They are present to great depths, but may be more open near the surface due to weathering and erosional unloading.

Fracture traces are linear zones of closely spaced sub-parallel, vertical to sub-vertical fracturing extending to great depth (hundreds to several thousand feet) that are a few tens of feet wide and several hundred to a few thousand feet in length.

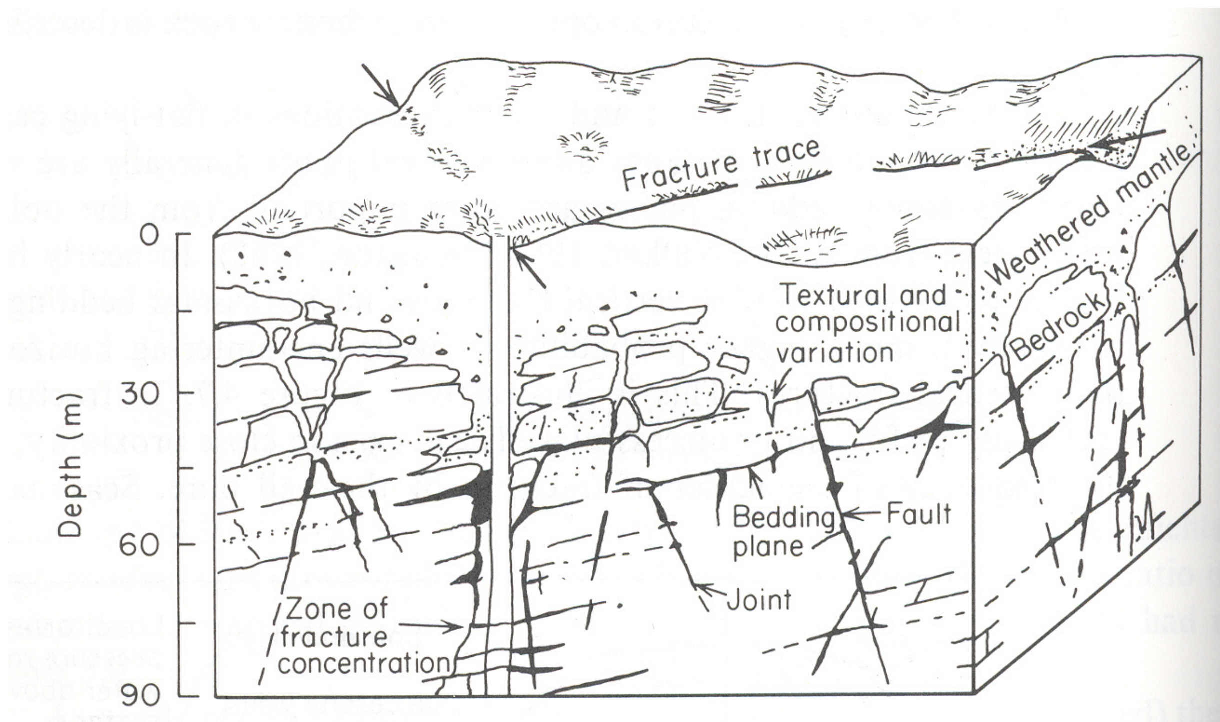

Figure 5. Diagram of Flow through Fractured Media (Lattman and Parizek, 1964)

Karst/conduit

Carbonates are readily soluble in acidic water. Groundwater flow along fractures in carbonate bedrock concentrates solutional activity along the fracture surfaces, gradually causing their enlargement and, locally, the formation of open cavities or conduits (Figure 6). Over time, an extensive, integrated network of karst conduits may develop. This network imparts a much higher permeability to the aquifer than the original fractures. Flow velocities are much higher than those for fracture flow and porous media flow, and may approach those of surface streams. The resulting water table is substantially more subdued than that for fractured bedrock or porous media aquifers. In advanced stages of karstification, groundwater flow may be oblique to surface topography and leave stream valleys perched well above the water table. Such valleys are said to be underdrained. Streams may continue to flow on relatively impermeable, clay-rich carbonate weathering residuum with only minor leakage, or they may exhibit losing reaches where leakage is substantial.

Signs of advanced karstification include the presence of extensive, dry (abandoned) trunk stream valleys, karst springs, perched stream reaches, losing streams, abundant sinkholes, and a lack of a normal (flowing) stream drainage network.

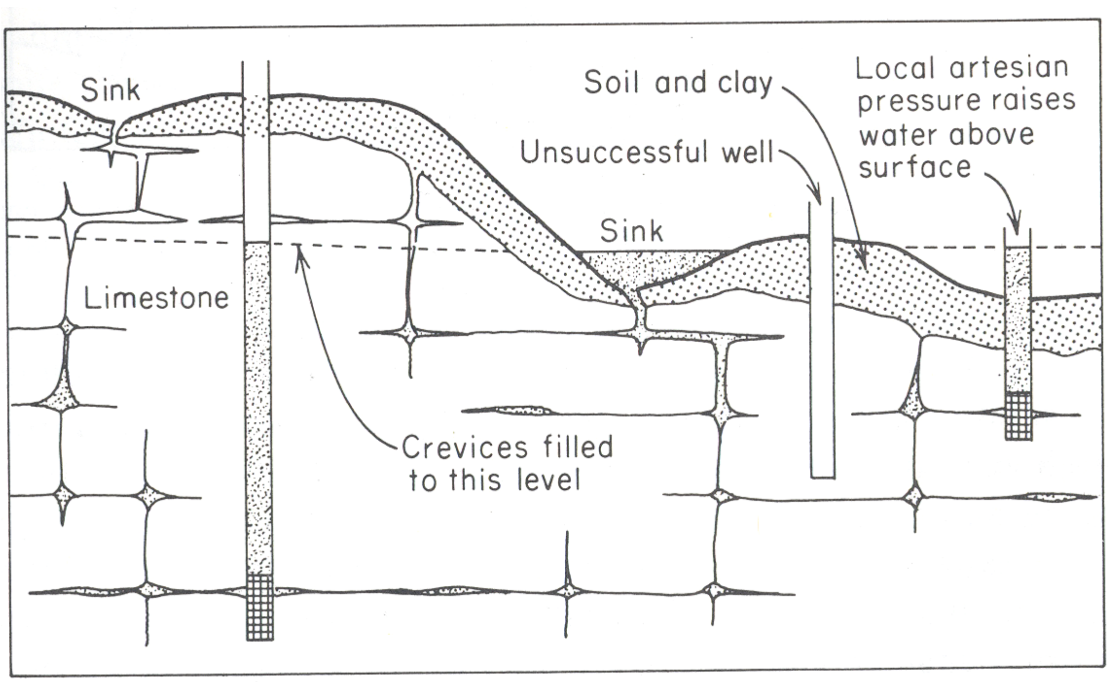

Figure 6. Diagram of Flow through Karst Features (Walker, 1956)

GROUNDWATER FLOW

Water Table Mapping

Water levels from more than 80 wells were measured in the spring (May 24-27, 2004) and fall (October 25-27, 2004) to allow a comparison between the spring and fall water tables in the study area. Water levels in southeastern Pennsylvania are generally highest in the late spring and lowest in early fall.

The water level data were collected from residential and municipal wells using electronic water tapes. Water levels were measured from the top of the well casing, and the height of the casing above ground surface was subtracted to obtain a depth to water below ground surface. Given the unevenness of the ground surface adjacent to the casing, the depth-to-water measurements are accurate to within approximately 1/10 foot. The elevation of the ground surface was estimated in the field from on-site observations and reference to a USGS 7.5-minute topographic map with a 20-foot contour interval. The ground surface elevation estimates depend on both the accuracy of the map contouring and the field interpretation. The ground elevations and, therefore, the water level elevations are accurate to within only a few feet. The depth to water was converted to a water table elevation by subtracting the depth to water below ground surface from the elevation of the ground surface.

The year 2004 was unusually wet throughout the spring, summer, and fall, and there was very little difference between the two data sets. Therefore, a water table contour map that depicts the configuration or "topography" of the water table was prepared only from the May 2004 data set (Figure 7).

Surface Water, Base Flow, and Groundwater

Water flowing in streams is a combination of surface runoff and groundwater discharge (base flow). The discharge of groundwater from springs and seeps in the channel and the valley alluvium supplies most of the water in streams during periods between precipitation and meltwater events. Streamflow increases markedly in response to the inflow of surface runoff; however, the high peak flows from precipitation and meltwater events are of relatively short duration. The flow in the small to medium-sized watersheds within and crossing the study area is dominantly base flow within hours to a few days after precipitation events.

Base flow is a measure of the groundwater recharge above the point of measurement. The base flow in a stream gradually increases, from headwaters to mouth, as the contributing aquifer area increases. Base flow somewhat underestimates the amount of groundwater recharge due to uptake by plants where the water table is within the root zone. There is also some loss due to evaporation from the surface of the stream. Nevertheless, base flow is a good measure of the groundwater available for development, after the water needs for riparian plants are met.

Streamflow Measurements

Stream discharge was measured at 67 stations from June 8-18, 2004, and October 29, 2004 to November 2, 2004 (Appendix A; Figure 8). Streamflow measurements were made with a Price Pygmy flow meter using a protocol used by the USGS and described in Buchanan and Somers (1969). Measurement accuracy was estimated in the field to have a margin of error of five to eight percent. Flow measurement locations were selected for accessibility, appropriate channel geometry, flow uniformity, measurement of surface water flows into and out of the carbonate valley, and proximity to mapped geologic contacts.

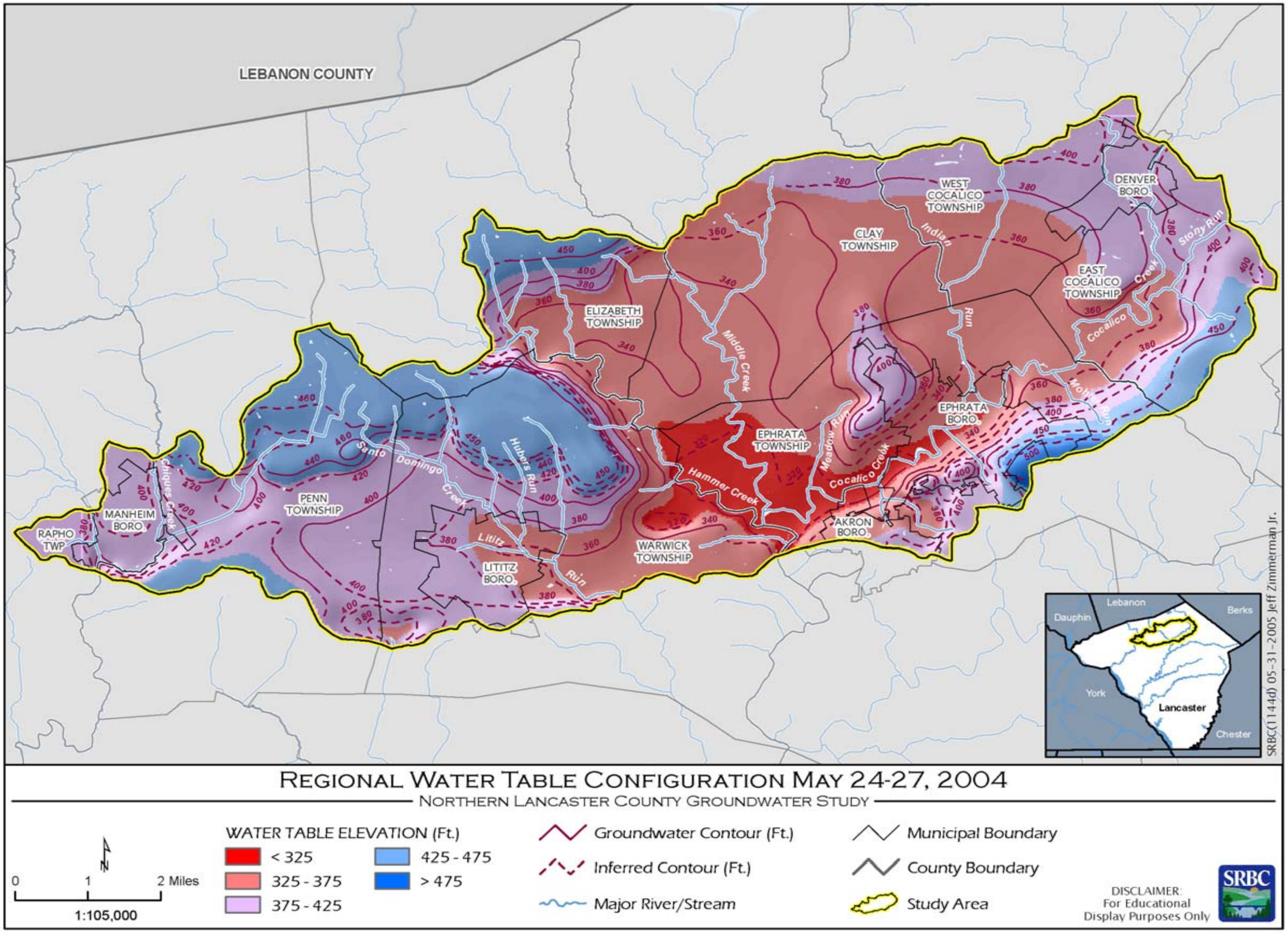

Figure 7. Regional Water Table Configuration of the Study Area, May 24-27, 2004

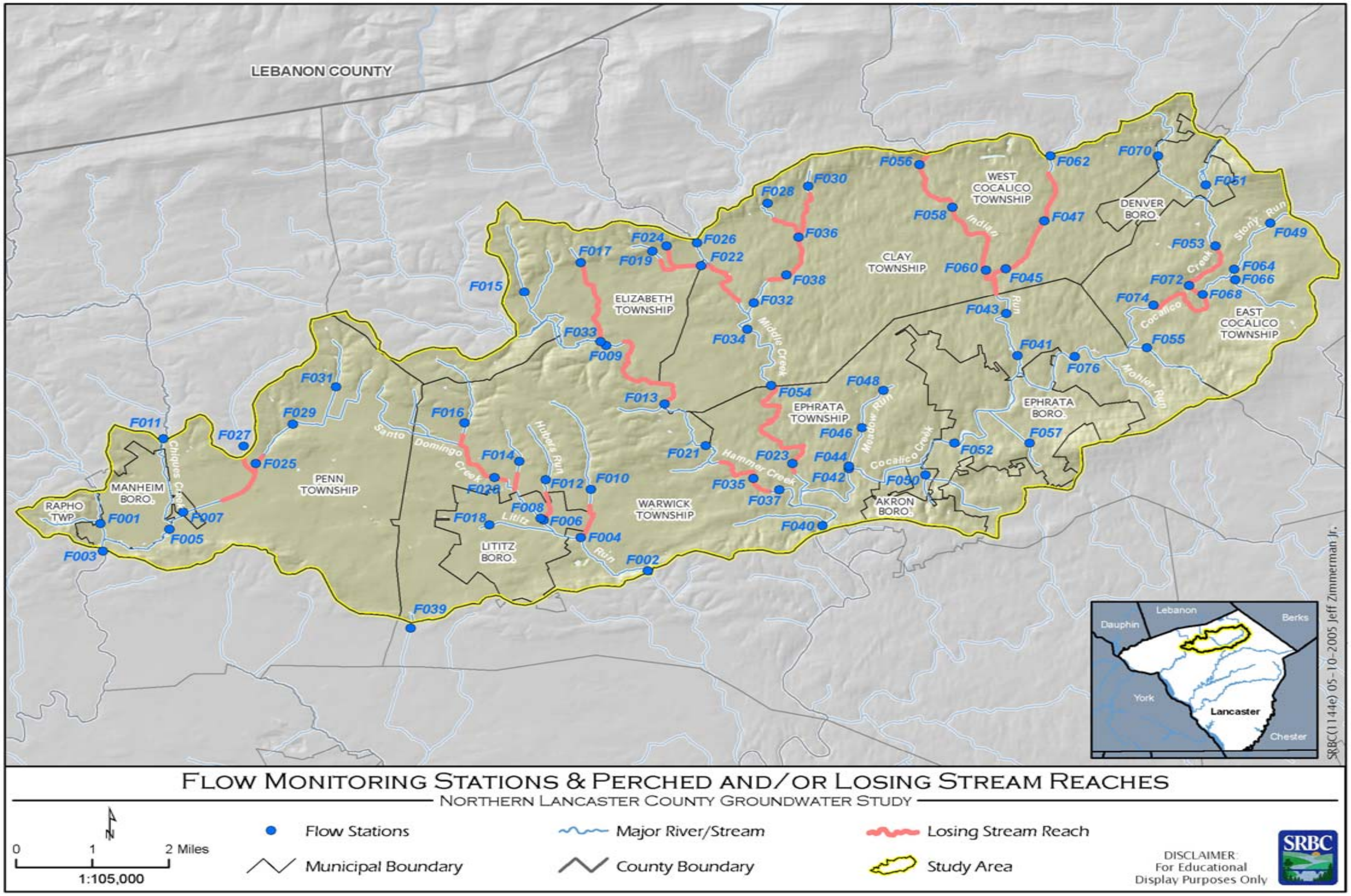

Figure 8. ***Location of Stream Discharge Measurement Stations and Perched or Losing Stream Reaches***

Streamflow measurements provided evidence of both losing and gaining stream reaches. As tributary streams leave the upland shale ridge area of the Cocalico Formation and enter the more permeable carbonates, they lose water by infiltration through streambeds. Some reaches observed during the field survey contained too little water to measure stream discharge, or were dry. More accurate seepage rates are required to determine the amount of recharge to the underlying formations. As streams flow across the carbonate valley, discharge measurements indicated a change from losing to gaining reaches mid-valley. Many of the measured streams behave similarly. The distribution and characteristics of streams throughout the study area suggest that the northern half of the carbonate valley is an important recharge area.

Groundwater and Surface Water Interactions

Streamflow measurements along the course of a stream during periods of base flow allow the determinations of flow gained or lost between stations. Streams within the study area exhibited reaches that either gained or lost measurable base flow, or had base flow that remained stable.

Losing stream reaches generally lose flow because their channels are above the water table, and there is a permeable flow path from the streambed to the water table. Since water flows from areas of higher head (elevation in unconfined, water table aquifers) to areas of lower head, stream water seeps through the bed of the channel downward to the water table, where it contributes water (i.e., recharge) to the aquifer. Losing streams can be found in many hydrogeologic settings. Nearly all of them have in common a localized area along the stream channel that is underlain by material with a much higher permeability than that up and downstream.

In areas underlain by carbonate bedrock, some beds or zones in the bedrock are more soluble than others and may, as a result, have greater karst-enhanced permeability. Where such a high permeability bedrock zone passes beneath a stream channel and has a connection to an area of lower head, the head in the bedrock may be lower than the water level in the stream. If the stream has a permeable connection with the underlying high permeability zone, substantial flow may be lost to the aquifer.

A stream reach is said to be perched if it flows over a bedrock zone with a water level lower than that in the stream, but no measurable flow is lost. This typically occurs where the stream is flowing over a low permeability material such as clay-rich carbonate weathering residuum.

Streams flowing across the carbonate valley that have gaining, perched, and losing reaches along their course (Figure 8) may vary in response to changing head conditions in the aquifer and the stream. Some reaches may be gaining during wet periods when the water table is high, and losing or perched (during dry periods) when the water table falls below the stream.

The longitudinal profile of Indian Run (Figure 9) illustrates the topography, groundwater table, and stream discharge measurements as it enters the carbonate valley from the siliclastic hills, and is representative of many of the larger, through-flowing streams in the study area. Groundwater from the siliciclastics north of the carbonate valley provides base flow to Indian Run. When Indian Run enters the carbonate area near the Hershey and Ontelaunee Formations, groundwater elevations begin to fall below the elevation of the streambed. On June 16, 2004, streamflow at stations F056, F058, and F060 over a 2-mile reach was 3.46 cubic feet per second (cfs), 3.20 cfs, and 3.33 cfs, respectively. The elevation of the water table and the steady flow rates through this reach suggest a generally perched stream with local losing reaches. Measurements made on October 29, 2004, for the same stations showed streamflows of 3.17 cfs, 3.20 cfs, and 2.95 cfs, respectively. The larger streams entering the carbonate valley have gaining, perched, and losing reaches as they flow out onto the carbonate valley, but are predominantly perched.

An eastern tributary to Indian Run is representative of many of the smaller streams that head in the siliclastic hills and flow out onto the carbonate valley. On June 16, 2004, the measured streamflow at the shale-carbonate contact was 0.79 cfs and reduced to 0.07 cfs at station F045 near the confluence with Indian Run. On October 29, 2004, no flow was observed at station F045.

A losing stream, such as Indian Run, that recharges the underlying aquifer is a valuable source of groundwater recharge. Riparian areas and floodplains associated with losing streams may allow infiltration of floodwaters or stormwater runoff. Similarly, small swales or the larger dry valleys may represent stream channels that historically flowed out onto the carbonate valley and be important for recharge and in the conveyance of stormwater. However, to obtain maximum recharge benefit, pollutant loads must be managed to avoid groundwater contamination.

Overall Hydrogeologic Setting

The overall hydrogeologic setting consists of a carbonate-aquifer floored valley, surrounded by much less permeable, topographically higher, siliciclastic aquifers. Surface water drainage is generally from north to south across the valley. The through-flowing streams decline in elevation at a rate of 10-15 feet per mile as they cross the valley. The total elevation change from entry to exit is approximately 25 feet for Chiques Creek, 60 feet for Hammer Creek, 75 feet for Middle Creek, 100 feet for Indian Run, and 100 feet for Cocalico Creek.

While Chiques Creek is a gaining stream throughout its course across the carbonate valley, the other major streams exhibit gaining, perched, and losing reaches. Smaller streams with headwaters in the siliciclastic hills surrounding the carbonate valley generally have losing reaches as they enter the carbonate valley. The loss of flow as small streams cross from siliciclastic formations to carbonates in other locations in Pennsylvania has been described from the Spring Creek watershed (Parizek, 1971) and the Cumberland Valley (Chichester, 1996).

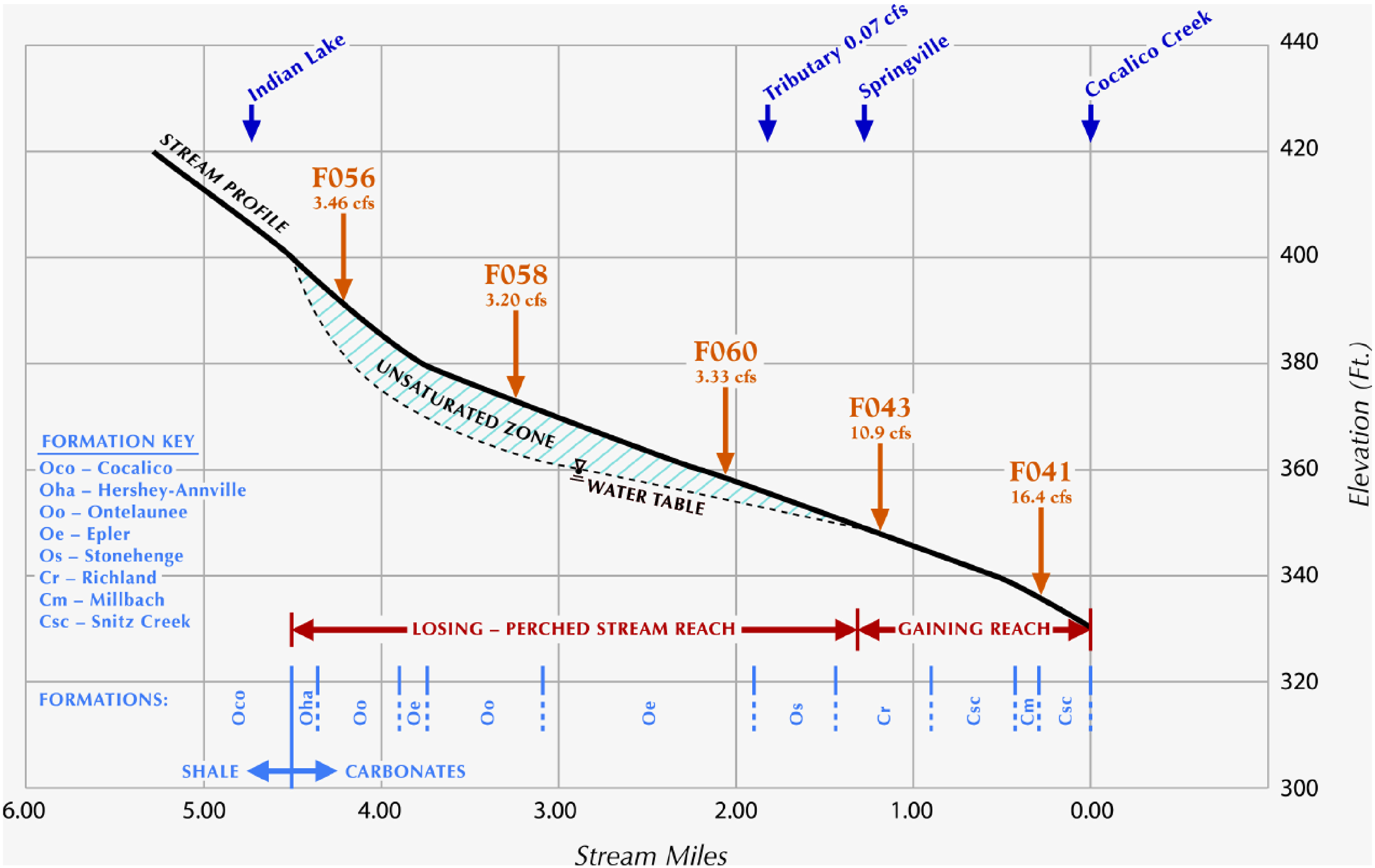

Figure 9. ***Profile of Indian Run from Shale Upland Area to Cocalico Creek***

The siliciclastic hills along the southern margin of the carbonate valley form a groundwater dam. Three water gaps through these hills act as spillways for both surface water and groundwater, and set both the lowest head in the groundwater flow system and the base level for streams in the carbonate valley. Along the southern margin of the carbonate valley, through-flowing streams gain flow as they leave the carbonates. Similar groundwater damming by low permeability formations has been described from the Spring Creek watershed (Parizek, 1971) and the Cumberland Valley (Chichester, 1996).

The water table in the carbonate valley is generally near the elevation of the major, through-flowing streams. However, smaller streams, such as Middle Creek and Indian Run, have extensive perched and losing reaches. Smaller tributaries are scarce, and there are large parts of the study area without perennial streams. The areas between the major through-flowing streams generally lack surface water flow and have underdrained, dry valleys similar to those described by Parizek and others (1971) in the Spring Creek watershed and Chichester (1996) in the Cumberland Valley.

Hydrogeologic Terrains

The water table mapping and seepage runs, in combination with the existing geologic and topographic mapping, allow the division of the carbonate valley into several distinct hydrogeologic terrains (Figure 10), including two major groundwater basins, each having several sub-regions.

Manheim-Lititz Groundwater Basin: The western end of the carbonate valley, herein called the Manheim-Lititz groundwater basin, is one to two miles wide (north-south) and nine miles long (east-west), and contains the Boroughs of Manheim and Lititz, and parts of Rapho, Penn, Warwick, and Elizabeth Townships. The western end is crossed by Chiques Creek and contains the most subdued terrain in the carbonate valley. On the valley floor, the hydraulic gradients are relatively low and graded to Chiques Creek. Chiques Creek is a gaining stream across the valley floor. A subtle, low relief groundwater divide separates the Chiques Creek section from the remaining portion of the Manheim-Lititz groundwater basin. In the area east of the Chiques Creek subbasin, the water table gradually declines from 400 to 340 feet above mean sea level, and is graded to the elevation of Lititz Run and the Lititz spring. Most of this area is "drained" by the Limerock dry valley. The Limerock dry valley is underlain by a groundwater trough, and appears to discharge to the Lititz spring. Conduits in the "headwaters" of the Limerock dry valley are probably very slowly extending westward, gradually underdraining and capturing the groundwater in that area.

A small headwater area for a tributary to Bachman Run, located along the southern margin of the carbonate valley between Manheim and Lititz, allows some "leakage" through the southern margin siliciclastic hills. The divide between this small basin and the Manheim-Lititz basin is subtle with very low relief, and probably changes position in response to seasonal variations in precipitation.

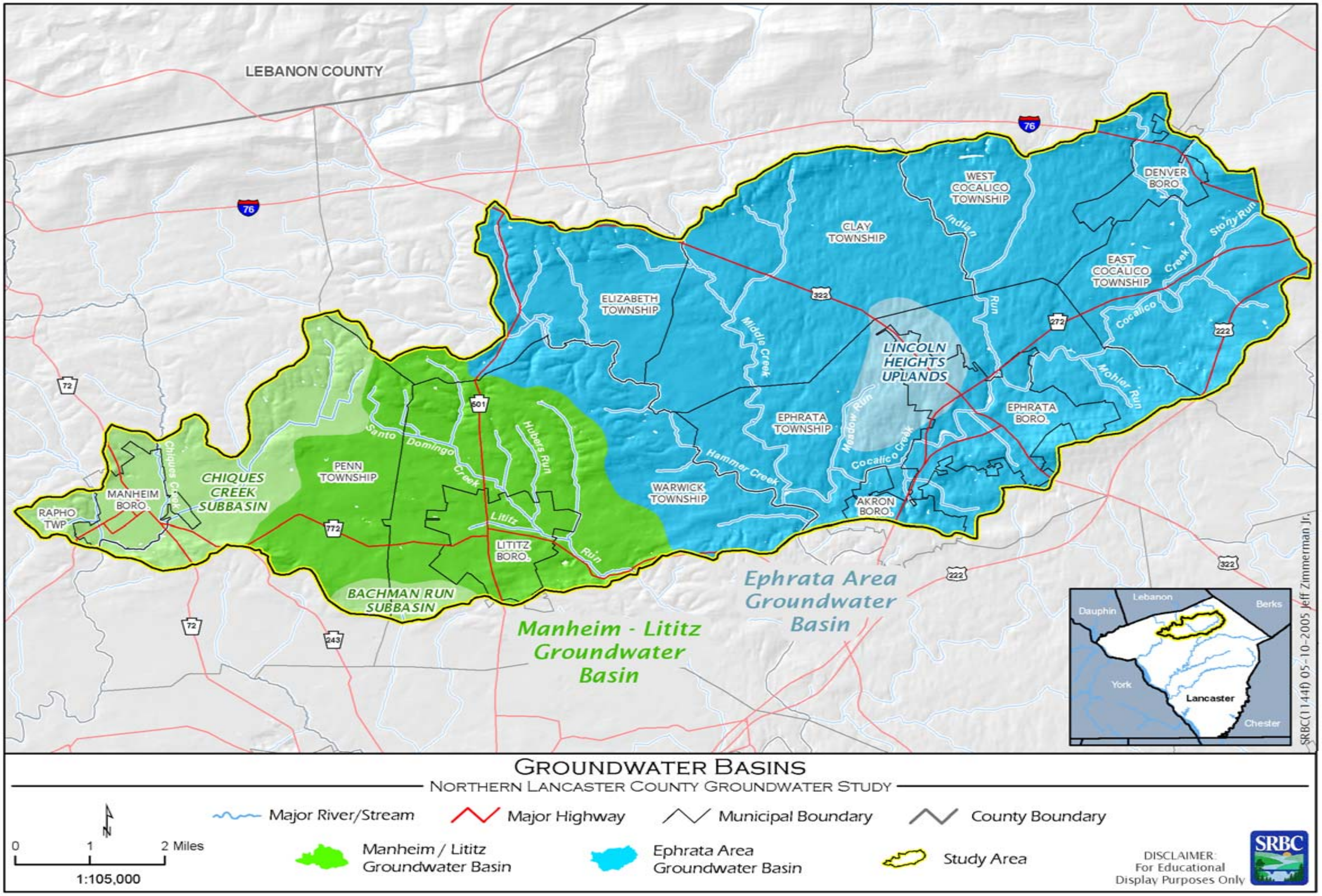

Figure 10. Groundwater Basins of the Study Area

Ephrata Area Groundwater Basin: East of the Lititz Run water gap, the water table rapidly falls 40 to 60 feet into the Hammer Creek valley and the Ephrata area groundwater basin. The Ephrata area groundwater basin contains parts of Elizabeth, Warwick, Clay, Ephrata, West Cocalico, and East Cocalico Townships, and parts of Akron, Ephrata, and Denver Boroughs within the Cocalico Creek drainage area. The groundwater divide between the Manheim-Lititz groundwater basin and the Ephrata area groundwater basin is markedly asymmetrical, with a gentle gradient to Lititz Run and a very steep gradient to Hammer Creek. The water table within the Ephrata area groundwater basin is graded to the major tributaries of Cocalico Creek and its exit from the carbonate valley at approximately 300 feet above mean sea level. The Ephrata area groundwater basin contains subbasins corresponding to the valleys of Hammer Creek, Middle Creek, Indian Run, and Cocalico Creek.

The northern half of the Ephrata area groundwater basin between Cocalico Creek and Middle Creek is largely underdrained. Several dry valleys are present, including the Weidmanville dry valley and the Stevens dry valley (Plate 1).

The Lincoln Heights is a hilly upland northwest of Ephrata, with approximately 120 feet of local relief. The relatively steep hydraulic gradients in this area suggest a minimum of karst conduit permeability and a dominance of fracture permeability.

GROUNDWATER RESOURCE EVALUATION

The Hydrologic Cycle

The natural cycle of water movement from the atmosphere to groundwater and surface water and back to the atmosphere is called the hydrologic cycle (Figure 11). Water falls to the ground as precipitation and follows many pathways on its way back to the atmosphere. Understanding the hydrologic cycle and human impact to these pathways is fundamental to the proper management of water resources.

The amount of water in the atmosphere, on the earth's surface (as water and ice), and in the ground is largely controlled by climate. An accounting of the amounts of precipitation, streamflow, evapotranspiration, and groundwater is called a water budget.

A water budget treats water in the hydrologic cycle in much the same way as a financial budget treats income, savings, and expenditures. In a water budget, the major components of the hydrologic cycle are quantified and itemized so that water income (precipitation) is balanced against water expenditures (evapotranspiration, groundwater flow, streamflow expenditures) and water savings (groundwater storage). This balance is often expressed in the simple equation:

Water Income (Precipitation) = Water Expenditures (Surface Runoff + Groundwater Discharge + Evapotranspiration) +/– Water Savings (Change in Groundwater Storage)

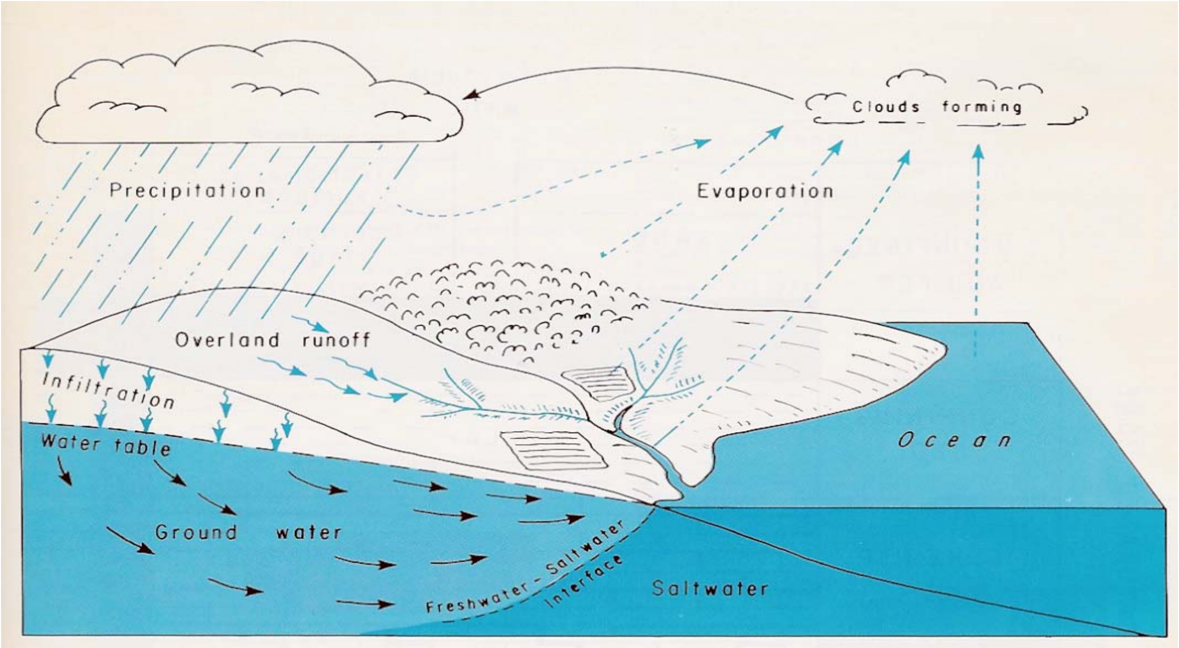

Figure 11. Diagram of The Hydrologic Cycle (After Heath, 1987)

Over the long term with no water resource development, the change in water storage (savings) is zero and the equation simplifies to:

Precipitation (Income) = Surface Runoff + Groundwater Discharge + Evapotranspiration (Expenditures)

Daily stream discharge measurements, at established USGS stream gages, and daily precipitation records provide the data sets needed to calculate water budgets for watersheds.

For several small watersheds where a stream gage record was available, water resource scientists have evaluated the relationship of groundwater discharge or base flow to total streamflow in the lower Susquehanna River Basin (Table 2). These water budgets illustrate how the water income (precipitation) is divided between the water expenses (evapotranspiration, surface runoff, and groundwater) on an annual basis for the period of record. The water budgets are averages for entire watersheds and do not reflect local topography, land cover, and hydrogeologic heterogeneity within the watersheds.

Table 2. Summary of Groundwater Contributions to Streamflow for Select Watersheds of the Lower Susquehanna River Basin

Watershed/ Reference	Drainage Area (sqmi)	Period of Record	Annual Precip (inches)	Average Streamflow (inches)	Average Groundwater Flow (inches)	Percent Groundwater of Total Streamflow
Little Conestoga Creek/ Meisler and Becher (1971)	38.2	01/1964-12/1964		15.3	11.6	76
Muddy Creek/ Lloyd and Growitz (1977)	133	01/1969-12/1970	43.00[1]	14.4	10.0	69
Yellow Breeches Creek/ Becher and Root (1981)	216	1968-1974	43.22	21.0	16.8	80
Conodoguinet Creek/ Becher and Root (1981)	470	1968-1974	42.23	19.9	13.3	67
Swatara Creek/ Stuart and others (1967)	337	42-year composite record	46.38	23.2	11.3	49
Quittapahilla Creek/ Meisler (1963)	42	10/1960-9/1961		17.3	15.1	87
West Conewago Creek/ Taylor and Werkheiser (1984)	510	1961-1980	39.87	16.9	8.4	50
East Mahantango Creek/ Taylor and Werkheiser (1984)	162	1961-1980	42.28	19.5	12.6	65
Chiques Creek/Gerhart and Lazorchick (1984b)	29	10/1978-9/1979	53.27	22.59	14.21	63
Conestoga River/Gerhart and Lazorchick (1984b)	324	10/1966-9/1967	41.78	12.57	9.05	72
Bowery Run/ Gerhart and Lazorchick (1984b)	5.98	10/1966-9/1967	38.9	15.14	10.75	71
Little Conestoga/Gerhart and Lazorchick (1984b)	38.2	11/1963-10/1964	34.97	16.45	13.82	84
Little Conestoga Gerhart and Lazorchick (1984b)	14	10/1963-9/1964	33.29	13.8	11.59	84
Pequea Creek Gerhart and Lazorchick (1984b)	148	10/1977-9/1978 10/1979-9/1980	51.9 37.32	27.15 17.48	19.28 15.16	71 87
Average from all studies			42.16	18.18	12.86	72

[1] Muddy Creek period of record from 1931-1939; modified after Taylor and Werkheiser, 1984 and Gerhart and Lazorchick, 1984b.

Groundwater Recharge Estimated from Base Flow

<u>Base flow</u>

Base flow is the groundwater contribution to streamflow originating from recharge areas upstream and upgradient of the streamflow measurement station. Under natural conditions and during a year with average recharge, the amount of recharge received by the aquifer is balanced by the groundwater discharged to streams (i.e., base flow) and used by riparian plants in the discharge zone. The water used by riparian plants in the discharge portion of the groundwater flow system is commonly combined with water use by riparian plants in the recharge portion as evapotranspiration. Recharge in this study refers to the amount of precipitation contributed to the groundwater flow system minus evapotranspiration by plants in the discharge zone. Base flow data can be used to estimate the amount of recharge per unit area of land surface. Drier periods yield lower base flows, and calculated “drought” base flows can be quantified as annual base flow for various recurrence intervals. The annual base flows for the various aquifers/formations were estimated for the 2-, 10-, and 25-year recurrence intervals.

Recharge estimation methodology

The recharge values used in this study were modified from those developed in studies by Gerhart and Lazorchick (1984a, 1984b, and 1988). Gerhart and Lazorchick derived average annual (i.e., 1-in-2-year) recharge rates from base flow separations for 26 watersheds in the lower Susquehanna River Basin. They developed average annual recharge values for specific rock types and geologic formations, and refined those values using regional finite-difference groundwater models.

The studies by Gerhart and Lazorchick (1984a, 1984b, and 1988) assumed that a year with average precipitation would have average base flow and, therefore, average recharge. The validity of this assumption depends upon a number of factors, including the following:

1. There was no deficit or excess of groundwater storage.
2. The distribution of precipitation over the year was average:
   a. The amount occurring while the ground was frozen was average; and
   b. The amount received prior to and during the plant growing season was average.
3. Soil moisture conditions inherited from the previous year were average.
4. The distribution of the precipitation events was not skewed by an unusual amount of precipitation received during high intensity events such as thunderstorms or hurricanes.

White and Slotto (1990) calculated the base flow frequency characteristics for Pennsylvania streams by performing base flow separations of streamflow data for the entire period of record. As a result, their calculated base flows include the factors not considered by Gerhart and Lazorchick (1984a, 1984b, and 1988). Their average annual (i.e., 1-in-2-year) recharge rate for the Conestoga River at Lancaster (station # 01576500) was 1.158 times greater than that calculated by Gerhart and Lazorchick. This factor was applied to the lithology and formation-specific 1-in-2-year recharge rates to derive the corrected 1-in-2-year recharge rates used in this study (Table 3). White and Slotto (1990) also provided annual minimum base flows for the 1-in-10-year and 1-in-25-year recurrence intervals. The 1-in-10-year base flow was 60.7 percent of the 1-in-2-year base flow. The 1-in-25-year base flow was 41.7 percent of the 1-in-2-year base flow. These factors were applied to the corrected 1-in-2-year recharge rates of this study to estimate formation-specific recharge values for the 1-in-10-year and 1-in-25-year recurrence intervals.

Table 3. Average Annual Recharge for Selected Recurrence Intervals for Geologic Formations within the Study Area

Map Symbol	Formation Name	1-in-2-Year Recharge[1] mgd/sqmi.	Unit Number [2]	Corrected 1-in-2-Year	1-in-10-Year	1-in-25-Year	Lithology
Oan	Annville	0.66	4	0.76	0.46	0.32	High-Calcium Limestone
Cbs	Buffalo Springs	0.53	6	0.61	0.37	0.26	Limestone
Oco	Cocalico	0.55	13	0.64	0.39	0.27	Shale
Oe	Epler	0.66	4	0.76	0.46	0.32	Limestone
Trhc	Hammer Creek	0.39	19	0.45	0.27	0.19	Quartz conglomerate

Map Symbol	Formation Name	1-in-2-Year Recharge[1] mgd/sqmi.	Unit Number [2]	Corrected 1-in-2-Year	1-in-10-Year	1-in-25-Year	Lithology
	Conglomerate						
Trh	Hammer Creek	0.39	18	0.45	0.27	0.19	Sandstone
Ohm	Hershey and Myerstown, undivided	0.66	4	0.76	0.46	0.32	Argillaceous Limestone
Oha	Hershey through Annville, undivided	0.66	4	0.76	0.46	0.32	Argillaceous Limestone
Cm	Millbach	0.51	7	0.59	0.36	0.25	Limestone
Trnc	New Oxford Conglomerate	0.40	21	0.46	0.28	0.19	Quartz Conglomerate
Oo	Ontelaunee	0.54	10	0.63	0.38	0.26	Dolomite
Cr	Richland	0.53	9	0.61	0.37	0.26	Dolomite
Csb	Snitz Creek and Buffalo Springs, undivided	0.53	6	0.61	0.37	0.26	Limestone
Csc	Snitz Creek	0.53	6	0.61	0.37	0.26	Dolomite
Os	Stonehenge	0.87	1	1.01	0.61	0.42	Limestone

[1]after Gerhart and Lazorchick (1984b) Table 11
[2]after Gerhart and Lazorchick (1984b) Table 2

Accuracy of recharge estimates

The recharge values developed in this report are estimates and, as such, are subject to a number of variables and based on a number of assumptions.

Areal Extent of Geologic Formations: Perhaps the most significant, practical limitation on the accuracy of the recharge estimates is the geologic mapping. Recent high resolution aerial photography reveals outcrop and structural trends that locally diverge from the mapped geology. The recharge estimates for the two groundwater basins would change only if, for example, some of the areas of formations with higher recharge rates were actually lower recharge units. All else being equal, the total recharge for the groundwater basin would increase. However, if the changes in formation areas are random, the increased area with higher recharge rates might be balanced by an increase in area of formations with lower recharge, and the total recharge to the basin would be essentially unchanged. While an exact balance between the changes in area for high and low recharge rate formations is unlikely, a strong imbalance is also unlikely. However, the change in total recharge to the two groundwater basins due to more accurate geologic mapping will only be known after the area is remapped.

Stream Gage Record: The record for the USGS Lancaster stream gage on the Conestoga River is somewhat compromised and does not provide an entirely accurate record or reflection of surface water and base flow responses to year-to-year variation in precipitation for the period of record due to hydrologic changes within the watershed. A stream intake for Lancaster has impacted the most recent half of the gage record. Records of withdrawal amounts are generally unavailable. Estimates based on related factors such as system water use and known withdrawals from other sources suggest a long-term maximum of 1.2 mgd, but with considerable variability. This represents about 1.2 percent of the 1-in-10-year base flow and 1.8 percent of the 1-in-25-year base flow.

The record has also been somewhat compromised by alteration of the landscape brought about by urbanization. The gradual change from a dominantly agricultural landscape to a mixed agricultural-urban landscape has brought about substantial changes in vegetative cover, impervious cover, and the micro-topography that affects drainage and drainage patterns. Studies of the impact of urbanization on the local water budget have generally produced less than clear results. While there is no doubt that impervious cover causes a virtually complete loss of recharge from the covered area, other changes appear to offset much of this loss. These complimentary changes include increased roadside infiltration for roads without curbs, and leakage from water mains and sewage lines.

Climatic Variability: Climatic variability would appear to be taken into account by the relatively long period of record (52 years) for the Lancaster stream gage. This would be true if the year-to-year variation in precipitation was varying about a central (i.e., average) value. If the climate was actually changing, the numerical average would simply be that and would not represent the increasingly wet or dry actual conditions. Climate change can significantly affect the hydrologic cycle (Sophocleous, 2004). Changes in precipitation quantities, when it is received, event intensity, evapotranspiration, and other factors could strongly alter the quantity of water resources available for development. Recent changes in global climate are suggested by the marked shrinkage of alpine glaciers and a rate of sea level rise that is ten times higher than that for the previous three thousand years (Sophocleous, 2004). While accurate records of climate exist for the last hundred years in many parts of the world, there is a lack of detailed knowledge about climatic variation for the Holocene or even the previous two thousand years. A number of paleoclimatological studies (for example, Solc and others, 2005; Linderholm and Chen, 2005; Van Beynen and others, 2004; Brown and others, 2000) suggest significant variability from the centennial and decadal scales to hundreds of years.

Groundwater resource availability

The formation-specific annual recharge rates for the 1-in-2-year, 1-in-10-year, and 1-in-25-year recurrence intervals were applied to the aerial extent of the study area and to the Manheim-Lititz and Ephrata area groundwater basins (Table 4).

Table 4. Water Availability in Million Gallons per Year for the Study Area and Select Sub-Areas

Area of Interest	*1-in-2 Year*	*1-in-10 Year*	*1-in-25 Year*	*Sqmi*
Manheim-Lititz Basin	5,822	3,531	2,449	21.79
Ephrata Area Basin	11,676	7,077	4,917	48.36
Total Study Area	17,498	10,608	7,366	70.15

Passby requirement

When the total withdrawal from a groundwater basin or local subbasin exceeds 10 percent of the lowest flow for 7 consecutive days in 10 years (Q7-10), the Commission, in coordination with the Commonwealth of Pennsylvania, may impose a passby requirement in order to protect aquatic habitat during periods of low flow. A passby flow is a prescribed quantity of flow that must be allowed to pass a prescribed point downstream from an intake at any time during which a withdrawal is occurring. When the natural flow is equal to, or less than, the prescribed passby flow, no water may be withdrawn from the water source, and the entire natural flow shall be allowed to pass the point of withdrawal. Passby flows may be associated with the Commission's surface water and groundwater withdrawal approvals.

The passby requirement triggers for a stream classified as a *warm water fishery*, when the flow falls below 20 percent of the average daily flow. At that time, withdrawals must cease and waters be allowed to "pass by" the point or area of taking, or the flow could be augmented with a release of water equal to the rate of withdrawal. Discharge of wastewater upgradient of or adjacent to groundwater withdrawals would largely mitigate this impact.

Groundwater withdrawals in the Ephrata area groundwater basin have not exceeded 10 percent of the Q7-10 for Cocalico Creek as it leaves the carbonate valley (Figure 12). However, most of the existing groundwater withdrawals are located in the southern half of the basin, and are potentially mitigated by the discharge from the Ephrata area wastewater treatment plant. However, future withdrawals could trigger the passby requirement in one of the subbasins. This can be avoided by locating wells in downstream areas where the Q7-10 flow is higher.

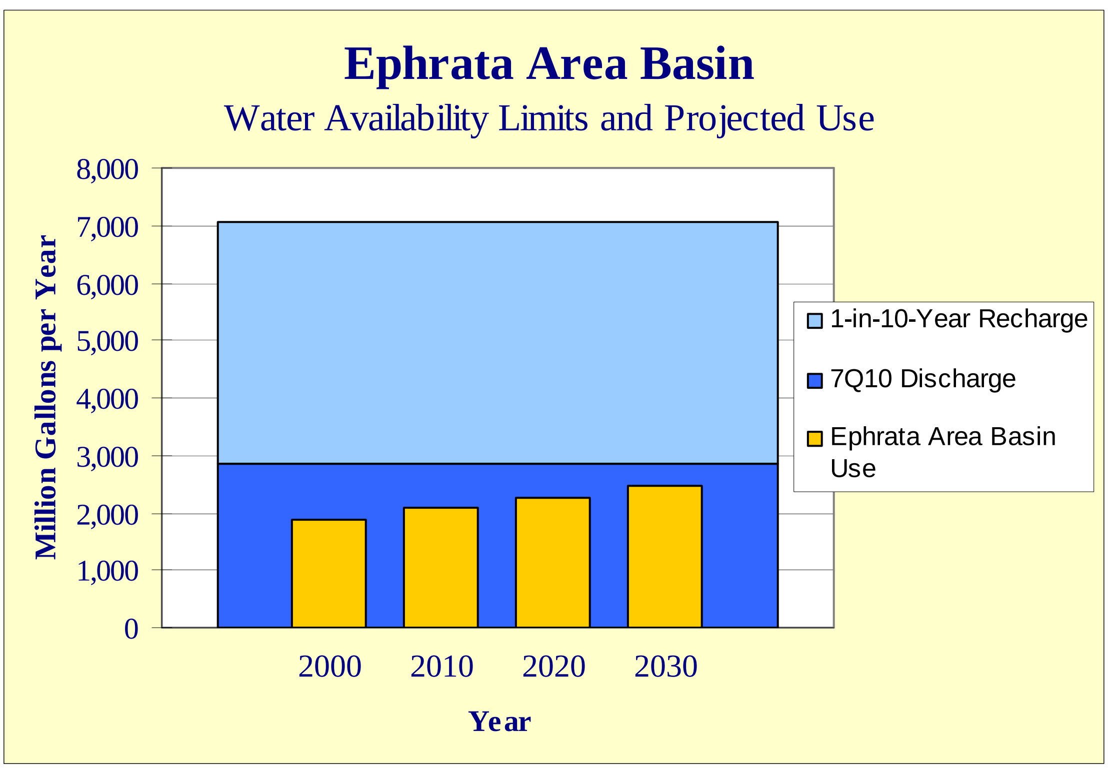

Figure 12. ***Current and Projected Water Use, Q7-10 for Cocalico Creek as it Leaves the Carbonate Valley, and the 1-in-10-Year Commission Withdrawal Limit***

Groundwater withdrawals in the Manheim-Lititz groundwater basin have exceeded the Q7-10 for the surface water flow (combined flow from Chiques Creek and Lititz Run) as it leaves the carbonate valley (Figure 13). However, most of the existing groundwater withdrawals are located in the southern half of the basin, and are compensated for by the discharge from the Manheim and Lititz wastewater treatment plants. Future withdrawals located in the northern half of the basin could trigger the passby requirement. The passby requirement can be avoided by locating wells in downstream areas where the Q7-10 flow is higher.

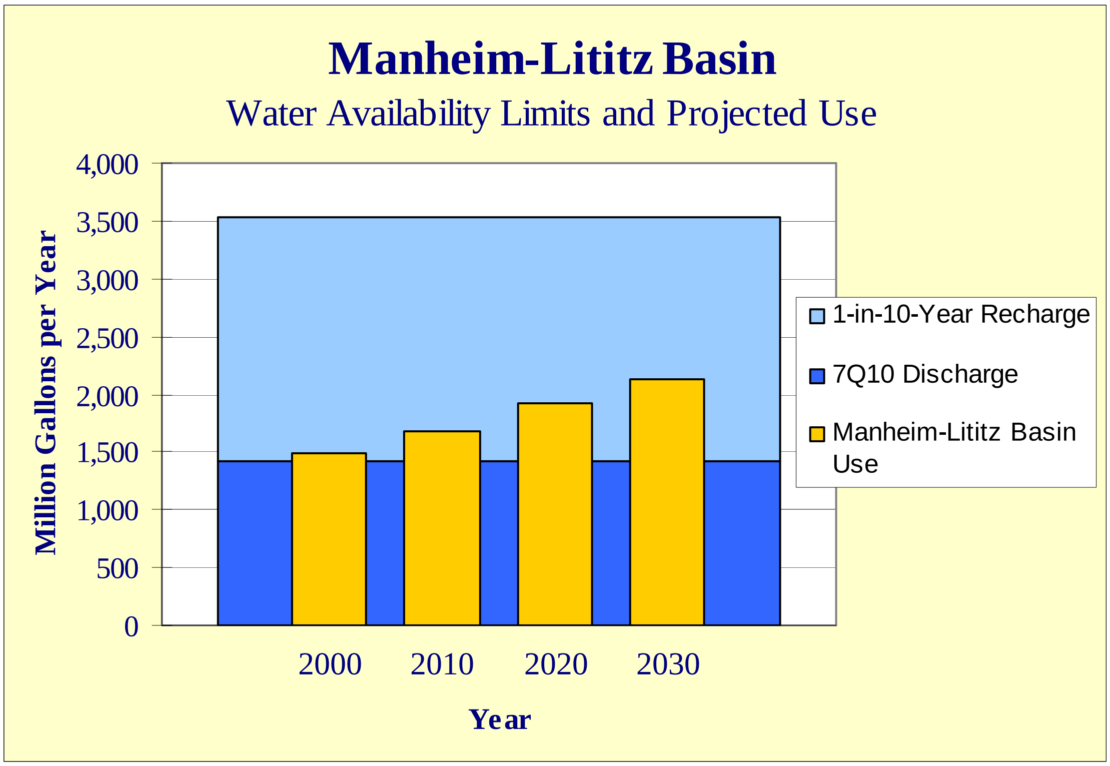

Figure 13. Current and Projected Water Use, Q7-10 for the Combined Flow of Chiques Creek and Lititz Run as it Leaves the Carbonate Valley, and the 1-in-10-Year Commission Withdrawal Limit

WATER USE

Information Sources and Methodology

The availability, reliability, and detail of water use information vary widely. Water use data in this report are based on several information sources, which were cross-referenced to obtain the most recent information on water use and specific withdrawal locations. The Commission developed a water use database for this study. Each record includes a reference to the data source.

The Water Use Data System (WUDS) initially developed for the Pennsylvania State Water Plan in the mid-1970s (PADER, 1975) and Ground Water Information System (DCNR,

2004) provided the base upon which the water use database was populated for this study. The annual water supply reports from 1998 through 2002 were reviewed and considered the most reliable source of public supply water use information.

The Commission's Project Review Database contains information on nonagricultural water users (public, industrial, and commercial) capable of withdrawing more than 100,000 gallons per day (gpd) on a 30-day average. This database provides an approved allocation and use summaries submitted on a quarterly basis, and is considered to be a reliable source of information.

Nonpublic water uses under 100,000 gpd on a 30-day average are based on WUDS unless more recent information was available.

During the course of the study, Pennsylvania enacted the Water Resources Planning Act (Act 220). Act 220 requires users of 10,000 gallons a day or more to register and then periodically report their water use to the Pennsylvania Department of Environmental Protection (PADEP). The Commission entered into an agreement (Memorandum of Understanding [MOU]) with PADEP to exchange the data collected. Any user's registration with PADEP satisfies the Commission's registration regulation. The Commission reviewed information from PADEP and updated the project database where appropriate.

The data on agricultural water uses are less reliable. The total estimated use for this sector is thought to be significantly underestimated. In 1998, the Commission initiated an agricultural water use registration program to obtain better water use information for the agricultural sector. While some results were obtained for individual operations, reviews of these records indicate estimates are less accurate than the information available for other sectors. Also, locations of groundwater withdrawals are approximated by address location.

The data presented in this report have several qualifications:

1. Withdrawals are reported on the basis of the location of the withdrawal point, not where the water is used.
2. Domestic use from non-serviced areas is based on census block data adjusted to the non-service area of the census block, and a per capita rate of 65 gpd.
3. Water withdrawn from groundwater is not equivalent to water consumed. Some water reenters the surface water system via treated discharge facilities.
4. The import of water from wells outside the study area is minimal.

Groundwater withdrawals were grouped into six categories or use sectors: Agriculture (AGR), Industrial & Commercial (IND), Mining (MIN), Public Supply (PWS), Product Incorporation (PRO) such as bottling, and Domestic (DOM) use (private wells). The withdrawal data were compiled from a series of information sources representing use over a period of years. The distribution of major groundwater withdrawals is shown on Figure 14.

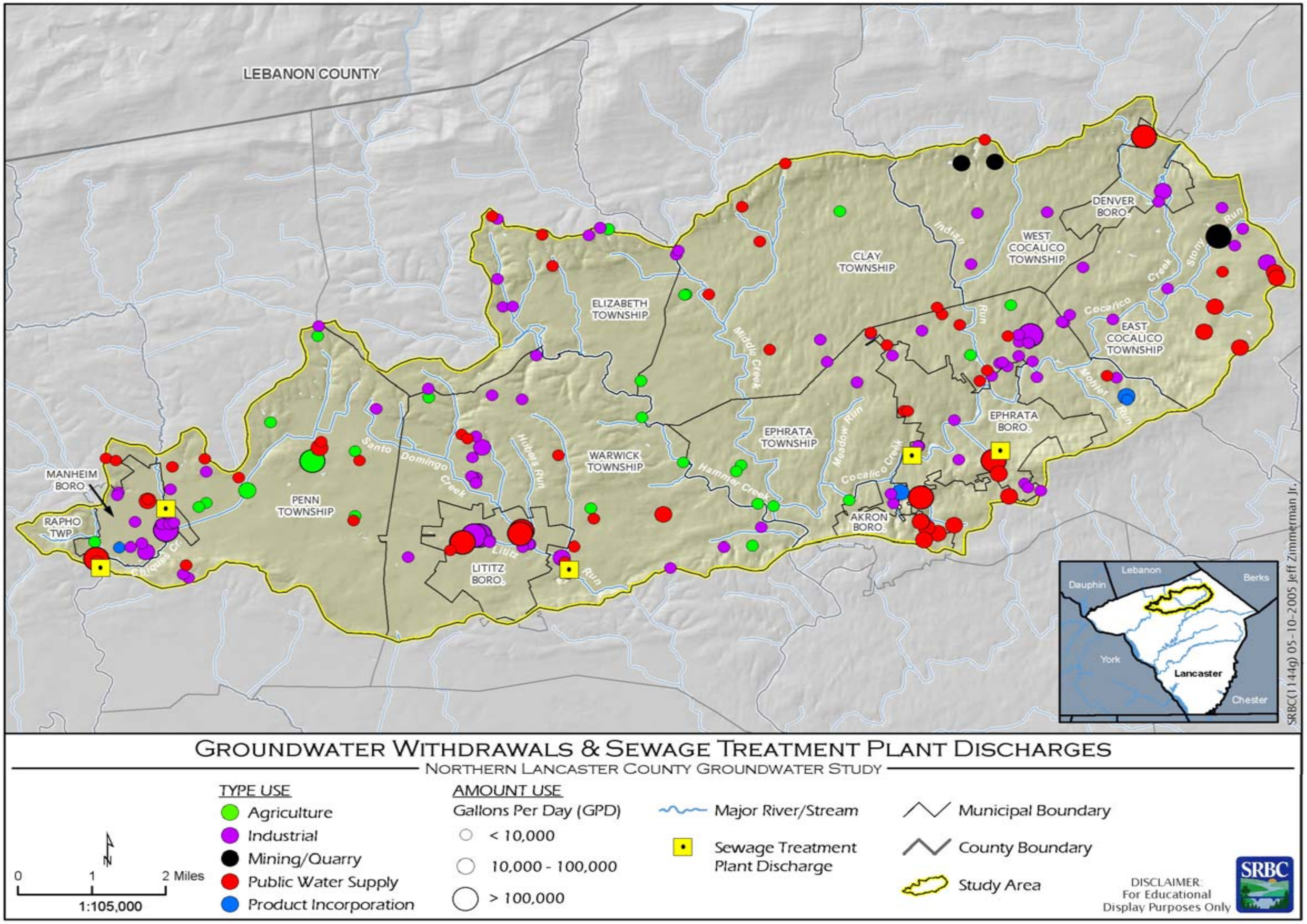

Figure 14. Major Groundwater Withdrawals

Table 5 presents the most recent data reported and results should be considered as an annual average for year 2000. The total use statistic is an estimate of current average annual use. The total allocated groundwater withdrawals in each basin includes both existing withdrawal amounts plus approved but unused amounts.

Year 2000 Water Use and Allocated Water vs. Resource Availability

The total estimated quantity of groundwater used in the year 2000 by all sectors in the study area is 2,990 million gallons per year (mgy) or an average of 8.2 mgd. When allocated amounts are considered, potential annual groundwater use is 4,896 million gallons or an average 13.4 mgd. Table 5 presents the annual use for defined sub-areas within the study area.

The public water supply sector is the largest user at 1,549 mgy or 4.2 mgd. This represents 52 percent of the total groundwater withdrawal in the study area. Based on the 2002 census and location of water service areas, approximately 75 percent of the population (45,765 persons) is served by public supply systems.

The year 2000 resident population not served by public systems, supplied by private wells was estimated at 15,320. Based on literature values, per capita water use ranges from 55 gpd in Pennsylvania to 70 gpd in Maryland (Van der Leeden and others, 1990). Pennsylvania's Act 57 states that water authorities can use a value of 65 gpd in designing facilities. Using that value, an estimate of the annual domestic water use is 363 million gallons (approximately 1 mgd) or 12 percent of the total groundwater use in the study area.

The second largest use sector is industry and commercial, with an average annual use of 523 millions gallons (1.4 mgd) or 17.5 percent of the total use in the study area.

Table 5. Groundwater Withdrawals in Million Gallons per Year for Select Areas

Area of Interest	***AGR***	***IND***	***MIN***	***PWS***	***PRO***	***DOM***	***Total Use***	***Total Allocated Use***
Manheim-Lititz Basin	106	356	0	890	0	141	1,493	2,478
Ephrata Area Basin	25	167	388	659	36	222	1,497	2,418
Total Study Area	131	523	388	1,549	36	363	2,990	4,896

AGR – Agriculture
IND – Industrial & Commercial
MIN – Mining
PWS – Public Water Supply
PRO – Product Incorporation (e.g., Bottling)
DOM – Domestic Use on Private Wells

The annual average recharge estimate was 17,498 mgy (Table 6) or 47.9 mgd. The current 2000 use and total allocated use represent 17 percent and 28 percent of the groundwater available during a normal year. However, recharge variability, groundwater withdrawal locations, and the size of the contributing areas are factors in determining groundwater availability.

Table 6. Current and Allocated Groundwater Demand, Resource Availability, and Utilization Level

Area of Interest	Total Use (mgy)	Allocated Use (mgy)	1-in-2 Year	1-in-10 Year	1-in-25 Year	Utilization Level (percent)
Manheim-Lititz Basin	1,493	2,478	5,822	3,531	2,449	70
Ephrata Area Basin	1,497	2,418	11,676	7,077	4,917	34
Total Study Area	2,990	4,896	17,498	10,608	7,366	46

Groundwater storage declines during times of drought and recovers during years of normal or above normal precipitation. The Commission has defined the sustainable limit of a watershed as the amount of recharge that occurs during a 1-in-10-year annual drought. For practical purposes, this value is considered the 1-in-10-year annual base flow. The selection of the 1-in-10-year annual drought recharge attempts to balance the amount of groundwater available for development, instream flow needs, and required reservoir or tank storage capacity.

As part of the regulatory review process of large groundwater withdrawals, the Commission identifies potentially stressed areas (PSAs) by evaluating several criteria. Criteria may include expanded dry stream reaches, diminishing stream or spring flows, and declining water levels. Another criterion is where known withdrawals for rapidly developing areas exceed 50 percent of the 1-in-10-year annual drought recharge. This provides a "milepost" where decision-makers should begin to consider taking additional steps to manage the resource.

Existing water withdrawals plus currently allocated unused quantities were identified and totaled for each groundwater basin, as well as the total study area. These total allocated withdrawals were compared with the 1-in-10-year recharge to assess if the utilization level exceeded 50 percent of the 1-in-10-year recharge (Table 6).

The allocated groundwater use of 4,896 million gallons (13.4 mgd) for the entire 70-square-mile study area is 46 percent of the 1-in-10-year annual drought recharge of 6,226 million gallons (17.1 mgd). The initial assessment indicates that the region has an adequate water supply.

The allocated groundwater use of 2,418 million gallons (6.6 mgd) for the 48.4-square-mile Ephrata area groundwater basin is 34 percent of the 1-in-10-year annual drought recharge of 7,077 million gallons (19.4 mgd). The initial assessment indicates that the region has an adequate water supply.

The allocated groundwater use of 2,478 million gallons (6.8 mgd) for the 21.8-square-mile Manheim-Lititz groundwater basin is 70 percent of the 1-in-10-year annual drought recharge of 3,531 million gallons (9.7 mgd). The initial assessment indicates that the region has an adequate water supply, but is approaching the Commission's allocation limit. The largest use sector in the Manheim-Lititz groundwater basin was public water supply using 890 mgy. A significant increase in public water use was due in part to a population growth of 33 percent in

Warwick Township from 1990 to 2000. New developments in the area are expected to increase public supply needs and continue the population trends.

Projected Water Demand vs. Availability

Projection Method: Population estimates in Table 7 were determined using year 2000 census block data and applying geographic information systems (GIS) techniques. The total population estimate was based on a sum of population values for each year 2000 census block located within the study area boundary. Similarly, the total population on public water supply was determined by overlaying the public service area boundaries in the study area with the 2000 census block data. The 2000 base population in the study area was 61,085, with nearly 75 percent (45,765) of the population being served by public water systems.

Table 7. Projected Annual Water Use in Million Gallons per Year and Population of the Study Area and the Ephrata Area and Manheim-Lititz Groundwater Basins, 2000-2030

Use Sector	2000	2010	2020	2030
AGR	131	153	175	197
IND	523	569	616	660
MIN	388	388	388	388
PWS	1,941	2,283	2,657	3,047
PRO	36	40	44	49
DOM	363	320	263	190
Total	**3,382**	**3,753**	**4,143**	**4,531**
Population on PWS	45,765	53,920	62,762	71,975
Population on private wells	15,320	13,480	11,076	7,997
Total Population	**61,085**	**67,400**	**73,838**	**79,972**
Ephrata Area Basin				
AGR	25	29	33	38
IND	167	182	197	211
MIN	388	388	388	388
PWS	1,051	1,236	1,439	1,650
PRO	36	40	44	49
DOM	222	196	161	116
Total	**1,889**	**2,070**	**2,261**	**2,452**
Population on PWS	28,087	33,092	38,518	44,173
Population on private wells	9,362	8,238	6,769	4,887
Total Population	**37,449**	**41,329**	**45,287**	**49,060**
Manheim-Lititz Basin				
AGR	106	124	142	159
IND	356	387	419	449
MIN	0	0	0	0
PWS	890	1,047	1,218	1,397
PRO	0	0	0	0
DOM	141	124	102	74
Total	**1,493**	**1,677**	**1,881**	**2,132**
Population on PWS	17,678	20,828	24,244	27,802
Population on private wells	5,958	5,242	4,307	3,110
Total Population	**23,636**	**26,071**	**28,551**	**30,912**

Population projections for years 2010, 2020, and 2030 were based on Lancaster County Planning Commission's preliminary population projections for Lancaster County and municipalities (Table 8) (Lancaster County Planning Commission, 2002). Population estimates by municipality within the study area were totaled, and the percent increase in population each decade was applied to the 2000 base population of 61,085.

Table 8. Population Projections for Municipalities in or Partially in the Study Area (modified after Lancaster County Planning Commission, 2002)

Municipality	2000 Census	2010 Projection	2020 Projection	2030 Projection
Akron Borough	4,046	4,244	4,432	4,588
Clay Township	5,173	5,762	6,357	6,918
Denver Borough	3,332	3,666	3,990	4,283
East Cocalico Township	9,954	11,291	12,653	13,961
Elizabeth Township	3,833	4,386	4,961	5,523
Ephrata Borough	13,213	14,010	14,771	15,422
Ephrata Township	8,026	9,284	10,606	11,931
Lititz Borough	9,029	9,483	9,913	10,270
Manheim Borough	4,784	4,648	4,521	4,391
Penn Township	7,312	8,151	9,017	9,849
Rapho Township	8,578	9,355	10,132	10,844
Warwick Township	15,475	18,084	20,828	23,586
West Cocalico Township	6,967	7,668	8,359	8,989
Total	**99,722**	**110,032**	**120,540**	**130,555**
Percent Increase	—	10.3	9.5	8.3
Study Area Total	**61,085**	**67,400**	**73,837**	**79,972**

For the public water supply sector, the average daily water use per resident of 116 gpd was determined from the total annual use estimate of 1,941 mgy (total groundwater withdrawal for public water supply of 1,549 mgy [Table 5] plus surface water withdrawals of 392 mgy from the Ephrata [1.0 mgd] and Denver [0.075 mgd] systems) and a population of 45,765 serviced by public water systems. The public water supply includes residential, institutional, commercial, and industrial use from these public systems. With the expected growth in public system service areas, the percent of the population served also should increase. For the succeeding years of 2010, 2020, and 2030, the percent of population served by public systems in the study area was assumed to be 80, 85, and 90 percent, respectively. Based on the expected growth of service areas, the assumption was made that some private domestic users will convert to public supplies.

Based on the findings of a 1994 Lancaster Water Systems Study noted in the Lancaster County Water Resources Plan (LCWRP) (Lancaster County Water Resources Task Force, 1996), the projected new industrial water use was determined by a per capita multiplier of 19.84 gpd for existing industrial water use not on public systems. The projected increase represents the water demand for self-supplied industries.

While the area of agricultural land may be expected to decrease with increasing land development, every indication points to continued growth of intensive animal operations. The LCWRP stated that growth in intensive animal operations during the last few decades has been accompanied by a doubling of total water use for livestock. Jarrett and Hamilton (2002) estimated agricultural consumptive water use for farm animals and irrigated crops in the lower Susquehanna River Basin, and reported a 41.7 percent increase in agricultural animal consumptive water use from 1970 to 2000 and a 19.7 percent increase from 2000 to 2025. Jarrett and Hamilton (2002) based their estimates on the Census of Agriculture county data. The latter rate of increase from 2000 to 2025 translates to a 25 percent increase over a 30-year period from 2000 to 2030. While these estimates were an average for several counties, it is reasonable to expect higher water use estimates for Lancaster County due to a higher number of farm animals as compared to other counties in the area.

Based on information presented in the LCWRP and Jarrett and Hamilton (2002) report, a 50 percent increase was applied to the 2000 agricultural water use value to obtain the 2030 agricultural water use. Water use estimates for the intervening periods were incrementally increased.

Mining operations are expected to continue at a constant rate and no new mining operations are expected in the study area. Therefore, water use from the mining sector is expected to remain constant.

Water bottling operations are expected to increase in the Susquehanna River Basin as a whole, and also in the study area, in response to market demands. In 1986, Pennsylvania ranked in the top 10 states for the consumption of bottled water in the United States (Van der Leeden and others, 1990). The Beverage Marketing Corporation indicated that bottled water was the fastest growing major beverage segment in the United States, increasing 7.5 percent in 2003 (Bottle Water Store, 2004). From 1991 to 1996, the Beverage Marketing Corporation provided growth statistics for non-sparkling water consumption by distribution sector (Van der Leeden and others, 1990). They reported growth rates of 4.0 percent, 4.8 percent, 5.0 percent, and 10.1 percent in the commercial, home, vending, and retail distribution sectors. These values translate to an annual growth rate of one to two percent.

Based on general information from industry sources, an increase of one percent per year was applied to the current use for water bottling withdrawals in the study area.

Projection Results: The projected water demand estimates in Table 7 were compared to groundwater availability presented in Table 6. Table 7 presents the projected water use demand by use sector and population for the study area. For comparison purposes, results from the LCWRP and linear interpolation of those results for future years are presented in Table 9. Discussion of projected demand is based on Table 7 results.

Table 9. Projected Water Use in Million Gallons per Year and Population Based on Lancaster Water Resources Plan

Use Sector	1990[1]	2000[2]	2010[1]	2020[2]	2030[2]
RICO[3]	1,836	2,319	2,801	3,284	3,766
Industrial	214	306	399	491	584
Total	**2,050**	**2,625**	**3,200**	**3,775**	**4,350**
Population	51,527		77,639		

[1]1990 and 2010 based on Table III-1 Lancaster County Water Resources Plan (Lancaster County Water Resources Task Force, 1996)
[2]2000, 2020, and 2030 projection based on linear trend of 1990 and 2010 data
[3]RICO defined as residential, institutional, commercial, and other.

For the 70-square-mile study area, the projected increase in water use based on Table 7 estimates from 2000 to 2030 is 1,149 mgy (3.1 mgd). This represents a 34 percent increase and a total annual use of 4,531 mgy (12.4 mgd) by the year 2030. The projected 2030 annual use estimate is less than 50 percent of the 1-in-10-year annual recharge of 5,304 mgy (14.5 mgd). In addition, the total allocated use of 4,896 mgy (13.4 mgd) exceeds the 2030 projected annual use estimate. This suggests that the available supply will meet the 2030 projected demand over the entire 70-square-mile area. However, increases in withdrawals may cause adverse local impacts.

Unused surface water system capacity could meet part of the projected demand. This capacity is the difference between the surface water allocation and average use. In the study area, the Pennsylvania Source Water Assessment Program identified two public water systems operating surface water facilities: Ephrata Area Joint Authority and Denver Borough Water Authority. Ephrata Area Joint Authority is allocated 1.0 mgd from the Cocalico Creek; however, withdrawals averaged nearly 1.0 mgd from January to June in 2002 (Susquehanna River Basin Commission, 2003a). Denver Borough Water Authority is allocated 300,000 gpd, but on average withdraws between 50,000 and 75,000 gpd (Susquehanna River Basin Commission, 2003b). The estimated potential surface water available from the Denver Borough Water Authority is 82 mgy (0.23 mgd). Considering the current system capacity of these two surface sources, the net projected groundwater demand for public water supply in the Ephrata area groundwater basin by 2030 is 517 mgy.

CRITICAL AQUIFER RECHARGE AREAS

Recharge occurs wherever the land surface is pervious and the water table is below the surface. However, some areas are characterized by features or attributes that provide an exceptional amount of replenishment (recharge) to the aquifer per unit area, and are herein termed critical aquifer recharge areas (CARAs). Four CARAs were identified in the course of this study.

Dry Valleys

Dry valleys occur throughout the carbonate valley. They consist of an integrated network (drainage net) of broad valleys that lack streamflow or even discrete stream channels, and resemble a surface drainage net. These valleys were abandoned (perennial streamflow ceased) when karst permeability in the underlying carbonate bedrock underdrained the valley, lowering the water table to the level of the solutional openings and leaving the surface streams deprived of base flow.

The valleys have been further modified by differential solution of the underlying carbonate bedrock, resulting in wider, subtly depressed areas over more soluble bedrock formations. During major precipitation and meltwater events, water floods the broad valley floor depressions and spills from pool to pool. As the amount of water delivered to the valley declines, continuous surface water flow breaks up into a series of shallow pools. The pooled water may be present for a period of days to weeks. The pools gradually diminish in area as the water evaporates and percolates to the water table. Use by plants (evapotranspiration) may be significant if the pooling occurs during the growing season, and the existing plants are adapted to saturated soil conditions.

The dry valleys are thought to contribute an exceptional amount of recharge because the underlying bedrock has greater karst permeability (more voids and conduits), the water table is below the land surface so that head conditions are favorable to recharge, and the surface runoff covers a large surface of absorption while pooled water is present. Although the rate of percolation for these soils is not exceptionally high (i.e., the soils are not well drained), percolation occurs over an extended period of time and over a large surface area due to the pooling of surface water. The pooling allows some of the rejected recharge (i.e., surface runoff) from surrounding uplands to percolate to the water table.

The larger dry valleys have been identified (Plate 1) and three major dry valley systems have been informally named: the Limerock Dry Valley System is located between Manheim and Lititz and has a surface water collection area of over 3 square miles; the Weidmanville Dry Valley System is located northwest of Ephrata and has a surface water collection area of over 2.5 square miles; and the Stevens Dry Valley System has a surface water collection area of over 2 square miles.

Losing Stream Reaches

Streams flowing over an underdrained carbonate terrain are typically perched on low permeability carbonate residuum (orange-brown silty clay) over much of their length and have minimal flow loss to the aquifer. However, where the channel crosses a stratigraphic horizon with well-developed karst conduits and a hydraulically efficient connection between the stream and the aquifer is present, streamflow is lost to the aquifer. A number of losing stream reaches were bracketed by the streamflow measurement stations. The actual losses were only a small fraction of the total streamflow for larger streams, but were a substantial fraction of the total flow for smaller streams. Losses ranged from a few tenths of a cubic foot per second for small streams to several cubic feet per second for the larger streams. Streamflow measurement locations and losing reaches are shown on Figure 8 and Plate 1. Measured flows are shown in Appendix A.

Siliciclastic to Carbonate Stream Crossings

Stream water draining siliciclastic terrains is generally acidic due to the lack to soluble buffering compounds in the rock. When streams with acidic water emerge onto a carbonate terrain that is underdrained, the acidic water may percolate through the streambed and valley floor alluvium, past the root zone and into the underlying carbonate bedrock aquifer. The seasonal to continuous supply of acidic water produces enhanced karst permeability beneath the percolation area, which may extend for some distance downgradient from the siliciclastic to carbonate crossing. This represents an increase in the amount of water in the carbonate basin above that derived from the recharge of local precipitation. This same process occurs to some degree all along the non-carbonate-carbonate contact, where local groundwater flow from the higher, non-carbonate terrain flows into the carbonate valley. However, it is more important at perennial stream crossings where recharging streamflow substantially augments the local groundwater flow from the non-carbonates.

Karst Modified Uplands

The broad uplands between the major stream valleys (see Plate 1) are inferred to have solution-enhanced permeability based on the occurrence of numerous small, shallow depressions. These depressions have dimensions similar to active sinkholes in the study area and have been interpreted as dormant sinkholes (Kochanov, 1990). While some of these may be of non-karst origin (i.e., pseudo-karst), the abundant carbonate bedrock pinnacles in these areas strongly suggest the presence of solution-enhanced permeability. The upland setting provides aquifer porosity for the storage of recharging water that is higher in elevation than local groundwater discharge areas, an essential characteristic for a recharge area.

WATER QUALITY

The amount and rate of precipitation, soil and rock composition, and the influence of human activities, such as the use of fertilizer and disposal of wastes and sewage, are all factors that influence the chemical quality of surface water and groundwater. The amount and type of dissolved mineral matter found in stream water are determined largely by the composition of the soil and rock through which water flows in its path to the stream.

In order to evaluate water quality within the study area, water samples were obtained from 65 wells and springs, and 70 stream sites during the spring and fall of 2004 (Appendix B).

Specific Conductance

Specific conductance of water depends on the amount and nature of its dissolved solids. Differences in the mineral composition of each geologic formation influence the amount of dissolved solids in that aquifer. Higher than normal values in isolated areas may be indicative of groundwater contamination.

Specific conductance of 65 groundwater samples ranged from 231 to 1,623 micromhos with 4 samples exceeding 1,000 micromhos. The median value was 684 micromhos. Figure 15 is a map showing the spatial distribution of specific conductance. Groundwater having high specific conductance (greater than 600 micromhos) is typical of groundwater in the carbonate valley. In the non-carbonate areas such as the Cocalico Formation and the Triassic sandstones and conglomerates, specific conductances below 600 micromhos predominate. Specific conductances of over 1,000 micromhos occur in the eastern portion of the Ephrata area groundwater basin.

Specific conductance of 61 stream samples ranged from 174 to 735 micromhos, with a median value of 407 micromhos. Surface water samples from Cocalico Creek upstream of Ephrata and streams flowing from upgradient, noncarbonate watersheds had low specific conductance (less than 300 micromhos). Specific conductances higher than 300 micromhos were scattered among the stream sites in the carbonate valley. With few exceptions, specific conductances higher than 500 micromhos predominate in the more populated areas.

Nitrate

Nitrogen is naturally a very abundant element found in air and water. However, high concentrations in the form of nitrate in water are indicative of contamination. Nitrate in well water may result from point sources such as sewage disposal systems and livestock facilities, and from non-point sources such as fertilized cropland, parks, golf courses, lawns, and gardens.

Nitrate concentrations of 64 groundwater samples ranged from 0.3 to 33.95 milligrams per liter (mg/l), with a median value of 9.08 mg/l. Figure 16 is a map showing the spatial distribution of nitrate-nitrogen sampling points and the measured values above and below safe drinking water standards. Groundwater having nitrate concentrations exceeding 10 mg/l is scattered throughout the study area, indicating that potential nitrate contamination of new water supplies is a significant concern.

For the 64 groundwater samples, nearly 47 percent of the nitrate concentrations exceeded the Environmental Protection Agency (EPA) drinking water limit of 10 mg/l. According to EPA, water containing more than 10 mg/l nitrate as nitrogen is potentially dangerous to infants, causing a blood disorder called methemoglobinemia. This blood disorder is caused by the interaction of nitrate with the hemoglobin in red blood cells, reducing the amount of oxygen carried to the body's cells. While rare among adults, the "blue-baby" syndrome has been reported among infants, where nitrate-contaminated well water was used to prepare formula and other baby foods.

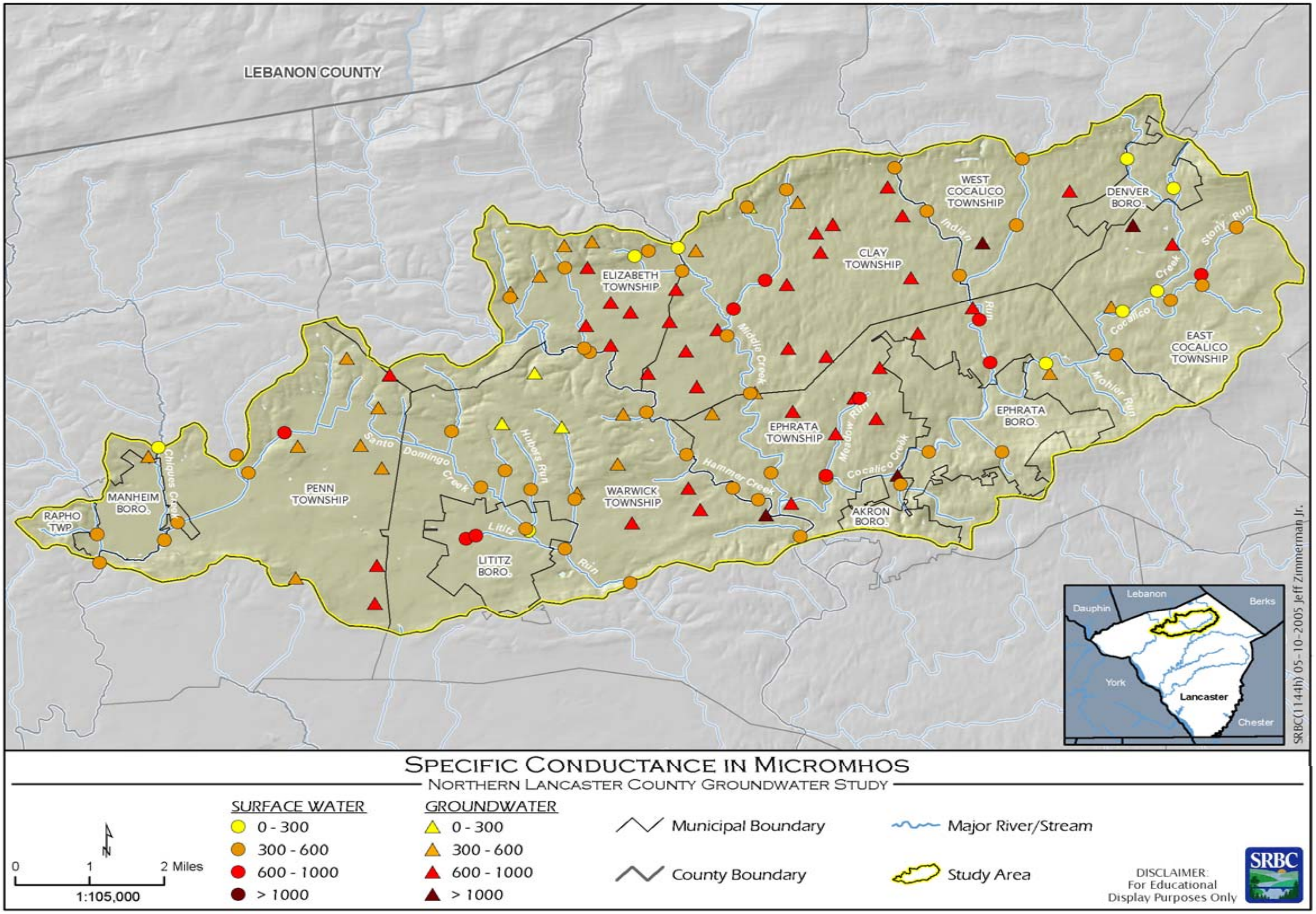

Figure 15. Spatial Distribution of Specific Conductance in Micromhos in the Study Area

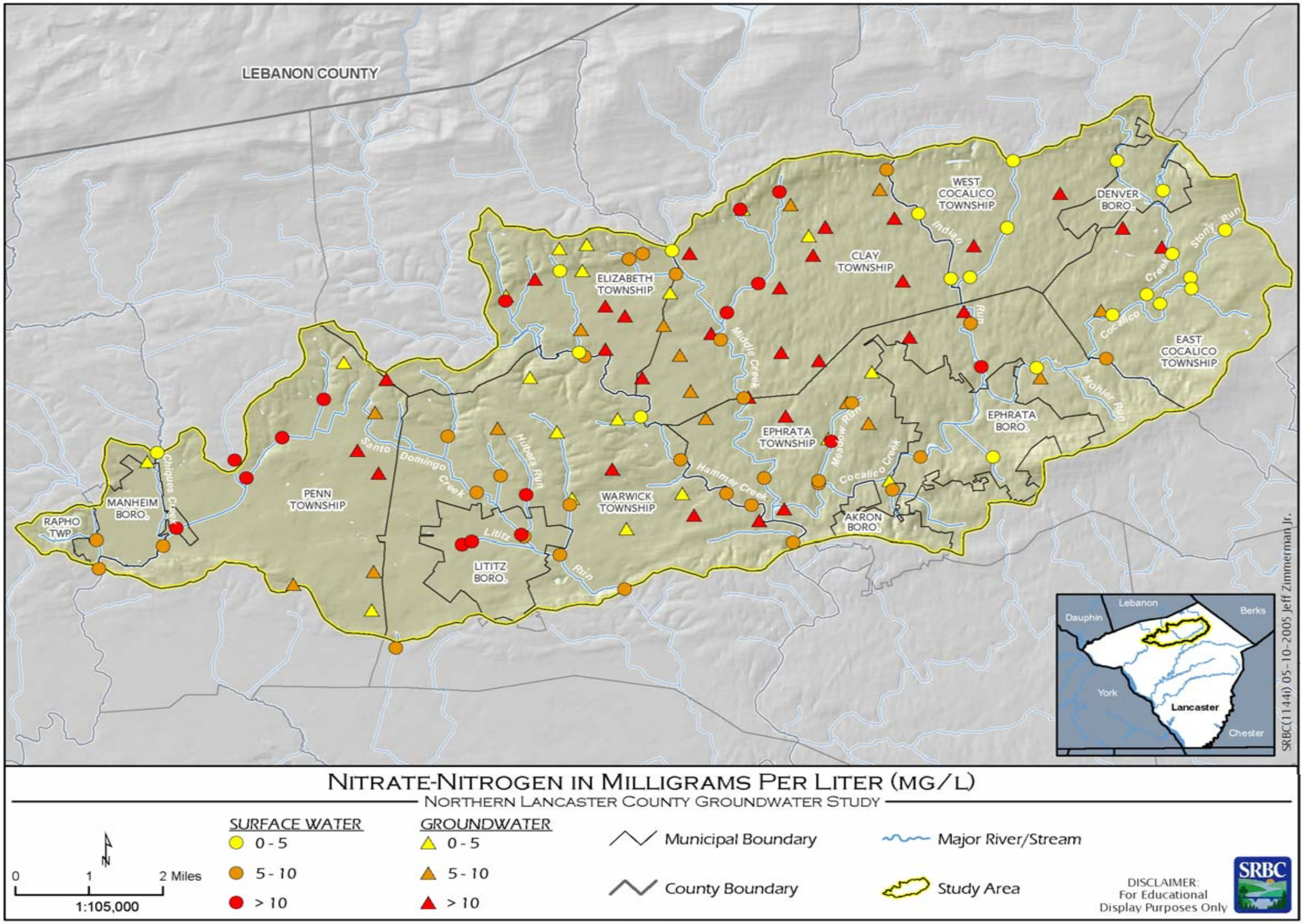

Figure 16. Spatial Distribution of Nitrate-Nitrogen in Milligrams per Liter in the Study Area

Nitrate concentrations in 70 stream samples ranged from 0.7 to 18.25 mg/l, with 23 percent exceeding the EPA drinking water limit of 10 mg/l. The median nitrate concentration in stream water was 6.58 mg/l. Spatially, the lowest nitrate concentrations (less than 5.0 mg/l) were located along Cocalico Creek and its tributaries upstream of Ephrata. West of Ephrata, stream nitrate concentrations greater than 5.0 mg/l predominate. Stream reaches where nitrate concentrations exceeded 10 mg/l include: (1) Doe Run, a tributary of Chiques Creek in Penn Township; (2) the upper reach of Lititz Run and the lower reach of Santo Domingo Creek in Lititz Borough; (3) tributary of Middle Creek, flowing south from Durlach; and (4) the lower reach of Indian Run, downstream of Springville.

WATER RESOURCE MANAGEMENT RECOMMENDATIONS

Management

The Commission, the Commonwealth of Pennsylvania, and other agencies and levels of government have a range of regulations, programs, policies, and options that influence and control water resources management in the study area. In particular, the Commission and PADEP have regulations that govern water withdrawals and use. At the local level, counties and municipalities can guide land use and growth. Local ordinances and land use regulations can help protect water quality and enhance water availability.

The Commission

The mission of the Commission is to achieve a balance among environmental, human, and economic needs. In its regulatory program, the Commission strives to:

1. Manage water as a sustainable/renewable resource;
2. Avoid conflicts among water users;
3. Protect public health, safety, and welfare;
4. Foster economic development; and
5. Protect fisheries, aquatic habitat, and the environment.

Some of the elements of its regulatory program and water management policies are described below.

Registration: The Commission adopted water withdrawal registration regulations to document water use throughout the basin and provide the necessary data to make informed water management decisions. Registration is important to the Commission’s regulatory activities because it provides basic water use data, thereby allowing the Commission to protect existing uses. Information on water use is important for other Commission water management activities, including preparation of water budgets.

Regulation of Groundwater Withdrawals: The Commission adopted withdrawal regulations to manage large water withdrawals (in excess of 100,000 gpd, or 20,000 gpd if used consumptively) in order to avoid conflicts between users and to ensure beneficial management of the water resources. By regulation, withdrawals are limited to the amount (quantity and rate) that is needed to meet the reasonably foreseeable needs of a project and that can be withdrawn without causing adverse impacts. The Commission's application process has a number of standard criteria that are applied to all projects. These include a constant-rate pumping test, metering, monitoring and reporting, mitigation of adverse impacts, water conservation, and a docket reopener provision.

Commission staff formulates specific recommendations so that the project can operate without causing any undesirable environmental effects. Water quantities and rates of withdrawal can be reduced from those requested or otherwise limited, as necessary, to protect other uses or mitigate impacts. Many projects are conditioned with instream passby flow requirements or a minimum groundwater level that must be maintained in the production well.

Compliance Monitoring and Enforcement: The Commission's objective is to have all water users in the basin in compliance with water management regulations in order to properly manage the basin's water resources. The Commission requires certain monitoring data to be submitted for approved projects.

Passby Flows: The Commission utilizes passby flows, conservation releases, and consumptive use compensation to help protect aquatic resources, competing users, and instream flow uses downstream from the point of withdrawal. Additionally, these requirements are intended to prevent water quality degradation and adverse lowering of streamflow levels downstream from the point of withdrawal.

Protected Areas: The Commission's Compact allows for the creation of protected areas in regions of water shortage within the basin. According to the Compact, protected areas are intended to correct, mitigate, and manage local area water supply shortfalls or threatened shortfalls on a quantitative basis. Protected areas may be managed to limit groundwater withdrawals, surface water withdrawals, both groundwater and surface water withdrawals, and cumulative consumptive water uses. To date, the Commission has not exercised its protected areas authority, but could do so if needed.

Water Conservation: A requirement to institute appropriate water conservation measures is included, by regulation, for any project that is subject to Commission approval. A number of specific requirements apply to public water suppliers (source and customer metering, unaccounted-for water to be less than 20 percent, an appropriate rate structure, etc.). The regulations do not include specific conservation measures for other water users. Incentives for promoting conservation measures and implementing technical solutions may also be considered by the Commission.

Water Reuse: Groundwater used by municipalities and industries is typically treated and discharged to a stream. The quality of treated water is generally quite good and is potentially usable for many non-potable uses. The reuse of treated wastewater may allow the water budget to be "stretched" in areas of rapid growth and limited water resources.

Conjunctive Use: The availability of groundwater and surface water resources frequently varies in a complimentary manner during the year, such that one of them is relatively abundant while the other is relatively scarce. Water users can develop both groundwater and surface water sources, and rely on each as it is "in season." This approach is called conjunctive use and it should be generally encouraged, especially in areas where groundwater resources are nearing exhaustion.

The Commonwealth of Pennsylvania

PADEP conducts many water resource management activities, most of which relate to water quality and pollution, as described in the following pages.

The Bureau of Water Supply and Wastewater Management regulates sewage disposal by both on-lot and community systems, spray irrigation, underground injection of wastes, surface impoundments (nonhazardous waste), and underground storage tanks. This bureau responds to miscellaneous groundwater pollution incidents, including hydrocarbon spills, and those resulting from the aerial application of agricultural fertilizers and pesticides. Public water supplies are regulated and monitored by field staff, with a primary concern being water potability. The Commonwealth of Pennsylvania regulates the quality and rate of groundwater withdrawals for public water supplies.

The Bureau of Waste Management regulates solid waste. All facilities for the storage, treatment, and disposal of municipal, residual, or hazardous waste are permitted including, but not limited to, landfills, incinerators, and land application sites. Storage and treatment facilities also pose a potential threat to the groundwater, and are also regulated by this bureau.

The Bureau of Mining and Reclamation and the district mining offices permit surface mines, deep mines, coal preparation plants, coal refuse disposal sites, and insure regulatory compliance of all permitted activities. District mining offices are charged with monitoring of groundwater quality around all regulated activities, and protecting the yield of groundwater sources (wells and springs) from being severely diminished as a result of surface mining activities. Impoundments associated with surface and deep mining activities are also regulated by district mining offices. The Bureau of Mining and Reclamation licenses mine operators.

The Bureau of Watershed Management manages Pennsylvania's Wellhead Protection Program, which serves as the cornerstone of the Source Water Assessment and Protection Program. While these programs address pollutants and water quality concerns, the bureau also is responsible for water quantity issues through managing surface water allocation permits to public water suppliers, comprehensive water resource planning for the Commonwealth (State Water Plan), and stormwater management through Act 167.

Surface Water Allocations: The Bureau of Watershed Management issues surface water allocation permits to public water suppliers both for direct withdrawal of surface waters (i.e., springs, streams, quarries, and deep mine discharges) and for purchase of surface water from another public water supply agency. The review process addresses source quantity requirements and effects of a surface water withdrawal on other resources protected by laws administered by PADEP. Therefore, the Bureau of Watershed Management review process coordinates internally with other department bureaus to assess potential adverse impacts related to their respective program areas from the requested allocation. These assessments are primarily reviewed for impacts on water quality. An example review activity is determining if the quantity of the requested withdrawal will result in any adverse water quality impacts downstream of the proposed taking point. PADEP also coordinates with other agencies and receives comments on the proposed surface water withdrawal. The Commission reviews these allocation applications for potential water quantity issues to both surface and groundwater.

PADEP reviews population projections and historical water use to determine projected need. This includes an evaluation of any consistent increase in total water use over the previous 10 years and a review of the total system per capita and residential per capita daily usage. A determination of the projected future need over a 20- to 30-year period is made. The proposed water use is reviewed for water conservation possibilities and to determine compliance with the Commission's water conservation policy and standards. The capacity of water supply sources is reviewed to determine the supply of water available during drought periods and what passby flow requirement at the intake is needed. Depending on the stream's designation standard, additional instream flows may be required. For example, streams designated as a Cold Water Fishery (CWF) with naturally reproducing trout may require a determination of instream flow needs to protect the fishery.

PADEP surface water approvals are given where it is determined that the: (1) proposed new source of supply will not conflict with the water rights held by any other public water supply agency; (2) water and water rights proposed are reasonably necessary for the present purposes and future needs of the public water supplier making application; and (3) taking of said water or exercise of water rights will not interfere with navigation and public safety, and will not cause substantial injury to the Commonwealth. Where conflict of interests may occur, PADEP considers the extent of conservation development and use of existing water resources to the best advantage. The life of water allocation permits is generally for a period of 25 years.

Comprehensive Water Resource Planning: Pennsylvania is currently implementing the Water Resources Planning Act (Act 220) under the guidance of a Statewide Water Resources Committee to develop the state water plan. The water resources planning program is to address basic questions regarding how much water the Commonwealth has, uses, and needs. Major components of Act 220 are:

1. Update the state water plan within five years;
2. Register and report certain water withdrawals;
3. Identify Critical Water Planning Areas (CWPAs);
4. Create critical area resource plans; and
5. Establish a voluntary water conservation program.

The critical area resource plans are to include a water availability evaluation, assess water quality and water quantity issues, and identify existing and potential adverse impacts on water resources uses. CWPAs are "any significant hydrologic unit where existing or future demands exceed or threaten to exceed the safe yield of available water resources." The methods by which a CWPA may be identified are through the state water planning process as a component of a regional plan, or in advance of the regional plan based upon information developed in (or during) the planning process.

The Lower Susquehanna Regional Water Resource Committee (LSRWRC) is implementing several priorities for the management of the region's water resources. These priorities include:

1. Water Supply: Inventory all sources of groundwater and surface water.
2. Water Quantity: Calculate total water budget for each watershed.
3. Water Quality: Ensure quality to protect designated uses.
4. Water Demand: Identify current and future water needs.
5. Managing Supply vs. Demand: Identify and assess alternatives to balance supply and demand.

Storm Water Management Act 167: The Pennsylvania Storm Water Management Act of 1978 (Act 167) has provided the legislative basis for much of the stormwater management planning carried out by the Commonwealth. Act 167 planning must be performed by the respective counties in a given watershed and then adopted and implemented by the municipalities. While Act 167 planning has been occurring for nearly 30 years, the program is being expanded to merge with the National Pollution Discharge Elimination System (NPDES) Phase II Municipal Separate Storm Sewer (MS4) Program. Also, NPDES Construction Permits required for land disturbances of more than one acre must be consistent with any existing Act 167 plans.

Another initiative is PADEP's Comprehensive Stormwater Policy, which is designed to:

1. Address critical water quality issues;
2. Sustain stream base flow, and groundwater in general, through stormwater management systems that infiltrate and provide for groundwater recharge;
3. Minimize site-specific and watershed-wide flooding problems; and
4. Prevent serious streambank erosion and overall stream impact with related aquatic biota damage.

One of the goals of PADEP's new policy is to replicate, to the maximum extent possible, preconstruction infiltration, water quality treatment, and volume and rate controls by preserving natural areas and utilizing constructed infiltration best management practices.

Local government

Within the study area, there are several forms of local government, including one county, eight townships, and five boroughs. These municipalities control land use, land development, stormwater management, and several aspects of water resource management. A summary of municipal ordinances in the study area is shown in Table 10.

The Pennsylvania Municipalities Planning Code enables comprehensive planning, zoning, and subdivision and land development regulation at the municipal and county level. Recent changes in the Municipalities Planning Code allow for and encourage more area-wide planning on a multi-municipal basis. This provides local governments an opportunity to comprehensively address stormwater management and groundwater protection issues on a watershed or regional basis.

The availability of an adequate water supply is important to a region's economic development and vitality. Therefore, local governments need to be well informed about the implications of their land use decisions on groundwater availability. A variety of tools are available for municipalities to plan and accommodate different types of land uses to promote or enhance water resources. With regard to ordinances that impact water resources, Table 10 provides a baseline of what is already being done by local governments in the study area and also identifies areas of inconsistency. The ordinances are categorized by impervious cover reduction, open space protection, stormwater management, land use and development, water supply and disposal, and agricultural land use.

Table 10. Summary of Municipal Ordinances for Municipalities in the Study Area

Ordinances	BOROUGHS					TOWNSHIPS								
	Akron Boro	Denver Boro	Ephrata Boro	Lititz Boro	Man-heim Boro	Clay Twp.	East Cocalico Twp.	Elizabeth Twp.	Ephrata Twp.	Penn Twp.	Rapho Twp.	War-wick Twp.	West Cocalico Twp.	Lancaster County SLDO
Impervious Cover Reduction														
STREETS														
Street width allowed < 24'		X		X	X			X					X	X
Alternative pedestrian networks may be substituted for sidewalks along roadways												X		
Joint use driveways encouraged and standard agreement provided							X					X		
Parking Ratios														
Minimum parking for profess-ional office (per 1,000 s.f.)	5		3.3	5	3.3	5	3.3		4	3.3	3.3	3.3		3.5 - 4.5
Minimum parking for shopping centers (per 1,000 s.f.)	5		4	5.5	5.5	5	5		4	5	5	5.5		4-5
Minimum parking for single family (per unit)	2		2-3	2	2	2	2		2	2	2	2		2
Shared parking is encouraged	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ratios reduced with shared/joint parking			X				X							
PARKING LOTS														
Minimum parking stall of < 10' x 20'		X	X	X	X				X	X	X	X		
Pervious paving materials permitted				X			X			X				
Landscape islands and landscaping required within parking lot			X	X			X		X	X	X	X	X	
Parking garages encouraged					X									

Table 10. Summary of Municipal Ordinances for Municipalities in the Study Area (continued)

Ordinances	BOROUGHS					TOWNSHIPS								
	Akron Boro	Denver Boro	Ephrata Boro	Lititz Boro	Man-heim Boro	Clay Twp.	East Cocalico Twp.	Elizabeth Twp.	Ephrata Twp.	Penn Twp.	Rapho Twp.	War-wick Twp.	West Cocalico Twp.	Lancaster County SLDO
Open Space Protection														
RESOURCE CONSERVATION														
Floodplain protection or district	X	X	X	X		X	X	X	X	X	X	X	X	
Steep slope protection	X	X				X	X	X	X	X			X	
Wetland protection			X	X			X				X	X		
Existing tree protection measures		X	X	X			X							
Forested land protection		X	X	X		X	X	X		X	X	X	X	X
Conservation development standards		X						X				X		
Ecologically sensitive or resource conservation district			X					X				X	X	
Riparian buffers	X	X	X		X	X	X			X	X	X		
Environmental performance standards				X										
Alternative energy - wind energy conversion systems				X										
Growth Limits/Agri-cultural Preservation														
Active farm preservation program							X	X	X	X	X	X		
TDR program												X		
UGB/VGB boundary in place						X			X	X	X	X		
Clean and green enrollment						X	X	X	X	X	X	X	X	
Agricultural security district						X	X	X	X	X	X	X	X	
Prime agricultural soils protection	X					X		X	X		X	X		
Agricultural Preservation District												X		
Adaptive re-use / infill development encouraged					X						X			
Sliding scale zoning	X										X			
Condensed housing or cluster use permitted with open space requirements			X	X	X		X	X	X	X	X	X	X	
By right			X								X			
Conditional or special use				X	X		X	X	X	X		X	X	

Table 10. Summary of Municipal Ordinances for Municipalities in the Study Area (continued)

Ordinances	BOROUGHS					TOWNSHIPS								
	Akron Boro	Denver Boro	Ephrata Boro	Lititz Boro	Man-heim Boro	Clay Twp.	East Cocalico Twp.	Elizabeth Twp.	Ephrata Twp.	Penn Twp.	Rapho Twp.	War-wick Twp.	West Cocalico Twp.	Lancaster County SLDO
Public Water Supply Protection														
Wellhead or aquifer recharge area protection				X			X					X		
OPEN SPACE MANAGEMENT														
Guidelines for establishing native plant communities								X				X		
Enforceable requirements to establish associations to effectively manage open space												X		
Open space may be managed by a third party using land trusts or conservation easements												X		
Storm Water Management														
ACT 167 ordinance in place			X			X	X					X	X	
Encourages reduction of impervious surfaces	X	X		X			X	X				X	X	X
SWM/ BMPs required	X	X	X	X		X	X		X	X	X	X	X	
Groundwater recharge encouraged			X	X		X	X		X	X		X		
Recommends replicating existing drainage patterns	X	X	X	X			X	X	X			X	X	
Standards or methods are in place to monitor and maintain SWM BMPs and infiltration facilities						X	X					X		
Transition from E&S facilities to retention facilities is monitored to ensure system is working following build-out. Delay construction of BMP until all land disturbance activities are completed to minimize clogging and remediation							X							

Table 10. Summary of Municipal Ordinances for Municipalities in the Study Area (continued)

Ordinances	BOROUGHS					TOWNSHIPS								
	Akron Boro	Denver Boro	Ephrata Boro	Lititz Boro	Man-heim Boro	Clay Twp.	East Cocalico Twp.	Elizabeth Twp.	Ephrata Twp.	Penn Twp.	Rapho Twp.	War-wick Twp.	West Cocalico Twp.	Lancaster County SLDO
Land Use/ Development														
KARST GEOLOGY ISSUES														
Hydrogeologic study req.			X				X			X	X	X		
Sinkhole and depression ID req.										X	X			X
Sinkhole protection measures		X					X			X	X		X	X
Limitations (blasting, land use, SWM basins, underground storage, tanks, manure storage, etc.)			X	X			X		X	X	X	X		
SPECIFIC WATER-RELATED USES														
Car wash facilities req to use public sewer and water system			X					X		X	X	X	X	
Car wash facility req to recycle water			X				X	X			X			
Swimming pool disposal and filling standards		X			X		X					X		
Ornamental ponds, wading pools, lakes, dams, or impoundments standards		X			X		X	X		X	X	X		
Quarry or extractive related use standards							X	X		X	X	X	X	
Mushroom operations/comp							X				X	X		
Septage and /or solid waste disposal and processing facilities			X				X	X		X	X	X		
Cemeteries not permitted in floodplain, flood fringe or areas of high water			X								X	X	X	
Subsurface storage or tanks	X					X								
Manure storage									X				X	
Hospital and medical facilities waste disposal											X	X		
Stockyard, slaughtering and feedlots											X	X		
Intensive farming operations													X	

Table 10. Summary of Municipal Ordinances for Municipalities in the Study Area (continued)

Ordinances	BOROUGHS					TOWNSHIPS								
	Akron Boro	Denver Boro	Ephrata Boro	Lititz Boro	Man-heim Boro	Clay Twp.	East Cocalico Twp.	Elizabeth Twp.	Ephrata Twp.	Penn Twp.	Rapho Twp.	War-wick Twp.	West Cocalico Twp.	Lancaster County SLDO
LAND DEVELOPMENT REVIEW														
Sketch Plan optional	X	X	X			X	X	X	X	X	X	X	X	X
Sketch Plan required				X										
Natural, cultural resources inventory		X					X	X		X	X	X	X	X
Environmental impact statements							X			X				
Site meeting with LCCD rep		X						X		X		X	X	X
Water Supply and Disposal														
PRIVATE WELLS														
Yield and quantity aquifer testing (quantity of water available for proposed use)		X				X	X	X		X	X	X	X	X
Hydrogeologic impact study or water supply study (impact on adjacent properties)		X	X			X	X	X		X	X	X	X	
Well capping requirements or standards										X				
Public system required				X										
SEWAGE DISPOSAL														
Sewage Enforcement Officer		X				X	X	X	X	X	X	X	X	
Lot size increased to ensure acceptable level of nitrate-nitrogen in adjacent groundwaters								X		X	X			
Alternative on-lot systems permitted							X			X	X			
Public system required				X										
Ag Land Use														
AGRICULTURAL MANAGEMENT														
PA Nutrient Management Plan recommended						X	X	X	X	X	X	X		
Ag Best Management Practices	X								X			X		
Manure Storage regs.						X	X					X		
Conservation Plan Requirements												X		

Recommendations

Using the information about groundwater use, groundwater availability, CARAs, and the current conditions and regulations within the study area, the Commission developed recommended actions to address issues identified. The issues, problems, and recommendations are presented below. The recommendations were developed through: (1) a review of existing ordinances and regulations that impact water resources; (2) a review of related plans and water resource initiatives; (3) community input on issues and concerns through the Water Budget Advisory Committee (WBAC) and at a June 2004, workshop; and (4) the findings of the Northern Lancaster County Groundwater Study. Some of the recommendations can be implemented on an individual basis by each municipality, while others will require a more comprehensive approach.

The recommendations address four major issues: (1) overall reduction of infiltration and groundwater recharge; (2) excess withdrawal of groundwater in PSAs; (3) overall increase in water use; and (4) consistency among municipal ordinances.

Issue: Overall reduction of infiltration and groundwater recharge

Historic changes in land use have led to increased urbanization and, with it, a sharp increase in impervious surfaces—roads, parking lots, driveways, and roofs—replacing meadows and forests. The result is a 70-square-mile area that is 9 percent impervious and contributes less infiltration and recharge, and has increased stormwater runoff. In the carbonate areas of the Manheim-Lititz and Ephrata area groundwater basins, 12.6 percent and 8 percent, respectively, of these areas are impervious.

Land use and land cover significantly affect the quantity of recharge of groundwater available for public supply, stream base flows, and wetlands. Awareness of this important connection is vital to local municipal governments charged with making land use decisions. Comprehensive municipal planning, protective ordinances, and stormwater management can address the issues of impervious cover and promote infiltration.

Land development commonly increases stormwater runoff. Conventional stormwater management practices have focused on the volume of runoff and on minimizing flooding problems using such practices as detention basins. However, in areas underlain by carbonate geology that are inherently susceptible to surface and subsurface failures, areas where standing water will occur can be lined with impervious material to prevent sinkholes. As a consequence, the natural infiltration and recharge of groundwater also can be reduced.

PADEP’s new comprehensive stormwater policy will expand Act 167 to include control standards that achieve objectives for infiltration and recharge, aquifer and stream base flow protection, and water quality management. Carbonate aquifers are now considered “Special Areas,” acknowledging the need for special control guidelines.

Problem: *Loss of critical aquifer recharge areas (CARAs) from future growth and development is a concern.*

The overall reduction in infiltration throughout the region is an important issue, but the loss of infiltration in CARAs is particularly vital to the overall sustainability of the water supply.

Recommendation: Municipalities should maintain or enhance the unique hydraulic characteristics of CARAs to maximize the amount of groundwater available for utilization within a groundwater basin. Management actions for CARAs commonly include limiting the amount of impervious land cover, preventing soil compaction, and concentrating or diverting stormwater. The management actions may locally restrict land use options, but can result in greater economic growth and community development by: (1) maximizing the amount of groundwater available for development as water supply; (2) minimizing economic loss due to flooding; and (3) providing natural filtering of some agri-chemicals. CARAs typically provide a substantial fraction of the recharge to the aquifer, while constituting only a small fraction of the basin's surface area. As a result, a large fraction of aquifer recharge can be protected and maintained while restricting development activities in a relatively small total area of the basin. Mapping of these important water resource areas provides information that municipal governments can use to make informed decisions on planning for future growth (Plate 1). A detailed data collection effort through site-specific field investigations would further refine the delineation of CARAs.

Problem: *Increased areas of impervious cover will reduce the potential for recharge.*

As development continues to expand in the study area, land that was once open to infiltration is covered with impervious material. The carbonate valley area important to groundwater recharge also is a highly desirable area for development.

Recommendation: Developers should reduce the effect of impervious cover by implementing technologies that increase the infiltration capability of that cover. They also should consider using designs such as porous pavement in areas where natural recharge rates are higher than other land areas. Where the infiltration capability of the land cover cannot be increased, such as rooftops, the stormwater runoff can be directed to other areas and enhance groundwater recharge through distributed infiltration best management practices.

Problem: *Floodplain systems that were once areas of natural recharge are now filled with fine sediment and less permeable, thereby reducing recharge.*

Groundwater monitoring results indicate that water table elevations in the northern part of the study area are several feet below the base of stream channels. Streams flowing from the shale to carbonate areas begin to lose water to the underlying aquifer. However, some stream reaches crossing this area that were naturally losing streams are now perched due to historic land use impacts. During settlement and rapid urbanization, much of the vegetation disappeared, soils were eroded, and floodplains were filled with fine sediment. Now stream channels are underlain by fine-grained, eroded materials and are disconnected from groundwater flow systems.

Recommendation: Many of the problems associated with perched streams can be effectively mitigated through floodplain restoration. Municipalities should consider floodplain restoration in a limited number areas that historically contained meandering stream channels, thereby improving groundwater recharge. Riparian root systems and vegetation can protect the valley floors from scour and provide a means to increase surface water infiltration. Other benefits of restored floodplain systems include attenuation of storm flows, increasing groundwater recharge along losing reaches, reducing erosion and sedimentation, filtering harmful nutrients from groundwater and surface water, and enhancing aquatic and riparian wildlife habitat.

Problem: *Lack of stormwater plans in the study areas misses opportunities to address infiltration and recharge of stormwater runoff.*

Many of the municipalities in the study area have not adopted an Act 167 plan. Only four municipalities (Ephrata Borough, East Cocalico Township, Warwick Township, and West Cocalico Township) have Act 167 plans in place.

Recommendation: County and local governments should complete Act 167 stormwater management plans for the remaining areas. They also should implement PADEP's new comprehensive stormwater policy, which promotes the use of distributed infiltration best management practices to increase groundwater recharge, for new and existing Act 167 plans.

Problem: *Certain carbonate areas, such as those identified as karst modified uplands, may not be suitable for on-site stormwater management best management practices.*

The use of on-site stormwater best management practices may increase the potential for sinkhole development and groundwater contamination in high-density karst areas. Development in urban areas may not allow for distributed infiltration best management practices.

Recommendation: Areas that are not conducive to on-site stormwater management best management practices should be located and mapped. County and local governments should consider distribution of stormwater runoff to regional stormwater management facilities in restored floodplains and CARAs. The benefits include maximizing the recharge potential of CARAs. Innovative approaches should be explored, such as the transfer of stormwater requirements to receiving areas (i.e., CARAs or stormwater management facilities) for the expansion of development rights in sending areas (i.e., areas in a development that would normally be set aside for stormwater best management practices).

Issue: Excess withdrawal of groundwater in potentially stressed areas (PSAs)

Intense growth and development from all use sectors have resulted in a greater demand for groundwater resources. As growth continues, these areas will experience impacts to the quantity and quality of water resources and their ability to serve as reliable water supplies. PSAs are those areas where the utilization of water resources is approaching the sustainable yield. The Manheim–Lititz groundwater basin is considered a PSA and is approaching the sustainable yield. While total water withdrawals in the Ephrata area groundwater basin did not meet the criteria for a PSA, localized areas of intense groundwater withdrawals could stress the aquifer.

The sustainable yield generally is considered to be equal to the average annual recharge for a groundwater basin, minus the amount of water needed to maintain groundwater-dependent ecosystems. The amount of flow required to meet ecosystem needs is dependent on the nature, sensitivity, and quality of the habitat. If groundwater withdrawals substantially reduce stream and spring flow and dry up wetlands, the sustainable yield is exceeded.

Problem: *Water use in the Manheim-Lititz and Ephrata area groundwater basins is 70 percent and 34 percent, respectively, of the sustainable limit.*

The Manheim-Lititz-Ephrata valley is a rapidly growing area. From 1990 to 2000, several municipalities in the study area exceeded the 11.3 percent growth rate of Lancaster County, with Warwick Township having the highest growth rate of 33.2 percent. Development of water supplies to serve the local needs has increased proportionally, placing greater demands upon groundwater resources. Findings from the study indicate that water use is approaching the sustainable yield for select areas.

Recommendation: Through its regulatory program, the Commission should continue to require groundwater availability analyses for new water withdrawal projects and detailed water budgets in PSAs. The Commission should educate the public and local land use planners about sustainability of water resources in PSAs and the need to properly manage them. The Commonwealth should work with municipal governments and water authorities to develop future water demand projections based on full build-out conditions under current zoning and land use plans. Regional and local planning agencies should evaluate the impacts of different post build-out scenarios on recharge and water demand. This process should provide insight on revising comprehensive and land use plans.

Problem: *Intensive groundwater withdrawals in localized areas will diminish groundwater yields, base flows, and perennial streamflow.*

The determination of a PSA is partly a function of the scale or size of a groundwater basin or recharge catchment area relative to the quantity of total withdrawals. While the 48.4-square-mile Ephrata area groundwater basin is not considered a PSA, localized areas may experience groundwater availability problems. The amount of groundwater available at a given location is proportional to the recharge area upgradient of the point of withdrawal. In growing areas, many wells may be located within close proximity to one another in a relatively small recharge area. The effective recharge area may also be reduced due to increased impervious cover. Wells may experience a loss of yield as groundwater drawdown areas for each well begin to overlap and the total withdrawal exceeds the recharge rate of the catchment area. Other impacts may occur such as the loss of perennial streamflow and adverse effects on aquatic habitat.

Recommendation: The primary management objective in these localized areas is groundwater sustainability. Groundwater models should be utilized to evaluate the impact and assist in determining the most effective solution to address sustainability. For localized areas where the sustainable yields have been exceeded, new wells should not be installed and additional withdrawals should be discouraged. Water resource management agencies should review existing permits and coordinate with existing users to adjust withdrawal rates to achieve groundwater sustainability.

Since existing allocations for groundwater withdrawal are sufficient to meet projected demands, the Commission should encourage municipalities and water authorities to consider addressing new demand with systems with existing excess capacity or through interconnections with water systems that have excess capacity.

Issue: Overall increase in water use

Whether an area is considered a PSA or not, an important consideration in water resources management is the overall increase in water use throughout the study area. The carbonate aquifer is often described as a "bathtub." This analogy should help municipalities understand that while the use of water may be localized and potentially intensive, water withdrawn from any place in the bathtub affects the water level of the entire tub. Thus, it is important to consider the overall sustainability of the aquifer within the entire region, not just the stressed areas or the areas closest to the where the water is being used.

Problem: *The public is not well educated about the limits of groundwater resources.*
Groundwater forms the "hidden part" of the hydrological cycle, which can lead to misconceptions by the public. When users turn on the tap, their expectation is that water will flow, which leads to a natural complacency about water supply. This results from a lack of understanding about the sustainability of groundwater.

Recommendation: Informing the public begins with the education of children. Material on water and the environment should be introduced into the curricula for grades K through 12. Water resource management agencies should partner with schools to conduct classroom presentations and workshops.

Water resource management agencies should conduct basinwide or regional workshops to acquaint citizens with water management issues, problems, and solutions. The Commission should present the findings and recommendations of this study to watershed groups, civic organizations, and legislative leaders.

Problem: *Insufficient or incomplete beneficial reuse of process water or wastewater results in increased water demand.*
Water use is generally demand-orientated rather than conservation-based. Therefore, water reuse may not be a major issue at established facilities, and conservation strategies may not have been explored or implemented. Peak water use is typically two to three times higher in the summer season when demand for lawn watering is high. Using treated wastewater or reuse water for non-potable applications to reduce peak demand is a very effective strategy. An emerging method of maximizing wastewater reuse is to locate small wastewater treatment plants, called scalping plants, in the collection system near large irrigation water users such as golf courses, cemeteries, or parks (Carter & Burgess's Quarterly, 2003). The use of treated wastewater from municipal wastewater treatment facilities also has been effectively recycled in cooling water for industrial processes.

Recommendation: Industrial and commercial users should identify opportunities to reclaim water from one application for use in another application. Within the context of appropriate water quality limitations, agricultural sites near urban areas may provide opportunities to recycle industrial and commercial water for irrigation.

Reuse water is a sustainable water supply. Municipalities should be evaluating ways to take advantage of their wastewater plant effluent for reuse, thus lessening the demand on their potable water supplies. Municipalities can perform “Reuse Master Plans” that focus on reuse opportunities as a water resource for their community and surrounding area.

Problem: *Inefficient water use or lack of conservation measures wastes water.*
The easiest and most cost-effective means of extending the current water supply is to use less water. Conservation can be achieved many ways, including the installation of water-saving devices and modifications to personal behaviors. As growth places increased demands on the water supply, purveyors and water authorities should implement strategies for reducing water demand. Businesses should consult with qualified engineering firms that specialize in on-site water use evaluations and assist in replacement of water-inefficient equipment. Watershed organizations can play an important role in public education by offering information on outdoor use practices such as landscaping alternatives and conservation practices.

Recommendation: The Commonwealth or Lancaster County Planning Commission should consider organizing a residential retrofit program where water purveyors could give away water-efficiency kits. Each kit could contain a low flow showerhead, faucet aerators, package of toilet leak detection tablets, and written information on residential water conservation and use efficiency.

Water authorities and purveyors, in partnership with municipalities, should offer residential water surveys. Water surveyors check for leaking plumbing, provide water conservation tips, offer advice on retrofitting with water-efficient fixtures, and may distribute water-efficiency kits (containing, for example, faucet aerators and low flow showerheads). Water surveys provide a way which encourages homeowners to install water-efficient appliances and implement water conservation practices.

When businesses apply for new or increased withdrawals in PSAs, water resource management agencies should encourage them to consult with qualified engineering firms that specialize in on-site water use evaluations and assist in replacement of water-inefficient equipment.

Watershed organizations should organize and conduct public information programs consisting of conservation brochures, displays, and classes dealing with water-saving irrigation methods and drought-tolerant planting methods.

Problem: *Water discharged from mining operations is underutilized as a resource.*
Mining of rock and mineral deposits below the water table requires that enough water be pumped to keep mine workings dry. This pumped water is released to surface streams where it becomes available to downstream communities. Within the appropriate water quality constraints, water available from both active and abandoned quarries may provide a resource for community water systems and other similar uses. Beneficial use also requires careful evaluation of potential surface withdrawals downstream of mine discharge outfalls.

Recommendation: The Commission should encourage cooperative efforts to promote alternative water supplies such as mining operations for public drinking water, commercial operations, and industrial supplies.

Issue: Consistency among municipal ordinances

Given the decentralized nature of municipal government and land management activities at the local level, there are inconsistencies in local ordinances among municipalities in the study area. This has hindered the consideration of groundwater protection and sustainability across municipal boundaries. Important resource areas and aquifers do not coincide with a single municipal boundary. The benefits gained from the good stewardship of one municipality may be exploited by a neighboring municipality, thereby causing conflicts. Thus, water resource gains may be short-lived.

Problem: *Municipal ordinances that influence water supply availability are inconsistent across municipal boundaries.*

Recommendation: Local governments should continue to utilize the opportunities presented in the Municipalities Planning Code to develop comprehensive land management ordinances that address groundwater resource protection and enhancement. The key to planning most effectively for future water needs within the 70-square-mile study area is the collaboration of municipalities, water authorities, agriculture, industry, and wellhead protection task forces. The current WBAC should consider moving forward as a planning team in accordance with the steps outlined in the Lancaster County Water Resources Plan. Local governments should be encouraged to participate in water resource planning efforts at the regional level.

SUMMARY

The Commission has performed a water resource study for a rapidly growing area located in northern Lancaster County, Pennsylvania. The study area includes an isolated carbonate aquifer of 50 square miles and a surrounding contributing area of 20 square miles. The study area includes parts of 13 municipalities, including the Boroughs of Manheim, Lititz, Akron, Ephrata, and Denver.

Two groundwater basins were delineated, based on water table mapping, and two sets of water levels made during this study. The annual recharge for each groundwater basin, for the 2-, 10-, and 25-year recurrence intervals, was based on previous regional studies that employed extensive base flow separations, water table mapping, and groundwater modeling.

The annual recharge for the Manheim-Lititz groundwater basin, for the 2-, 10-, and 25-year recurrence intervals was estimated to be 5,822 million gallons, 3,531 million gallons, and 2,449 million gallons, respectively.

The annual recharge for the Ephrata area groundwater basin, for the 2-, 10-, and 25-year recurrence intervals was estimated to be 11,676 million gallons, 7,077 million gallons, and 4,917 million gallons, respectively.

Existing water withdrawals were identified and totaled for each groundwater basin. Withdrawal totals were compared to the Commission's utilization level for identification as a PSA, which is 50 percent of the 1-in-10-year recharge.

Actual groundwater use for the total study area was projected for 10 (year 2010) and 25 years (year 2025), and compared with availability. Utilization at 10 years (year 2010) is estimated to be 35 percent of the 1-in-10-year recharge and 51 percent of the 1-in-25-year recharge. Utilization at 25 years (year 2025) is estimated to be 41 percent of the 1-in-10-year recharge and 59 percent of the 1-in-25-year recharge.

The Commission uses the 1-in-10-year annual recharge as the sustainable limit of groundwater development. This limit is a compromise between maximum developable water, instream flow needs, and required reservoir or tank storage capacity. This limits groundwater withdrawals to 3,531 mgy for the Manheim-Lititz basin and 7,077 mgy for the Ephrata area basin.

Actual, current (year 2000) withdrawals for the Manheim-Lititz basin, the Ephrata area basin and the entire study area do not exceed 50 percent of the 1-in-10-year recharge.

Allocated groundwater withdrawals (year 2000) in the Manheim-Lititz groundwater basin were 70 percent of the 1-in-10-year recharge, which exceeds the Commission’s PSA standard (50 percent of the 1-in-10-year recharge). Allocated withdrawals (year 2000) from the Ephrata area groundwater basin were 34 percent of the 1-in-10-year recharge. Allocated groundwater withdrawals (year 2000) in the entire study area were 46 percent of the 1-in-10-year recharge.

In order to protect riparian and aquatic habitat, the Commission, in coordination with the Commonwealth of Pennsylvania, requires that withdrawals cease or be augmented with a release of makeup water when the flow in a stream falls below a set percentage of the average daily flow. All of the streams within the carbonate valley are classified (Pennsylvania Chapter 93) as warm water fisheries.

Withdrawals in the study area must cease or be augmented with a release of makeup water when the flow in local streams falls below 20 percent of the average daily flow. Streamflows in the study area will be below 20 percent of their average daily flow an average of 30 days per year. Discharge of wastewater adjacent to or upgradient of groundwater withdrawals would largely mitigate this impact. For municipal water supply withdrawals located in the Manheim-Lititz basin or in the southern portion of the Ephrata area basin, the withdrawals are made-up by the releases from the municipal wastewater treatment plants.

The results of two detailed seepage runs on the trunk streams and principal tributaries performed during this study were used to identify aquifer discharge areas and losing stream reaches.

Areas contributing unusually high amounts of recharge, termed CARAs, were identified in the study area. These included several “siliciclastic to carbonate streamflow crossings,” three dry valleys, and several losing stream reaches. Preservation of the hydrologic (recharge) function of these areas will help to maintain the natural abundance of water resources available in the study area. The emplacement of impervious cover and other growth-related changes to the land surface that result in reduced recharge should be carefully considered.

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APPENDIX A

Seepage Run Measurements

Stream Discharge from 2004 Field Survey

Station ID	Latitude Dec Degree	Longitude Dec Degree	Date	Flow cfs	Date	Flow cfs	Stream Name
							Chiques Creek Watershed
F011	40.177111	-76.389639	06/09/04	18.86	10/28/04	20.97	Chiques Creek-1
F005	40.157167	-76.388278	06/09/04	25.82	10/28/04	24.58	Chiques Creek-2
F003	40.152500	-76.404667	06/08/04	33.06	10/28/04	32.03	Chiques Creek-3
F007	40.160900	-76.384800	06/09/04	1.48	10/28/04	3.90	Doe Run, at mouth
F007	40.160900	-76.384800	06/13/04	1.65			Doe Run, at mouth
F031	40.188194	-76.346889	06/13/04	0.58			Doe Run, headwaters
F029	40.180056	-76.357556	06/13/04	0.967	10/28/04	1.67	Doe Run, upstrm F025
F025	40.171528	-76.366778	06/13/04	1.55	10/28/04	2.20	Doe Run, upstrm trib 1
F001	40.158556	-76.405222	06/08/04	5.59	10/28/04	5.92	Rife Run
F027	40.175333	-76.369750	06/13/04	1.22	10/28/04	2.02	Trib 1 to Doe Run
							Cocalico Creek Watershed
F070	40.237444	-76.143417	06/17/04	16.08	11/01/04	18.00	Cocalico Creek-1
F053	40.217639	-76.129444	06/17/04	29.67			Cocalico Creek-2
F072	40.209083	-76.136111	06/17/04	26.73	11/02/04	23.63	Cocalico Creek-3
F074	40.204667	-76.144917	06/17/04	31.96	11/02/04	18.20	Cocalico Creek-4
F076	40.193583	-76.164500	06/17/04	37.8	11/02/04	42.27	Cocalico Creek-5
F052	40.174889	-76.194389	06/14/04	49.24	11/02/04	50.26	Cocalico Creek-6
F042	40.169389	-76.220556	06/14/04	58.43	11/02/04	61.38	Cocalico Creek-7
F040	40.157000	-76.227167	06/14/04	126.7	11/02/04	134.70	Cocalico Creek-8
F055	40.195361	-76.146667	06/17/04	0.581	11/02/04	0.38	Coover Run
F051	40.231056	-76.131639	06/17/04	10.69	11/01/04	9.87	Little Cocalico Creek
F044	40.170000	-76.220500	06/14/04	1.14	11/02/04	0.90	Meadow Run at mouth
F048	40.186528	-76.211833	06/14/04	0.037	11/01/04	0.00	Meadow Run, headwaters
F046	40.178444	-76.217167	06/14/04	0.903			Meadow Run, mid-reach
F068	40.207056	-76.132806	06/16/04	3.74	11/02/04	2.24	Stony Run at mouth
F064	40.212528	-76.124944	06/16/04	2.47	11/01/04	2.51	Stony Run mid-reach
F049	40.222528	-76.115889	06/16/04	1.66	11/01/04	1.13	Stony Run upstrm quarry
F050	40.167889	-76.201611	06/14/04	0.632	11/02/04	0.51	Trib from Akron
F057	40.174722	-76.175944	06/17/04	0.601	11/02/04	0.28	Trib near Fulton School
F066	40.210167	-76.124667	06/16/04	0.324	11/01/04	0.39	Trib to Stony Run
							Hammer Creek Watershed
F009	40.196833	-76.280083	06/09/04	32.04	10/28/04	65.53	Hammer Cr-1
F013	40.183889	-76.265917	06/10/04	30.71	10/28/04	48.27	Hammer Cr-2
F013	40.183889	-76.265917	06/14/04	37.46			Hammer Cr-2
F021	40.174750	-76.255778	06/10/04	31.71	10/28/04	59.06	Hammer Cr-3
F035	40.167444	-76.244167	06/14/04	42.78	10/28/04	44.46	Hammer Cr-4
F037	40.164944	-76.237722	06/14/04	43.59	10/28/04	48.27	Hammer Cr-5
F017	40.215083	-76.286167	06/10/04	0.176	10/28/04	0.32	Trib from Brickerville, headwater
F017	40.215083	-76.286167	06/14/04	0.243			Trib from Brickerville, headwater
F033	40.197639	-76.281472	06/14/04	0.109	10/28/04	0.36	Trib from Brickerville, mouth
F015	40.208778	-76.300222	06/10/04	0.437	10/28/04	0.73	Trib near Speedwell, headwater
							Indian Run Watershed
F056	40.235972	-76.202389	06/16/04	3.46	10/29/04	3.17	Indian Run-1
F058	40.226583	-76.194333	06/16/04	3.2	10/29/04	3.20	Indian Run-2
F060	40.212778	-76.186250	06/16/04	3.33			Indian Run-3
F060	40.214440	-76.186860			10/29/04	2.95	Indian Run-3 (new location)
F043	40.203139	-76.181306	06/16/04	10.9	10/29/04	10.31	Indian Run-4
F041	40.193944	-76.178611	06/16/04	16.43	10/29/04	13.29	Indian Run-5
F062	40.237639	-76.169917	06/16/04	0.785	10/29/04	0.73	Trib from Schoeneck, headwater
F047	40.223444	-76.171611	06/16/04	0.206	10/29/04	0.16	Trib from Schoeneck, mid-reach
F045	40.213056	-76.181278	06/16/04	0.065	10/29/04	0.00	Trib from Schoeneck, mouth
							Lititz Run Watershed
F012	40.167528	-76.295333	06/09/04	0.302	11/01/04	0.65	Hubers Run, headwater
F006	40.158639	-76.295917	06/09/04	0.201	11/01/04	0.44	Hubers Run, mouth
F018	40.157694	-76.309306	06/10/04	4.86	11/01/04	7.41	Lititz Spring

Station ID	Latitude Dec Degree	Longitude Dec Degree	Date	Flow cfs	Date	Flow cfs	Stream Name
F002	40.147389	-76.270417	06/09/04	21.23	11/01/04	40.76	Lititz Run
F010	40.165361	-76.284250	06/09/04	0.59	11/01/04	0.93	Moores Run, headwater
F004	40.154806	-76.286806	06/09/04	0.426	11/01/04	0.84	Moores Run, mouth
F008	40.159028	-76.296750	06/09/04	0.901	11/01/04	2.97	Santo Domingo Run
F020	40.168028	-76.307972	06/10/04	0	11/01/04	0.00	Santo Domingo Run
F014	40.171556	-76.301778	06/10/04	0	11/01/04	0.20	Trib 2 from Bethel Cemetery
F016	40.180083	-76.315250	06/10/04	0.655	11/01/04	0.87	Trib 3, headwater
							Middle Creek Watershed
F026	40.219194	-76.257444	06/10/04	14.74	10/28/04	19.82	Middle Cr-1
F034	40.200167	-76.245278	06/10/04	23.68	10/28/04	28.64	Middle Cr-2
F054	40.187750	-76.239472	06/14/04	27.82	10/28/04	34.87	Middle Cr-3
F023	40.170667	-76.234444	06/10/04	29	10/28/04	33.43	Middle Cr-4
F036	40.220306	-76.232333	06/10/04	0	10/28/04	0.00	Trib 1 near Snyder Park
F038	40.212111	-76.235472	06/10/04	0	10/28/04	0.33	Trib 1 rte 322
F030	40.231417	-76.229917	06/10/04	0.101	10/28/04	0.17	Trib 1, headwater Durlach
F032	40.205917	-76.243528	06/10/04	2.39	10/28/04	3.95	Trib 1, mouth
F019	40.217444	-76.268444	06/10/04	0.227	10/28/04	0.24	Trib 2, headwater
F022	40.214278	-76.256444	06/10/04	0.158	10/28/04	0.12	Trib 2, mouth
F028	40.227806	-76.239917	06/10/04	0.068	10/28/04	0.12	Trib to Trib 1 near Snyder Park
F024	40.218583	-76.264917	06/10/04	0.075	10/28/04	0.06	Trib to Trib 2
							Bachman Run Watershed
F039	40.135139	-76.328972	06/14/04	1.06			Trib to Bachman Run, out of basin

APPENDIX B

Water Quality Analytical Results

Average Nitrate Concentration, Conductivity, pH, and Temperature of Wells, Springs, and Streams from May and October 2004

Station Type	Station ID	Temp degree C	pH	Nitrate mg/l	Conductance micromhos
Well	A-04	15.1	6.9	4.6	402
Well	A-05	16.5	6.78	10.95	645
Well	A-06	17.3	6.31	9.3	389
Well	A-07	15.9	7.1	22.1	529
Well	A-09				539
Well	A-16	16	7.1	1.7	478
Well	A-17			6.8	390
Well	A-18	19.1	7.22	1.95	682
Well	A-19	14.2	7.02	8.85	826
Well	A-20	17	6.9	26.1	553
Spring	A-LSP	15	7.07	19.75	655
Well	B-01			0.3	409
Well	B-03			17.6	752
Well	B-04	14.5	7.06	15.25	811
Well	B-05	15.1	7.09	12.8	722
Well	B-07	15.9	7.08	18.3	749
Well	B-08	17.4	7.07	2.25	509
Well	B-09	14.4	7.07	11.2	485
Well	B-10	16.3	7.06	4	834
Well	B-11	15.6	7.07	3.1	467
Well	B-12	15.1	7.04	4.2	364
Well	B-13			13.2	526
Well	B-14	17.4	7.06	1.35	231
Well	B-16	16.8	7.08	0.65	285
Well	B-18	16.6	7.06	8.15	248
Well	B-19	15.2	7.07	1.2	777
Well	B-20	13.9	7.08	9.95	691
Well	B-21	19	7.07	13.7	674
Well	B-22	18.7	7.07	8.25	838
Well	B-23	15.6	7.08	8.6	654
Well	B-24	15	7.04	14.8	586
Well	B-25	20.4	7.06	2.8	1275
Well	B-26			2.8	696
Well	B-27	14.1	7.06	8	840
Well	B-28	12.4	7.05	5.5	684
Well	B-29	15.5	7.02	2.8	897
Well	B-30	13.2	7.06	12.5	909
Well	B-31	17.9	7.07	1.4	603
Well	B-32	14.4	7.08	1.4	570
Well	B-34	19.5	7.08	3.6	688
Well	B-35	16.7	7.08	14.75	734
Well	B-36	12.3	7.06	13	1466
Well	B-37	14.4	7.04	13.95	755
Well	B-40	14.9	7.04	6.3	880
Well	B-41	15	7.07	10.6	712
Well	B-42	15.1	7.06	10.8	854
Well	B-43	15.6	7.06	5.7	592
Well	C-01	18		12.55	498
Well	C-02	18.5		4.4	253
Well	C-03	18		5.85	595
Well	C-04	15		7.1	730
Well	C-06	19		20.8	762
Well	C-07	17.5		10.9	705
Well	C-14	14.5		8.2	532

Station Type	Station ID	Temp degree C	pH	Nitrate mg/l	Conductance micromhos
Well	C-15	16.5		7	566
Well	C-18	15		33.95	1623
Well	C-19	12.5		23.7	765
Well	C-21	12.5		11.9	687
Well	C-22	12.5		10.75	748
Well	C-23	13		22.05	778
Well	C-29A	17		12.75	704
Well	C-30	15.5		21.35	768
Well	C-31	14.5		16.7	681
Well	C-W01	14.5		2.2	646
Well	C-36	16.5		16.5	1168
Stream	F001	11		8.1	365
Stream	F002	18.9	7.03	9.1	511
Stream	F003	11		6.35	358
Stream	F004	18.9	7.03	8.2	367
Stream	F005	10.5		6.65	350
Stream	F006	18.7	7.04	10	246
Stream	F007	13		15	525
Stream	F008	18.5	7.03	13.4	594
Stream	F009	13.6	6.9	5.45	402
Stream	F010	18.9	7.03	6.1	330
Stream	F011	10.5		4.4	275
Stream	F012	20.2	7.02	11.25	381
Stream	F013	15.7	6.89	5.95	396
Stream	F014	17.6	7.02	6.5	423
Stream	F015	11.8	6.94	10.15	368
Stream	F016	18.4	6.91	8.1	385
Stream	F017	12.9	6.92	4.3	344
Stream	F018	17.1	7.03	14	718
Stream	F019	13.3	6.94	6.65	288
Stream	F020	18.7	6.8	6.8	440
Stream	F021	16.8	6.88	5.2	389
Stream	F022	11.7	6.95	7.5	395
Stream	F023	13.9	6.9	7.35	394
Stream	F024	12	6.96	9.15	487
Stream	F025	15		18.25	553
Stream	F026	12.2	6.93	2.6	174
Stream	F027	14		13.3	485
Stream	F028	12.4	6.92	10.15	365
Stream	F029	13		13.55	602
Stream	F030	12.5	6.9	11.4	436
Stream	F032	16.5	6.85	14.35	718
Stream	F033	12.8	6.91	4.1	452
Stream	F034	14.8	6.9	5.1	344
Stream	F035	17.2	6.87	5.75	378
Stream	F037	17.4	6.87	6.1	414
Stream	F038	13.2	6.93	12.8	692
Stream	F040	14.5		6	478
Stream	F041	13.8	6.87	10.65	643
Stream	F042	14		6.85	590
Stream	F043	13.9	6.87	8.05	606
Stream	F044	15		7.55	735
Stream	F045			0.7	
Stream	F047	12.6	6.88	3.6	391
Stream	F048	12		9.35	703
Stream	F049	14		2.5	337
Stream	F050	14		6.9	518
Stream	F051	13		2.5	258

Station Type	Station ID	Temp degree C	pH	Nitrate mg/l	Conductance micromhos
Stream	F052	13		5.2	476
Stream	F054	14.3	6.92	6.8	407
Stream	F055	18.4	7.02	5.1	363
Stream	F056	11.1	6.91	6.1	450
Stream	F057	19.7	7.03	1.9	472
Stream	F058	11.3	6.9	5	479
Stream	F062	12	6.89	4.9	366
Stream	F064	14.5		1.05	605
Stream	F066	14.5		2.75	415
Stream	F068	17.7	7.03	1.3	550
Stream	F070	14		3.35	230
Stream	F072	15.9	7.05	3.4	186
Stream	F074	19.6	7.02	2.6	298
Stream	F076	19.6	7	3.9	261
Stream	F060a	11.3	6.91	7.3	465
Stream	F007a			12.5	
Stream	F013a			4.3	
Stream	F017a			3.5	
Stream	F031			13.3	
Stream	F039			9.7	
Stream	F046			12.7	
Stream	F053			2.3	
Stream	F060			3.3	
All Streams	**Min**	10.50	6.80	0.70	174
	Max	20.20	7.05	18.25	735
	Med	14.00	6.92	6.58	407
	Count	61	42	70	61
All Wells	**Min**	12.30	6.31	0.30	231
	Max	20.40	7.22	33.95	1623
	Med	15.50	7.06	9.08	684
	Count	59	41	64	65