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December 21, 2015

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street NE, Room 1A
Washington, DC 20426
Via eFiling

RE: PennEast PennEast Pipeline Company, LLC ("PennEast") – PennEast Pipeline Project: FERC Docket No. CP15-558-000

Dear Ms. Bose,

On behalf of the Cooks Creek Watershed Association ("CCWA"), we submit this letter in response to PennEast's November 13, 2015 filing ("Response") that purported to address concerns of various intervenors, including CCWA. We also submit this letter in response to the Commission's request to PennEast for more information relative to environmental impacts. Included as attachments to this letter for the Commission's consideration are documents on the Cooks Creek Watershed, and a United States Geological Survey document and article on trout and climate change stress cited in this letter.

PennEast confirmed in its Response that the pipeline path will impact the watershed. (PennEast 11/13/15 Response at App. A, p.9). Despite such a recognition, PennEast's Response was long on platitudes and short on specifics, particularly in regard to the watershed. An example of the cursory nature of PennEast's comments is evidenced by its inability to correctly spell the watershed's name on page 9 of Appendix A. With such lack of care evident, CCWA retains significant concerns about the pipeline's path through the watershed. These concerns are set forth more at length below.

I. <u>Pipeline Path Would Cross One of the Last, Generally Undeveloped Portions of the Watershed</u>

As CCWA has noted repeatedly, the Cooks Creek watershed is particularly fragile due to the underlying limestone geology, and the threat that development poses to the fragile system in the watershed. This threat arises from groundwater use, impacts to surface water quality, and inducement of geologic changes due to the underlying limestone that result in further impacts to the watershed's hydrologic system.

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The fragile state of the watershed is exemplified by one of the areas of the watershed that PennEast plans to directly impact. CCWA is deeply concerned about one of these areas especially because it already shows signs of stress. PennEast's proposed activity will only further this along, and yet PennEast has provided hardly any information on how it can avoid this area entirely, much less use tangible mitigation measures to minimize harm.

PennEast's Resource Report 2 and Appendix I, Part 5 show the pipeline route crossing two portions of the watershed.[1] These include tributaries and wetlands around MP 75.7 (Figure 2 Map Page 236 of 242; RR2 - PDF pg.85), and another portion of the watershed in the area of MP 76.4-76.5 (RR2 – PDF pg.85) for the access road. For purposes of this comment, CCWA will focus on the area around MP 75.7, which is labeled at Tributary 111314. This tributary/wetland area will also be impacted by a work space to be located within 50 feet of the stream. (RR2 – PDF p.105); App. A at 21 (USGS Quad Map).

This area is one of the last, largely undeveloped portions of the Cooks Creek Watershed. PennEast plans to cross a headwater wetland for what used to be a flowing tributary. The watertable is near the surface in the wetland area, and the stream leaves the area, but then enters a farm field downhill and disappears below ground due to depressed groundwater and/or drainage. It never reappears, but the dry stream bed is very apparent along Stout's Valley Road all the way to Red Bridge/Rattlesnake. The fact that this is occurring on its own is evidence of changes occurring in the watershed. PennEast's activity would only further this damage.

Despite this, PennEast has not provided sufficient information to evaluate whether the lack of tributary flow is due to the underlying karst geology (i.e. a sinkhole has swallowed up the stream) or whether changes to the groundwater (whether due to geologic conditions or human causes) has eliminated the flow in the stream. Given the significant level of disturbance associated with the proposed pipeline construction, this type of analysis must be done because the disturbance would further damage whatever is left of the hydrologic system in this area, particularly if geologic factors are at play.

Further, PennEast has failed to provide *any* information on where it intends to use blasting. While this will be further discussed below, this utter lack of information is unacceptable and shows that PennEast has not engaged in the analysis (or done so with the proper level of care) to demonstrate that putting a 3-foot diameter high-pressure transmission gas pipeline should be located where PennEast wants.

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[1] This said, in Table 10.3-10 of the Alternatives Analysis, PennEast represents that the proposed route is no longer crossing any Exceptional Value watersheds between MP 75-97. This is incorrect – there is one EV watershed it is still crossing in that segment of the line, and that is the Cooks Creek Watershed. This same error is repeated later in the table when PennEast represents that no EV watersheds with naturally-reproducing trout are being crossed. This is incorrect for the same reasons.

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PennEast also attempts in its filings with the Commission to separate wetlands from stream water quality and protection. As is made evident by the tributary discussed above, wetlands and streams are part of the same system and cannot be divorced from one another. Neither logic nor science supports such an approach.

II. Blasting Not Appropriate in Karst Areas

PennEast repeatedly notes that it may have to use blasting. (RR2 at 2-31 to 2-32; App. O). However, in Appendix O, the table that is supposed to show where PennEast would use blasting is *completely* blank.

Aside from yet another indication that PennEast is not proceeding with a high level of care, there is a more significant problem with its general statements about blasting. If PennEast and FERC are serious about minimizing environmental impacts, blasting *should not be used* in karst areas. Even FERC's letter to PennEast allows for the eventuality that such methods may be used, despite the fact that blasting is not consistent with minimizing harm to the local environment. (FERC 11/24/15 Ltr. to PennEast, p.11). In a publication on mining in karst areas, the U.S. Geological Survey states: "Blasting can negatively affect karst habitat and biota. Blast-induced vibrations and shock waves can cause cave roofs to crack or collapse, and karst environmental conditions can be altered by just one new crack." ("USGS Publication"), at p.13 http://pubs.usgs.gov/of/2001/ofr-01-0484/ofr-01-0484so.pdf

CCWA reserves the right to comment on any blasting plan proposed for the Cooks Creek watershed.

III. PennEast Has Failed to Show that Avoidance of Proposed Impacts is Not Feasible

PennEast has not demonstrated avoidance of Exceptional Value ("EV") wetlands and streams in the watershed. Approximately four stream crossings and proposed wetland intrusions are not avoidance, especially when there are other local areas directly nearby the proposed pipeline path that are not EV. 25 Pa. Code Chapter 93 clearly states that "The water quality of Exceptional Value Waters shall be maintained and protected." 25 Pa. Code § 93.4a.

Property owners in the watershed cannot intrude on stream buffers and wetland buffers, absent specific and detailed studies and restoration plans. See, e.g. Durham Twp. Zoning Ordinance and Springfield Twp. Zoning Ordinance Sections 508B.3(e), B.4(e)(establishing buffer protection) see also Section 508B.5 (requiring specific and detailed study and restoration requirements for any intrusions); Williams Twp. Zoning Ordinance Sections 1501 and 1505. These rules exist for a reason, which is to protect water quality and, in turn, aquatic life. PennEast is seeking to become a property owner in the watershed and should be subject to the

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same rules as every other property owner. So far, it has failed to show that it can comply with the same standards as every other property owner.

IV. Water Quality in Karst Areas Particularly Susceptible to Pollution from Development

The Geological Survey publication quoted earlier states:

> Karst systems have very low self purification capabilities (Kresic and others, 1992), which makes karst water very susceptible to pollution. A major concern is that polluted materials, including pathogens, can be carried long distances without being fi ltered because of high flow velocities (several hundreds of thousands of meters per day) (Assad and Jordan, 1994).
>
> The sources of pollutants do not necessarily have to be man-made; there also are natural sources of pollution (Kresic and others, 1992). Generally, karst occurs in areas that contain large amounts of organic material and bacteria, which can naturally degrade water quality.

USGS Publication, p.14.

PennEast brushes off surface water contamination, claiming in part that it will include "measures to protect surface waters as applicable." (PennEast 11/13/15 Response at App. A., p.9); see also (id. at App. A, p.35 (referring back to RR2 re: surface water protection)). It further relies on its erosion & sedimentation and spill prevention plans, among other measures. However, the same Geological Survey publication notes that karst areas are particularly at risk of water pollution once vegetation and upper soil layers are disturbed or removed:

> In temperate areas removing vegetation and soil reduces evapotranspiration and increases the effective rainfall. Unless measures are taken to control runoff and sedimentation, deterioration of ground water is likely. In some karst areas the soil overlying the rock normally is a zone of filtration and water purification (Gunn and Hobbs, 1999).

USGS Publication, p.14.

PennEast's claim that it will only do the minimum, i.e. protect surface waters as it has to, does not instill confidence that it is truly attempting to avoid harm to water quality in the first

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place, and minimize whatever harm is not avoidable. Indeed, its reliance on a spill prevention plan demonstrates that it hopes that it can build its pipeline and just mop up the inevitable problems that may result.[2] This approach is problematic to begin with; it is only worse when it is the strategy proposed for a fragile limestone watershed like Cooks Creek.

As CCWA has noted previously, the Cooks Creek Watershed has very little leeway for a company's hope that no damage will occur. This is a limestone watershed, underlain by karst, that supports brook and brown trout. Removal of vegetation, poorly-planned erosion and sedimentation measures, and changes to stormwater flow all negatively impact the water quality and in turn, the trout species in the watershed. These species are already under stress from climate change; they need no further stress from PennEast. See "Brook Trout Study Identifies Top Climate Change Pressure Factor," http://www.umass.edu/newsoffice/article/brook-trout-study-identifies-top-climate (finding high summer temperatures detrimental to trout species; recommending maintaining cold water inflow to streams and *improving* and protecting forested riparian buffers). The area proposed for the crossing includes springs, wetlands, forested buffers and headwater streams – all areas that provide and maintain cold-water flow in the watershed.

CCWA requests a site-specific plan for crossing of the Exceptional Value ("EV") wetlands and streams in the Cooks Creek watershed to ensure that the water quality of the creek is not degraded. 25 Pa. Code Chapter 93 clearly states that "The water quality of Exceptional Value Waters shall be maintained and protected." 25 Pa. Code § 93.4a. There are no exemptions. Compare 25 Pa. Code § 93.4c(b)(specifying social or economic justification for High Quality waters). EV streams and wetlands are clearly protected from any significant change in water quality as measured by chemistry. CCWA is particularly concerned about nutrients, suspended sediments, arsenic and mercury, all of which have been identified as issues either in the Cooks Creek watershed or in neighboring watersheds.

Because the anti-degradation standards clearly apply, PennEast must provide a concrete (rather than general) plan for maintaining hydrology during and following construction, for both headwater streams and wetlands in the watershed, no matter how small. This is the same type of plan that is already required of other property owners in the watershed. See, e.g. Durham Twp. Zoning Ordinance and Springfield Twp. Zoning Ordinance Sections 508B.3(e), B.4(e)(establishing buffer protection) see also Section 508B.5 (requiring specific and detailed study and restoration requirements for any intrusions); see also Sections 508B.9 (requiring

[2] PennEast further refers to Appendix I of its application for a waterbody and wetlands protection plan – Appendix I merely identifies where streams and wetlands are according to PennEast's survey, not how PennEast will avoid, minimize, and mitigate harm (in that order).

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specific studies in carbonate geology areas); Williams Twp. Ordinance 2005-1 (requiring specific protections in carbonate geology areas). Again, if PennEast wants to become a property owner in the watershed, it must play by the same rules as everyone else.

V. PennEast Has Not Shown Avoidance of Harm to Groundwater Quality and Neighboring Property Owners

The recurring theme in PennEast's application and response to comments is of hoping that impacts will not happen, and if they do, PennEast promises to mitigate the damage then. (See, e.g., PennEast 11/13/15 Response at App. A, at p.24). This approach, as already noted, is highly problematic in the Cooks Creek watershed. There is no room for "a little" damage, and failing to avoid and minimize harm (in that order) in a karst area will make mitigation of the subsequent damage difficult to impossible. USGS Publication, at p.13 ("[K]arst environmental conditions can be altered by just one new crack.")

If karst areas are going to be entered upon, then PennEast must perform *a complete and thorough* survey. Compare Durham Twp. Zoning Ordinance and Springfield Twp. Zoning Ordinance Sections 508B.9. So far, there is only an interim survey in the application materials. If karst bodies are found in the area, then PennEast must first avoid damage, up to and including filling of karst cavities. They must also demonstrate that their construction does not impact groundwater quality. The watershed has had significant water quality issues (mostly nitrates) in the area in which the proposed pipeline would be located. PennEast should conduct a baseline evaluation of water quality, prepare an ongoing monitoring plan, and conduct monitoring before, during, and after construction. The plan should include, at a minimum, monitoring for changes in pH, water level, nitrates, arsenic, and mercury.

In addition to a full survey, avoidance of damage (including to groundwater quality), and water quality monitoring, PennEast must have a site-specific plan in place to address what PennEast terms "loss of subgrade." This plan must be in place to protect groundwater quality, as well as the life and health of surrounding property owners in the event that the ground gives way under the operating transmission line. PennEast currently lacks such a plan of what it would do if it found evidence of loss of support under the built pipeline due to subsidence. (11/13/15 Response at App. A, p.24)(noting regular inspections will occur, but providing no further details on what will happen if evidence of subsidence is found).

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VI. Conclusion

In closing, we urge the Commission to request from PennEast, the following:

1. An explanation as to why an alternative route that avoids the Cooks Creek Watershed entirely was not considered. In fact, it appears that PennEast specifically chose to traverse a headwater/wetland area. None of the alternatives presented avoid this sensitive resource, and PennEast has failed to explain why this could not be done.

2. Information on where blasting will occur along the pipeline route.

3. A complete and thorough survey of all karst/carbonate geology areas that PennEast will enter upon and impact.

4. If the Watershed cannot be avoided, then PennEast must provide a watershed-specific work plan that details best management practices that will maintain the existing hydrology and minimize any impacts to sensitive karst geology, groundwater, springs and seeps, wetlands, headwater surface water resources, and aquatic life in this Exceptional Value Watershed.

5. A baseline evaluation of water quality, preparation of an ongoing monitoring plan, and conducting monitoring before, during, and after construction. The plan should include, at a minimum, monitoring for changes in pH, water level, nitrates, arsenic, and mercury.

6. If unavoidable impacts are expected or may reasonably be expected in the future due to this project, a detailed, site-specific mitigation plan that addresses the specific resources impacted must be provided.

7. Require that this information be presented in a forum that allows for meaningful public participation and comment.

We have provided for the Commission's benefit copies of the following:

1) the Cooks Creek Watershed Wetlands Management Plan;
2) the Cooks Creek Watershed Conservation Plan and selected appendices;
3) the USGS karst publication cited in this letter; and
4) the article on trout and climate change stress cited in this letter.

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Thank you for your time and consideration.

Sincerely,

Lauren M. Williams
For CURTIN & HEEFNER LLP

cc: All Parties

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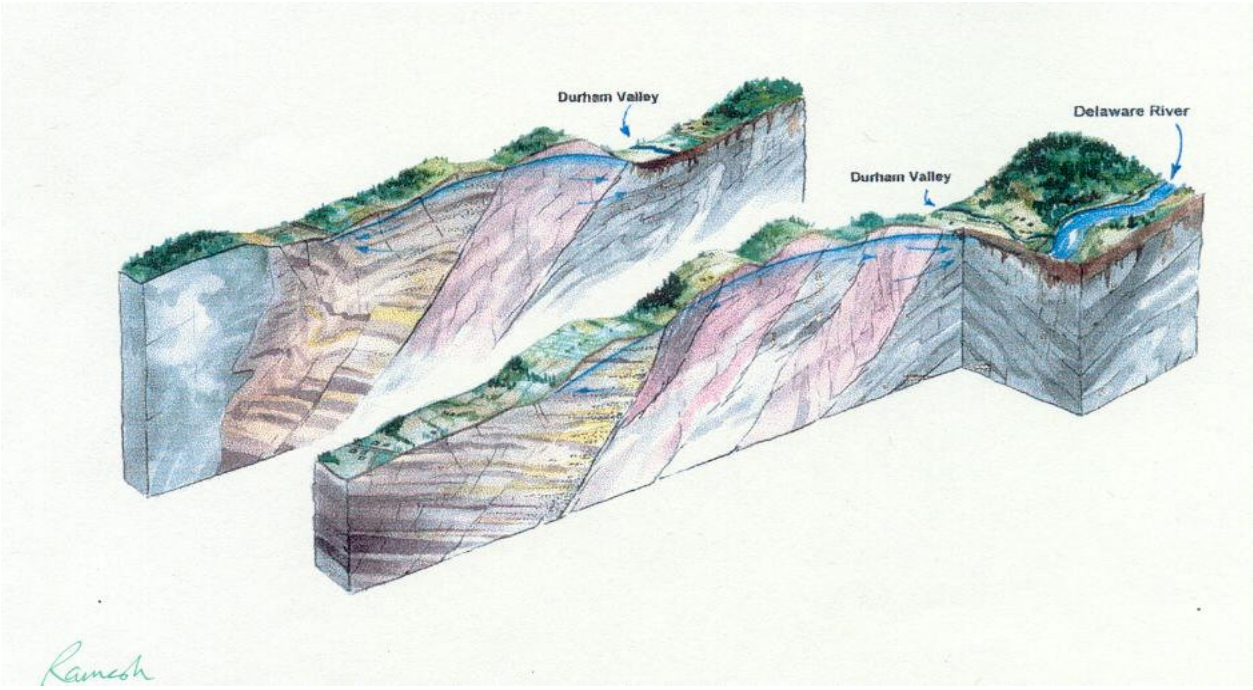
DURHAM TOWNSHIP ENVIRONMENTAL ADVISORY COUNCIL

Cooks Creek Watershed Monitoring and Planning Program

Wetlands Management Plan

Submitted by:

MJ Environmental Associates, Ltd.



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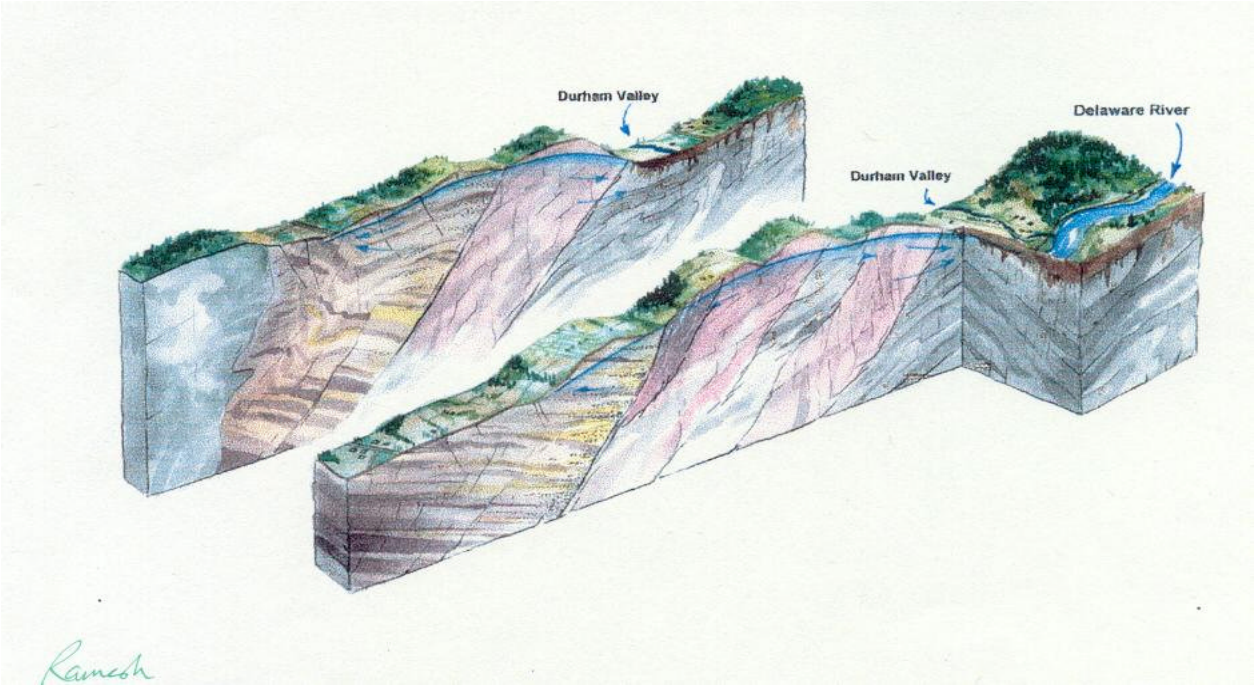

May 22, 2000

Durham Township • 215 Old Furnace Road • POB 4 • Durham • Pennsylvania 18039

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May 22, 2000

1. INTRODUCTION

MJ Environmental Associates Ltd. (MJE), Golder Associates Inc. (Golder) and EEE Consulting, Inc. (EEE) are pleased to provide the Final Report to the Durham Township Environmental Council (DTEAC). The goal of the project is to provide information to the DTEAC for a wetlands conservation plan that would be supported by the municipalities and will be integrated with a total water resources management plan of the hydrologic system within the project area.

The Cooks Creek Watershed located in northern Bucks County, Pennsylvania is an area of approximately 30 square miles in size, which traverses Durham and Springfield Townships. The study area is shown on Figure 1.1. The Cooks Creek watershed has a number of unique geologic, scenic, and natural resources, including the following:

- The Cooks Creek Watershed has been designated as an Exceptional Value waters in accordance with the Pennsylvania Code Chapter 93;
- The entire Cooks Creek has been designated as a 1-A priority for consideration as a state scenic river. According to Mr. Terry Hough, with the Department of Conservation and Natural Resources, no official request for designation as a Scenic River has been filed. However, there has been a state moratorium on designation of new state scenic rivers since 1992;
- The watershed supports threatened and endangered species, both federal and state-listed species;
- Cooks Creek is a wild brown trout stream; and,
- The watershed contains some unusual geologic conditions, such as karst-prone areas and a Triassic basin. The local geology, particularly karst areas, makes the stream and groundwater vulnerable to contamination

To protect this unique watershed, the Durham Township Environmental Advisory Council (DTEAC) wishes to implement the Cooks Creek Watershed Monitoring and Planning Program (CCWMPP). The CCWMPP is aimed at developing a water resources management strategy that would be used to help development of a revised Comprehensive Plan for the Durham Township. The specific project goal is to develop a comprehensive database from which development plans and zoning ordinances appropriate for the watershed can be made that take into account the current quality of the watershed, the quality of the available drinking water, and its sensitivity to degradation.

There are several principal objectives that are targeted to meet the goal. These objectives include:

- Wetland delineation and determining the soils characteristics of the study area;
- Delineating Karst features, and other hydrogeologic properties of the geologic formations in the study area;
- Determining the important hydrologic characteristics and preparing a water budget of the study area;
- Cooks Creek continuous stage recording and computation of discharge; and,
- Initial GIS development, structured to allow for the inclusion of additional information collected in the future;

The central element of the fieldwork for this project was collecting data to develop a Wetland Management Plan for the study area. This was accomplished through review of available literature for the study area, site

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reconnaissance, and field measurements. This phase of the project does not include any sampling and analysis of surface water, groundwater, or soil to determine "water quality".

All work was conducted in accordance with the Quality Assurance Plan (QAP) approved by the EPA. There were three main subject areas that involved field work/ evaluation methodologies:

- Hydrologic investigations of Cooks Creek and water supply wells;
- Geologic mapping of the watershed , including karst-prone areas;
- Natural resource studies;

Surface water bodies and wetlands in the Cooks Creek watershed, within Durham Township and Springfield Township, were identified using the existing National Wetlands Inventory Maps (NWI), the existing County Soil Survey, and using field techniques consistent with the U.S. Army Corps of Engineers Wetlands Delineation Manual (1987). The fieldwork targeted potential wetland areas that do not appear on the NWI maps, such as areas with hydric soils that are not delineated on NWI maps. Wetland functions and values were also identified by using the Wetland Evaluation Technique (WET II) developed by the US Army Corps of Engineers (1987). Finally, a database search and field reconnaissance was conducted of threatened and endangered species within the Cooks Creek watershed.

The geological survey task included a desktop study and follow-up field reconnaissance. The desktop study included a detailed topographic map interpretation and inventory of potential geologic features where there is an immediate groundwater-to-surface water connection. The field reconnaissance included geologic features such as karst, spring discharges, sinkholes, and loosing streams.

The Pennsylvania Department of Conservation and Natural Resources (PaDCNR) existing database of groundwater wells in this area has been reviewed. Selection of wells to be surveyed included that will provide a spatial distribution related to the main topographic features such as divides, Cooks Creek tributaries, wetlands, flat areas, side hills, etc.

Water level measurements were collected at selected wells. The measurements were based on depth to water from the ground surface. (Ground surface elevation of the selected wells was taken from USGS Quadrangle Maps, scale1:24,000). One round of water levels was collected over a three day period. A drawing of the ground water table map was generated for a 20-foot contour interval and included in the GIS graphics and 3-D block diagram representation.

The preliminary water budget is estimated as the amount of water entering and leaving the basin, plus or minus changes in storage, for a given period of time. Water enters as precipitation and leaves as stream flow, ground-water underflow, diversion of ground water from the basin where it was pumped, and evapotranspiration, plus or minus interbasin flow and changes in ground-water and soil-moisture storage. During dry periods, streamflow is sustained by base flow, which is groundwater discharge to streams. The water budget evaluation has been designed and developed as a computer application, and is included in WAMOS (Water Monitoring System) computer application.

WAMOS software package is a computer friendly-user interface designed for downloading stage data, calibrating and develop rating curves for the stream gauge, maintaining database and calculating flows, statistics analysis, water budget, and finally integration the monitoring stream gauge data in the Township Management Plan.

2. COOKS CREEK STREAM GAGE - DATA COLLECTION AND DATA ANALYSIS

2.1. Cooks Creek Stream Gage Installation

This effort included the following:

- Installation of a stream gage monitor on Cooks Creek at the Durham Furnace Bridge Location;
- Interpret previously collected stream gage data for determination of significant hydrogeologic properties from the previously 2-years data monitored by the U.S. Geological Survey from 1991 - 1993 (Sloto and Schreffler, 1994);
- Maintenance of a rating curve on the Cooks Creek gauging station;
- Periodic downloading of data from the monitor station.

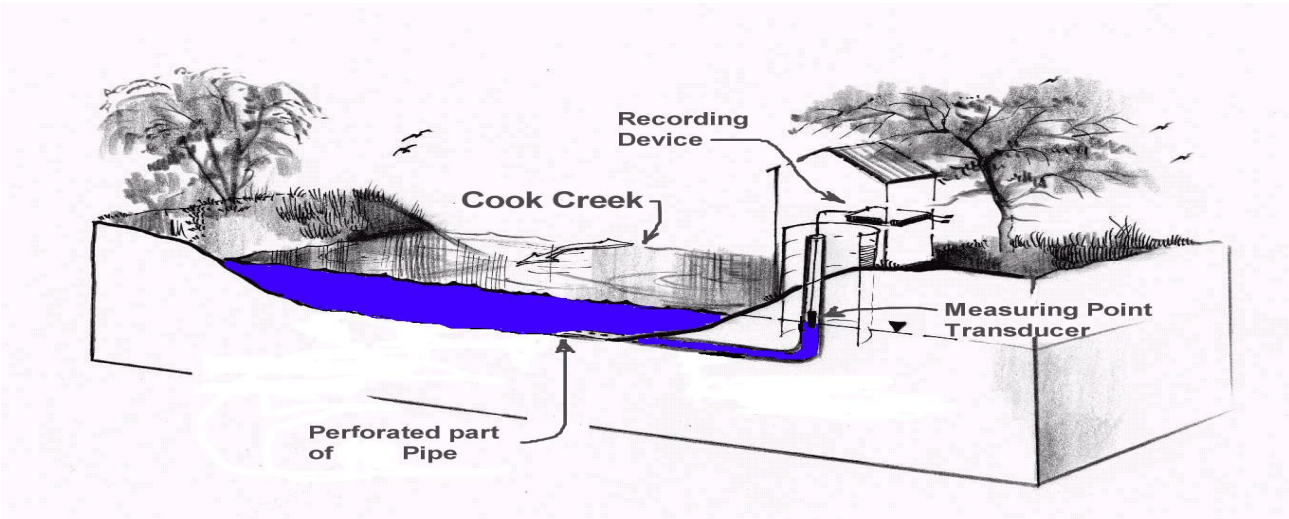

Figure 2.1 Cooks Creek gauging schematic

This data was loaded onto a PC in the computer application hereafter called WAMOS. The WAMOS application has two screens, Analysis and Calibration. Pressing the CALIBRATE button in the Analysis screen will switch to the Calibration screen and pressing the ANALYSIS button in the Calibrate screen will switch back to the Analysis screen.
REMARK: The Calibration screen is used only if the creek bed profile is changed which is expected to be very seldom.

2.2. WAMOS User Interface

WAMOS consists of two screens, i.e. the Analysis screen (Figure 2.2) and Calibration screen (Figure 2.3). The

application starts up displaying the Analysis screen.

The elements contained by the Analysis screen are:

1. The screen title and subtitle;
2. Streamflow chart;
3. Time base selection control;
4. Results table; and,
5. Command buttons.

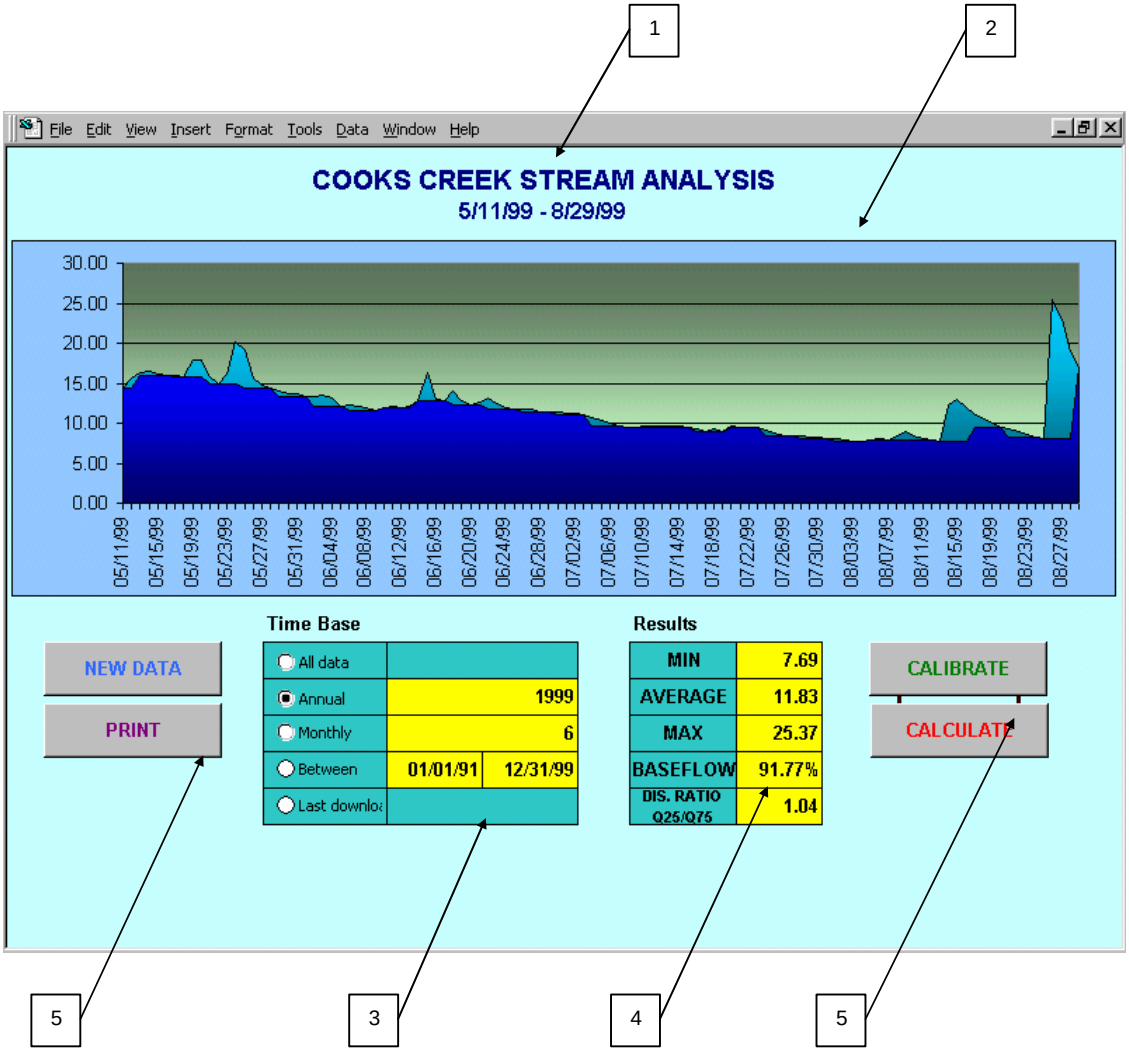

Figure 2.2 The Analysis screen of WAMOS .

The Calibration screen contains the following elements:

1. The screen title;
2. The river bed profile chart;
3. The flow rating curve chart;
4. The general parameters table;
5. The corelation parameters table;
6. The river bed profile tables;
7. The river bed profile controls; and,
8. The command buttons.

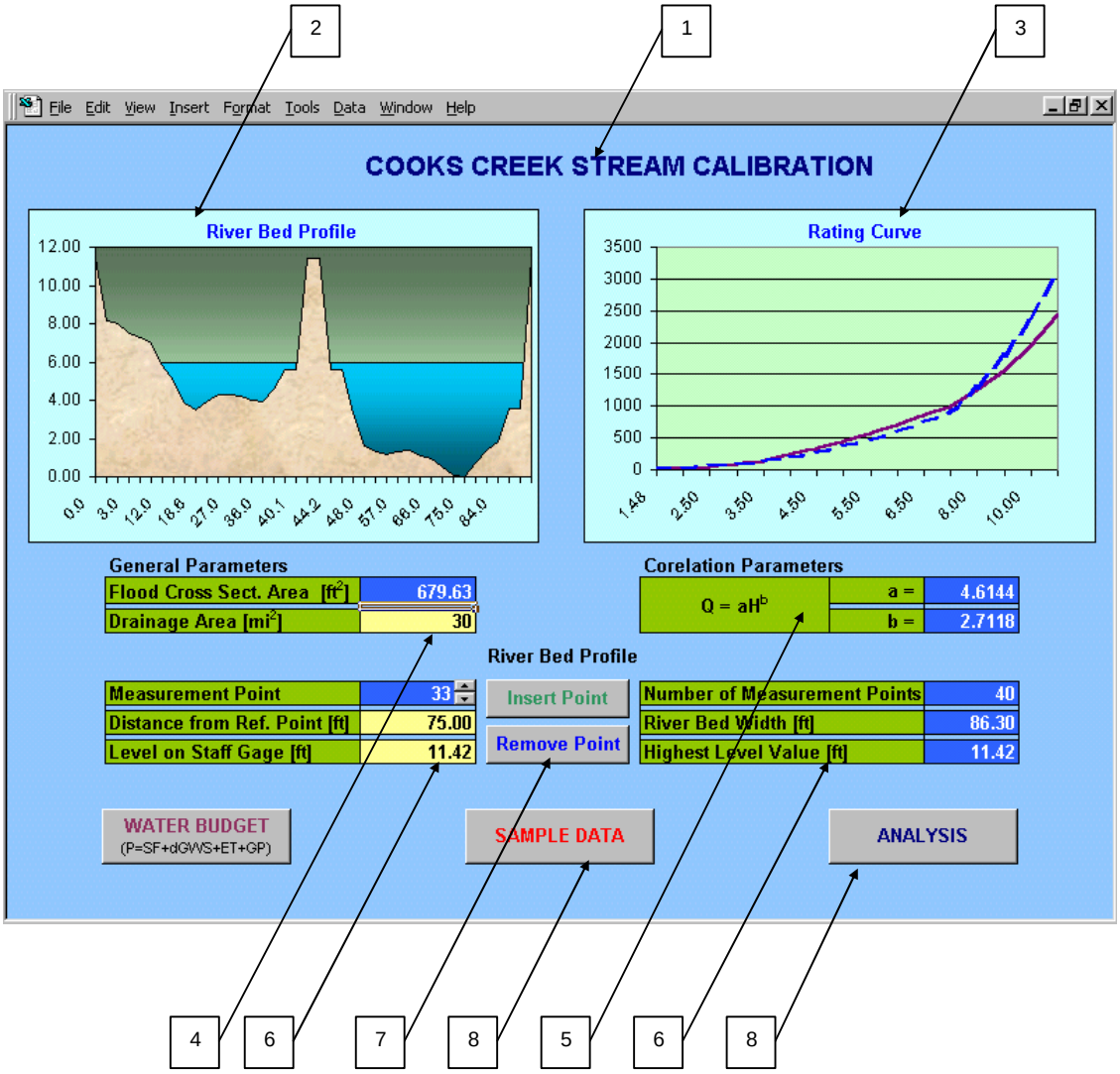

Figure 2.3 The Calibration screen of WAMOS.

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Year	Total streamflow (inches)	Base flow (inches)	Percentage of streamflow as base flow	Surface runoff (inches)	Percentage of streamflow as surface runoff
1990	32.33	14.48	45%	17.85	55%
1991	18.19	11.17	61%	7.02	39%
1992	19.01	8.29	44%	10.73	56%
1993	4.55	3.96	87%	0.59	13%
1999	5.35	4.91	92%	0.44	8%

Figure 2.4 Annual stream flow and estimated base flow report.

Year/ Month	Precipi-tation (inches)	Steam-flow (inches)	Percentage of precipitation as streamflow	Change in ground-water storage (inches)	Percentage of precipitation as change in groundwater storage	Evapotran-spiration and other losses (inches)	Percentage of precipitation as evapo-transpiration	Ground-water pumpage (inces)	Percentage of precipitation as ground-water pumpage
1990/12	0	0							
1991/01	0	0							
1991/02	0	0							
1991/03	0	0							
1991/04	0	0							
1991/05	0	0							
1991/06	0	0							
1991/07	0	0							
1991/08	0	0							
1991/09	0	0							
1991/10	0	0							
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1999/08	0	0							

Figure 2.5. The monthly water budgets Report.

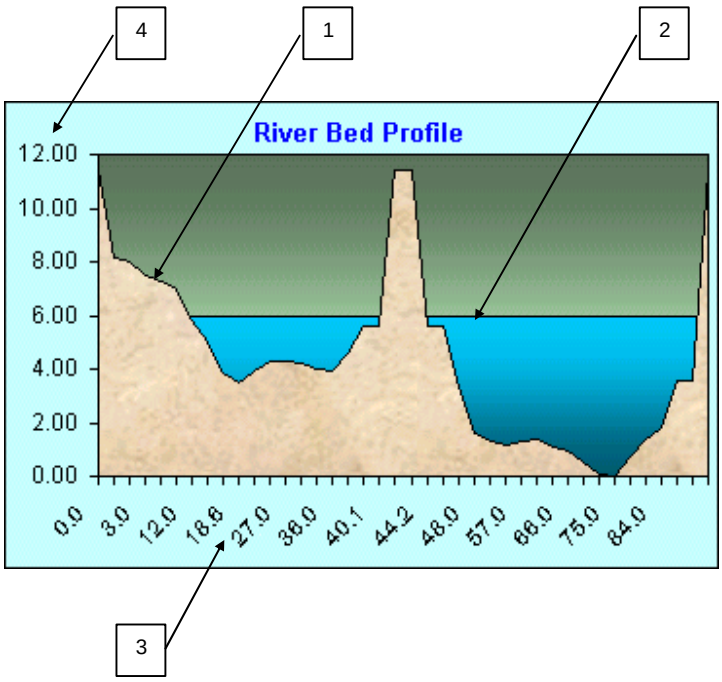

Figure 2.6 Stream bed profile chart.

The cross section is expressed in riverbed levels (item 4) versus distance from a reference point on the riverbank (item 3). The measurement units are feet on both axes.

An arbitrary water level was graphically represented by item 2. This arbitrary water level does not change when input the actual data.

A. The Flow Rating Curve Chart

According with the applicable methodology, the measured stream levels (H) are converted to flow values (Q) using a power correlation function having the following expression:

$$Q = aH^b,$$

where a and b parameters are experimentally determinated.

The Flow rating curve chart (Figure 2.6, next page) displays the experimental measured values (item 1, brown continuous curve) and the correlation power function (item 2, the blue dashed curve) as flow (item 3) in cubic feet per second versus stream level in feet (item 3).

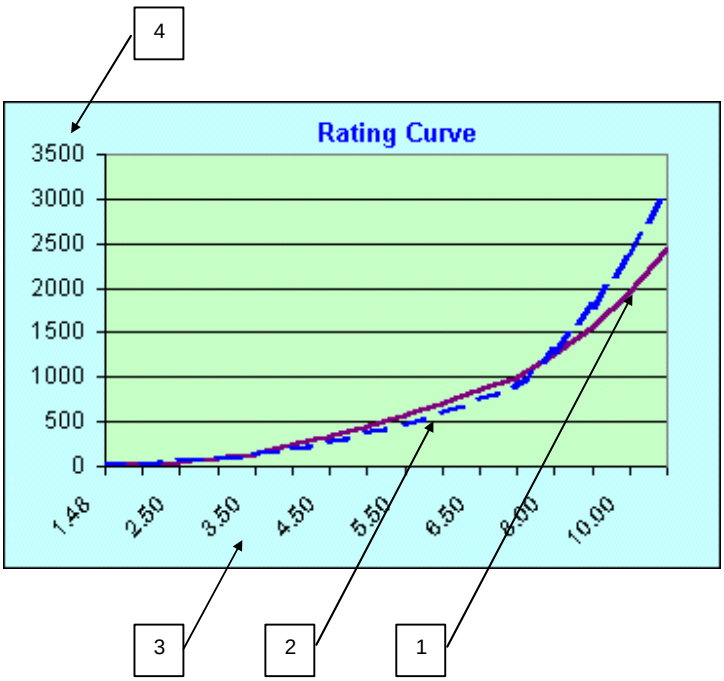

Figure 2.7 The flow-rating curve chart.

B. The Correlation Parameters Table

The Correlation parameters table (Figure 2.14) contains the calculated values of the power function parameters that interpolets the experimental measured values.

Corelation Parameters		
$Q = aH^b$	a =	4.6144
	b =	2.7118

Figure 2.8 The correlation parameters table.

The flow function (Q) is represented together with the experimental measured values on the Flow rating curve chart (Figure 2.6).

C. The Water Budget Parameters Table

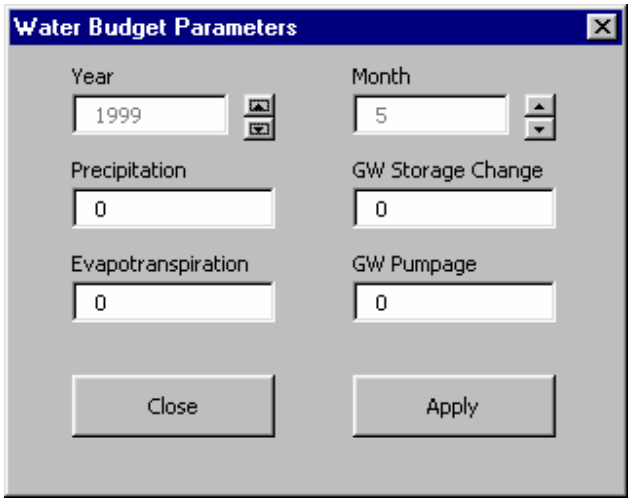

Figure 2.9 Water budget parameters dialog window.

This dialog window allows the user to enter or modify the following measured parameters all expressed in inches:

- Precipitation;
- Ground water storage change;
- Evapotranspiration; and,
- Ground water pumpage.

3. SURFACE GEOLOGICAL SURVEY

3.1 Regional Geology

The geologic units of the Cooks Creek watershed area include crystalline rocks of Precambrian age of the reading prong and crystalline rocks of Lower Paleozoic age of the Great Valley sequence along the northern border of the study area (see Figure 3.1). Together these are age-undifferentiated in this geologic report, and effectively form the "basement" for the overlying unmetamorphosed sedimentary rocks of the Newark-Gettysburg Basin. Triassic and Jurassic age sedimentary rocks , and Jurassic age igneous rocks belonging to the Newark-Gettysburg Basin occur south of the Newark Basin border fault. These sedimentary rocks contain several inliers of the basement and are exposed as narrow fault-bounded slivers (as along Mine Hill in Durham Township and Durham Valley). The Geologic Map appended to this report shows areal extent of the major rock units mapped at a reconnaissance scale for this project.

The Precambrian crystalline rocks of the Reading prong occurs along the ridges bounding the northern slopes of Durham Valley and consist of a series of stacking, thrust fault bounded blocks which were thrust over the Cambrian and ordovician age carbonates and clastics of the Great Valley sequence. The crystalline rocks consist of pyroxene geneiss, amphibolite gneiss and schist, hornblende gneiss and granite and a suite of meta sedimentary pelitic rocks.

The crystalline rocks have undergone several stages of metamorphic episodes as high as amphibolite-granulite facies and are accordingly classified as gneiss and schist. The foliation in these rocks also displays the internal folding and tectonism and generally strikes parallel with the strike of the Newark Basin Border Fault, which is east northeast to west-southwest. Foliations is generally steep and dips between 30 degrees and 70 degrees to the south.

The Paleozoic rocks of the Great Valley exposed within the lower topographic reaches of Durham Valley, but north of the Newark Basin Border Fault. This sequence is dominated by shallow marine, and marginal marine carbonate rocks including the Cambro-Ordovician Allentown Dolomite, Cambrian age Leithsville Formation and local slivers of the youngest, Ordovician age Rickenbach Dolomite. Narrow bands of the underlying Hardystone Quartzite occur along the lower stratigraphic contact of the Leithsville Formation, but only along the northern part of Durham Valley. In the southern part of the Durham Valley the above sequence has been tectonically abbreviated, and much faulting and fault truncation has resulted in a thinner Paleozoic sequence south of Cooks Creek. The carbonate rocks are generally argillaceous, and become purer in carbonate content higher up in the stratigraphic sequence; i.e., the Rickenbach Dolomite is a much purer carbonate sequence than the underlying Allentown and Leithsville units.

The Paleozoic sequence has been assigned to the Furlong Klippe of the overthrusted blocks, is much deformed into north-verging recumbent to steeply overturned synformal anticlines and synclines. Although many faults must occur within this unit, poor outcrop precludes their detailed mapping.

The Newark-Gettysburg Basin deposits of Mesozoic age were mainly derived from erosion of the crystalline rocks southeast and northwest of the Newark Basin Border Fault. The strata within the basin are assigned to the Stockton

Formation (herein equivalent with the Brunswick) which in turn overlies the Lockatong Formation. The beds in general, dip gently to the northwest although deformation along the border fault have resulted in many gentle, open folds and faults. The Border Fault is known to dip to the southeast gently at 20 to 25 degrees, and much work showing that the border fault is the result of reactivation of the Paleozoic age thrust faults of the

Appalachians is well known. These sedimentary rocks of the basin are dominantly interbedded, clastic and include sandstone, siltstone, shales and claystone interbedded with local calcarous siltstone beds.

Several diabase intrusions of early Jurassic age are also exposed within the study area. The largest intrusive body has been named the Coffman Hill sheet which is as much as 4 miles wide and a little over 5 miles long (along strike) and occurs along the southwestern, and southern border of the study area in Spring, Tinicum and Nockamixon townships.

Faulting continues contemporaneously with sedimentation within the evolving Newark half-graben, hence the strata thicken towards the border fault, which is again marked by numerous discrete fanglomeratic horizons which include both quartz and limestone fanglomerates.

3.2 Cooks Creek Watershed Geology

3.2.1 Geological Control Approach in the Watershed Analysis

Watershed analysis is the primary tool that provides the basis for a sound understanding of watershed conditions and management options. Two independent factors influence watershed condition. These are geology and climate. Within the confines of a watershed, geology also controls vegetation, soils, hydrology, and morphology (basin slopes etc.), and climate modifies the each of the above variables which therefore, are interdependent upon each other. Geology is an important component of the watershed that does not change with time, and is largely unaffected by climate and the four interdependent factors (soils, hydrology, vegetation and watershed-morphology. However, land use practices at a human time scale can indeed modify all the four interdependent factors. Vegetation, soils, hydrology and the morphology of land has are ephemeral and may change during a period of several years to several decades.

Land- and water-use potential are therefore, a function of both geology and climate, as wells as vegetation, soils, hydrology and morphology. Watershed condition at any given time results from an integration of these six natural factors, and left undisturbed changes within the watershed are gradual and slow. However, as land and water use practices have increased- the influence of man on the environment and watershed is more profound and immediate.

Geology

The following provides an overview of how geology may be the most important underlying factor controlling watershed processes and conditions in the Cooks Creek drainage basin. Lithology, structural geology and topography are considered the primary elements which have allowed definition of the various parts of Cooks Creek drainage basin. Because geology controls the lay of the land, surface water flow and groundwater flow, the area of the drainage basin has been subdivided into discrete parts or “compartments” wherein each part has its own defining geologic elements. After a brief overview of the various controlling geologic factors, the compartments illustrated in Figures 3.2 through 3.4.

Elements of Compartment Definition

In geologic practice, the geologic formation based on rock type or groups of rock type serves as the basis for assigning names to geologic units; however, groups of formations or parts of formations (members) may be similar enough geologically, hydrogeologically or in other factors and may thus be accommodated into rational groupings. In like manner the recognition of individual compartments as defined above has utilized the same approach. Other components that need to be incorporated into defining the compartments are the bedrock

lithology, structural geology, which includes faults, illustrates primary jointing directions, and shows fold axes and dip direction, and finally a generalized description of the topography of the compartment.

Topography

The Cooks Creek drainage basin is underlain by several diverse geologic formations which occupy discrete positions in the topographic setting of the drainage basin. These topographic positions are not random, but in general, the harder, more resistant rocks occupy highlands or are topographically elevated. These highlands may rise to elevations as high as 300 feet above the lowlands. The softer, erosionally less resistant rocks occupy lowlands or occur within topographic low areas or valley bottoms. More details about the effect of geology on local area topography are discussed below in the section on geology.

Softer rocks being easily eroded, result in broad open valleys, and gentler stream gradients. In harder, more resistant rocks, the valleys are narrower, and also steeper. Many of the streams draining the ridges surrounding the valley of Cooks Creek (for example, the streams that run along Dogwood Road in Durham Township, or Lower Saucon Road in Springfield Township) flow down more resistant rocks that underlie the ridge crest and mid slopes. These streams occupy steeper and narrower valleys. Cooks Creek occupies the broad, open, lowland valley bottomlands. The gradient of the stream determines the current velocity. Current velocity determines the composition and particle size of deposits that are carried along the stream bottom. The size of these deposits, and current velocity together helps determine what organisms can live there. Thus, it is obvious that watershed geology also helps determine the nutrient and dissolved mineral content of the water. For example, limestone geology tends to contribute more dissolved nutrients and minerals to the water, providing essential materials for biological activity. Nutrients can enter the stream dissolved in runoff, attached to eroded soil particles, or in decomposing organic matter.

Within this overall framework, of highlands and lowlands, Cooks Creek and its many tributary streams comprise what is the Cooks Creek drainage basin.

3.2.2 Generalized Geology of Cooks Creek Drainage Basin

Geology, for the purposes of watershed analysis, can be described by two parameters: rock unit lithology and geologic structure. Lithology describes the physical and chemical properties of a rock unit such as rock strength, type of minerals or fossils that comprise the rock, and it may also thickness of beds, whereas structure describes the rearrangement of a rock unit by tectonic (mountain building) forces.

Geologists map rock bodies, and the principle unit used by them to describe the rocks is “formation”. A formation is a body of rock that consists of a certain lithologic type or combination of types; it may be igneous, sedimentary, or metamorphic and be consolidated or unconsolidated. As an example, the principle rocks underlying Cooks Creek in Durham Township are the Allentown Formation and Leithsville Formation. Both rocks are carbonate mineral bearing rock - limestone and dolomite. The Leithsville is older than the Allentown and both formations can be differentiated by an experienced geologist. Based on the above principles, the rocks of Cooks Creek drainage basin can be divided into several formations as shown on the Geologic Map (Figure 3.1), and summarized below from the oldest to the youngest as follows:

- ***The Precambrian crystalline rocks*** of the Reading Prong occurs along the ridges bounding the northern slopes of Durham Valley and consist of a series of stacking, thrust fault bounded blocks which were thrust over the Cambrian and Ordovician age carbonates and clastics of the Great Valley (Northampton County) and Lehigh Valley sequence (southern Northampton County and northern Bucks County). The crystalline rocks consist of pyroxene gneiss, amphibolite gneiss and schist, hornblende gneiss and granite and a varied suite of meta-sedimentary pelitic rocks.

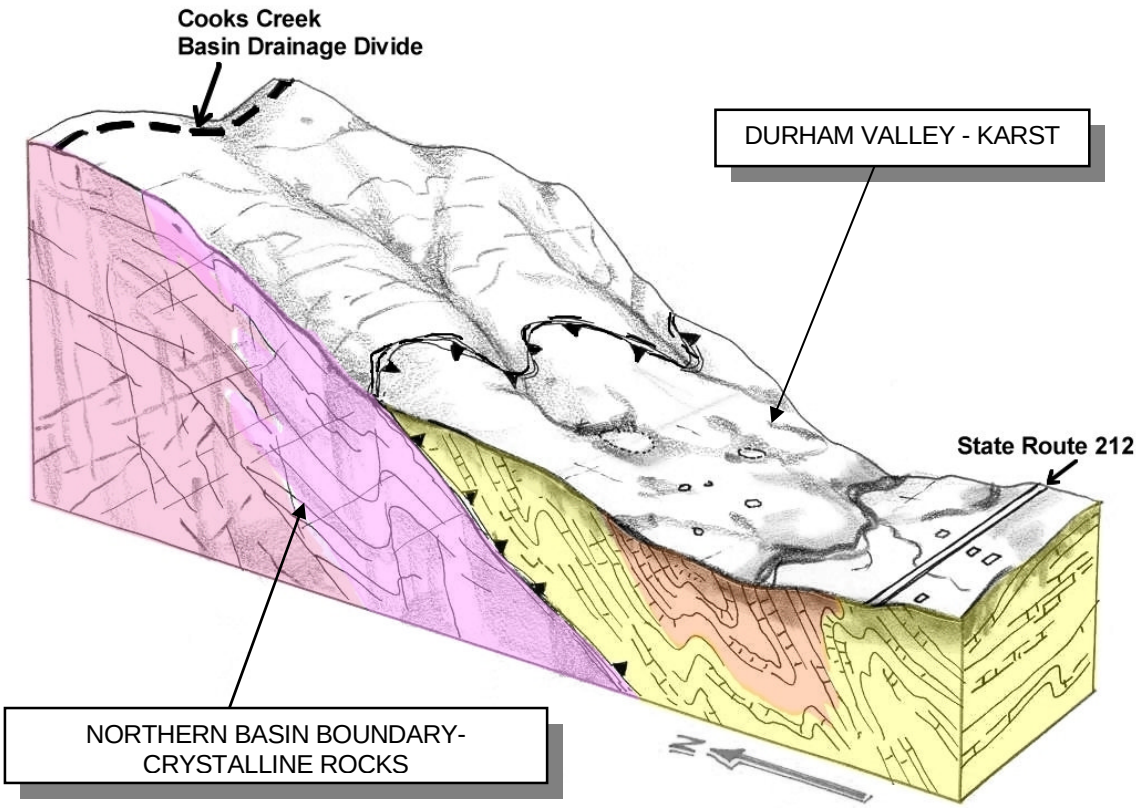

Figure 3.2 Block diagram of the areas Northern Basin - Crystalline Rocks and Durham Valley - Karst

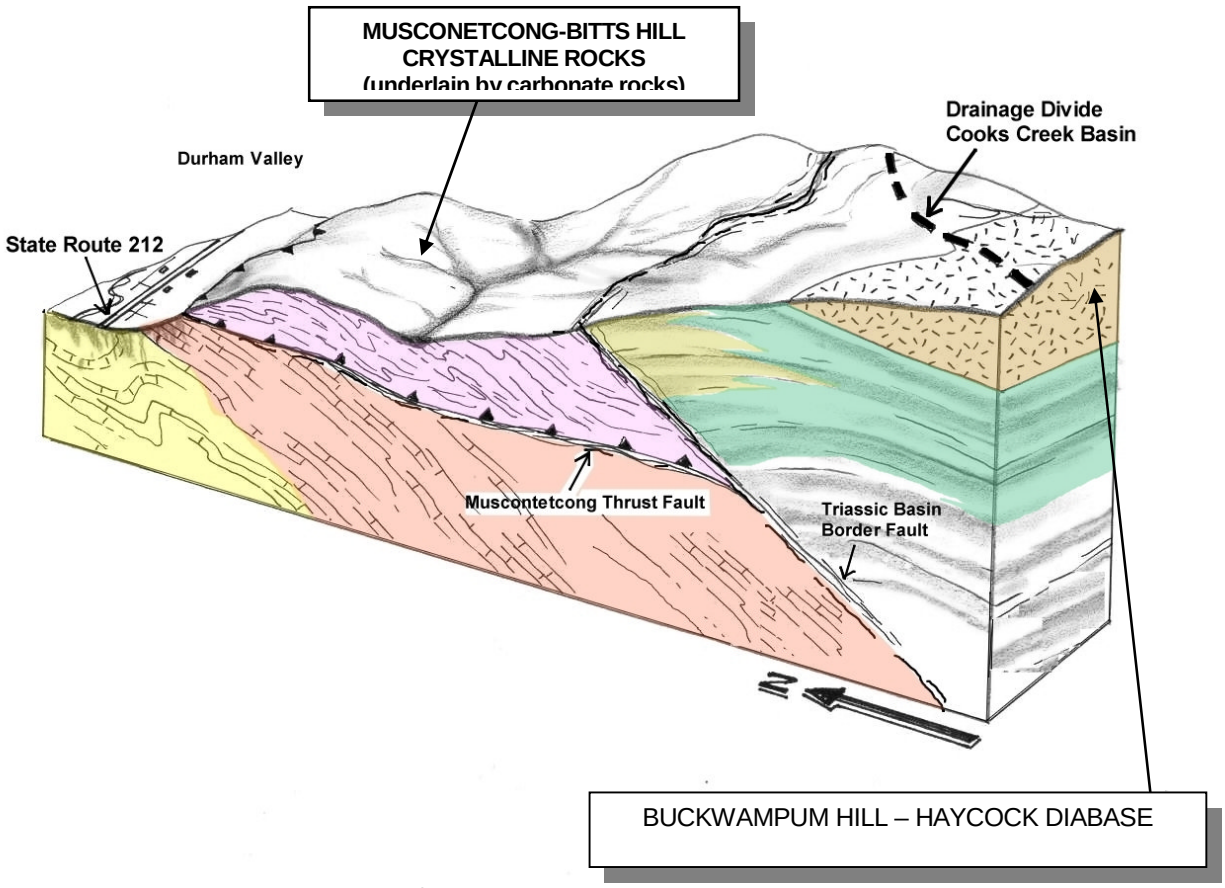

Figure 3.3 Block diagram of the areas Musconetong - Bitts Hill Rocks and Buckampum Hill

The crystalline rocks have undergone several stages of metamorphic episodes as high as amphibolite-granulite facies and are accordingly classified as gneiss and schist. The foliation in these rocks also displays the internal folding and tectonism and generally strikes parallel with the strike of the Newark Basin Border Fault, which is east northeast to west-southwest. Foliation is generally steep and dips between 30 degrees and 70 degrees to the south.

These rocks are hard, resistant to erosion and therefore, occur as ridges or highlands. The drainage basin divide in the north for Cooks Creek is underlain by these crystalline rocks along Kolbehr's Ridge, Steely's Hill and Bougher Hill almost parallel with the Bucks County-Northampton County line. Other outcrops of the crystalline rocks are also found along portions of the southern Cooks Creek Basin boundary within the

Musconetcong thrust fault as at Mine Hill in Durham Township and Bitts Hill in Springfield Township. Good outcrops of these southern, crystalline rocks can be seen as one drives along Lehlenberg Road which almost follows the drainage divide for Cooks Creek drainage basin (see Figure 3.2). Many outcrops of these crystalline rocks can also been seen as one drops down to State Route 212 along Coon Hollow Road in Durham Township.

Erosion over time, by Cooks Creek has also isolated some of these southern crystalline rocks, which being more resistant, rise from Durham Valley; Bitts Hill is one such example.

- ***The Paleozoic rocks*** of the Great Valley –Lehigh Valley Sequence are exposed within the lower topographic reaches of Durham Valley, but only north of the Newark Basin Border Fault. This sequence is dominated by shallow marine, and marginal marine carbonate rocks including the Cambro-Ordovician age Allentown Dolomite (Formation) , Cambrian age Leithsville Formation and local slivers of the youngest, Ordovician age Rickenbach Dolomite (Formation). Narrow bands of the older, underlying Hardystone Quartzite occur along the lower stratigraphic contact of the Leithsville Formation, but only along the northern part of Durham Valley. In the southern part of the Durham Valley the above sequence has been tectonically abbreviated, and much faulting and fault truncation has resulted in a thinner Paleozoic sequence south of Cooks Creek. The carbonate rocks are generally argillaceous, and become purer in carbonate content higher up in the stratigraphic sequence; i.e., the Rickenbach Dolomite is a much purer carbonate sequence than the underlying Allentown and Leithsville units.

  Outcrops of these carbonate strata can be seen all along Cooks Creek Valley (in Durham Township), along the mid-slopes of the valley walls such as at Haupts Mill Bridge near the Durham-Springfield Township line, Hollow Run Road (in Durham Township), and as far west as the county line on either side of Springtown Road, west of Springtown.

  The Paleozoic sequence has been assigned to the Furlong Klippe of the overthrusted blocks, is much deformed into north-verging recumbent to steeply overturned synformal anticlines and synclines. Although many faults must occur within this unit, poor outcrop precludes their detailed mapping.

- ***The Newark-Gettysburg Basin deposits*** of Mesozoic age were mainly derived from erosion of the crystalline rocks southeast and northwest of the Newark Basin Border Fault. The strata within the basin are assigned to the Passaic Formation (undifferentiated) and include the Stockton Formation (herein equivalent with the Brunswick) which inturn overlies the Lockatong Formation. The best and most complete section of these strata is exposed on either side of the Delaware River and can be seen in impressive bluffs along State Route 611.

  The beds in general, dip gently to the northwest although deformations along the border fault have resulted in many gentle, open folds and faults. The Border Fault is known to dip to the southeast gently at 20 to 25 degrees, and much work showing that the border fault is the result of reactivation of the Paleozoic age thrust faults of the Appalachians is well known. Excellent exposures of the border fault can be seen along the Delaware River, north of Bukwampum Hill along Lehnenberg Road, and along the abandoned railroad tracks northeast of Knechts Bridge (on Springhouse Lane) in Springfield Township. These sedimentary rocks of the basin are dominantly interbedded, clastic and include sandstone, siltstone, shales and claystone interbedded with local calcarous siltstone beds.

  Many smaller outcrops of these sedimentary rocks generally striking north-south, with gentle to moderate westerly dips are readily seen along State Route 211 north from Gruversville to Knechts Bridge. This narrow band of northerly striking bedrock has controlled the course of the south branch of Cooks Creek which flows north from Gruversville, past Pleasant Valley and farther north to Knechts Bridge. A much wider tract of these sedimentary rocks, with remarkably gentle dips and uniform lithology consisting of quartz pebble conglomerate (the Flint Hill fan of Drake, 1996) occurs in the western and southwestern portion of Springfield Township (along State Road, and Peppermint Valley Road) forming a gently rolling upland plateau from Flint Hill (in Lehigh County) to the north-south flowing branch of Cooks Creek.

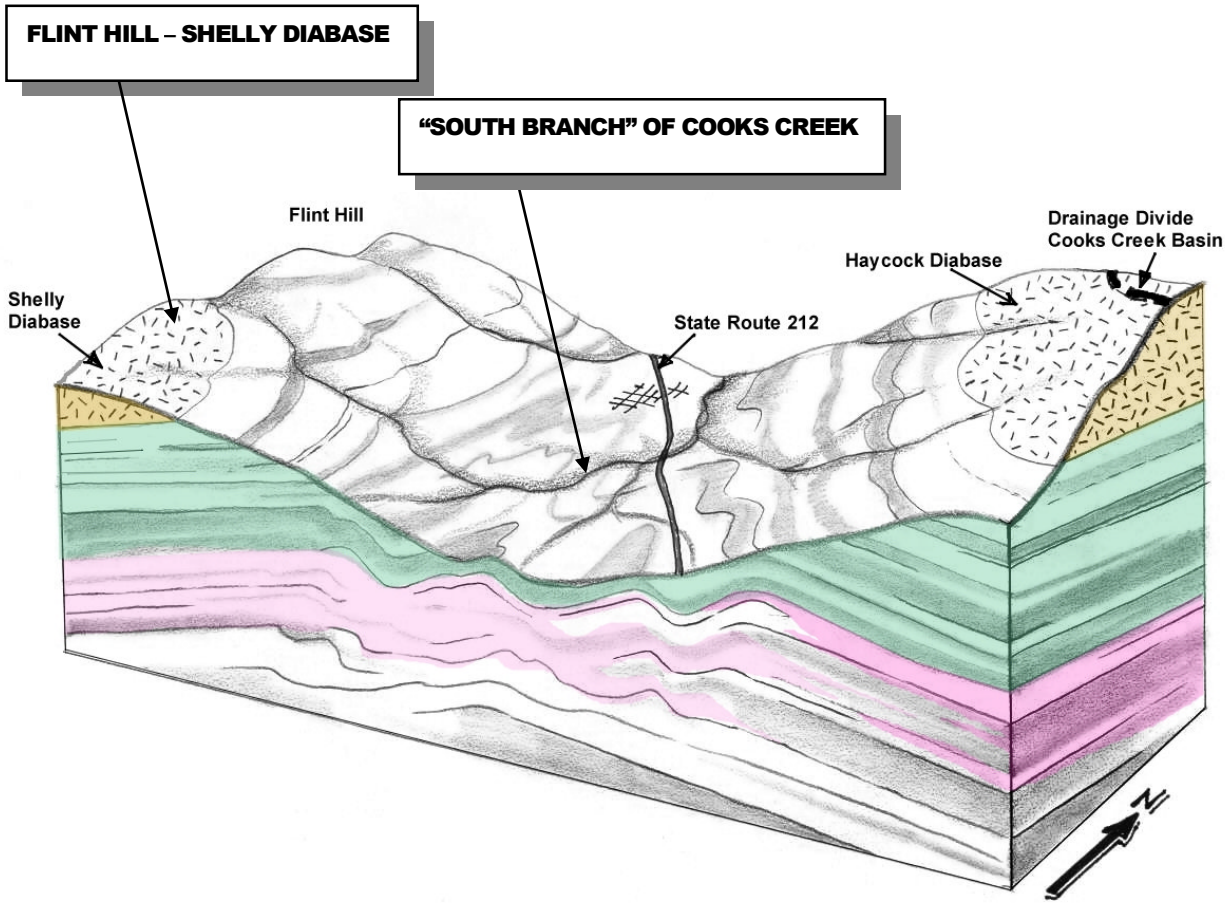

Figure 3.4 Block diagram of the areas South Branch of Cooks Creek and Flint Hill - Shelly Diabase

- ***Several diabase intrusions of early Jurassic age*** are also exposed within the study area, although outcrops are few and far between. The problem of mapping the geologic contact between the diabase and sedimentary rock was exacerbated by the wooded nature of these ridges underlain by the diabase . The largest intrusive body has been named the Coffman Hill sheet which is as much as 4 miles wide and a little over 5 miles long (along strike) and occurs along the southwestern, and southern border of the study area in Springfield, Tinicum and Nockamixon townships. The Haycock diabase sheet occurs in the south-central portion of the study area and forms a prominent hill serving as the drainage basin divide to the Haycock drainage basin in the south. The northern flank of the Haycock diabase forms Cressman Hill.

Faulting continued contemporaneously with sedimentation within the evolving Newark half-graben, hence the strata thicken towards the border fault, which is again marked by numerous discrete fanglomeratic horizons which include both quartz and limestone fanglomerates. A few isolated exposures of these conglomerates can be seen adjacent to Knechts Bridge on Slifer Valley Road (Springfield Township), and at Bursonville (on Route 412).

3.2.3 Outline of the Major Compartments

A watershed may be treated as an open system with inputs, outputs, and measurable physical and chemical conditions that describe the state of the system. The main physical and chemical processes at work in a watershed are geology, light, temperature, water (both surface and groundwater), and nutrients. The fundamental physical process at work in a watershed is the cutting of stream channels and the carrying of materials downstream. This process is governed by the underlying geology of the watershed.

Lithology

A primary step in watershed analysis is therefore the development of a sound geologic understanding. Because geology can be quite complex, identifying areas that can be evaluated as uniform units is a simple, yet effective approach. These units are presented in the Geologic Map (Figure 3.1) and are diagramatically shown in the Figures 3.2 through 3.4. In addition to the these units the various geologic units in relations to topography have been identified herein as "groundwater flow compartments" within the Cooks Creek drainage basin, as shown in Figures 3.5 through 3.7. These compartments as defined herein allow the development of a watershed analysis approach which would then be incorporated into a watershed plan when assessing the surface water hydrology and groundwater hydrogeology of the Cooks Creek Watershed.

Structural Geology

Deformation of the Earth's crust is manifested in rock units as faults (displacement along fractures), joints (brittle fractures with no displacement), and folds (flexures). Faulting and folding provide for initial topographic relief and may differentially raise or lower formations with respect to one another. For example, the fault bounded Mine Hill underlain by geologically older crystalline rock is topographically high, and is more resistant than the younger rocks within Durham Valley.

Faults and areas of fractured rock are weaker and more subject to erosion than unfractured rock. Because of this weakness, these areas may form topographic low spots and control the drainage network of a watershed. The easterly course of Cooks Creek through northern Spring Township and Durham Township are a reflection of lithologic and structural control of the drainage. Likewise, interbedded stronger and weaker rock formations may be exposed at the surface by fold structures, with the stream network influenced by the outcrop pattern of the rock units as seen in the southern portion of Cooks Creek Basin.

Watershed Morphology and Sediment Yield

The bedrock underlying a watershed and soils derived from that bedrock have a significant effect upon watershed morphology. Stronger rocks provide the opportunity for greater relief, whereas weaker rocks generally create low-relief topography. Geologic structures may define the pattern of the drainage network. Streams draining softer rock are generally more turbid, whereas stream draining more resistant, stronger rock not only have steeper gradients, but also their channels are strewn with boulder and cobbles.

Soil permeability and infiltration rates roughly correlate with hydraulic conductivity. Drainage density is inversely correlated with permeability, and has been shown in the published literature to be related to bedrock geology in a region of climatic similarity.

Stream Character

Slope, sinuosity, entrenchment, and sediment size are characteristics used in the procedure to classify a stream as a given type. However, bedrock geology can often provide an explanation of why a stream has those characteristics. A stream's sediment size is related to sediment source rock strength and distance of transport. At a reach scale, slope, sinuosity, and entrenchment may be a function of rock strength and the stream's relationship to geologic structure. Understanding the dependencies of stream character upon the underlying geology can provide guidance in stream and watershed restoration.

Runoff Hydrology

Geology affects hydrograph characteristics including mean annual runoff, baseflow, and flood hydrology. Little surface runoff occurs from highly permeable dune fields or karstic carbonate rocks, whereas these areas may sustain a near-constant year-round baseflow. However, in areas where structural folds cause bedrock to dip away from the watershed outlet, baseflow may be reduced because groundwater movement is not coincident with watershed topography.

Flood runoff is more efficient and more quickly reaches a watershed outlet when drainage densities are higher. Since drainage density is inversely related to the hydraulic conductivity of the underlying bedrock and derived soil, watersheds areas underlain by impervious shales should produce higher peaks than those underlain by pervious sandstones.

Water Quality

Rock unit chemistry directly influences water quality, as water flowing over or through a rock unit and its residuum dissolves salts from the unit. Analysis of stream water quality may be classified based upon major ionic constituents. Grouping water quality sample sites by water quality categories shows a direct correspondence with the bedrock geology underlying the source watershed.

Vegetation and Land Use

Geology may influence potential land use. Man has long occupied this region and has extensively altered the original vegetative boundaries by farming, forest practices and urbanization. However, in the more rugged upland portions of the watershed, forest cover is quite extensive, whereas the lowland areas have been cultivated or urbanized. However, vegetation type may change even more abruptly at contacts or faults separating distinct rock lithologies. In areas where plant community differentiation is dominated by geology, geologic mapping could be used for wildlife resource management planning.

3.3 Groundwater and Geologic Observation

A significant portion of the downstream end of the Cooks Creek watershed is underlain by comprising the Allentown Dolomite and Leithsville Formation, and small outliers of the Rickenbach Dolomite (see Geologic Map, Figure 3.1), karstic groundwater interaction with Cooks Creek is common. Numerous effects of the karst interaction are evident in the presence of sinkholes, springs and seeps as mapped during the field reconnaissance survey, and otherwise mottled areas (as detected on aerial photographs) which reflect the presence of shallow, mantled karst dissolution features.

Cooks Creek also traverses areas both north and south of the Triassic Border fault zone. In the hangingwall (i.e. south of the Triassic Border fault), and within the ridges of Musconetcong Mountain (generally north of the Border Fault) underlain essentially by crystalline metamorphic units, with slivers of the footwall carbonate rocks,

the groundwater flow is equally complex, but is anticipated to be controlled by fracture flow with minimal karst conduit flow, although upland (or ephemeral) wetlands may be present locally.

In the upstream sections of the Creek, bedded units of the Newark-Gettysburg Triassic Basin strata including siltstones, shales, sandstones and occasional conglomerates are common. The bedding dips and strikes of these units serve to focus groundwater flow along strike in gently dipping strata and generally along dip in steeper dipping strata. Accordingly, seeps and springs are localized where a stream or creek cuts across bedrock strike.

Farther south from the border fault, and within the Newark Basin strata, groundwater flow is controlled by the interaction of the strike and dip of bedding planes and joint planes. As noted elsewhere in the published literature of the Newark Basin -Gettysburg basin system rocks equivalent with the quartz-, and limestone- pebble border conglomerates mapped in the Cooks Creek watershed are generally very poor water bearing units, and are therefore not considered significant water-bearing units.

A review of the available hydrogeologic data suggests that most groundwater flow in Durham Township, and Durham Valley is indeed strongly controlled by the bounding relief of the ridges on resistant rock which parallel bedrock strike; with significant groundwater discharge to the intervening stream valleys floored by the carbonate rocks. Musconetcong River in adjacent Warren County (NJ) is indeed a remarkable example of lithologic control. The bounding ridges run more or less parallel with the course of Cooks Creek, and hence hydraulic flow of groundwater is into the Cooks Creek valley, locally controlled largely by the hydraulic interactions of the bedrock units discussed above.

Hydraulic conductivity (or permeability) is the rate at which water moves through a porous medium under a unit potential-energy gradient. It is primarily a function of the cross-sectional area available for water transmission for saturated groundwater conditions, and is also a function of degree of saturation for unsaturated conditions. Generally, saturated hydraulic conductivity increases with increasing grain size and sediments of uniform grain size. Interlocking grains or crystals, as in igneous rocks, yield extremely low conductivities, whereas unconsolidated deposits generally have high conductivities. Conductivities may be very high where solution has dissolved rock and provided large flow pathways, as is often the case for carbonate rock units such as karst. The importance and complexity of karst systems is discussed below.

3.3.1 Karst

The geologic units that possess karst characteristics in the Cooks Creek drainage basin are from the youngest to the oldest:

- Limestone Pebble Conglomerate – occurring as small isolated outcrops along the generally east-west striking Triassic Basin border fault seen in outcrop along the Delaware River, and northeast of Knechts Bridge.

- The following three carbonate rock formations Allentown Formation, Rickenbach Formation, and Leithsville Formation occupy the lowland Durham Valley across the northern part of Springfield Township and a large area of Durham Township between Steeleys and Bougher's Hill in the north and Mine Hill in the south.

Rivers in karst (caves, limestone, sinkholes) areas often lose water to sinkholes or conduits in the bed of the river. In addition, shallow conduit systems in the uppermost part of the bedrock may be interconnected with deeper conduit systems resulting in an extremely complex fracture and conduit controlled groundwater flow system. Given this dynamic, significant groundwater to wetland interaction occurs along the valleys of Cook Creek and its tributaries, with a greater probability of karstic (or other) spring discharges or segments of loosing surface water bodies along the valley floor and margins.

Sinkholes and other surficial expressions of the groundwater conditions appear to be localized in areas where fluctuations of the groundwater level may be pronounced. Of note is the general lack of many sinkholes, and the

presence of mostly mantled sinkholes (i.e. sinkholes formed by collapse of a mantle of soil above bedrock), and the general absence of exposed bedrock in the topographically lowest portions of the valley suggest that the Cooks Creek karst system is mature, with most surface expressions of carbonate rock dissolution having been masked by extensive soil development.

Consequently, karst hydrologic definition and assessment is difficult for several reasons:

- The watershed cannot be determined by examination of a topographic map as non-karst areas can overlie bedrock prone to karst development; detailed field geologic mapping assisted by other means such as aerial photographic interpretation and geophysical investigations may be necessary to better understand karst hydrogeology;
- The area of the watershed can change as a function of water level because conduits at different levels act as relief valves. This situation is particularly important adjacent to surface drainage basin divides where water infiltrating into the ground in one drainage basin may flow the other way into an adjacent drainage basin;
- Many of the features of interest lie underground and are inaccessible or accessible only with great difficulty. Because carbonate rock terrain in Cooks Creek drainage basin generally occurs as lowlands, outcrops of the underlying bedrock are masked and overlain by unconsolidated soils, alluvium and other material washed in from the surrounding highlands;
- The discharge point or points of a drop of water falling in a karst watershed can only be assigned a probability;
- Discharge points in karst can change periodically as plugging and unplugging of conduits occur with storms of different intensities
- Karst water tables are discontinuous;
- Residents of a watershed can protect groundwater by minimizing land disturbances, soil erosion, heavy runoff of stormwater, and pollutants. Groundwater is at a much higher risk where watersheds are characterized by overgrazing, high-density development, agricultural or urban runoff, and mismanaged commercial facilities sites;
- Storm water runoff in karst areas should be managed. Since the bulk of storm water runoff in the areas underlain by carbonate is directly discharged into the bedrock through sinkholes and other such features, storm water management from urbanized areas needs to be managed.
- A watershed is an area of land from which all water drains into a common water body. Rainfall, spring runoff, and groundwater drain from upland areas to a low point or basin, usually a larger stream, river, lake, or bay.
- Water enters a karst watershed through both direct and indirect means. Precipitation in the form of rain and snow, which is usually the greatest during January through May, enters the aquifer directly as surface runoff or indirectly as water seeping through the soil and bedrock. Drainage in karst watersheds tends to be three dimensional; flowing laterally across the surface, as well as vertically underground.

3.3.2 Surface and Groundwater Flow Compartments

Cooks Creek drains a wide variety of geologic terrain including, igneous, sedimentary and metamorphic rock. However, for the purposes of defining the characteristics of Cooks Creek Watershed, it is prudent to categorize the different geologic terrain elements within bounds of some common elements. As discussed above, geology

serves this very purpose. These diverse geologic terrain can be grouped further into compartments illustrated in Figures 3.5 through 3.7.

A. Northern Basin Boundary- Crystalline Rocks

As shown on Figure 3.5 and discussed above, the northern boundary of Cooks Creek drainage basin is underlain by crystalline rocks of the Lehigh Valley Sequence (of Drake, 1996). These metamorphic rocks are quite resistant to erosion and form a continuous bedrock strike parallel line of ridges (Kohlber's Hill, Steeley's Hill and Bougher's Hill). Both surface and groundwater flow is southerly into Durham Valley, and Cooks Creek and its tributaries serves as the groundwater discharge zone. Much of the groundwater in these rocks occurs beneath a fairly thick mantle of weathered rock and saprolite under locally confining conditions. The secondary porosity of the rock is entirely restricted to joints and other fractures with foliation playing a secondary role.

B. Durham Valley-Karst

The downstream portion of Cooks Creek, in Durham Valley is underlain by carbonate sedimentary rock, and the valley is bounded both to the north and south by metamorphic and igneous rock (see Figure 3.5 and Figure 3.6). The area underlain by carbonate rock is a lowland, characterized by karst groundwater flow, and a lack of significant surface drainage other than Cooks Creek. A thick mantle of colluvium, alluvium and saprolite serves to mask much of the bedrock and outcrops are relatively few and far between. In such an area, sinkholes are not as common as elsewhere in carbonate terrains in Pennsylvania.

The carbonate formation which include the Rickenback, Allentown and Leithsville formations are thinly to thickly bedded, with significant argillaceous and chert content. Much of the karst dissolution activity appears to be restricted to the upper portion of the bedrock and along bedding planes because of the bedded, argillaceous nature of the carbonate formations. Sinkhole collapse where observed in the area can be classified as collapse of the overburden material into conduits and other solution enlarged features in the bedrock below. These areas where field evidence showed effects of karst dissolution have been shown on Figure 3.1 as karst-prone areas. Most of the sinkholes where observed, did not possess adjacent bedrock outcrops, and occurred as shallow saucer or deeper bowl-shaped depressions, often elongate along underlying bedrock strike, and in narrow zones parallel possibly with underlying karst features. Only additional invasive subsurface field investigations or geophysical surveys would allow better definition of the karst in Durham Valley.

C. Musconetcong-Bitts Hill Crystalline Rocks

Along the south of Durham Valley, both crystalline metamorphic rocks and igneous rock form prominent hills (Mine Hill and Cressman Hill, and as isolated hills such as Bitts Hill) again focusing surface water and groundwater flow into the Cooks Creek Valley. These thrust-fault bounded blocks lying adjacent to the Newark-Gettysburg Basin border fault may locally serve to mound groundwater recharge, but are underlain by the carbonate rocks of the Durham Valley (see Figure 3.6).

D. "South Branch" of Cooks Creek The linear lowland south of Knechts Bridge to Springfield Township line near Gruversville (along State Route 211) is an outstanding example of the Cooks Creek Watershed is strongly controlled in this area by underlying geology. This course of Cooks Creek is underlain by relatively less resistant siltstones and shales bounded to the east and west by the Haycock and Shelly diabase sheets; both igneous rock masses highly resistant to erosion thus forming prominent hills in northern Bucks County. In addition, the strike of the sedimentary strata is generally north-south, and in sections along Cook Creek are underlain by one bed of sandstone or a narrow horizon of shales over considerable length along the stream valley.

Groundwater flow in this compartment is anticipated to be entirely controlled by bedrock fractures such as joints and bedding plane partings. Fracture intensity and density is anticipated to be higher in thinly bedded shales and

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siltstone, and lesser in the thicker bedded sandstones and conglomerates. Being bounded by the prominent ridges underlain by both the Haycock diabase in the east and the Flint Hill fan-Shelly diabase in the west, this portion of the north-south flowing Cooks Creek serves as a groundwater discharge zone for much of the southern part of the drainage basin south of Knechts Bridge. Groundwater flow in the sedimentary rocks would be parallel with bedrock strike which is northerly.

E. Buckwampum Hill- Haycock Diabase

This compartment forms the southern and southeastern divide for the Cooks Creek drainage basin. Groundwater flow is anticipated to be radially downhill towards Cooks Creek. The diabase bedrock serves as a very poor water bearing unit as reflected in the many deep wells installed in this bedrock. Fractures although present, are few and far in between, and deeper wells are installed to intercept as many water-bearing fractures as possible within the diabase. Often, the wells are drilled deeper than the lower margin of the diabase to intercept sedimentary strata beneath the diabase. In general such wells are present along the geologic edge of the diabase. Much of the northerly flow of surface water and groundwater from the Haycock diabase is impeded locally by the intervening blocks underlain by the crystalline metamorphic rocks bounded by the Musconetcong –Bitts Hill crystalline rocks discussed above.

F. Flint Hill-Shelly Diabase

The southwestern part of Springfield Township occupies a gently rolling, upland rise that culminates at "The Lookout" on Quarry Road underlain by the Shelly diabase sheet, and at the county line on Richlandtown Road. This broad plateau is underlain by the quartz-sandstone, and quartz pebble conglomertes and siltstones of the Flint Hill Fan of the Passaic Formation. Uniform lithology with simple geologic control, expressed in the gentle topography and characterized by radial stream drainages eventually curving around to form the headwaters of Cooks Creek is typical of this part of drainage basin. This portion of Springfield Township is indeed quite different from much of the Cooks Creek drainage basin, both in topography and surface drainage.

Thus, as outlined above, geology determines the nature of both surface and groundwater flow.

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4. WELL SURVEY AND WATER TABLE MAP

The subtasks for the Well Survey Search and Water Table Map task included:

- Search for available wells;
- Field survey and solicitation of well owners for permission to measure water levels in their private wells, especially at properties adjacent to wetlands but also, throughout the watershed system.
- Generate water table map for the entire project area;
- Create ARC/Info GIS version for head distribution and archiving.

On Figure 4.1 the potentiometric contours shows altitude of potentiometric surface as defined by measured water levels, altitudes of streams and springs, and topography. The contours are approximately located for most of the mapped areas where the distance between wells are significant large. Measured and reported depths to water are summarized in Table 1.

Intermittent streams are discharge areas during periods of high ground-water levels. Contoured potentiometric surface represents the water table except at wells that are completed in semiconfined zones in the aquifer. Contour interval is 20 feet except north of Springtown, where the contour interval is 20 feet up to an altitude 400 feet and then 50 feet to an altitude 800 feet.

On areas of Buckwampum Hill, north of Springtown, the Lookout, Bitts Hill and two hills west of Buckwampum the contours were inferred based of 1992 USGS data. The altitude is in feet above National Geodetic Vertical Datum of 1929.

The dot symbol gives location of a well site. Number is elevation of water level in feet above National Geodetic Vertical Datum of 1929. Wells outside the study area are shown where they were used to contour the potentiometric surface.

Depression on water table contours shows the altitude of water level that represents a potentiometric surface other than the water table. Measuring points include wells that may penetrate a deeper semiconfined zone, and data may reflect a composite bead. These data were not used to contour the potentiometric surface and are included for information only.

The mapped area is underlain by layered sedimentary rocks chiefly consisting of shale, mudstone, and siltstone and by a diabase sheet that has intruded the sedimentary rocks (see Figure 3.1). Also, a part of the mapped area is underlain by dolomite and crystalline rocks .

4.1 Triassic Sedimentary Rocks Aquifer

The Triassic Sedimentary Rocks Aquifer includes Brunswick Group and Lockatong Formation. The groundwater system can be visualized as a series of sedimentary beds with a relatively high transmissivity separated by beds with a relatively low transmissivity. The beds, a few inches to a few feet thick, act as a series of alternating aquifers and confining or semi-confining units that form a leaky, multiaquifer system. Each bed generally has different hydraulic properties, and permeability commonly differs from one bed to another. Soft shale beds deform without breaking under stress and, as a result, have lower permeability than the harder sandstone beds,

which tend to develop fractures and joints and are more permeable. Thick, hard, competent sandstone beds develop fewer joints than thin sandstone beds (Wood, 1980, p. 16) and bedding planes are widely spaced; therefore, they are less permeable.

Groundwater is unconfined in the shallower part of the aquifer and confined or semiconfined in the deeper part of the aquifer. Under confined conditions, ground water is confined under pressure greater than atmospheric by less permeable beds or hydrogeologic units and is not free to rise and fall. Differences In vertical hydraulic conductivity within and among hydrogeologic units create confining conditions.

The water level in a well constructed in a confined aquifer rises above the top of the aquifer. The imaginary surface to which water will rise in wells tightly cased in a confined aquifer is the potentiometric surface. If the potentiometric surface is above the land surface, the well will flow.

Most deep wells are open to several water-bearing zones and are multiaquifer wells. Some wells may be open to more than one hydrogeologic unit. Each water-bearing zone usually has a different hydraulic head. The hydraulic head in a deep well is the composite of the heads in the several water bearing zones penetrated. This can cause water levels in some wells to be different than water levels in adjacent wells of different depths. If the composite head is below the uppermost water-bearing zone or zones, water from these zones will drain into the well and cascade down the borehole to the water surface. In the area of the former mining activity is possible that deep wells to intercept fractures which are connected with the tunneling system. The altitude of these old mines are believed to be near 150 feet-msl.

Where differences in hydraulic head exist between water-bearing zones, water in the well bore flows under non-pumping conditions in the direction of decreasing head. Flow from an upper zone of higher head to a lower zone of lower head can result in a cone of depression forming around the well under non-pumping conditions and can locally lower water levels, in special for those wells located in former mines area. Under seasonal fluctuation conditions the flow direction may even reverse. Could this explain why some times the water pumped from wells located in the Mine Hill area taste very bad, likewise bats excrements? Bat colonies are known to exist in the closed mines tunnels and shafts.

The ground-water-flow system in Triassic sedimentary rocks is highly anisotropic with the predominant flow direction in the direction of strike (Vecchioli and others, 1969, p. 154). The network of interconnected water-bearing openings is more or less continuous along strike, but the continuity of individual beds downdip is limited because fractures are closed by compression or absent with depth.

Because of anisotropy, wells aligned parallel to strike generally show more interference than wells aligned perpendicular to strike. Drawdown in wells aligned along strike may be many times greater than in wells aligned in other directions (Vecchioh and others, 1969, p. 157). Wells drilled to the same depth along strike generally penetrate the same water-bearing beds, whereas wells drilled to the same depth several hundred feet downdip of each other rarely intersect the same water-bearing beds. Therefore, the potential for well interference caused by pumping is greater in wells along strike than in wells in the direction of dip. In the anisotropic Triassic formations, cones of depression are usually elliptical, with the long axis aligned parallel to strike.

In the anisotropic systems of the Newark Basin, groundwater flow is not necessarily perpendicular to lines of equal hydraulic head, but may be skewed in the direction of strike (Lewis, 1992, p. 96). Because the beds dip and because fractures are absent or dosed at depths greater than a few hundred feet, ground water flows preferentially along strike, even in places where the cross-strike hydraulic gradient is substantial.

Ground-water flow in the Triassic sedimentary rocks has local and regional components. Shallow ground water discharges locally to nearby streams. Deeper, regional ground-water flow is toward points of regional ground-water discharge, such as the Delaware River.

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Groundwater divides may be different for each zone of groundwater flow, and may not coincide with surface-water divides. Groundwater flow directions may be different for each zone. More water level data have to be collected to assess groundwater divides for each area.

Brunswick Group

Rocks of the Brunswick Group underlie 32% percent of the study area. The Brunswick is highly fractured and has many closely spaced joints, which accounts for the relatively high well yields from a shale and siltstone formation. Bedding plane openings may extend to 300 ft below land surface Wasabach, 1966, p. 33). However, the upper part of the weathered zone, although more fractured than the lower part, may be less permeable than the lower part because the fractures may be clogged with day derived from weathered shale and siltstone.

Lockatong Formation

Depth to water depends on many factors, including geology, topography, and proximity to pumped wells and quarries. Geologic controls often influence depth to water. For example, a well drilled in the Lockatong Formation near the contact with the Brunswick Group may penetrate the underlying Brunswick Group. The Stockton Formation may have a lower hydraulic head than the Brunswick Group, and the water level in the well would be a composite of heads in the Lockatong and the Brunswick Group. The composite head would be higher than the head in the Brunswick Group and lower than the head in the Lockatong Formation.

Table 1. Summary of Water Table Level Measurements

WELL ID	NAME	ADDRESS	DEPTH TO WATER	ELEVATION
1	Takahashi, Mark	273 County Line Rd	178.25	729.60
2	Wagenvoord, Anita	291 County Line Rd	48.67	718.99
3	Ponzol, Kim & Danton	275 County Line Rd	67.92	742.84
4	Klein, Jill & Ken	185 County Line Rd	18.00	560.10
5	Ulrey, Bill and Kim	95 County Line Road	47.50	578.00
6	Tade, Stephanie & Philip	105 County Line Rd	50.75	577.57
7	Juall David and Bonnie	Dogwood Lane, Durham	46.92	650.74
8	Peacock	969 Spring Hill Rd	56.75	394.12
9	Beerer, Jim & Karen	Spring Hill Rd	5.33	362.40
10	Anderson, Ken	940 Spring Hill Rs	73.67	361.84
11	Marschewski, Fred	803 Stouts Valley rd	7.92	227.04
12	Millett, Bart	4395 Rte 212 Riegelsville Pa	5.08	209.12
13	Jones, Cheryl	275 Valley View Rd	166.17	359.32
14	Miller, Bob	4227 Lehnenburg Rd	17.33	411.43
15	Oleksa, David	902 Durham Rd	11.42	235.21
16	Apgar, Wayne & Marti	299 Old Furnace Rd	42.67	188.94
17	Reed, Lynette & John	180 Mine Hill Rd	149.00	326.96
18	Willey, Stephen and Sharon	4912 Rte 212	75.00	224.93
19	Davis, Janet	443 Mine Hill Rd	28.92	326.70
20	Martz, Valerie	215 Mine Hill Rd, Durham	72.00	349.65
21	Killcoyne, Andy & Liz	281 Old Furnace Rd	32.54	208.53

WELL ID	NAME	ADDRESS	DEPTH TO WATER	ELEVATION
22	Hughes, Tom and Linda	120 River View Lane, Durham	86.75	201.48
23	UTTARD ROBERT & CHRISTINE	930 EBERT RD	80.00	868.49
24	MORGAN, DOUGLAS & PRISCILLA	1654 HIGH POINT RD	62.42	714.49
25	WALTER RUDI	1720 HIGHTOP Rd.	56.67	695.52
26	MITCHELL, DAVID & ERINFLY-M	2159 QUARRY RD	68.42	728.86
27	SEIFERT, DAVID	2212 RICHLANDTOWN	25.50	636.07
28	PROSS, EARL & MARY ANN	2279 DEER TRAIL RD	75.33	819.71
29	Lawrence, Bruce & Anne	2050 Chestnut Rd	16.42	573.26
30	COOPER, JAMES	2233 CHESTNUT RD	41.00	714.34
31	FRYE, TIMOTHY & SHARON	1382 PLEASANT VIEW RD	127.83	731.15
32	BILGER, RAYMOND & GRETA	1706 STATE RD	95.92	561.80
33	BAUMAN, GARY & DEBORAH	1544 GRUVERSVILLE RD	65.33	589.49
34	KURTESAN, MILTON & ELIZABET	1801 PEPPERMINT VALLEY	31.17	581.10
35	HUNT, JOHN & MARJORIE	2916 LOWER SAUCON RD	17.00	370.46
36	SINGER, WEBSTER & NANCY	2371 TOWNSHIP RD	50.25	490.07
37	Bodian Alex	2412 Hickory Lane	14.08	523.73
38	LOVEKIN, VIRGINIA	2789 SLIFER VALLEY RD	22.00	339.63
39	Dunlap, Anne & Bill	3005 Slifer Valley Rd		554.09
40	Jones, Mel & kathy	Rte 212, Springtown	17.75	326.60
41	Young, Nancy	Rte 212	-0.50	393.56
42	Douglas, Scott & Aimee	3450 rte 212	7.50	322.46
43	McMath Margaret & Barrie	3030 Cooks Creek Rd	17.83	518.66
44	SEIFERT, HARRY & THERESA	3220 DRIFTING DRIVE	52.83	823.47
45	Lodwig David	3055 Funks Mill Road	21.17	349.44
46	BAIER, ARTHUR	3024 FUNKS MILL RD	38.92	320.43
47	Orben, Jim	3465 Owl hollow Rd	45.21	492.20
48	MILLETT, VIRGIL & ADELE	3020 HAUPTS BRIDGE RD	56.42	318.97
49	MORAN, THOMAS & NANCY	2710 BODDER RD	96.42	459.04
50	JENSEN, ERIC & JANET	6395 RTE 412	165.54	453.56
51	FEHER, JOSEPH & JUDITH	3775 HAUPTS BRIDGE RD61	37.30	398.43
52	Chipman Doug	4470 Rt 212	124.25	280.37
53	KUCHER, DONALD & VIOLET	1520 OAK LANE	106.00	523.49
54	Durrwachter, Doris	2917 Grouse Lane	10.50	321.31
55	HUTCHINSON, STUART & LOUISE	1661 OAK LANE	71.17	604.78
56	Hoffman Diana	1529 Maple Rd	28.83	328.59
57	CAMPEAU, DAVID & BETSEY	1559 MAPLE RD	24.08	548.48
58	Lang, Lisa and Chris Olsen	6145 Rt 412		458.35
59	HERMO, RAYMOND	3590 LENAPE WAY	115.58	459.30
60	Becker, David & Lee	3750 Lehnenburg Rd	107.70	308.89
61	Halderman, Charles	3760 Lehnenburg Road	147.75	644.56
62	BELL, ROBERT & HELENE	3465 SCHOOL RD	23.42	594.83
63	Rosenthal Richard	3341 School Rd	17.17	549.33
64	Kocsis Martha	1810 Gallows Hill Rd	69.50	594.21

Some anthropogenic activities, such as pumping of nondomestic wells may lower water levels and create a cone of depression around the pumping well. For example, the potentiometric-surface map of Figure 4.1 shows a cone of depression around residential wells at the addresses shown in the following table (Table 2).

Table 2. Water table depression, residential wells location.

WELL_ID	NAME	ADDRESS
17	Reed, Lynette & John	180 Mine Hill Rd
33	Bauman, Gary & Deborah	1544Ggruversville Rd
39	Dunlap, Anne & Bill	3005 Slifer Valley Rd
48	Millett, Virgil & Adele	3020 Haupts Bridge Rd
52	Chipman Doug	4470 Rt 212

4.2 Carbonate Rocks Aquifer

19% percent of the study area is underlain by carbonate rocks, which crop out in parts of Durham Valley. The principal formations are the Limestone Formation, Allentown Dolomite, and Leithsville Formation. Most ground water in carbonate rock flows through a network of secondary openings-fractures, joints, and bedding planes enlarged by solution. Some openings enlarged by solution are several feet wide; however, most are only a fraction of an inch wide, but they are capable of transmitting large quantities of water. The vertical distribution of solution openings is irregular and unpredictable. Adjacent wells may tap different systems of openings in the bedrock.

Permeability of carbonate rock is predominately the result of solution-enlarged fractures. Where solution has been active, permeability may be high; elsewhere, the same unit may be nearly impermeable. Solution is the principle weathering agent of carbonate rocks, which are soluble in acidic water. Solution generally is most active above and within the zone of water table fluctuation where water movement is relatively rapid and recharge water is acidic. Below the zone of water table fluctuation, water movement is slower, and acidic recharge water is neutralized.

Clay and unconsolidated material sometimes move downward from the surface, plugging openings. This plugging results in decreased well yields and turbid ground-water discharge from some wells.

4.3 Crystalline Rocks Aquifer

Nine percent of the study area is underlain by crystalline rocks. Crystalline rocks are found in Durham Valleys and in the Reading Prong to the north of Durham Valley. The crystalline rocks in the northern part of the study area are Hardyston Quartzite in Durham Valley and granitic and hornblende gneisses in the Readiftg Prong.

In crystalline rocks, ground water moves through intergranular openings in the weathered zone (saprolite) and through a network of interconnecting secondary openings - fractures and joints - in the underlying unweathered rock. The permeability of fractured crystalline rock depends on the number of fractures, the size of the fracture openings, and the degree of interconnection of the fractures. A considerable quantity of water may be stored in the weathered zone where ft is thick.

The ground-water-flow system in crystalline rock is local with streams acting as drains. Flow paths are short, and ground water flows from areas of higher elevation to adjacent streams. Groundwater and surface water divides usually coincide. The hydrologic system generally is under unconfined (water-table) conditions; the water-table surface is a subdued replica of the land surface. In areas where the fractures are far apart and poorly interconnected, a true water table may be absent and each system of fractures may have its own water level. Semiconfined ground water may occur locally.

5. PRELIMINARY WATER BUDGET

The preliminary water budget evaluation has been included in WAMOS computer application (see Section 2.2).

A water budget is an estimate of water entering and leaving a basin, plus or minus changes in storage, for a given period of time. Water enters as precipitation and leaves as stream flow, ground-water underflow, diversion of ground water from the basin where it was pumped, and evapotranspiration, plus or minus interbasin flow and changes in ground-water and soil-moisture storage. During dry periods, streamflow is sustained by base flow, which is groundwater discharge to streams.

The water budget might be complicated by several factors:

- Groundwater pumping may shift ground-water divides so that they do not coincide with surface-water divides.
- Number of wells available for water-level measurements, so a detailed water-level map to be constructed to show the groundwater divides. As a result, estimates of interbasin flow are difficult.
- In addition, pumping wells withdraw quantities of water, making changes in ground-water storage difficult to determine.

After all other components in the water budget are estimated the simplified annual water budget can be expressed as:

$$P = SF + ET + GP + L + LGWS$$

where P = precipitation,
SF = streamflow,
ET = evapotranspiration,
GP = groundwater pumpage,
LGWS = increase in ground-water storage.

Assuming no groundwater pumping, no ground-water infiltration to sewers, and no change in groundwater storage, the estimated water budget for an average year is:

$$P = SF + ET$$

Due to incomplete data a water budget for 1999 could not be estimated. Preliminary water budget will be estimated for 2000, expressed in inches of water. Precipitation will be measured at the Durham station, and Monthly potential evapotranspiration at Philadelphia station or other the nearest temperature station with complete record for 2000.

R. Sloto calculated average water budgets for the Cooks Creek watershed for 1991 –1992 periods. Average annual precipitation (P) was 42.5 inches; average annual evapotranspiration (ET) and other losses were 23.8 inches or 56 percent of precipitation; average annual strearnflow was 19.0 inches or 45 percent of the average precipitation; and the average annual change in ground-water storage was a decrease of 0.2 in., or less than 1 percent of the average annual precipitation.

Table 3. Annual water budget for Cooks Creek for 1991-1992, after R. Sloto, USGS, 1994

Year	Precipitation (inches)	Percentage of Precipitation As streamflow	Change in Groundwater Storage (inches)	Percentage of precipitation as change in groundwater storage	Evapotranspiration and other losses (inches)	Percentage of precipitation as evapotranspiration
19991	41.1	18.6	-0.7	2	23.2	56
1992	43.9	19.4	+0.3	1	24.3	55
Average	42.5	19.0	-0.2	<1	23.8	56

In the case of a water balance study, the water budget is balanced at the land surface and in the subsurface (aquifer systems). At the land surface, precipitation (P) falling on the ground surface divides into three components: runoff (R), evapotranspiration (E) and infiltration(I). The available amount of water recharging an aquifer system is defined by infiltration (I). The water budget at the land surface is:

$$P-E=I+R$$

In the subsurface, the volume of water entering an aquifer system and the volume of water discharged from the aquifer should balance (the best method for a subsurface water budget is anyway the groundwater flow model). Differences between the amount of water entering the aquifer (Q_{in})and the amount of water discharged from an aquifer (Q_{out}) will result in a change in aquifer storage (ΔQ) as follows:

$$Q_{in} - Q_{out} = \Delta Q$$

The change in aquifer storage averages zero for longer periods of time or it can be positive or negative if shorter periods of time are considered.

The total amount of water that infiltrates into a fluviokarst drainage basin (surface water and groundwater systems) includes several specific components as shown by White, 1988 (see. page 157, Figure 6.7). The water entering the limestone wedge includes flow from allogenic intermittent sinking streams, or allogenic infiltration (Q_A), internal run-off (Q_I), diffuse infiltration (Q_D) and seepage infiltration (Q_K). These terms are defined below:

- Allogenic Infiltration (Q_A) - Infiltration due to intermittent sinking streams refers to that portion of infiltration that enters the limestone wedge at discrete locations along intermittent surface water courses (e.g., Freshwater drainage ditchs and/or the ephemeral stream Reaches. This may result in rapid, localized recharge to the groundwater system;

- Internal Run-off (Q_I) - Overland flow that enters the limestone wedge groundwater system at sinkhole locations is termed internal run-off. Internal run-off may result in rapid, localized recharge to the groundwater system along the outcrop extent of the limestone wedge;

- Diffuse Infiltration (Q_D) - Diffuse infiltration refers to the infiltration of rainwater through the soil column that covers the limestone wedge outcrop area; and,

- Seepage Infiltration (Q_K) - Seepage infiltration refers to the flow into the limestone wedge from the surrounding crystalline rocks.

Based on the flow components identified above, the inflow of water (Q_{in}) into the limestone wedge can be written as:

$$Q_{in} = Q_A + Q_I + Q_D + Q_K$$

The discharge points for groundwater entering the limestone wedge are the Cooks Creek reaches on limestone.

Therefore the outflow of water from the limestone wedge (Q_{out}) is:

$$Q_{out} = BF \text{ (Base flow of Cooks Creek for the limestone subbasin)}$$

By combining the equations above the water balance equation for the limestone wedge is:

$$Q_{in} - Q_{out} = \Delta Q \text{ or,}$$

$$Q_A + Q_I + Q_D + Q_K - BF = \Delta Q$$

As indicated above, the change in aquifer storage averages zero for longer periods of time or it can be positive or negative if shorter periods of time are considered.

Some of the flow components included in the limestone wedge water balance can be evaluated with a higher degree of confidence (i.e. Cooks Creek Base Flow (BF), diffuse infiltration (Q_D), and seepage infiltration (Q_K)). Other flow components (i.e., allogenic infiltration (Q_A), and internal runoff (Q_I)) are difficult to estimate, but their magnitude can be evaluated based on estimates of total runoff available for the Cooks Creek hydrographic basin.

Some of the information needed to estimate the subsurface water budget are not available at this time, i.e. ephemeral stream reaches on limestone, the geometry and dimensions of the limestone wedge, infiltration of rainwater through the soil. These information are pending (Cooks Creek Rivers Conservation Plan program) and/or will be finalized during the Groundwater Flow Modeling program after installing the second stream gauge station which will allow separation of Limestone flow base from Triassic and Crystalline rocks flow base.

6. WETLANDS, WATERS, AND NATURAL RESOURCES

This effort included two tasks related to wetlands and threatened and endangered species.

6.1. Procedures for Wetlands Identification and Classification

The scope of work included office review of existing information and field reconnaissance of wetlands, springs and waters of the U.S. The office based portion of the work included review of published maps, including National Wetlands Inventory Maps (NWI), Figure 6.1, and the Soil Survey of Bucks and Philadelphia Counties, PA (1975). Hydric soils were identified on the soil maps and overlain on the NWI maps in order to identify target areas for the field reconnaissance. These target areas were chosen because they represent potential wetlands that are not identified on the NWI maps. These areas and representative NWI mapped wetlands within the watershed were selected for field reconnaissance.

A field reconnaissance of the Cooks Creek wetlands and associated streams was conducted by scientists from EEE Consulting, Inc. during the period from June 13-16 and July 17-22. Field techniques consistent with the U.S. Army Corps of Engineers Wetlands Delineation Manual (1987) were used to map the approximate extent of wetlands. Wetland determination forms were completed for specific wetland types. In addition, the approximate

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limits of waters of the U.S. were identified, as were areas with potential for wetland mitigation. Soils, vegetation and hydrology indicators were used to map the approximate location of wetlands. This wetland mapping does not constitute a delineation level survey and the mapping was not confirmed with the U.S. Army Corps of Engineers (USACE) or Pennsylvania Department of Environmental Protection (PADEP). The wetland areas were numbered and placed on base topographic maps in the field, which were then digitized into a GIS compatible format. Depth to saturated soils (if present) was recorded from one hand augered boring in each wetland area investigated. A photograph was taken of the wetland at each location where a boring was completed. All wetlands were classified in accordance with Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et.al., 1979,FWS/OBS-79/31). Also recorded for each wetland were the proximity to development, wildlife and aquatic life observations, degree of disturbance, evidence of public use and evidence of water quality problems. This information was collected as part of the effort to determine the functions and values of wetlands within the watershed and to identify stressed or "at-risk" wetlands.

Hydric soil assessment procedures were performed in accordance with Part III, Paragraph 44 of the U.S. Army Corps of Engineers Wetlands Delineation Manual. Mapped soils were compared to listed hydric soils in the Hydric Soils of the United States (December 1987) plus revisions. All soil colors were determined from moist undisturbed peds using Munsell Soil Charts (1975). The abundance, contrast, and size of redoxymorphic features were also described. Plant community assessment procedures were performed in accordance with the field indicators and sampling techniques described in Part III, Paragraph 35 and Appendix C of the Manual. Vegetative data were interpreted and indicator status was determined using the US Fish & Wildlife Service's Wetland Plants of the United States (Reed, 1996).

Streams, intermittent drainages and other waters were recorded and placed on maps based on the application of the hydrology parameter and the regulatory definition of ordinary high water.

In order to identify important functions and values of the Cooks Creek watershed, an analysis was completed in accordance with the Wetland Evaluation Technique (1987). This technique, which was developed by the USACE Waterways Experimental Station, evaluates social significance, effectiveness and opportunity, and habitat suitability for wetlands. The social significance evaluation is a measure of the probability that a wetland is of value to society because of its natural features, economic value, and strategic location. This analysis was conducted at level 1. The effectiveness and opportunity measure the probability that a wetland has the capacity and opportunity to perform a function such a flood attenuation, groundwater recharge, etc. This part of the analysis was conducted at level 1 and 2.

For the purposes of the evaluation, Assessment Area, Input Zone, watershed and Service Area were determined based on the recommended procedures by the WET. The assessment area was deemed to include contiguous wetlands/open water areas within 0.5 miles of the channel. The input zone was deemed to be 300 feet upslope of the Assessment Area.

6.2 Procedures for Identifying Threatened and Endangered Species

In order to identify important natural resources within the Cooks Creek watershed, a database search was conducted of the U.S. Fish and Wildlife Service and Pennsylvania Department of Conservation and Natural Resources lists of federal and state listed and proposed threatened and endangered species. During the field reconnaissance for wetlands, scientists looked for habitats that could support special status species and recorded observations of wildlife and aquatic organisms. This reconnaissance was not a formal survey or comprehensive search. Qualified biologists that are recognized by the USFWS must be used to conduct surveys for threatened and endangered species.

6.3 Results

A. Wetlands and Waters of the U.S.

The Cooks Creek watershed supports a great abundance and diversity of wetlands. Figure 6.2 show the approximate location, classification, and extent of wetlands and waters of the U. S. that were field identified within the watershed.More than 200 wetland areas exist within the basin according to the field reconnaissance and the NWI maps. These wetlands represent only about 5 to 6 percent of the total area within the basin. Field identified wetlands represent wetlands that were not identified on the NWI maps, wetlands that were correctly identified by NWI maps or wetlands that were incorrectly classified or delineated on the NWI maps. These figures also show potential areas for wetland mitigation. The field identified and NWI-mapped wetlands are also included in the GIS database (see Sheet xxx). The field identification differentiated between Waters of the US and wetlands because Waters of the US are not wetlands according to the Corps of Engineers Manual. The Cowardin Classification system generally does not distinguish between wetlands and waters of the US. For example, open-water and riverine wetlands are included as wetlands under the Cowardin system, but often do not meet the regulatory definition of a wetland (according to the Corps Wetland Delineation Manual).

The wetland types that were identified within the Cooks Creek watershed include:

- palustrine forested
- palustrine scrub shrub
- palustrine emergent
- palustrine open-water
- palustrine unconsolidated bottom
- palustrine flat-bottom
- riverine perennial
- riverine intermittent
- riverine unknown perennial

The NWI maps provide a fairly conservative picture of the extent of wetlands but are reasonably accurate in depicting the type of wetland. The field reconnaissance identified numerous wetlands not identified on the NWI maps along the main channel of Cooks Creek and tributaries that feed into the main channel. These non-NWI mapped wetlands are particularly abundant in Springfield Township along the headwaters of Cooks Creek and the tributaries that feed into it. The field reconnaissance also identified several areas that are shown as wetlands on the NWI maps that were determined to be “non-wetlands”. A number of potential sites were identified that may be suitable for wetland mitigation. These sites were considered as potential wetland mitigation sites based on their position in the landscape, their proximity to existing wetlands, their current vegetative cover, and the relative cost that it would take to convert them to wetlands. Further work including hydrogeological investigation, soils analyses, wetland delineation, and consultation with the property owners would be needed to confirm the potential suitability of these sites.

Waters of the U.S. exist primarily as intermittent tributaries (1st order streams) that drain into Cooks Creek. However, some of these tributaries are perennial and they along with the main channel of Cooks Creek also qualify as waters of the US. Cooks Creek is a limestone influenced stream with a naturally high fertility, good buffering capacity, pH above 7.0 and water quality better than all applicable water quality criteria, physical, chemical, and biological characteristics that support a diverse biotic community, including numerous macroinvertebrates and fish species as well as migratory American eels. All of Cooks Creek (except for the lower 1 mile) and about 37 miles of unnamed tributaries are included in the designated exceptional value waters (Pennsylvania Bureau of Water Quality Management (1991).

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The following summarizes important characteristics about each area that was evaluated in the field. Appendix A includes a copy of the Corps of Engineers Wetland Delineation forms that were completed. Also included in Appendix A are data sheets containing general observations about social, wildlife, and recreational use, plus water quality problems, proximity to development, and degree of disturbance. Areas were assigned letter codes, which correspond with the designation used on the figures and on the data sheets.

Area A

This area includes several thousand feet along the lower portion of Cooks Creek near its confluence with the Delaware River. The stream channel, which is waters of the US, is the dominant feature of the area. The area includes several fringe wetlands (palustrine forested) located along the length of the stream channel. Two potential mitigation areas were identified, as were two NWI wetlands that did not appear to meet the criteria for jurisdictional wetlands. Development was noted within several hundred feet of the stream on both sides of the channel. There were no unique habitats or wildlife observations recorded. The wetlands and Waters of the US in this area are located in a rock unit that is prone to karst development.

Area B

This area is located along the main Cooks Creek channel near the crossing of Haupts Bridge Road. The area includes only waters of the US within the main channel of Cooks Creek and a small tributary that drains an area to the south. Trout were observed in the main channel. Development was about 800 feet away from the channel. The Waters of the US in this area are located in a rock unit that is prone to karst development.

Area C

This area is the headwaters of the small intermittent tributary that joined with Cooks Creek in Area B. This area had no wetlands or waters of the US or unique wildlife observations. The Waters of the US in this area are located in a rock unit that is prone to karst development.

Area D

This area includes a small tributary of Cooks Creek that drains from the north of the main channel along Haupts Bridge Road. A palustrine forested wetland was identified in this area, although none is shown on the NWI map. Relatively steep slopes, springs/seeps, and potential habitat for the bog turtle characterize the area. Development has encroached within about 300 feet of the site. The wetlands and Waters of the US in this area are located in a rock unit that is prone to karst development.

Area E

This area includes two portions of a small tributary of Cooks Creek that is located near Funks Mill Road, just to the east of Springtown. The area includes waters of the US in the lower and upper portion of the tributary and two areas of palustrine forested, and one area of palustrine scrub/shrub wetland, which was not NWI identified. A small palustrine open-water wetland is located in the upper segment of the tributary. The drainage area of the tributary includes relatively steep slopes. No unique habitat or water quality problems were observed and trout were observed. There was evidence of hunting in the area. Development ranged from approximately 800 to 100 feet away from the site.

Area F

This area included the main channel of Cooks Creek near the Crossing of Durham Road. Several fringe wetlands exist along the channel including an NWI identified palustrine forested wetland, several NWI identified palustrine open-water wetlands and a field identified palustrine scrub/shrub wetland. The hydrology of this area had been altered somewhat by construction of a levee/dam downstream of the site. Development ranged from 100 to 600 feet away. The site was used for recreational fishing and trout were observed in the stream. The wetlands and Waters of the US in this area are located in a rock unit that is prone to karst development.

Area G

This area includes a broad expanse of palustrine forested wetlands at the confluence between Cooks Creek and an unnamed tributary that drains the area around and to the west of Springtown. The NWI maps accurately depicted the extent of wetlands. At the southern end of this area, field reconnaissance identified a palustrine emergent wetland that is regularly mowed. This wetland is depicted as a palustrine forested wetland on the NWI maps. No significant wildlife observations or water quality problems were noted. Development is not proximal to the site.

Area H

Area H is a small tributary of Cooks Creek that drains an area of relatively steep slopes along Drifting Drive, to the east of Springtown. The area includes waters of the US, several palustrine forested fringe wetlands, and two open water wetlands. The area included a number of seeps and could potentially support the bog turtle and other special status species. Development ranged from several hundred feet to several thousand feet away. No unique wildlife or water quality observations were noted. The wetlands and Waters of the US in this southern half of this area are located in a rock unit that is prone to karst development.

Area I

This area included a segment of an unnamed tributary to Cooks Creek along the south side of Springtown. A number of field identified waters of the US were identified as were more extensive areas of palustrine forested wetlands than were depicted on the NWI maps. The wetlands include a complex of palustrine forested and palustrine shrub/scrub that exist as fringe wetlands along the stream. The wetlands and Waters of the US in this area are located in a rock unit that is prone to karst development.

Area J

This area includes a waters of the US, which is a small tributary of Cooks Creek that extends northward through Springtown. A spring was noted at the headwaters of this tributary, as were several seeps along the course of the stream. Some segments of this stream were located in close proximity to residences. The area appeared to be used for recreation and water supply. There was evidence of alteration through channelization, small check dams, culverts, and water withdrawal through pumping. Relatively steep slopes characterize much of the watershed. No evidence of significant water quality problems was observed.

Area K

Area K is a portion of an unnamed tributary that crosses Moyer Road, near the northwestern limits of the Cooks Creek watershed. The area includes a large palustrine emergent wetland and a smaller palustrine open-water wetland. Field reconnaissance identified a larger area of palustrine forested wetlands than was depicted on the NWI maps and a potential wetland mitigation site. No unique habitat, water quality problems or wildlife observations were noted. The wetlands and Waters of the US in this area are located in a rock unit that is prone to karst development.

Area L

Area L includes only a waters of the US, which is a 1st order tributary that crosses PA Route 412 and Hellertown Road. No significant observations of water quality problems, wildlife habitat, or public use of the area were noted.

Area M

Area M includes the headwaters of a 1st order stream near Springtown Road. Several small ponds were identified in the headwaters along with a palustrine emergent wetland that was not depicted on the NWI maps. The ponds supported ducks, blue heron, and numerous songbirds. Some areas of wetlands were mowed and used for recreation. Most development was about 1000 feet away from the site.

Area N

Area N was a segment of an unnamed tributary to Cooks Creek that parallels Peppermint Road. The area includes a continuous stretch of palustrine emergent and palustrine scrub/shrub wetlands and one open-water wetland. Field reconnaissance found more extensive areas of the scrub/shrub and emergent wetlands than were depicted on the NWI map. No water quality problems, disturbance, public use, or wildlife habitat were noted.

Area O

Area O includes the headwater segment of a 1st order tributary to Cooks Creek that crosses State Road. The area is characterized by a long, continuous stretch of waters of the US, with several fringe wetlands (palustrine forested and emergent, and unconsolidated bottom type wetlands) scattered along the stream. Several areas of more extensive wetlands were identified than appear on the NWI maps. No significant water quality problems, wildlife observations, or public uses were observed although some evidence of sedimentation was noted. Development was located within about 400 feet of the site in several areas.

Area P

Area P includes several segments that are located near the headwaters of the main stem of Cooks Creek. The area includes a continuous stretch of waters of the US, plus numerous fringe wetlands scattered along the channel. Wetland types included predominantly palustrine forested, with smaller areas of palustrine emergent and palustrine scrub/shrub. Many of these field-identified wetlands are not depicted on the NWI maps. One potential wetland mitigation site was identified near the southern end of this area. Some recreational use, and disturbance of wetlands by mowing and livestock grazing were noted. Development ranged from 200 to 2000 feet away from the site. No significant water quality problems were observed. Some potentially suitable habitat for bog turtles was observed.

Area Q

This Area includes all of a 1st and 2nd order tributary and part of another 1st order tributary that join together before draining into Cooks Creek. The drainage area of Area Q extends to the northwest of Quakertown Road. The NWI maps were reasonably accurate in depicting the extent and type of wetlands (palustrine emergent, palustrine scrub/shrub, palustrine forested, and palustrine open-water); however, several palustrine emergent and palustrine forested wetlands not shown on the NWI maps were identified in the field. Several stretches of waters of the US and one open-water wetland were field identified. No significant water quality problems were identified. Some of the wetlands have been invaded with purple loosestrife and phragmites, and an electric transmission line crossed one wetland. No significant recreational uses or wildlife observations were noted.

Area R

Area R includes a short segment of a 1st order tributary of Cooks Creek that crosses Pleasant View and State roads. The area includes a riverine wetland, three palustrine open-water wetlands and a palustrine emergent wetland, none of which are depicted on the NWI maps. The roads bisect the wetlands; otherwise, there is little development and little disturbance to the wetlands. No unique wildlife or water quality problems were noted.

Area S

Area S includes a section of Cooks Creek about 4000 feet long and a small-unnamed tributary of Cooks Creek. The area includes only waters of the US and an NWI mapped wetland that was determined to be "non-wetland" during the field reconnaissance. Relatively steep slopes along the channels of both streams characterize the area. Significant development exists approximately 2000 feet away. No water quality problems were noted. No unique wildlife habitat or recreational use was observed.

Area T

Area T includes about a 3000 foot segment of an unnamed tributary to Cooks Creek near Amity. The channel was determined to be waters of the US. The area includes several NWI mapped palustrine open-water and emergent wetlands scattered along the length of the stream. Two additional fringe wetlands were identified in the field. No significant water quality problems or unique habitat were noted. In many places, wetlands and riparian areas were mowed to the edge of the channel. Development averaged about 200 feet away from the channel.

Area V

Area V included a palustrine emergent and palustrine scrub/shrub wetland that were field identified. The wetland crosses Krunsman Road. The wetland is part of a small-unnamed tributary of Cooks Creek.

Area W

Area W includes the headwaters of two 1st order tributaries of Cooks Creek near Old Bethlehem Road and Sliffer Valley Road. Waters of the US (riverine wetlands) and small areas of palustrine emergent and palustrine open-water characterize the area. The area has several horse trails, had a debris pile, and is mowed. No significant water quality problems or unique habitats were noted. Development ranged from several hundred feet to several thousand feet away.

Area X

Area X includes about a 4000-foot section of the main channel of Cooks Creek along Springhouse Lane. The area is predominantly waters of the US, although several fringe wetlands (palustrine scrub/shrub and palustrine emergent) were scattered along the length of the channel. Three wetlands were field identified that are not shown on the NWI maps. Some of the area was cleared and a power line crossed the area. No significant water quality problems were noted although algal blooms were observed in one area. One area showed some potential for bog turtle habitat.

Area Y

Area Y includes about a 2000-foot segment of Cooks Creek near Sliffer Valley and Knech Bridge roads. Several field-identified wetlands were discovered along the length of two small intermittent tributaries to Cooks Creek. These wetlands were riverine, and palustrine emergent types. The area did have some habitat that could

potentially support bog turtles. No significant water quality problems (although cattle were observed in the stream), recreational uses or disturbance were noted.

Area Z

Area Z includes about a 2000-foot segment of Cooks Creek near the intersection of Sliffer Valley and Hickory Lane. The area is characterized by waters of the US along the main channel of Cooks Creek and two small tributaries that support palustrine emergent wetlands along the sides of the channels. An area of palustrine forested wetlands was noted at the headwaters to one of the tributaries. No significant disturbance, water quality conditions, wildlife, or unique habitat were noted. The wetlands and Waters of the US in this area are located in a rock unit that is prone to karst development.

Area AA

Area AA includes segments of two unnamed tributaries and their confluence. The area is located near Walnut Lane and Sliffer Valley Road. The area is dissected by channels that qualify as waters of the US. One large palustrine forested, one fairly large palustrine emergent, and one large palustrine open-water wetland were depicted accurately on the NWI map. The field reconnaissance identified a large palustrine forested wetland and several small palustrine forested fringe wetlands. Bog turtles have been reported in this area, but were not observed. The hydrology of the area has been modified by construction of an old dam. The area was used for fishing and horseback riding. No significant water quality problems were observed.

Area AB

Area AB is the headwater segment of a 1st order tributary in the southeastern corner of the Cooks Creek watershed. The area includes several channels, which qualify as waters of the US and two palustrine open-water wetlands. The ponds had algal "build-up" and showed some sedimentation. Several segments of the channels were rip-rapped.

Area AC

Area AC is a headwater segment of an unnamed tributary to Cooks Creek near Bursonville Road. The area includes palustrine scrub/shrub, palustrine emergent and palustrine open-water wetlands. Only the open-water was identified by the NWI map. The area did have some potential habitat for bog turtles. No significant disturbance, development, public use, or water quality problems were observed.

Area AD

Area AD is the headwaters of a 1st order tributary of Cooks Creek that is located near Harrow Road. A fairly extensive area of palustrine scrub/shrub and palustrine emergent wetlands were identified that are not depicted on the NWI map. Several small areas of palustrine open-waters were correctly mapped on the NWI maps. A spring was identified at the headwaters of the tributary. The area did have potential habitat for special status species. No significant water quality problems, public use, or disturbance from humans were noted.

B. Wetland Functions and Values

Cooks Creek and its associated wetlands provide a number of important benefits to society and the living resources in the region. These important functions were qualified using the WET II Evaluation. The results of this analysis are summarized in Table 3.

Table 3
Wet II Evaluation Summary

Wetland Functions and Values	Social Significance		Effectiveness		Opportunity	
	Segment of Cooks Creek					
	Third & Fourth Order	First & Second Order	Third & Fourth Order	First & Second Order	Third & Fourth Order	First & Second Order
Ground Water Recharge	H	L	H	L	*	*
Ground Water Discharge	H	H	L	H	*	*
Floodflow Alteration	H	H	H	H	M	M
Sediment Stabilization	M	M	M	M	*	*
Sediment/Toxicant Retention	H	M	L	L	H	H
Nutrient Removal/Transform.	H	H	L	L	M	M
Production Export	*	*	M	M	*	*
Wildlife Diversity/Abundance**	H	H	*	*	*	*
Breeding	*	*	L	L	*	*
Migration	*	*	H	M	*	*
Wintering	*	*	H	M	*	*
Aquatic Diversity/Abundance	H	H	H	H	*	*
Uniqueness/Heritage	H	H	*	*	*	*
Recreation	H	H	*	*	*	*

* Not applicable according to WET II
** Wildlife Diversity/Abundance assesses only wetland-dependent birds. Other wildlife (e.g., game mammals) should be evaluated using other methods.
H - High
M - Moderate
L - Low

The representative segments of the watershed included in this evaluation were:

- Fourth Order Segment of Cooks Creek. This segment includes the portion of the Cooks Creek from Springtown to about 1,000 feet upstream of its confluence with the Delaware River.

- First and Second Order Segment of Cooks Creek. This segment includes the headwaters of Cooks Creek to approximately the crossing of Township Road.

Ground Water Recharge

Definition – For purposes of this method, recharge Assessment Area (AA's) or wetlands are considered to be those where: (a) recharge to underlying materials or ground water (deep or shallow) exceeds ground water discharge to the wet depression on a net annual basis, and/or (b) the rate of recharge typically exceeds the rate of recharge from terrestrial environments.

Rationale (HIGH) – There are three general sets of conditions which indicate a wetland has a high probability of recharging ground water on a net annual basis. The first set of conditions consists of direct evidence of recharge through the use of groundwater wells or piezometer tubes at various seasons. Specific evidence consists of measurements showing that the water table slopes away from the AA on most of its sides, with no downslope water table divide occurring in the immediate vicinity, and/or where the depth to water is progressively deeper in a cluster of piezometers drilled at the same location but to different depths. A second set of conditions exists for wetlands in a precipitation deficit region. These

wetlands must be not permanently flooded, have a negative discharge differential, or have an inlet but no outlet and not be a fringe wetland. In addition, one of the following conditions must be true: topography is favorable, watershed soils have a slow infiltration rate, watershed is impervious, wetland is located upslope from a dam or dike, or water quality anomalies exist. The third set of conditions are for wetlands not in precipitation deficit regions. These wetlands must have a negative discharge differential and water quality anomalies or have a permanent inlet but no permanent inlet but no permanent outlet and be a fringe or island wetland. In addition, the wetland must have one of the following conditions: not be permanently flooded, have favorable topography, impervious watershed, soils of slow infiltration, located upslope of a dam, having fine mineral soils or be in a karst region, or having expansive flooding or unstable flows.

Ground Water Discharge

Definition – For purposes of this method, ground water discharge areas are those where the rate of discharge from ground water (deep or shallow) into the wetland exceeds the rate of recharge to underlying ground water from the wetland on a net annual basis.

Rationale (LOW) – The only wetlands believed to have a LOW probability for ground water discharge are those: (a) rated HIGH for ground water recharge or (b) nonpermanently flooded wetlands that do not have at least two of the characteristics described above.

Floodflow Alteration

Definition – For purposes of WET, floodflow alteration occurs in those areas where surface water is stored or its velocity is attenuated to a greater degree than typically occurs in terrestrial environments. No judgement is made as to the value of such flow alteration, in fact, there may be situations in which reduction of flow velocity causes increased flooding due to flow synchronization.

Rationale (HIGH) – There are five types of AA's that most clearly are effective for altering floodflows. These include AA's which: (a) have regulated outflows (reservoirs, dams), (b) have outflows that are measured as being less than inflows, (c) have neither an outlet nor an inlet, (d) expand their surface area by at least 25 percent for 20 days of the year and are larger than five acres, or (e) are larger than 200 acres and are either in a precipitation deficit region or (if flowing water is present) are at least 70% covered with juxtaposed woody vegetation. Additionally, they must not be tidal. Thus, the simple presence of vegetation which adds to channel roughness is considered insufficient to result in a rating of HIGH; the wet depression must remove (through evapotranspiration) or store water as well as create a lag (desynchronized) effect.

Sediment Stabilization

Definition – For purposes of this method, HIGH sediment stabilization areas are those which are more effective for binding soil and dissipating erosive forces than are typical upland environments.

Rationale (MODERATE) – There is no formal designation for MODERATE, but an area rated HIGH must be characterized by one of the following characteristics: potential erosive forces present, unsheltered or Zone C greater than Zones A and B, ditches, canals or levees are present that confine water, high water velocity, evidence of long-term erosion, or a water table influenced by an upstream impoundment. In addition, one of the following characteristics must also be present: rubble substrate, protective of nearby shorelines, greater than 20 ft width of erect vegetation, presence of forest of scrub-shrub, or good water and vegetation interspersion.

Sediment/Toxicant Retention

Definition – For purposes of this method, HIGH sediment/toxicant retention areas are those which physically (or chemically in the case of the toxicants) trap and retain on a net annual basis the inorganic sediments and/or chemical substances generally toxic to aquatic life.

Rationale (LOW for Effectiveness) – Wetlands considered to have a LOW probability of being effective for sediment trapping are one of five basic types: (a) wetlands with tilled (farmed) soils and having a permanent outlet, (b) wetlands with cobble-gravel, rubble, or bedrock substrates and no vegetation, instream debris, or pools; (c) wetlands fringing the channel immediately downstream from an impoundment; (d) wetlands where measured nontidal outputs of inorganic particulates are greater than inputs (especially during storms); (e) wetlands where prevailing current velocities are sometimes greater than the suspension thresholds of the prevailing sediment types; or (f) wetlands having most of the following characteristics: exposed to boat wakes or channelized; unconstricted outlet; tilled soil; not in a depositional gradient or not being in an AA that expands greatly when flooded; shallow depths with large fetch (and minimal aquatic bed vegetation); and minimal fringe vegetation if sediment enters as overland flow (or minimal vegetation interspersion if sediment enters as channel flow).

Wetlands meeting any of the criteria in the above paragraph must also (if such data are available) show no evidence of accretion, based on historic photographic or field coring data.

Nutrient Removal/Transformation

Definition – For purposes of this method, HIGH nutrient removal/transformation areas are those which retain or transform inorganic phosphorus and/or nitrogen into their organic forms or transform (remove) nitrogen into its gaseous form, on either a net annual basis or during the growing season, and which are generally more effective at doing so than typical upland environments.

Rationale (LOW for Effectiveness) – Wetlands are rated LOW for nutrient removal if they are also rated LOW for sediment trapping, plus have primarily peat sediments, anoxic water column conditions, and no woody or floating-leaved vegetation, or if they are marine.

Production Export

Definition – For purposes of this method, HIGH production export is the flushing of relatively large amounts of organic plant material (specifically, net annual primary production) from the AA into downslope waters. No judgement is made as to the value of such export; indeed, there may be instances where such export represents a nutrient loss to the exporting system or where such exported material causes water quality problems downslope.

Rationale (MODERATE) - There is no formal designation for MODERATE, but an area rated HIGH, must have conditions favoring primary productivity (relative to similar wetland types within the same region) of wetland plants, as well as having a permanent outlet. Specifically, if the wetland system is marine, primary productivity must not be low or potentially eutrophic conditions are present. If the wetland system is riverine the following conditions must be present: or all of the following conditions must be present: potentially eutrophic conditions present, watershed greater than 100 square miles, significant areas of erect or submerged vegetation present. If the wetland system is estuarine the following conditions must be present: significant areas of erect vegetation must be present, should be wider than 20 ft and flooded vegetation, high plant productivity, erosion potential is high, Zone B must cover at least 10% of the AA, and potential eutrophic conditions. If the wetland system is lacustrine the following conditions must be present: significant areas of erect vegetation exist, aquatic or emergent

vegetation dominate the AA, plant productivity high, pH not acidic, potential for eutrophic conditions or existing high level of dissolved solids, high erosion potential and watershed not small. If the wetland system is palustrine the following conditions must be present: significant areas of erect vegetation, potential erosive conditions, Zone B greater than 10% of AA, potential for expansive flooding, potential for eutrophic conditions or high levels of dissolved solids, high plant productivity, and fringe or island situation. In addition, for all wetland systems, one of the following conditions must be present: moss-lichen class extensive, sandy substrate, water velocity high or AA unsheltered, low water/vegetation interspersion, presence of direct alteration, artificially manipulated water levels, small watershed, or low levels of suspended solids.

Wildlife Diversity/Abundance for Breeding

Definition – For purposes of this method, a HIGH rating for a wetland means that during the breeding season the wetland normally supports a notably great on-site diversity and/or abundance of wetland-dependent birds. This definition does not take into account the contribution of the AA to off-site (regional) faunal richness or the uniqueness/rarity of the species.

Rationale (Level 2 – LOW) – There are seven types of wetlands which, in a natural context, have a LOW probability of supporting exceptional diversity of breeding birds. Certain individual wetlands within the following seven types may be rated LOW if they are in a precipitation surplus region:

1. Upper riverine, forested, shrub or moss wetlands unconnected to adjoining forests by vegetated corridors, and smaller than 40 acres.
2. Small wetlands with potential toxic inputs.
3. Estuarine/marine wetlands that are either:
   (a) small and exposed to large waves, or
   (b) contain little vegetation
4. Palustrine/lacustrine wetlands that either:
   (a) are predominantly moss (peat bogs) and have low vegetation class diversity and no open water, or
   (b) are small, surrounded by urban development, and if forested have no connecting corridors, or
   (c) are small and have low vegetation class diversity, low edge irregularity, no open water, <u>and</u> are not part of an oasis/cluster.

Wildlife Diversity/Abundance for Migration and Wintering

Definition – For purposes of this method, a HIGH rating for a wetland means that during migration for winter, the wetland normally supports a notably great on-site diversity and/or abundance of wetland-dependent birds.

Rationale (Migration/Wintering – HIGH) – This key recognizes three general types of wetlands which, in a national context, have a HIGH probability of supporting an exceptional diversity of wildlife during migration. Certain individual wetlands within the following types may be rated HIGH:

1. West Coast freshwater wetlands located within 5 miles of estuarine wetlands larger than 5 acres (or vice versa).
2. Moderate or large-sized mudflats with good visibility and adjoined by emergent marsh.
3. Wetlands with good vegetational diversity and interspersion, generally large and in agricultural areas or along river valleys or coastlines.

Wetlands potentially rated HIGH for wintering wildlife include 1 and 2 above and also 3 above if the wetland is unfrozen.

Aquatic Diversity/Abundance

Definition – For purposes of this method, a HIGH rating for an area means that, at least seasonally, the AA supports a notably great on-site diversity of fish or invertebrates (i.e., most trophic groups of secondary consumers with complex food webs). Other aquatic animals (e.g., waterfowl) are covered under other functions.

Rationale (HIGH) – A majority (not all) of several conditions must be present for a HIGH probability rating to be achieved.

If marine, the hydroperiod must be "regularly flooded" or "intermittently exposed" (intertidal or subtidal). Such areas must comprise of at least 10% of the AA, must not be dominantly sand, and must have a diversity of depths and current velocities.

If riverine, in addition to the conditions required of marine wetlands, wetlands must not be channelized, leveed, or have the seasonal timing of their flows altered. Natural flooding must expand the AA to a significant extent and seasonal duration if they are in southern regions, while in northern regions there should be minimal natural variation in flow (suggesting ground water inputs). In both regions, streambanks should be neither completely forested nor totally unshaded, and adequate instream cover, dissolved oxygen, and (in headwater or intermittent streams) adequate pools should be present.

If estuarine, "great storm intensity/frequency" is substituted for the seasonal flood index used for riverine systems. It implies increased access to (and use of) supratidal areas. In addition to the other above-named requirements, estuarine wetlands should have a freshwater inlet or a watershed that is at least 5% freshwater wetlands (diversity of estuarine salinity conditions) and moderate amounts of adequately interspersed erect vegetation.

If lacustrine, the AA: (a) should have an inlet and outlet; (b) should be larger than 200 acres or, if smaller and in an ice-hazard region, should have a large watershed; (c) should not be dominated by sand bottom; (d) should be permanently flooded (at least in part; (e) should have a shallow area with diverse cover and vegetation that covers at least 10% of the area of the deepwater; (f) should have a diversity of depth categories and adequate dissolved oxygen; (g) should not be leveed or ditched; (h) should expand substantially with natural seasonal flooding; and (i) should not be oligotrophic or should have suitable values for the morphedaphic index.

If palustrine, in addition to characteristics in the above paragraph, the wetland: (a) should have moderate amounts of erect vegetation well juxtaposed with open water; (b) if forested, should have some flow present throughout; and (c) should not have its water levels subject to artificial manipulation (except for intentional ecological management).

C. At-Risk Wetland Resources

Based on this desktop study and field reconnaissance, it appears that the wetlands and watershed are largely undisturbed and unstressed. However, there are certain areas that are important to water quality protection, the potable water supply and the continued existence of rare species. These areas include:

- Wetlands and the streams located in karst prone formations that may serve as groundwater recharge areas.

- Headwater segments of the tributaries, which are vulnerable to disturbance and development.
- Springs and seeps, especially along the base of the channel banks. These groundwater discharge areas contribute cool, high quality water that is the base flow for Cooks Creek.
- Habitats that support or potentially could support threatened and endangered species.
- Segments near developed areas primarily Springtown, Pleasant Valley and the eastern portion of Durham Township.

D. Threatened and Endangered Species and Other Living Resources

In summary, the watershed supports a diverse range of living resources and provides habitat for a number of special status species. According to the USFWS, the Cooks Creek supports several populations of bog turtles (*Clemmys muhlenbergii*), which is listed as a federally threatened species (Appendix A). Bog turtles inhabit shallow, spring-fed fens, sphagnum bogs, swamps and pastures that have an open-canopy and are characterized by soft muddy bottoms and clear cool water that is usually ground-water fed. According to the USFWS, occasional transient species that are federally threatened or endangered may visit the Cooks Creek watershed as well. A list of these species is included in Appendix B. The Pennsylvania Department of Conservation and Natural Resources database showed that the following state threatened or endangered species have been recorded within or near the watershed:

Species	Status
Spreading Globeflower (*Trollius taxus Salisb.*)	State endangered
Red-bellied turtle (*pseudemys rubriventris*)	State threatened
Least bittern (*Ixobrychus exilis*)	State threatened
Peregrine falcon (*Falco peregrinus*)	State endangered
Sedge wren (*Cistothorus platensis*)	State threatened
Bog turtle (*Clemmys muhlenbergii*)	State endangered

Information about the habitat, natural history, management practices, and identifying characteristics for each of these species is included in Appendix B. According to the Nature Conservancy, the bog-turtle and other special status species including the red-bellied turtle and the eastern mud salamander have been documented at 1 site within the watershed (Bureau of Water Quality Management, 1991).
Fish surveys have collected a diverse population of primarily cold-water fish species including brown trout, brook trout, rainbow trout, rock bass, redbreast sunfish, bluegill, green sunfish, pumpkinseed, rock bass, largemouth bass, smallmouth bass, longnose dace, white sucker, blacknose dace, common shiner, swallowtail shiner, spotfin shiner, silvery minnow, bluntnose minnow, cutlips minnow, creek chub, margined madtom, tesselerated darter, and slimy sculpin. (Bureau of water Quality Management, 1991).

The Audubon Society has completed a number of bird surveys within the Cooks Creek basin. At least 196 avian species have been recorded, of which approximately 39 are directly dependent on water resources for their survival. According to the Bureau of water Quality Management (1991), the Cooks Creek watershed is also important to the migratory birds that use the Delaware River as an important stop-over point during spring and fall migrations.

- The Cooks Creek watershed is an exceptional value waters that supports rare species, provides abundant recreational opportunities and has a complex hydrological and hydrogeological situation.

- The wetlands along the Fourth Order segment of Cooks Creek are located in karst prone formations and probably serve an important role in aquifer recharge. These wetlands from a "potential conduit" for contaminant migration to the groundwater and therefore are important to the protection of the potable water supply.

7. GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT

Development of the GIS database for Cooks Creek Watershed Conservation Plan project will incorporate as many of the parameters that affect watershed wetland planing decisions as possible.

This entails a considerable amount of data collection, synthesizing, interpreting, processing and presentation. The initial phase of the GIS development includes a detailed hydrogeologic, geologic and wetland base map. The GIS is structured to allow for the inclusion of additional information collected in the future. This will insure the GIS remain both representative and current.

Cooks Creek Watershed databases and a GIS base map was prepared based on the PaDCNR database and other Metabases. The Cooks Creek Watershed Database consists of:

- County boundary;
- Township boundary;
- Streams;
- Springs;
- Wells;
- Road centerlines / edge of pavements;
- Bridges / railroads;
- Geology;
- Flood plains;
- Groundwater levels; and,
- Wetlands.

8. COOKS CREEK WETLANDS MANAGEMENT PLAN

This section expands on the findings and recommendations from the Cooks Creek Management Plan that was prepared for the Durham Township Environmental Advisory Committee. That study identified a number of important conditions or characteristics of the Cooks Creek watershed, which are summarized below:

- **Wetlands Mapping** - The existing National Wetland Inventory maps (NWI) maps did not accurately identify the full extent of wetlands in the headwaters or upper reaches of streams. The NWI maps provide a reasonably good picture of the extent and type of wetlands in the lower portions of Cooks Creek. In general, the wetlands shown on the NWI maps do exist and are classified properly. However, many additional wetlands (non-NWI mapped) and waters of the US were found during the field reconnaissance.

- **Springs and Seeps** - Numerous springs or seeps from the base of slopes were found in the watershed, especially in the headwaters of the tributaries to Cooks Creek. Some of the springs and seeps are located in wetlands although others are outside of jurisdictional wetlands. These springs and seeps are probably critical to the continued existence of nearby wetlands and special status species and the trout population because the discharges provide year-round base flow to the stream/wetlands and contribute cool, high quality water that is vital to the survival of the populations.

- **Wetland Threats** - The wetlands in the watershed do not appear to be significantly stressed due to hydrological modification, development, or human activities. However, many of the wetlands appear to be vulnerable to hydrological modification because groundwater discharge and stream flows provide the crucial water source. In addition, increased development or intense development could affect these wetlands if it is proximal to them.

- **Wetland Functions and Values** - According to the WET II analysis, wetlands in the Cooks Creek are highly effective in providing groundwater recharge, groundwater discharge, flood-flow alteration, wildlife migration and wintering, aquatic diversity and show high social significance for groundwater recharge, groundwater discharge, flood-flow alteration, nutrient removal, wildlife diversity/abundance, aquatic diversity/abundance, uniqueness/heritage and recreation.

Recommendations

The DTEAC and Durham and Springfield Townships should consider a number of possible actions for the maintenance and preservation of the wetlands and the unique natural resources within the Cooks Creek watershed. EEE recommends consideration of the following actions:

- **Watershed Management**- Because of the unique and sensitive nature of the Cooks Creek system, it will be important to manage and protect the creek, aquifer, springs, and wetlands as a system. For example, management of the wetlands alone will not necessarily preserve the springs and seeps, which are critical to the special status species that live in the watershed. In addition, management of the wetlands alone will not necessarily help to protect the shallow aquifer, especially within the karst-prone areas of the watershed. Therefore, we recommend a holistic management approach that recognizes the connections between the different elements and uses a number of different approaches. Some of the tools that could be considered are summarized below:

- **Comprehensive Plan** –Environmental Element- One important step is to develop an element of the Comprehensive Plan that discusses the valuable social and environmental benefits of the Cooks Creek watershed. This is important because the Comprehensive Plan serves as the "Blueprint" for County decisions

on land use and development; therefore, a thorough discussion should be included in the Comprehensive Plan from which to incorporate environmental considerations into the planning process. The Environmental Element should include a discussion on the natural resources inventory as well as goals, objectives, and strategies for protecting valuable environmental resources.

- **Cooks Creek Overlay District or Environmental Ordinance** – One option to consider is an "overlay" ordinance for Cooks Creek that would require new development projects to identify sensitive resources and use best management practices to protect these resources. An overlay district is a special designation within the Zoning Ordinance that typically covers the watershed or a specified distance from the edge of the stream and establishes certain performance standards for development and subdivisions within the district. An overlay district is simply an "overlay" to existing zoning, which has additional requirements beyond that required by the zoning. Overlays are typically used for valuable river systems, public water supply reservoirs, historic areas etc. As an alternative, a Township-wide environmental ordinance could be developed that has similar requirements to the overlay district. Some of the basic features included in such ordinances are described below:

  - Identification or inventory of sensitive resources such as karst or aquifer recharge areas, wetlands, springs, steep slopes, highly erodible soils, highly permeable soils, and 100-year floodplains within the overlay zone. In addition, most overlay zones include a vegetated buffer (i.e. 100 feet) that extends landward of the sensitive features. This vegetated buffer is important to the protection of water quality because it traps some of the pollutants that would otherwise be transported into the stream with stormwater.

  - A requirement for evaluation of the impacts to sensitive resources and water quality (surface water and ground water) from proposed development. This approach can be broadened to require an analysis of the natural, physical and socio-economic environment for new development projects anywhere in the jurisdiction. For example, Tinicum Township has an ordinance that requires an Environmental Impact Assessment Report with similar broad ranging requirements for new development.

  - Mitigation steps to avoid, minimize, or mitigate for the impacts to sensitive resources described above.

- **Growth Management**- Other planning tools that could be considered include growth management ordinances that promote cluster development, preservation of open space and riparian corridors, and transfer of development rights to protect rural areas.

- **Education** - Continue to expand public outreach efforts that emphasize the public benefits of environmental stewardship and watershed management. This approach could involve seminars or newsletters for residents, industries, and farmers on the importance of protecting the watershed and how they can help.

- **Water Monitoring Program** - Consider developing a water quality-monitoring program of the stream and the primary water supply aquifer. Several stream monitoring programs have been implemented elsewhere including one developed by the PADEP and a nationwide program by the Isaac Walton League, which relies on citizen efforts. Information on the basics of this program is included in Appendix C. A similar program has been developed by the Alliance for the Chesapeake Bay, within the Chesapeake Bay Watershed. One option is to consider a program that uses remote sensing to track the health, type, and extent of wetlands in the watershed and water quality. Such programs have been implemented in other important watersheds such as the Everglades and Chesapeake Bay. Remote sensing has the ability to cost-effectively identify many water quality problems, drought stress in vegetation, and plant community changes. This effort would require a source of funding or a collaborative effort with a research institution or consultant with the capability to perform such analysis.

- **Funding** - Consider seeking additional funds to develop a watershed approach for management and preservation of the Cooks Creek natural resources, water quality, and groundwater resources.

- **Protection of Sensitive Areas** - Promote the protection of sensitive segments of watershed and wetlands through fee simple acquisition and use of conservation easements. The focus of this effort should be areas that are important to aquifer recharge, springs and seeps that contribute to base flow to the stream, and habitats that support rare species and headwaters segments of the Cooks Creek tributaries.

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Glossary of Geologic, Hydrogeologic, and Wetland Terms

acid mine drainage Water contamination by sulfuric acid produced by seepage through sulfur-bearing spoil and tailings from coal and metal mining; also referred to as AMD.

acid rain The acidity in rain due to gases from internal combustion engines and coal- and oil-burning power plants, or simply the burning of fossil fuels releases acid fumes into the air which upon mixing with atmospheric water may result in “acid rain”.

active layer The seasonally thawed zone above permafrost; or the uppermost zone of the soil that under the action of weather remains “active”, for example, moves downhill .

alluvial Pertaining to material or processes associated with transportation and or subaerial (above ground) deposition by concentrated running water (running water can be rivers and such).

alluvium Unconsolidated clastic material subaerially deposited by running water, including gravel, sand, silt, clay, and various mixtures of these.

alluvial fan Land counterpart of a delta . An assemblage of sediments marking a place where a stream moves from a steep gradient to a flatter gradient and suddenly loses transporting power. Typical of arid and semiarid climates but not confined to them.

amygdule A gas cavity (vesicle) in volcanic rock that has been filled with mineral matter such as calcite, chalcedony, or quartz.

angle of repose The maximum angle at which loose material will come to rest when added to a pile of similar material.

angular unconformity An unconformity in which the beds below the unconformity dip at a different angle than the beds above it. An unconformity, in general is an interpreted time-interval during which either deposition did not occur, or erosion occurred in a sedimentary sequence of strata. In general it is considered a time-interval between two geologic units of different age.

anticline A fold that is convex upward, or that had such an attitude at some stage of its development. In a fold, rocks have been subjected to directed stresses that have caused them to buckle either upward (as in an anticline) or downward (as in a syncline); compare syncline .

aphanitic A textural term meaning "fine-grained" that applies to igneous rocks. Generally, igneous rocks that cooled from a magma that emerged at the ground surface or was emplaced in a zone where they cooled quickly tend to have small grain size (because the crystals did not have enough time to grow).

aquifer A permeable region of rock or soil through which ground water can move. An aquifer is also considered a body of rock or soil that would sustain a continuous yield of groundwater when such groundwater is withdrawn from it. When an aquifer is the primary source of all or most drinking water to a community, the aquifer may be designated a “sole source aquifer” in order to protect it from misuse or contamination.

aquitard A material of low permeability that greatly slows the movement of ground water.

Archean An eon of geologic time extending from about 3.9 billion years to 2.5 billion years ago.

arkose A sedimentary rock formed by the cementation of sand-sized grains of feldspar and quartz.

artesian *well* A well in which the water in the aquifer is under pressure that raises the water above the point that the well first encounters it.

Assessment area (AA): The area for which functions and values are being assessed using the Wetland Evaluation Technique (WET II). The AA is characterized by a high degree of hydrologic interaction.

asymmetric rock knob or hill Bedrock forms with a gentle slope on one side created by glacial abrasion and a steep slope on the opposite side created by glacial plucking, or because of the lay of the rock strata. .

aquifer: A water-bearing layer of rock or sediment capable of holding and transmitting fluid (such as water, gas, or oil).

aquifer, confined *(or artesian)* An aquifer overlain by a non-permeable layer or layers, in which pressure will force water to rise above the aquifer.

aquifer, perched An aquifer containing unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone.

aquifer, principal The aquifer or combination of related aquifers in a given area that is the important economic source of water to wells; or “sole source aquifer”

aquifer, secondary Any aquifer that is not the main source of water to wells in a given area.

aquifer, unconfined *(or water table)* An aquifer in which the upper surface is the water table.

aquiclude An impermeable geologic formation or stratum which will not hold or transmit fluid.

aquitard A geologic formation or stratum that significantly retards fluid movement.

artesian well*:* A well in an aquifer where the groundwater is confined under pressure and the water level will rise above the top of the confined aquifer.

Artificial Recharge The unnatural addition of surface waters to groundwater. Recharge could result from reservoirs, storage basins, leaky canals, direct injection of water into an aquifer, or by spreading water over a large land surface.

aureole A zone surrounding an igneous intrusion, in which contact metamorphism has taken place. The sedimentary strata surrounding the diabase sills (Haycock etc.) in the Cooks Creek Watershed have been metamorphosed by coming into contact with the hot, intruding igneous rock. These altered rocks are termed to occur within the metamorphic aureole of the intruding igneous rock.

axial plane A geometric plane that intersects the trough or crest of a fold in such a way that the limbs of the fold are more or less symmetrically arranged with reference to it.

axis The line formed by the intersection of the axial plane of a fold with a bedding plane, marking where the bed shows its maximum curvature.

bankfull stage A stream discharge that just fills the stream channel.

basalt A dark colored extrusive igneous rock composed chiefly of calcium plagioclase and pyroxene. Extrusive equivalent of gabbro, underlies the ocean basins and comprises oceanic crust.

base flow Ground water that enters a stream channel, maintaining stream flow at times when it is not raining.

base level Of a stream is the point below which the stream cannot cut. A temporary base level along a stream, such as a lake may be removed by stream action . Ultimate base level is the ocean.

basin A synclinal structure, roughly circular in its outcrop pattern, in which beds dip gently toward the center from all directions.

bed load Material in motion along a stream bed.

bedding A collective term used to signify presence of beds, or layers, in sedimentary rocks and deposits.

bedding plane Surface separating layers of sedimentary rocks and deposits. Each bedding plane marks termination of one deposit and beginning of another of different character, such as a surface separating a sandstone bed from an overlying mudstone bed. Rock tends to breaks or separate, readily along bedding planes.

bedrock Any solid rock exposed at the Earth's surface or overlain by unconsolidated material.

biogenic sediment Sediments produced directly by the life processes of plants or animals.

biogenic sedimentary rock A sedimentary rock composed primarily of biogenic sediments.

braided stream A stream with a complex tangle of converging and diverging channels separated by sand bars or islands.

branch work cave Cave with passage ways formed along bedding planes and with an areal pattern similar to that of surface streams.

breccia A clastic rock in which the gravel-sized particles are angular in shape and make up an appreciable volume of the rock.

brittle Structural behavior in which a material deforms permanently by fracturing.

burial metamorphism Takes place in an environment where pressure and temperature are barely more intense than during diagenesis , typically in a deepening sequence of sediments.

capacity The total amount of material a stream is able to carry under given conditions.

capillary water Water in the zone of aeration held to soil particles by surface tension of the water molecules for each other and for the soil particles.

carbonate rock A rock consisting primarily of a carbonate mineral such as calcite or dolomite, the chief minerals in limestone and dolostone, respectively.

cataclastic metamorphism Takes place in an environment where intense pressure due to shearing is common, as in a major fault zone.

cation An ion that has a positive electrical charge. That is, an atom that has lost one or more electrons.

cave A natural open space underground, large enough for a person to enter. Most commonly occur by the dissolution of soluble rocks, generally limestone.

cementation Process by which a binding, or cementing, agent is precipitated in spaces among individual particles of a deposit. Common cementing agents are calcite, quartz, and dolomite.

Cenozoic The current geologic era, which began 66.4 million years ago and continues to the present.

chalk A variety of limestone made up in part of biochemically derived calcite, in form of skeletons or skeletal fragments of microscopic oceanic plants and animals mixed with fine-grained calcite deposits of biochemical or inorganic-chemical origin.

chemical bond The interactions among the electrons of atoms that hold atoms together to form chemical compounds. If electrons cluster primarily around one atom of a pair, the bond is ionic . If they are shared more or less equally, it is covalent . If electrons move freely between atoms over an extended region, the bond is metallic. A weak electrostatic bond due to uneven distribution of electrons around atoms or groups of atoms is a Van der Waals bond.

chemical element A fundamental substance that cannot be further refined or subdivided by chemical means. All atoms of a chemical element have the same number of protons.

chemical sediment Sediment formed by chemical precipitation from water. Example:
halite precipitated as the result of the evaporation of sea water. chemical sedimentary rock A sedimentary rock made up of chemical sediments. Example: rock salt.

chemical weathering see decomposition

chert A cryptocrystalline form of quartz, microscopically granular. Occurs as nodules and as thin, continuous layers. Duller, less waxy luster than chalcedony. Occurs in limestone, dolostone, and mudstones.

clastic Refers to rock or sediments made up primarily of broken fragments of pre-existing rocks or minerals.

clay *1*. The name for a family of finely-crystalline sheet silicate minerals. 2. Fine-grained soil consisting of mineral particles, not necessarily clay minerals, that are less than 0.074 mm in their maximum dimension.

claypan A layer of stiff, compact, relatively impervious clay which is not cemented. compare caliche , fragipan, hardpan.

cleavage 1. of a mineral: The tendency of a mineral to split along planes determined by the crystal structure. 2. of a rock: see slaty cleavage

coal Sedimentary rock composed of combustible matter derived from the partial decomposition of plant material.

coast A narrow strip of land along the margin of the ocean extending inland for a variable distance from low water mark.

column Pillar formed as a stalactite and stalagmite meet.

columnar jointing The type of jointing that breaks rock, typically basalt, into columnar prisms. Usually the joints form a more or less distinct hexagonal pattern.

compaction Reduction of pore space between individual particles as the result of overlying sediments or of tectonic movements

competence The maximum size of particle that a stream can carry. As discharge in a stream increases during a storm event, the competence of a stream increases.

Comprehensive Soil Classification System (CSCS*)* The classification system in most common use by North American soil scientists. Categories are based on the chemical and physical characteristics of a soil. compare USDA Soil Classification System .

compression Squeezing a material from opposite directions.

concordant Lying parallel to, rather than cutting across surrounding strata. (see also diabase, sill)

concretion A compact mass of mineral matter, usually spherical or disk-like in shape and embedded in a host rock of different composition. They form by precipitation of mineral matter about a nucleus such as a leaf, or a piece of shell of bone.

conduction Heat transport by direct transfer of energy from one particle to another, without moving the particle to a new location. compare convection , radiation .

cone of depression A downward distortion or dimple in the water table that forms as a well pumps water faster than it can flow through the aquifer, also: area around a pumping water well where the water table has been artificially lowered.

conglomerate A clastic sedimentary rock composed of lithified beds of rounded gravel mixed with sand or finer grained material.

contact metamorphism Metamorphism genetically related to the intrusion (or extrusion) of magmas and taking place in rocks at or near their contact with a body of igneous rock.

continental crust The part of the crust that directly underlies the continents and continental shelves. Averages about 35 km in thickness, but may be over 70 km thick under largest mountain ranges.

coquina A coarse-grained, porous variety of clastic limestone made up chiefly of shells and shell fragments.

correlation Process of establishing contemporaneity of rocks or events in one area with rocks or events in another area.

creep 1. The very slow, generally continuous downslope movement of soil and debris under the influence of gravity. 2. The movement of sand grains along the land surface.

cross-bedding see inclined bedding .

cross-cutting relationships Geologic discontinuities that suggest relative ages: A geologic feature is younger than the feature it cuts. Thus, a fault cutting across a rock is younger than the rock.

crust The upper part of the lithosphere , divided into oceanic crust and continental crust .

crystal The multi-sided form of a mineral, bounded by planar growth surfaces, that is the outward expression of the ordered arrangement of atoms within it.

crystal settling Gravitational sinking of crystals from the liquid in which they formed, by virtue of their greater density. A type of igneous differentiation.

crystal structure The regular and repeated three-dimensional arrangement of atoms or ions in a crystal.

crystalline 1. Having a crystal structure. 2. When referring to sedimentary rocks, crystalline designates a texture in which mineral crystals have formed in an interlocking pattern. see nonclastic. 3. As a generic term, geologists use the term "crystalline rocks" as a rough synonym for "igneous or metamorphic rocks".

current ripple mark An asymmetric ripple mark formed by wind or water moving generally in one direction. Steep face of ripple faces in direction of current. compare oscillation ripple mark .

Darcy's law A formula describing the flow of water through an aquifer.

debris flow Fast-moving, turbulent mass movement with a high content of both water and rock debris. The more rapid debris flows rival the speed of rock slides.

decomposition (chemical weathering) Weathering processes that are the result of chemical reactions. Example: the transformation of orthoclase (felsdpar) to kaolinite (clay).

deflation A process of erosion in which wind carries off particles of dust and sand.

dehydration Any process by which water bound within a solid material is released. Example: Gypsum ($CaSO_4 \cdot 2H_2O$) becomes anhydrite ($CaSO_4$) by dehydration.

delta An assemblage of sediments accumulated where a stream flows into a body of standing water and its velocity and transporting power are suddenly reduced. . A "delta plain" is the upper surface of a delta.

denudation The sum of the processes that result in the wearing away or the progressive lowering of the Earth's surface by weathering, erosion, mass wasting, and transportation.

depositional environment The nature of the environment in which sediments are laid down. They are immensely varied and may range from the deep ocean to the coral reef and the glacial lake of the high mountains. The nature of the depositional environment may be deduced from the nature of the sediments and rock deposited there.

Diabase An igneous rock with the composition of a basalt. It is generally fine grained (see also aphanitic), dark green to olive green in color. The Haycock, Shelly and other large intrusive rocks seen in the watershed.

dike A tabular igneous intrusion that cuts across the surrounding rock. The Haycock diabase body was probably fed by a dike.

dip The angle that a structural surface such as a bedding plane, joint plane or fault surface makes with the horizontal, measured perpendicular to the strike and in the vertical plane.

dip slip fault A fault on which the movement is parallel to the dip of the fault plane.

directed pressure Pressure applied predominately in one direction, rather than uniformly.

discharge In a stream, the volume of water passing through a channel in a given time. Gnerally measured with respect to a known cross sectional area of the channel. The flow meter at Cooks Creek measures discharge across the channel of the stream.

disconformity An unconformity in which the beds above the unconformity are parallel to the beds below the unconformity.

discordant Cutting across surrounding strata. A dike is generally a discordant body of igneous rock. The Haycock and Shelly diabase bodies in the Cooks Creek Watershed are concordant, or they are parallel with the surrounding strata.

disintegration (mechanical weathering) The processes of weathering by which physical actions such as frost wedging break down a rock into fragments, involving no chemical change.

dissolution A chemical reaction in which a solid material is dispersed as ions in a liquid. Example: Halite ($NaCl$) undergoes dissolution when placed in water. When precipitation enters bedrock it is generally acidic. This acidic infiltrating water can dissolve carbonate rocks such as limestone, dolomite or marble. Limestone is more dissolvable than dolomite.

dissolved load Amount of material water carries in solution.

distributary channels Stream channels that fan out from the upstream point of the delta and carry the sediments that build the delta.

dolostone A carbonate rock made up predominately of the mineral dolomite, CaMg(C03)2, also: *DOLOMITE*: A carbonate sedimentary rock consisting chiefly (more than 50% by weight) of the mineral dolomite.

drag fold A minor fold produced within a weak bed or adjacent to a fault by the movement of surrounding rocks in opposite directions.

drainage basin The area from which a stream and its tributaries receives its water.

drainage divide The line that separates one drainage basin from another. Generally, the drainage divide is taken at the highest topographic point of a stream as one walks upstream. At the headwaters of a stream network, the highest points comprise the divide.

drainageway A general term for a course of channel which water moves in draining an area.

dripstone Calcium carbonate deposited from solution as water enters a cave through the zone of aeration. Forms stalactites, stalagmites and other cave deposits.

earthflow A form of slow, but perceptible, mass movement, with high content of water and rock debris. Lateral boundaries are well-defined and the terminus is lobed. With increasing moisture content grades into a mudflow.

Effectiveness: Effectiveness assesses the capability of a wetland to perform a function due to its physical, chemical and biological attributes. Effectiveness does not estimate the magnitude at which a function is performed, only the probability that a wetland will perform the function.

Emergent: Erect, rooted herbaceous plants (ie bulrushes).

eon The primary division of geologic time which are, from oldest to youngest, the Hadean, Archean, Proterozoic, and Phanerozoic eons.

epicenter The point on the Earth's surface that is directly above the focus of an earthquake.

epoch A division of geologic time next shorter than a period. Example: the Pleistocene epoch is in the Quaternary period.

era A division of geologic time next smaller than the eon and larger than a period. Example: The Paleozoic era is in the Phanerozoic eon and includes, among others, the Devonian period.

erosion: The movement of weathered material downslope under the influence of gravity. Water acts as a catalyst and as a lubricant. Some common types of erosion includes landslides, rockfalls, creep, etc. Erosion takes weathered material and puts it in a river so it can be transported to the beach or other depositional area.

eutrophication The process of aging of lakes by the addition of nutrients.

evaporite A mineral or rock deposited directly from a solution (commonly seawater) during evaporation. For example, gypsum and halite are evaporite minerals.

exfoliation The process by which concentric scales, plates, or shells of rock are stripped or spall from the bare surface of a large rock mass.

extrusive Pertaining to igneous rocks or features formed from lava released on the Earth's surface.

facies see metamorphic facies , sedimentary facies

fall When applied to mass movement of material refers to free fall of material moving without contact with the surface.

fault The surface of rock rupture along which there has been differential movement of the rock on either side; also A crack or fracture in the earth's surface in which there has been movement of one or both sides relative to the other. Movement along the fault can cause earthquakes or, in the process of mountain-building, can release underlying magma and permit it to rise to the surface as a volcanic eruption.

fault gouge Soft, uncemented, pulverized clay-like material found along some faults.

ferromagnesian Containing iron and magnesium, applied to the mafic minerals. Example: olivine.

field capacity see specific retention.

flash flood A flood that rises and falls very rapidly.

flashy stream A stream with a high, short flood peak and short lag time.

flint A variety of chert , often black because of included organic matter.

flood Peak flow in a stream that tops the banks of a stream channel.

flood recurrence interval The number of years of record plus 1 divided by the rank of each maximum annual flood.

floodplain Area bordering a stream over which water spreads when the stream tops its channel banks.

flow When applied to mass movement, refers to a chaotic movement of material in continuous contact with the ground surface, commonly involving a moderate to high amount of water.

flowstone General term for deposits formed by dripping and flowing water on walls and floors of caves.

focus The point within the Earth which is the center of an earthquake, at which strain energy is first released and converted to elastic wave energy.

foliation A planar structure that develops in metamorphic rocks as a result of directed pressure
.

fold and thrust mountains Mountains, characterized by extensive folding and thrust faulting, that form at convergent plate boundaries on continents.

foot wall block The body of rock that lies below an inclined fault plane. compare hanging wall block

formation water The water, held in pore volume in sedimentary rocks, that has persisted with little change in composition since it was buried with the sediment.

fossil Evidence in rock of the presence of past life, such as a dinosaur bone, an ancient clam shell, or the footprint of a long-extinct animal.

frost wedging A type of disintegration in which jointed rock is forced apart by the expansion of water as it freezes in fractures.

Functions: The physical, chemical and biological processes or attributes of a wetland without regard to their importance to society.

Inlet: The point at which surface water enters the AA via a channel.

gabbro A coarse-grained igneous rock, chemically equivalent to a basalt .

geode Roughly spherical, hollow or partially hollow accumulation of mineral matter. A few centimeters to nearly 0.5 m in diameter. Outer layer of chalcedony lined with crystals that project toward the hollow center. Crystals, often perfectly formed, usually quartz although calcite and dolomite and - more rarely other minerals. Most commonly occur in limestone, and less often in shale.

geologic column The arrangement of rock units in the proper chronological order from youngest to oldest.

geologic time scale The chronological sequence of units of Earth time.

geology The science that deals with the study of the planet Earth--the materials of which it is made, the processes that act to change these materials from one form to another, and the history recorded by these materials; the forces acting to deform the outer layers of the Earth and create ocean basins and continents; the processes that modify the Earth's surface; the application of geologic knowledge to the search for useful materials and the understanding of the relationship of geologic processes to people.

glass An inorganic solid in which there is no crystalline structure .

glassy A texture of extrusive igneous rocks that develops as the result of rapid cooling, so that crystallization is inhibited.

global warming The prediction that climate will warm as a result of the addition to the atmosphere of humanly produced greenhouse gases.

gneiss A coarse, foliated metamorphic rock in which bands of granular minerals (commonly quartz and feldspars) alternate with bands of flaky or elongate minerals (e.g., micas, pyroxenes). Generally less than 50% of the minerals are aligned in a parallel orientation.

gneissosity The style of foliation typical of gneiss.

gouge see fault gouge

graben see rift

graded bedding Type of bedding sedimentary deposits in which individual beds become finer from bottom to top.

gradient Slope of a stream bed or hillside. The vertical distance of descent over horizontal distance of slope.

granite Light colored, coarse grained, intrusive igneous rock characterized by the minerals orthoclase and quartz with lesser amounts of plagioclase feldspar and iron-magnesium minerals. Underlies large sections of the continents.

gravitational moisture Water in the zone of aeration that is moving down toward the zone of saturation.

graywacke (lithic sandstone) A variety of sandstone characterized by angular-shaped grains of quartz and feldspar, and small fragments of dark rock all set in a matrix of finer particles.

greenhouse gases Gases (primarily water and carbon dioxide, but also a variety of sulfur and nitrogen compounds and gaseous hydrocarbons) that trap the Sun's heat in the atmosphere.

greenstone An altered or metamorphosed mafic igneous rock that owes its dark color to the presence of chlorite, epidote, or amphiboles.

ground water table see water table .

ground water Water beneath the Earth's surface.

hanging wall block The body of rock that lies above an inclined fault plane. compare foot wall block

hardness Resistance of a mineral to scratching, determined on a comparative basis by the Mohs scale .

hardpan A general term for a relatively hard layer of soil at or just below the ground surface, cemented by silica, iron oxide, calcium carbonate, or organic matter. compare caliche , claypan, fragipan.

head (hydraulic head) The level to which ground water in the zone of saturation will rise.

heat flow The amount of thermal energy leaving the Earth per cm2/sec.

heave In mass movement the upward motion of material by expansion as, for example, the heaving caused by freezing water.

hiatus A gap or interruption in the continuity of the geologic record either because the record was never formed or because it was destroyed by erosion. It represents the time interval spanned by an unconformity .

humus The generally dark, more or less stable part of the organic matter in a soil, so well decomposed that the original sources cannot be identified.

hydraulic conductivity Measure of permeability in Earth materials, also: a coefficient of proportionality describing the rate at which water can move through a permeable medium.

hydraulic gradient The slope of the water table. Measured by the difference in elevation between two points on the slope of the water table and the distance of flow between them.

hydraulic head see head.

Hydric soil: Soil that is wet long enough to periodically produce anaerobic conditions, thereby influencing the growth of plants.

hydrograph Graph of variation of stream flow over time.

hydrologic system (or hydrologic cycle) The pattern of water circulation from the ocean to the atmosphere to the land and back to the ocean, also Hydrologic cycle: The transfer of water between numerous temporary storage reservoirs. These include the ocean, rivers and streams, glacial ice, groundwater etc.

hydrolysis A decomposition reaction involving water, in which hydrogen ions (H+) or hydroxyl ions (OH-) replace other ions. The result is a new residual mineral. Example: the addition of water to orthoclase produces kaolinite and releases K+ and silica into solution.

Hydroperiod: A term used to indicate the seasonal occurrence of flooding and/or saturated soil conditions.

Hydrophyte, hydrophytic: Any plant growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content.

igneous rock A rock that has crystallized from a molten state.

inclined bedding (cross-bedding) Bedding laid down at an angle to the horizontal, as in many sand dunes.

inclined fold A fold whose axial plane is inclined from the vertical, but in which the steeper of the two limbs is not overturned. compare overturned fold.

infiltration movement of fluids from surface, through the unsaturated zone (or vadose zone) into an aquifer.

intensity A measure of the size of an earthquake in terms of the damage it causes.

intrusive Pertaining to igneous rocks or features formed by the emplacement of magma in pre-existing rock.

ion An atom that has an electrical charge, by virtue of having gained or lost electrons. see cation, anion

ionic radius The effective distance from the center of an ion to the edge of its electron cloud.

ironpan A hardpan in which iron oxides are the primary cementing agents.

isoclinal fold A fold in which the limbs are parallel.

joint A surface of fracture in a rock, without displacement parallel to the fracture.

Jurisdictional Wetland: Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.

karst A landscape that develops from the action of ground water in areas of easily soluble rocks. Characterized by caves, underground drainage and sinkholes.

laccolith A concordant igneous intrusion with a flat floor and a convex upper surface, usually less than 8 km across and from a few meters to a few hundred meters thick at its thickest point.

lacustrine *deposit* Clastic sediment and chemical precipitates deposited in lakes.

lakebed The flat to gently undulating ground underlain or composed of fine-grained sediment deposited in a former lake.

landform Any physical, recognizable form or feature on the earth's surface,having a characteristic shape and range in composition, and produced by natural causes.

lag time The delay in the response of stream flow between precipitation and flood peak.

laminar flow Fluid flow in which flow lines are distinct, and parallel and do not mix. compare turbulent flow .

lateral continuity The extent of a rock unit over a considerable but definite area.

lava Molten rock that flows at the Earth's surface.

levees Banks of sand and silt along stream bank built by deposition in small increments during successive floods.

limb The portions of a fold that are away from the hinge; the "sides" of the fold.

limestone A sedimentary rock composed mostly of the mineral calcite, $CaCO_3$ or: A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of calcite.

lithic sandstone see graywacke.

lithification The process by which an unconsolidated deposit of sediments is converted in to solid rock. Compaction, cementation and recrystallization are involved.

load of a stream, the amount that it carries at any one time.

mafic Referring to a generally dark-colored igneous rock with significant amounts of one or more ferromagnesian minerals, or to a magma with significant amounts of iron and magnesium.

magma Molten rock, containing dissolved gases and suspended solid particles. At the Earth's surface, magma is known as lava .

mantle That portion of the Earth below the crust and reaching to about 2,780 km, where a transition zone of about 100 km thickness separates it from the core.

marble A metamorphic rock composed largely of calcite. The metamorphic equivalent of limestone.

mass movement The downslope movement of material under the influence of gravity.

maze cave Caves in which passageways have interconnecting loops that form a maze-like pattern.

meander A sharp bend, loop or turn in a stream's course. When abandoned, called a meander scar or an oxbow .

Mesozoic An era of time during the Phanerozoic eon lasting from 245 million years ago to 66.4 million ago.

metamorphic facies A set of metamorphic mineral assemblages, repeatedly associated in space and time, such that there is a constant and therefore predictable relationship between mineral composition and chemical composition. That relationship is a consequence of conditions of temperature and pressure under which the assemblages are stable.

metamorphic rock A rock changed from its original form and/or composition by heat, pressure, or chemically active fluids, or some combination of them, also: From the Greek "meta" (change) and "morph" (form). Commonly occurs to rocks which are subjected to increased heat and/or pressure. Also applies to the conversion of snow into glacial ice. Mineral: A naturally occurring, inorganic, crystalline solid with a definite internal structure and chemical composition.

metamorphic zone A mappable region in which rocks have been metamorphosed to the same degree, as evidenced by the similarity of mineral assemblages in them.

metamorphism The processes of recrystallization, textural and mineralogical change that take place in the solid state under conditions beyond those normally encountered during diagenesis.

Modified Mercalli Scale A commonly used scale of earthquake intensity.

Mohs scale The ten-point scale of mineral hardness , keyed arbitrarily to the minerals talc, gypsum, calcite, fluorite, apatite, orthoclase, quartz, topaz, corundum, and diamond.

mud cracks Cracks, generally polygonal, caused by the shrinking of a deposit of clay or silt under surface conditions.

mudflow Form of mass movement similar to a debris flow but containing less rock material.

mudstone A fine-grained detrital sedimentary rock made up of clay- and silt-sized particles.

mylonite A chert-like rock without cleavage but with a banded or streaky structure produced by extreme shearing of rocks that have been pulverized and rolled during intense dynamic metamorphism.

nappe A sheet of rock that has moved over a large horizontal distance by thrust faulting, recumbent folding, or both, so that it lies on rocks of markedly different age or lithologic character.

neck cutoff Occurs as a river cuts through the narrow neck of a meander. Sometimes called simply a "cutoff."

nonclastic A term applied to sedimentary rocks that are not composed of fragments of pre-existing rocks or minerals. The term "crystalline" is more commonly used.

nonconformity An unconformity that separates profoundly different rock types, such as sedimentary rocks from metamorphic rocks.

normal fault A dip-slip fault on which the hanging wall block is offset downward relative to the foot wall block . compare reverse fault .

open pit mining Surficial mining, in which the valuable rock is exposed by removal of overlying rock or soil.

ore The naturally occurring material from which a mineral or minerals of economic value can be extracted at a profit.

ore deposit A continuous well-defined mass of material of sufficient ore content to make extraction economically feasible. compare mineral deposit .

original horizontality Refers to the condition of beds or strata as being horizontal or nearly horizontal when first formed.

orogen Linear to arcuate in plan, intensely deformed crustal belt associated with mountain building. compare craton .

orogeny The process of mountain building.

oscillation ripple mark A symmetric ripple mark formed by waves, which move water back and forth. compare current ripple mark .

outer core The outermost part of the core. It is liquid, about 1,700 km thick, and separated from the inner, solid core by a transition zone about 565 km thick.

overbank deposits Sediments deposited from flood water on the flood plain.

overturned fold An inclined fold in which one limb has been tilted beyond the vertical, so that the stratigraphic sequence within it is reversed. compare inclined fold.

oxbow An abandoned meander .

oxbow lake A lake in an abandoned meander.

oxidation The decomposition process by which iron or other metallic elements in a rock combine with oxygen to form residual oxide minerals.

Paleozoic An era of geologic time lasting from 570 to 245 million years ago.

Permeability the amount of hydraulic conductivity resulting from pore space alone.

phreatic zone the saturated zone or water table.

phaneritic A textural term meaning "coarse-grained" that applies to igneous rocks.

Palustrine Wetland: All non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses and all tidal wetlands that occur in areas with a salinity below 0.5%.

Phanerozoic the most recent eon of geologic time beginning 570 million years ago and ontinuing to the present.

phenocryst Any relatively large, conspicuous crystal in a porphyritic igneous rock.

phyllite A metamorphosed mudstone with a silky sheen, more coarse-grained than a slate and less coarse-grained than a schist.

plunging fold A fold in which the axis is inclined at an angle from the horizontal.

pluton An igneous intrusion.

point bar Accumulations of sand and gravel deposited in slack water on inside of a winding or meandering river.

porosity The percentage of material occupied by pore space.

porphyritic A texture of an igneous rock in which large crystals (phenocrysts) are set in a matrix of relatively finer-grained crystals or of glass.

potentiometric surface The level to which water will rise in an artesian system when its confining aquitard is pierced.

pothole A hole or basin cut into bedrock of a stream by the abrasive action of pebbles and sand swirled by turbulent stream flow.

Precambrian An informal term to include all geologic time from the beginning of the Earth to the beginning of the Cambrian period 570 million years ago.

precession of the equinox The wobble of the Earth as it spins changes the direction in which its axis of rotation points. One wobble takes about 23,000 years.

pressure melting The phenomenon causing increased melting of ice by increase of pressure.

Proterozoic The geologic eon lying between the Archean and Phanerozoic eons, beginning about 2.5 billion years ago and ending about 0.57 billion years ago.

quarrying 1**.** The process by which building stone, usually in blocks or sheets, is extracted from the Earth.. 2. Similar to plucking of rock by glacial ice movement over it.

quartz arenite A sandstone in which the sand grains are predominantly quartz.

quartzite A metamorphic rock consisting largely of interlocking quartz grains; the metamorphic equivalent of a sandstone or chert

recumbent fold A fold in which the axial plane is horizontal.

regional metamorphism Metamorphism affecting an extensive region, associated with orogeny
.
regolith A layer of unconsolidated fragmental rock material.

relative time Dating of rocks and geologic events by their positions in chronological order without reference to number of years before the present.

residual (resistant) mineral A mineral that persists in soil after weathering, either because it was resistant to weathering or because it was formed during the weathering process.

residual soil (also saprolite) A soil presumed to have developed in place as the product of decomposition and disintegration of bedrock .

resources The reserves of a valuable mineral commodity plus all other mineral deposits that may eventually become available, even those that are presumed to exist but have not yet been discovered and those that are not economically or technologically exploitable at the moment. The total mineral endowment ultimately available for extraction.

reverse fault A dip-slip fault on which the hanging wall block is offset upward relative to the foot wall block . compare normal fault .

Richter scale A commonly used measure of earthquake magnitude , based on a logarithmic scale. Each integral step on the scale represents a tenfold increase in the extent of ground shaking, as recorded on a seismograph.

rift (graben) A valley caused by extension of the Earth's crust. Its floor forms as a portion of the crust moves downward along normal faults .

rock An aggregate of one or more minerals in varying proportions.

rock cycle The concept of a sequence of events involving the formation, alteration, destruction and reformation of rocks as a result of geologic processes and which is recurrent, returning to a starting point. It represents a closed system. compare rock system.

rockslide (rock avalanche) A slide involving a downward and usually sudden movement of newly detached segments of bedrock sliding or slipping over an inclined surface of weakness such as a bedding plane, fault plane, or joint surface.

rock system The concept of a sequence of events involving the formation, alteration, destruction and reformation of rocks as a result of geologic processes. Unlike the rock cycle it is an open system and does not return to a starting point. compare rock cycle

rockfall The sudden fall of one or more large pieces of a rock from a cliff.

roundness The degree to which a sedimentary particle's corners and edges are rounded.

runoff The precipitation that runs directly off the surface to stream or body of standing water.

saltation A process of sediment transport in which a particle jumps from one point to another.

sand dune An accumulation of wind driven sand into a distinctive shape.

sandstone A clastic sedimentary rock in which the particles are dominantly of sand size, from 0.062 mm to 2 mm in diameter.

sandstorm A blanket of wind-driven sand with an upper surface about a meter above ground level.

sanitary land fill An artificial hill formed by the refuse of present-day civilization.

schist A strongly foliated, coarsely crystalline metamorphic rock, produced during regional metamorphism, that can readily be split into slabs or flakes because more than 50% of its mineral grains are parallel to each other.

schistosity The foliation in a schist, due largely to the parallel orientation of micas.

Scrub-shrub: The wetland class dominated by woody vegetation less than 6 meters high.

sedimentary facies An accumulation of deposits that exhibits specific characteristics and grades laterally into other sedimentary accumulations that were formed at the same time but exhibit different characteristics.

sedimentary rock Rock formed from the accumulation of sediment, which may consist of fragments and mineral grains of varying sizes from pre-existing rocks, remains or products of animals and plants, the products of chemical action, or mixtures of these.

seismology The study of earthquakes, and of the structure of the Earth by both natural and artificially generated seismic waves.

Service area: The service area is a well-defined point to which a wetland service is delivered (e.g., downstream developed area, dredged channel, water supply reservoir, etc.)

shale A mudstone that splits or fractures readily.

silica Silicon dioxide (SiO2) as a pure crystalline substance makes up quartz and related forms such as flint and chalcedony . More generally, silica is the basic chemical constituent common to all silicate minerals and magmas. silica tetrahedron The basic structural unit of which all silicates are composed, consisting of a silicon atom surrounded symmetrically by four oxygen atoms. The structure, therefore, has the form of a tetrahedron with an oxygen atom at each corner.

sill A tabular igneous intrusion that parallels the planar structure of the surrounding rock. The Haycock diabase and Shelly diabase bodies are sills, in that they occupies zones parallel with the surrounding strata.

sinkhole (or doline) Depression in ground surface caused by collapse into a cave below.

sinking stream A stream that empties into the underground into a cave, usually through a sinkhole.

slate A compact, fine-grained metamorphic rock that has slaty cleavage.

slaty cleavage A style of foliation common in metamorphosed mudstones, characterized by nearly flat, sheet-like planes of breakage, similar in appearance to a deck of playing cards. compare cleavage

slump Downward and outward rotational movement of Earth materials traveling as a unit or series of units.

Social Significance: A nonstatistical measure of the importance society (locally or nationally) may attach to a wetland due to the official recognition of its natural features, economic value attributable to the wetland, strategic location of the wetland, or other factors.

soil All unconsolidated materials above bedrock. Natural earthy materials on the Earth's surface, in places modified or even made by human activity, containing living matter, and supporting or capable of supporting plants out of doors.

soil horizon A layer of soil that is distinguishable from adjacent layers by characteristic physical properties such as texture, structure, or color, or by chemical composition.

soil moisture Ground water in the zone of aeration

soil structure The combination of soil particles into aggregates or clusters which are separated from adjacent aggregates by surfaces of weakness.

soil texture The physical nature of the soil, according to its relative proportions of sand, clay, and silt.

sorting The range of particle sizes in a sedimentary deposit. A deposit with a narrow range of particle sizes is termed "well-sorted."

specific gravity The ratio of the density of a material to the density of water.

specific retention (field capacity) The amount of capillary water retained in a soil after the drainage of gravitational moisture.

spoil Overburden or non-ore removed in mining or quarrying.

spring Occurs at the intersection of the water table with the ground surface.

stalactite An icicle-shaped accumulation of dripstone hanging from cave roof.

stalagmite A post of dripstone growing up from a cave floor.

storm surge A ridge of high water associated with a hurricane and which floods over the shore .

strain Change in the shape or volume of a body as a result of stress.

strain rate The rate at which a body changes shape or volume as a result of stress.

strain seismograph A seismograph that is designed to detect deformation of the *stratification* The accumulation of material in layers or beds.

stratigraphy The succession and age relation of layered rocks., also: stratigraphy (stra-tig'-ra-phy) Stratigraphy is the science of rock strata. It is concerned with all characters and attributes of rocks as strata; and their interpretation in terms of mode of origin and geologic history. All classes of rocks, consolidated or unconsolidated, fall within the general scope of stratigraphy. Synonym: stratigraphic geology.

stream terrace A relatively flat surface along a valley, with a steep bank separating it either from the floodplain, or from a lower terrace.

strike The compass direction of the intersection between a structural surface (e.g., a bedding plane or a fault surface) and the horizontal.

strip mining Open pit mining, typically for coal.

superposition A statement of relative age in layered rocks: In a series of sedimentary rocks that has not been overturned, the topmost layer is always the youngest and the bottommost layer is always the oldest.

tailings Washed or milled ore that is too poor to be further treated.

talus A slope built up by the accumulation of rock waste at the foot of a cliff or ridge.

trap *1.* Any barrier to the upward migration of petroleum, allowing it to accumulate. 2. Any dark colored extrusive igneous rock. A reference to the tendency of basalt and similar rocks to form columnar joints.

travertine *(*tufa) Variety of limestone which forms stalactites and stalagmites and other deposits in limestone caves (dripstone) and the mouths of hot and cold calcareous springs.

turbidite Sedimentary deposit settled out of turbid water carrying particles of widely varying grade size. Characteristically displays graded bedding.

turbulent flow Fluid flow in which the flow lines are confused and mixed. Fluid moves in eddies and swirls. compare laminar flow.

unconformity A buried erosion surface separating two rock masses.

uniformitarianism The principle that applies to geology our assumption that the laws of nature are constant As originally used it meant that the processes operating to change the Earth in the present also operated in the past and at the same rate and intensity and produced changes similar to those we see today. The meaning has evolved and today the principle of uniformitarianism
acknowledges that past processes, even if the same as today, may have operated at different rates and with different intensities than those of the present. The term "actualism" is sometimes used to designate this later meaning.

unloading The release of confining pressure associated with the removal of overlying material. May result in expansion of rock, accompanied by the development of joints or sheeting .

USDA Soil Classification System A classification of soils on the basis of the processes and conditions by which they form. compare Comprehensive Soil Classification System.

Values: Wetland processes or attributes that are valuable or beneficial to society.

vesicle A cavity in a lava, formed by the entrapment of a gas bubble during solidification of the lava.

vesicular A textural term applied to an igneous rock containing abundant vesicles, formed by the expansion of gases initially dissolved in the lava.

viscosity The internal resistance to flow in a liquid.

water gap A gap in a ridge or mountain through which a stream flows.

water table The surface between the zone of saturation and the zone of aeration.

weathering The process by which Earth materials change when exposed to conditions at or near the Earth's surface and different from the ones under which they formed. compare decomposition versus disintegration .

well An artificial intersection of the surface and the water table., or A hole dug into the ground in the attempt to intersect water or other subsurface fluids.

Wetland hydrology: The sum total of wetness characteristics in areas that are inundated or have saturated soils for a sufficient duration to support hydrophytic vegetation.

zone of aeration Zone immediately below the ground surface within which pore spaces are partially filled with water and partially filled with air.

zone of leaching The upper horizons in a soil, through which gravitational moisture travels, removing soluble decomposition products.

zone of saturation The zone below the zone of aeration in which all pore spaces are filled with water.

COOKS CREEK WETLANDS MANAGEMENT PLAN

This document expands on the findings and recommendations from the Cooks Creek Management Plan that was prepared for the Durham Township Environmental Advisory Committee. That study identified a number of important conditions or characteristics of the Cooks Creek watershed, which are summarized below:

- **Wetlands Mapping -** The existing National Wetland Inventory maps (NWI) maps did not accurately identify the full extent of wetlands, especially in the headwaters or upper reaches of streams. The NWI maps provide a reasonably good picture of the extent and type of wetlands in the lower portions of Cooks Creek. In general, the wetlands shown on the NWI maps do exist and are classified properly. However, many additional wetlands (non-NWI mapped) and waters of the US were found during the field reconnaissance.

- **Springs and Seeps -** Numerous springs or seeps from the base of slopes were found in the watershed, especially in the headwaters of the tributaries to Cooks Creek. Some of the springs and seeps are located in wetlands although others are outside of jurisdictional wetlands. These springs and seeps are probably critical to the continued existence of nearby wetlands and special status species and the trout population because the discharges provide year-round base flow to the stream/wetlands and contribute cool, high quality water that is vital to the survival of the populations.

- **Wetland Threats -** The wetlands in the watershed do not appear to be significantly stressed due to hydrological modification, development, or human activities. However, many of the wetlands appear to be vulnerable to hydrological modification because groundwater discharge and stream flows provide the crucial water source. In addition, increased development or intense development could affect these wetlands if it is proximal to them.

- **Wetland Functions and Values -** According to the WET II analysis, wetlands in the Cooks Creek are highly effective in providing groundwater recharge, groundwater discharge, flood-flow alteration, wildlife migration and wintering, aquatic diversity and show high social significance for groundwater recharge, groundwater discharge, flood-flow alteration, nutrient removal, wildlife diversity/abundance, aquatic diversity/abundance, uniqueness/heritage and recreation.

Recommendations

The DTEAC and Durham and Springfield Townships should consider a number of possible actions for the maintenance and preservation of the wetlands and the unique natural resources within the Cooks Creek watershed. EEE recommends consideration of the following actions:

- **Watershed Management-** Because of the unique and sensitive nature of the Cooks Creek system, it will be important to manage and protect the creek, aquifer, springs, and wetlands as a system. For example, management of the wetlands alone will not necessarily preserve the springs and seeps, which are critical to the special status species that live in the watershed. In addition, management of the wetlands alone will not necessarily help to protect the shallow aquifer, especially within the karst-prone areas of the watershed. Therefore, we recommend a holistic or watershed-based management approach that recognizes the connections between the different elements and uses a number of different approaches. Some of the tools that could be considered are summarized below:

- **Comprehensive Plan –Environmental Element-** One important step is to develop an element of the Comprehensive Plan that discusses the valuable social and environmental benefits of the Cooks Creek watershed. This is important because the Comprehensive Plan serves as the "Blueprint" for County decisions on land use and development; therefore, a thorough discussion should be included in the Comprehensive Plan from which to incorporate environmental considerations into the planning process. The Environmental Element should include a discussion on the natural resources inventory as well as goals, objectives, and strategies for protecting valuable environmental resources.

- **Cooks Creek Overlay District or Environmental Ordinance –** One option to consider is an "overlay" ordinance for Cooks Creek that would require new development projects and redevelopment to identify sensitive resources and use best management practices to protect these resources. An overlay district is a special designation within the Zoning Ordinance that typically covers the watershed or a specified distance from the edge of the stream and establishes certain performance standards for development and subdivisions within the district. An overlay district is simply an "overlay" to existing zoning, which has additional requirements beyond that required by the base zoning. Overlays are typically used for valuable river systems, public water supply reservoirs, historic areas etc. As an alternative, a Township-wide environmental ordinance could be developed that has similar requirements to the overlay district. If an environmental ordinance or overlay district is implemented, it must be consistent with Section 603 of the Pennsylvania Municipal Planning Code, which authorizes local governments to regulate, prohibit, restrict and determine land use, including wetlands and riparian zones. Some of the basic features that should be considered for inclusion in an overlay ordinance are described below:

  - The recommended overlay district is the entire watershed of Cooks Creek because land use activities within the entire watershed can have a significant impact on water quality. This watershed type approach offers the most protective strategy. A map depicting the recommended overlay district is attached to this document. An alternative approach would be an overlay district that extends 1000 feet landward of the creek channel, including the tributaries. This approach would be slightly less protective, but should still provide sufficient area within the watershed to protect the most important components of Cooks Creek. In order to be most effective, the Overlay District should be adopted by all jurisdictions within the watershed.
  - New development and redevelopment projects should be required to conduct an inventory of sensitive resources on the portion of the subject property that is included in the overlay district. The inventory focuses on physical features that are important to the preservation of surface water and groundwater quality as well as special status species. We recommend consideration of the following features for the inventory:
    - karst or aquifer recharge areas
    - jurisdictional wetlands as defined by the Corps of Engineers Wetland Delineation Manual
    - perennial springs and seeps
    - perennial and intermittent streams
    - steep slopes (typically greater than 15 percent)

- highly erodible soils (typically defined as soils with an erodibility index (EI) equal to or greater than 8 as calculated from the EI equation defined in the Food Security Act Manual of 1988.
- highly permeable soils (soils with a permeability index equal to or greater than 6 inches per hour as defined in the National Soils Handbook of 1983)
- 100-year floodplains as defined by the Federal Emergency Management Act Flood Insurance Rate Maps)
- threatened and endangered species and their critical habitat (as identified by consultation with the US Fish and Wildlife Service and the Pennsylvania Department of Conservation and Natural Resources

- The overlay district could include a requirement for evaluation of the impacts to sensitive resources and water quality (i.e. wetlands, threatened and endangered species, surface water and ground water) from proposed development. This approach can be broadened to require an analysis of the natural, physical and socio-economic environment for new development projects anywhere in the jurisdiction. For example, Tinicum Township has an ordinance that requires an Environmental Impact Assessment Report with similar broad ranging requirements for new development.
- The overlay district should require development and re-development projects to satisfy several performance to protect water quality and living resources, such as the following:
  - Establishment or preservation of a riparian buffer (i.e.100 feet) that extends landward of the stream and associated wetlands. This vegetated buffer is important to the protection of water quality because it traps some of the pollutants that would otherwise be transported into the stream with stormwater
  - Minimization of land disturbance and preservation of existing vegetation to the maximum extent possible consistent with the use and development allowed
  - Minimization of impervious cover consistent with the use or development allowed
  - An approved erosion and sediment control plan
  - A stormwater management plan that is consistent with the Pennsylvania Stormwater Management Act and the plan being considered by Bucks County.
  - Inclusion of the wetlands, springs/seeps, riparian buffers, floodplains, aquifer recharge areas, habitat for threatened and endangered species within open space in the development plan
  - Submission of all relevant permits from the state and federal agencies for impacts to wetlands, floodplains, streams, threatened and endangered species
  - Submission and approval of a plan of review or site plan for all development and redevelopment projects
  - A description of mitigation steps to avoid, minimizes, or mitigate for the impacts to sensitive resources described above.

- **Growth Management-** other planning tools that could be considered include growth management ordinances that promote cluster development, preservation of open space and riparian corridors, protection of water supplies, and transfer of development rights to protect rural areas.

- **Education -** Continue to expand public outreach efforts that emphasize the public benefits of environmental stewardship and watershed management. This approach could involve seminars or newsletters for residents, industries, and farmers on the importance of protecting the watershed and how they can help.

- **Water Monitoring Program -** Consider developing a water quality-monitoring program of the stream and the primary water supply aquifer. Several stream monitoring programs have been implemented elsewhere including one developed by the PADEP and a nationwide program by the Isaac Walton League, which relies on citizen efforts. Information on the basics of this program is included in Appendix C. A similar program has been developed by the Alliance for the Chesapeake Bay, within the Chesapeake Bay Watershed. One option is to consider a program that uses remote sensing to track the health, type, and extent of wetlands in the watershed and water quality. Such programs have been implemented in other important watersheds such as the Everglades and Chesapeake Bay. Remote sensing has the ability to cost-effectively identify many water quality problems, drought stress in vegetation, and plant community changes. This effort would require a source of funding or a collaborative effort with a research institution or consultant with the capability to perform such analysis.

- **Funding -** Consider seeking additional funds to develop a watershed approach for management and preservation of the Cooks Creek natural resources, water quality, and groundwater resources.

- **Protection of Sensitive Areas and Vulnerable Wetlands -** Promote the protection of sensitive segments of the watershed (i.e. riparian zones) and wetlands through fee simple acquisition, use of conservation easements, and re-establishment of vegetated buffers. The focus of this effort should be wetland areas that are important to aquifer recharge, wetlands that are disturbed or impacted, springs and seeps that contribute base flow to the stream and wetlands, and habitats that support rare species and headwaters segments of the Cooks Creek tributaries. The following wetland areas such be targets of this effort:
  - Wetlands within karst prone geologic formations
  - Wetlands with potentially suitable habitat for endangered and threatened species such as Area D, Area P, Area X, Area Y, Area AA, Area AC, Area AD,
  - Disturbed wetlands included in Area J, Area M, Area T, Area W, Area X

Prior to developing the ordinance or overlay district, the following actions should be considered:

- Hold workshop sessions with local government officials from the different jurisdictions, stakeholders (potentially affected parties such as landowners, conservation groups, sport fishery groups, businesses, and farmers) to describe the process and the need for the project, and solicit ideas about the program. This approach is often critical to developing the public support for such ordinances.
- Identify the “other” (non-wetland) environmental components that should be included in the overlay besides wetlands, such as aquifer recharge areas, threatened and endangered species, floodplains, water supply, steep slopes, highly erodible soils, and highly permeable soils.

- Consider notification of intent to develop an environmental ordinance. The jurisdictions could request that development plans submitted prior to adoption of the ordinance attempt to complete the environmental inventory and implement the listed performance criteria.

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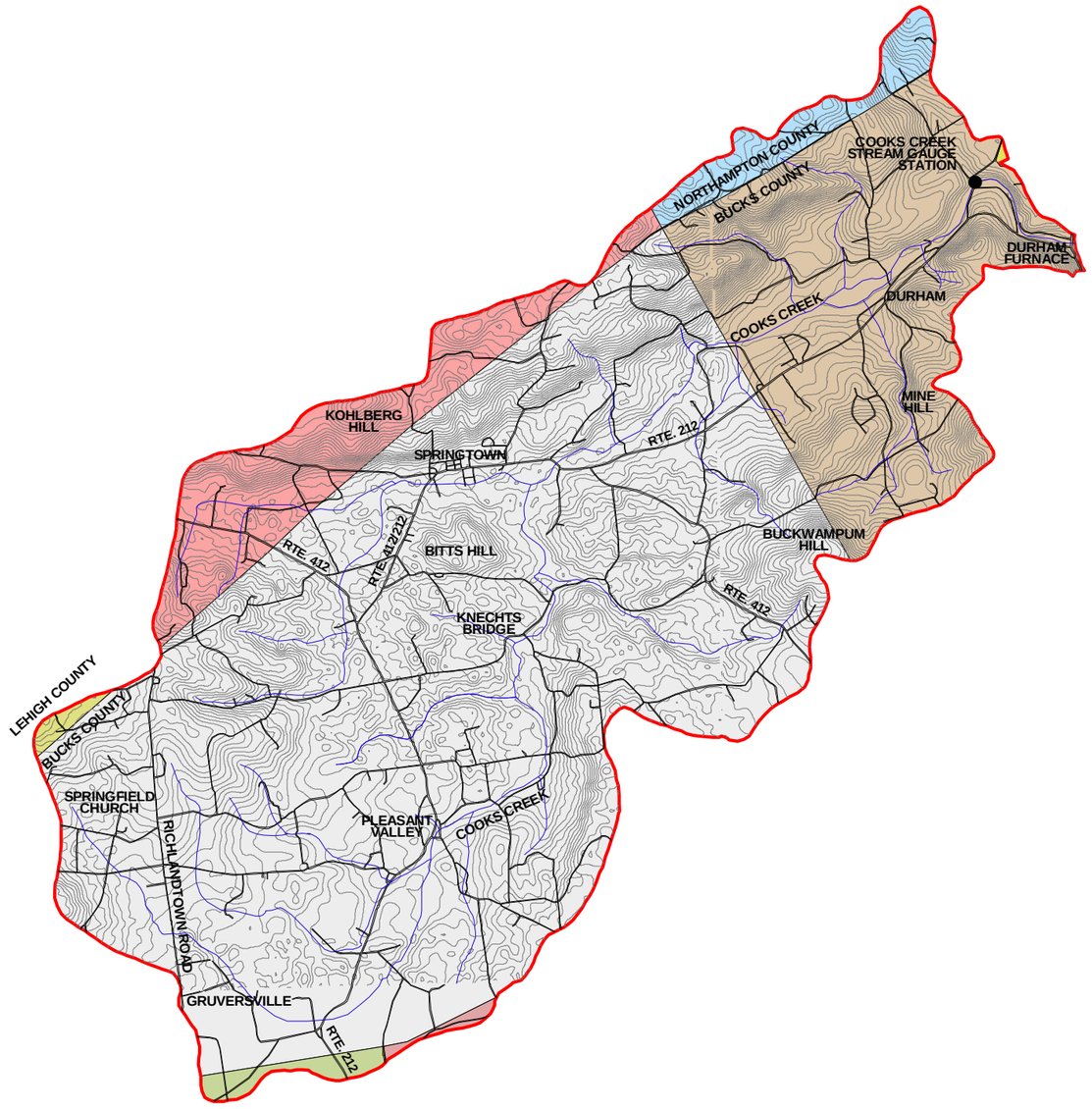
BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis



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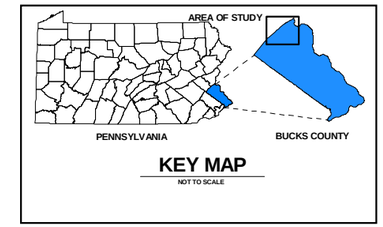

- Figure 1.1 -
Study Area

LEGEND

- Streams
- Watershed
- Major Roads
- Minor Roads
- Ground Surface Elevation Contour

Municipalities:

- DURHAM
- HAYCOCK
- LOWER SAUCON
- RICHLAND
- RIEGELSVILLE
- SPRINGFIELD
- UPPER SAUCON
- WILLIAMS

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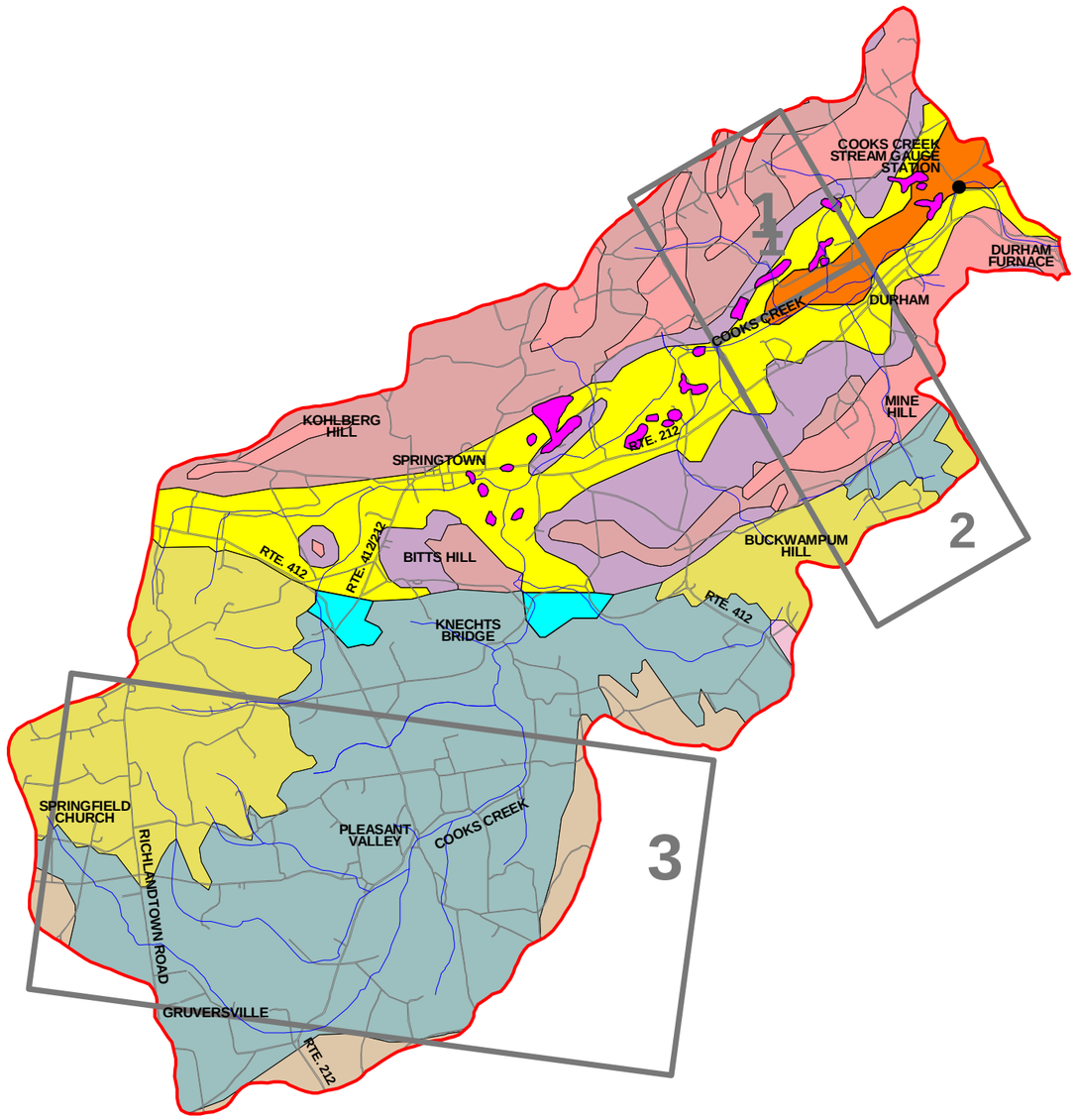

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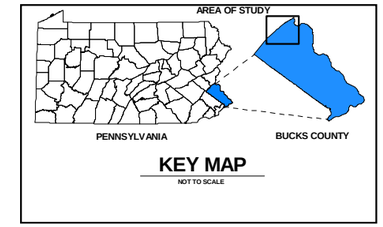

- Figure 3.1 - Geology

LEGEND

- Watershed
- Waterbody
- Stream
- * Karstic
- Areas Susceptible to Karst Dissolution Features

3D Block Diagrams
(see text for discussion)

- 1 Northern Basin - Crystalline Rocks Durham Valley - Karst
- 2 Musconetcong - Bitts Hill Rocks Buckwampum Hill - Haycock Diabase
- 3 South Branch of Cooks Creek Flint Hill - Shelly Diabase

- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Rickenback Formation *
- Allentown Formation *
- Leithsville Formation *
- Epler Formation
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

GEOLOGIC DESCRIPTION

DIABASE

IGNEOUS SHEETS, INTRUSIVE INTO THE BRUNSWICK FORMATION. MEDIUM TO COARSELY CRYSTALLINE, DARK GREY TO NEARLY BLACK, DIABASE COMPOSED OF CALCICPLAGIOCLASE AND AUGITE.

PASSAIC FORMATION (Undifferentiated)

Brunswick & Lockatong Formations and Quartz Pebble & Limestone Pebble Conglomerates

RED TO REDDISH BROWN, GREY AND GREEN COLORED CLAYSTONE, SILTSTONE, SANDSTONE AND SHALE IN THIN TO THICK INTERBEDDED SEQUENCES WITH QUARTZ PEBBLE AND LIMESTONE PEBBLE CONGLOMERATES NEAR BORDER FAULT.

RICKENBACK FORMATION

MEDIUM TO DARK GREY, DOLOMITE, FINELY CRYSTALLINE AND LAMINATED, INTERBEDDED WITH LENSES OF CHERT AND ARGILLACEOUS DOLOMITE.

ALLENTOWN FORMATION

FINE TO COARSE GRAINED, MEDIUM TO THICK BEDDED, DARK GREY TO LIGHT GREY DOLOMITE WITH INTERBEDS OF ORTHOQUARTZITE.

LEITHESVILLE FORMATION

DARK GREY TO BUFF WEATHERING DOLOMITIC LIMESTONE AND DOLOMITE, RHYTHMICALLY BEDDED, WITH MUCH INTERCALATION OF CALUAREOUS SHALES AND SILTSTONE.

HARDYSTON FORMATION

FINE TO COARSE GRAINED, THIN TO MEDIUM BEDDED ARKOSIC SANDSTONE AND QUARTZ PEBBLE CONGLOMERATE.

HORNBLENDE GNEISS AND GRANITIC GNEISS

MEDIUM TO COARSELY CRYSTALLINE, HORNBLENDE BEARING GRANITE-GNEISS, OFTEN DISTINCTLY FOLIATED AND BANDED.

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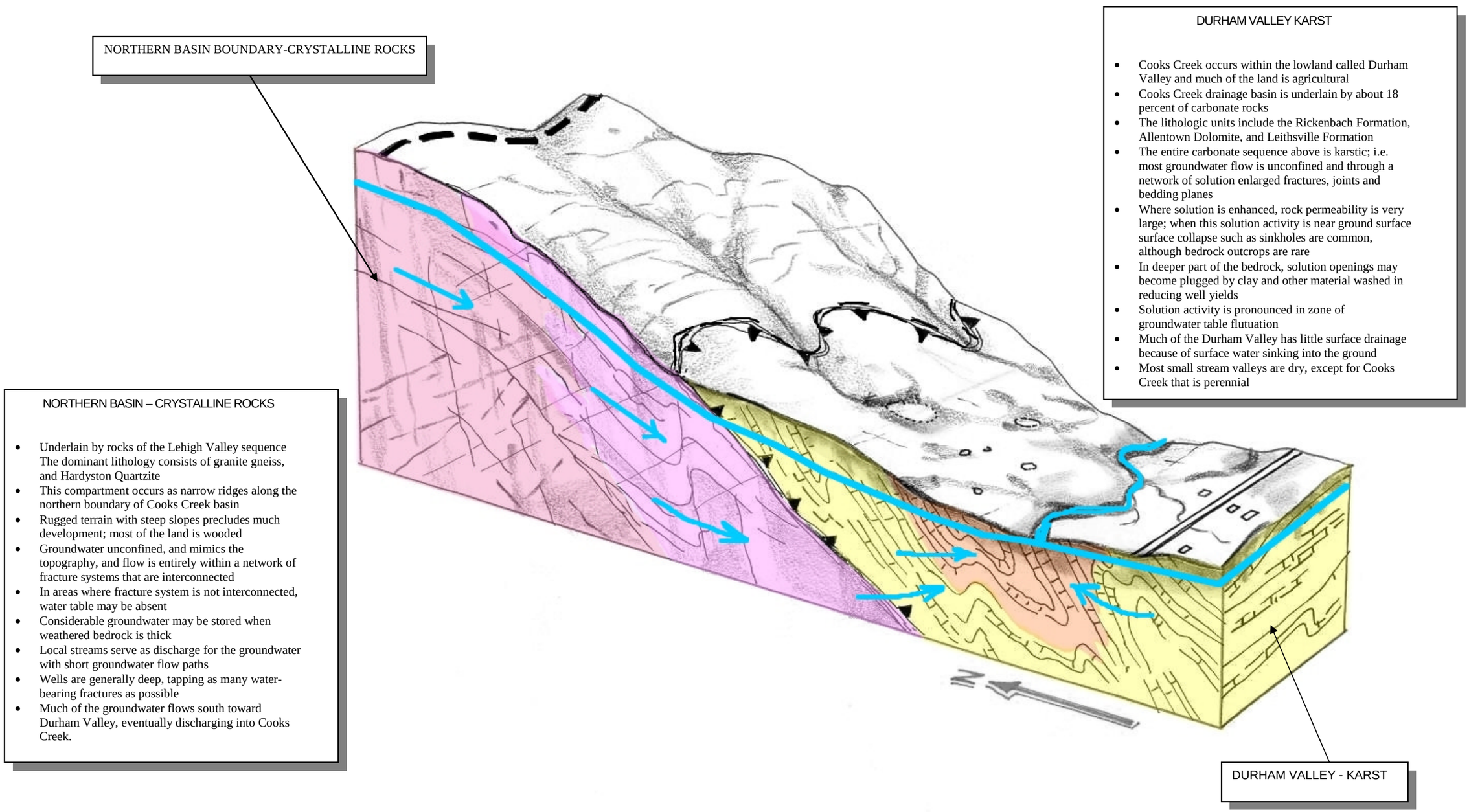
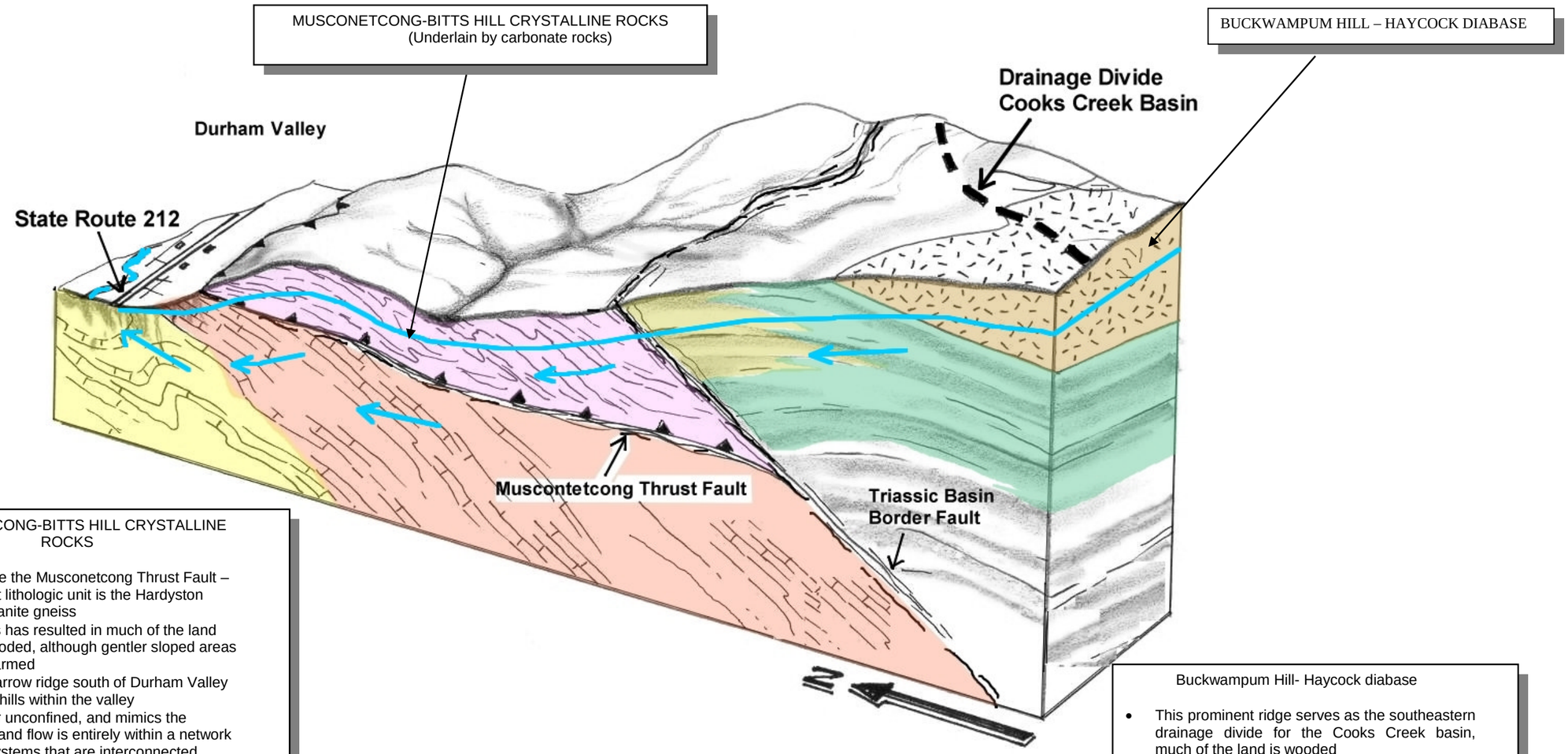


Figure 3.5 Block diagram of the areas Northern Basin - Crystalline Rocks and Durham Valley – Karst, surface and groundwater flow pattern.



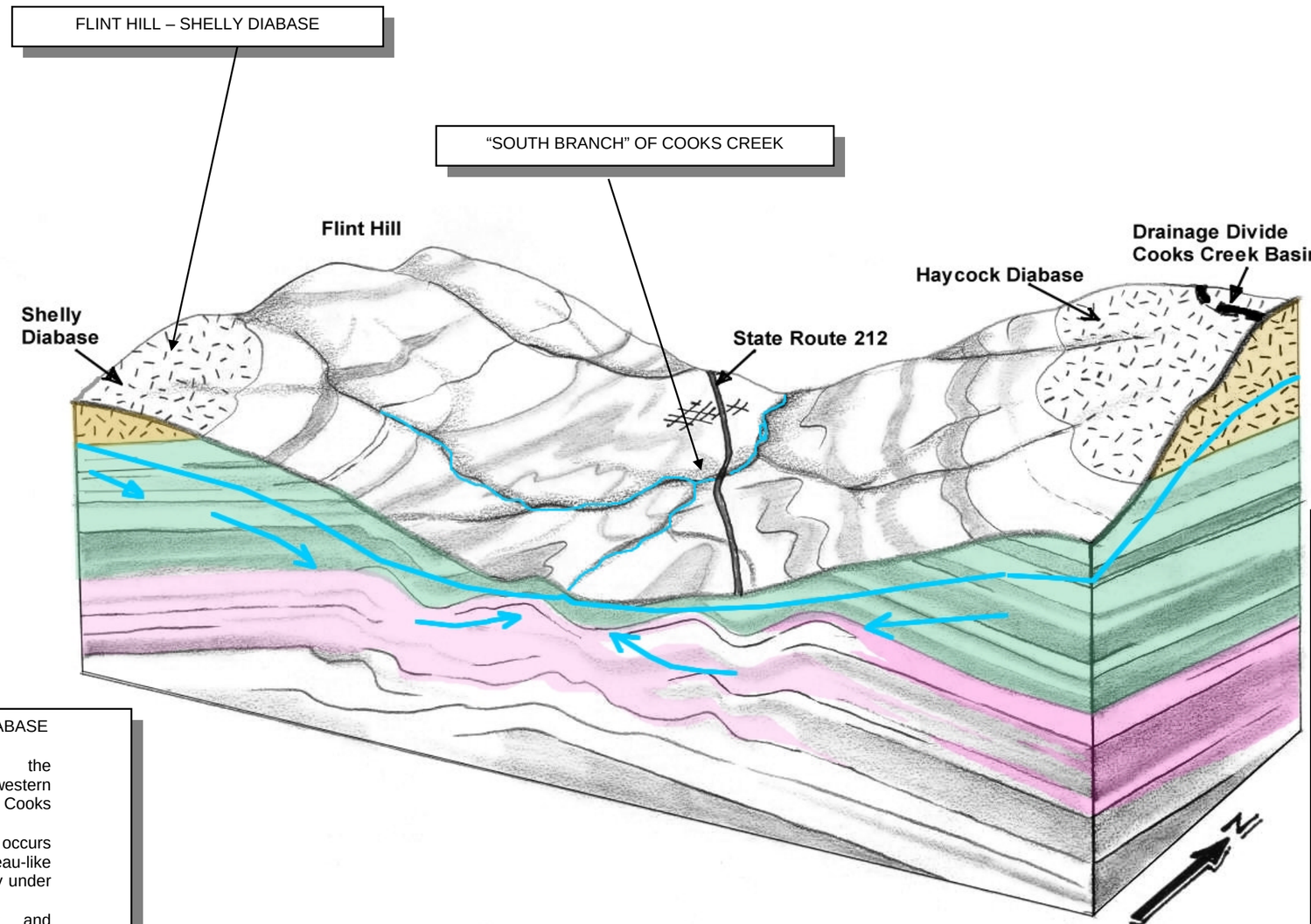
MUSCONTECONG-BITTS HILL CRYSTALLINE ROCKS

- Occurs above the Musconetcong Thrust Fault – the dominant lithologic unit is the Hardyston Quartzite, granite gneiss
- Steep slopes has resulted in much of the land being left wooded, although gentler sloped areas have been farmed
- Occurs as narrow ridge south of Durham Valley and isolated hills within the valley
- Groundwater unconfined, and mimics the topography, and flow is entirely within a network of fracture systems that are interconnected
- In areas where fracture system is not interconnected, water table may be absent
- Considerable groundwater may be stored when weathered bedrock is thick
- Local streams serve as discharge for the groundwater with short groundwater flow paths
- Isolated hill-outcrops of this compartment may serve to locally mound groundwater table
- Wells are generally deep, tapping as many water-bearing fractures as possible

Buckwampum Hill- Haycock diabase

- This prominent ridge serves as the southeastern drainage divide for the Cooks Creek basin, much of the land is wooded
- Although largely underlain at depth by sedimentary clastic rocks of the Passaic Group (undifferentiated) the "cap" of the surficial Haycock diabase sheet controls the groundwater system
- Diabase is massive, crystalline, and lacks primary porosity. All groundwater occurrence is confined to fractures and joints
- Poor porosity and permeability, and rugged terrain precludes the diabase areas from serving as groundwater bearing zones

Figure 3.6 Block diagram of the areas Musconetong - Bitts Hill Rocks and Buckampum Hill, surface and groundwater flow pattern.



FLINT HILL-SHELLY DIABASE

- Serves as the southwestern and western drainage divide for Cooks Creek basin
- This compartment occurs as a broad, plateau-like upland that is mostly under agriculture
- Groundwater flow and groundwater yields are similar to those noted in the Buckwampum Hill-Haycock diabase compartment

"SOUTH BRANCH" OF COOKS CREEK

- Located between the high ridges held up by the Haycock diabase and Shelly diabase, much of the land is agricultural
- The major lithologic units are the clastic, bedded sedimentary rocks of the Passaic Formation (undifferentiated) including shales, sandstones, siltstones and conglomerates
- Groundwater system consists of a series of sedimentary beds that are more permeable sandwiched between less permeable strata
- When non-permeable stata dominate a section, groundwater may be confined
- More permeable strata serve as principal groundwater-bearing zones
- Much of the groundwater flow is controlled by bedrock fractures that are interconnected and bedding plane partings
- Deeper wells intercept more water-bearing zones and therefore, yield greater quantities of water, although plugging of fracture systems may reduce groundwater flow
- Groundwater flow system is generally along bedrock strike (in this comparment it is approximately to the north from about Gruversville to Knechts Bridge) discharging into streams

Figure 3.7 Block diagram of the areas South Branch of Cooks Creek and Flint Hill - Shelly Diabase, surface and groundwater flow pattern.

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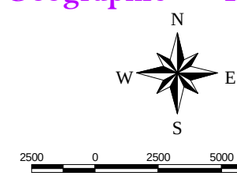

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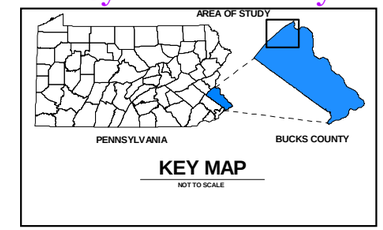

- Figure 4.1 -
Groundwater Contours and Geology

LEGEND

- Watershed
- Waterbody
- Stream
- 525 Water-Level Measurement Site with Elevation
- Potentiometric Contour
- Depression on Water Table Contour

Geologic Formation

- Allentown Fm
- Brunswick Fm
- Diabase
- Epler Fm
- Granitic Gneiss
- Hardyston Fm
- Hornblende Gneiss
- Leithsville Fm
- Limestone Fanoglomerate
- Lockatong Fm
- Quartz Fanoglomerate
- Rickenback Fm

NOTES

1.) POTENTIOMETRIC CONTOUR - SHOWS INFERRED ALTITUDE OF POTENTIOMETRIC SURFACE AS DEFINED BY MEASURED WATER LEVELS AND INFERRED ALTITUDES OF GROUND SURFACE AT WELL LOCATION, STREAMS, AND TOPOGRAPHY FROM USGS 7.5 MINUTES SERIES TOPOGRAPHIC MAPS. CONTOURED POTENTIOMETRIC SURFACE REPRESENTS THE WATER TABLE EXCEPT AT WELLS THAT ARE COMPLETED IN SEMICONFINED ZONES IN THE AQUIFER. CONTOUR INTERVAL IS 20 FEET EXCEPT NORTH OF OF SPRINGTOWN, WHERE THE CONTOUR INTERVAL IS 20 FEET UP TO AN ALTITUDE 400 FEET AND THEN 50 FEET TO AN ALTITUDE 800 FEET. ALTITUDE IS IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM OF 1929.

2.) WATER-LEVEL MEASUREMENT SITE - SYMBOL GIVES LOCATION OF SITE FOR WHICH WATER LEVEL DEPTH WAS TAKEN IN THE RESIDENTIAL WELLS BETWEEN NOVEMBER 13 AND NOVEMBER 15, 1999. NUMBER IS ALTITUDE OF WATER LEVEL IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM OF 1929. WELLS AND SPRINGS OUTSIDE THE STUDY AREA ARE SHOWN WHERE THEY WERE USED TO CONTOUR THE POTENTIOMETRIC SURFACE.

3.) DEPRESSION ON WATER TABLE CONTOUR - ALTITUDE OF WATER LEVEL THAT REPRESENTS A POTENTIOMETRIC SURFACE OTHER THAN THE WATER TABLE. MEASURING POINTS INCLUDE WELLS THAT MAY HAVE BEEN OVERPUMPED OR PENETRATE A DEEPER SEMICONFINED ZONE, AND DATA MAY REFLECT A COMPOSITE HEAD. THESE DATA WERE NOT USED TO CONTOUR THE POTENTIOMETRIC SURFACE AND ARE INCLUDED FOR INFORMATION ONLY.

4.) GEOLOGIC UNITS ARE SCREENED BACK FOR LEDGIBILTY PURPOSES; SEE FIGURE 2 FOR DETAILS.

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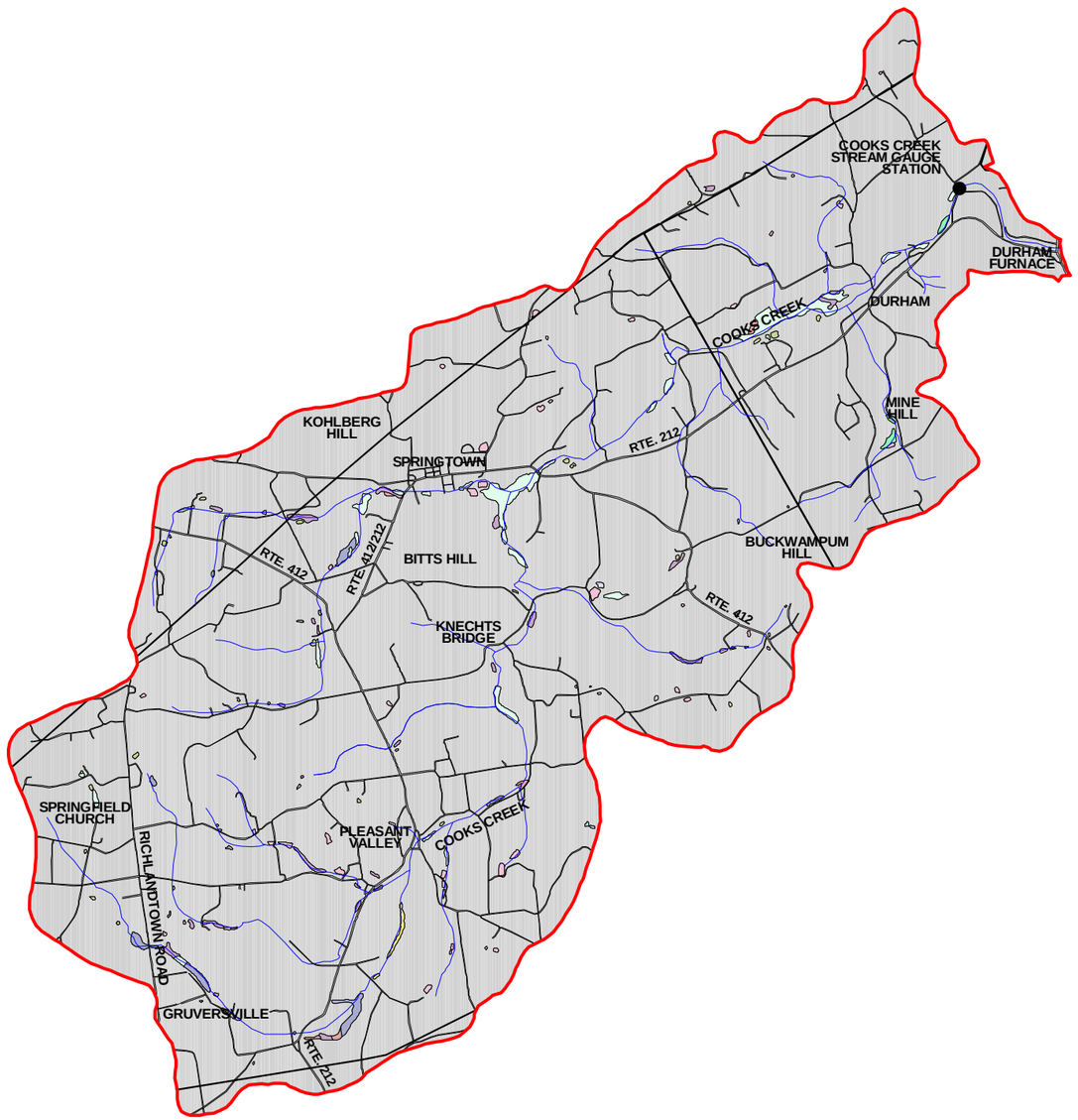

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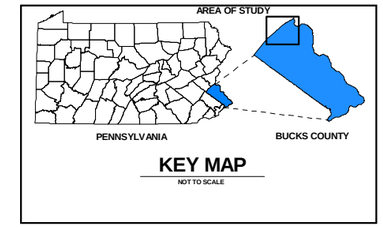

- Figure 6.1 - National Wetlands Inventory

LEGEND

- Watershed
- Waterbody
- Stream

L1OWHH	PFO5HH	PFO/SS1A	PSS1A
PEM5A	POWF	PFO/SS1C	PSS1C
PEM5C	POWKH	PFO/SS1E	R2OWH
PEM5CD	POWZ	PFO1/EM5	R2USA
PEM5CH	POWZH	PFO1A	R2USC
PEM5E	POWZX	PFO1C	R5OWH
PEM5FH	PSS1/EM5	PFO1E	U

NOTES

1.) WETLAND TYPES IN ACCORDANCE WITH CLASSIFICATION OF WETLANDS AND DEEP WATER HABITATS OF THE UNITED STATES (COWARDIN et al, 1971)

SOURCE

NATIONAL WETLAND INVENTORY MAPS, US FISH AND WILDLIFE SERVICES

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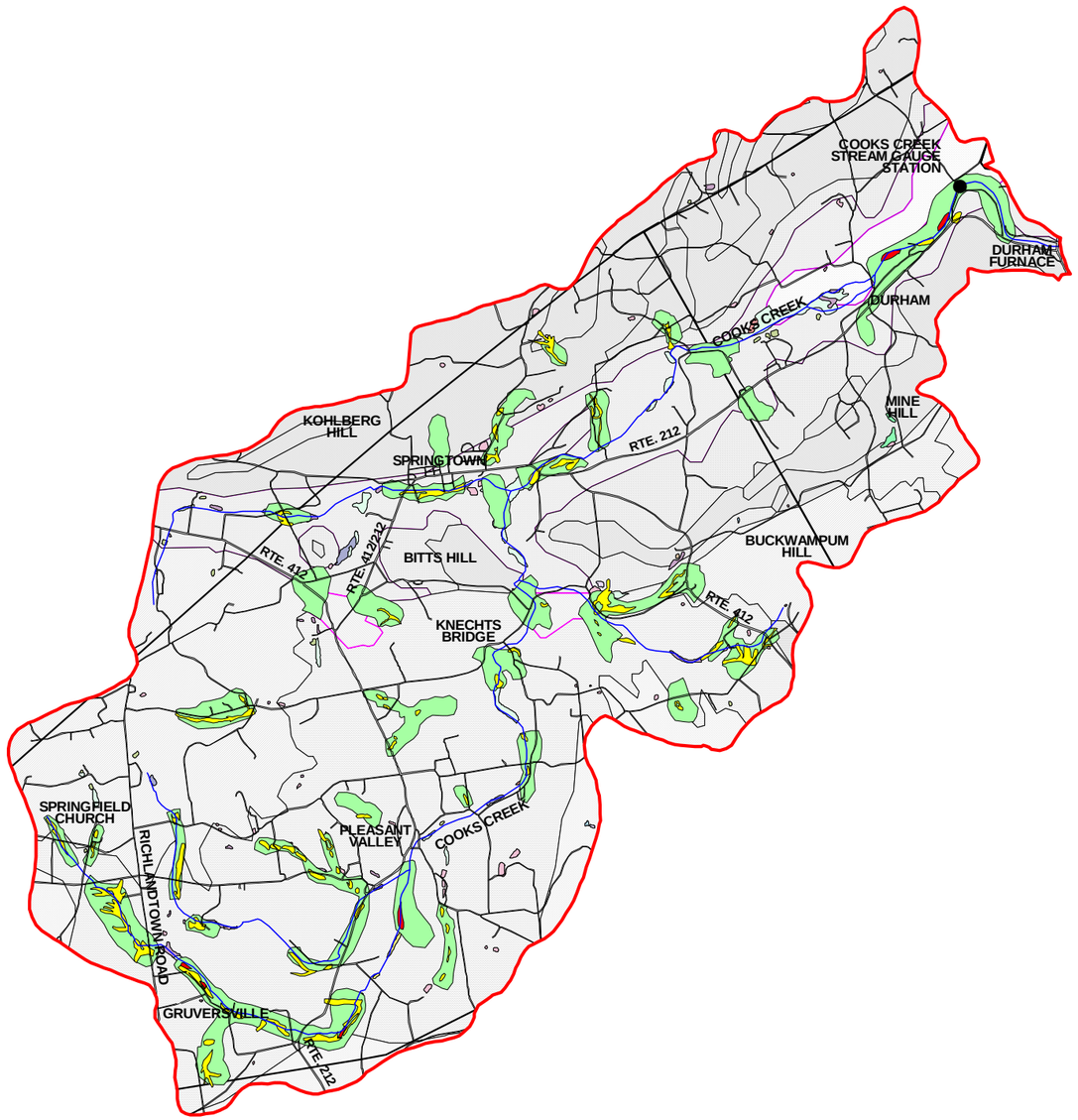

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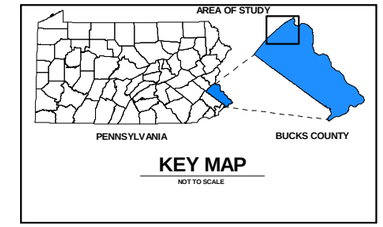

- Figure 6.2 -
Wetlands and Geology

LEGEND

- Watershed
- Waterbody
- Stream
- Field Identified Wetlands
- Not A Wetland (incorrectly identified on NWI)
- Wetlands Study Areas

L1OWHH, PEM5A, PEM5C, PEM5CD, PEM5CH, PEM5E, PEM5FH, PFO5HH, POWF, POWKH, POWZ, POWZH, POWZX, PSS1/EM5, PFO/SS1A, PFO/SS1C, PFO/SS1E, PFO1/EM5, PFO1A, PFO1C, PFO1E, PSS1A, PSS1C, R2OWH, R2USA, R2USC, R5OWH, U

GEOLOGY

- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate

Passaic Formation (Undifferentiated)

- Rickenback Formation
- Allentown Formation
- Leithsville Formation
- Epler Formation
- Hardyston Formation
- Hornblende Gneiss
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NOTES

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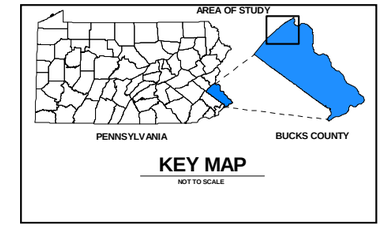

- Figure 7.1 -
Groundwater Contours and Wetlands

LEGEND

- Watershed
- Waterbody
- Stream
- Field Identified Wetlands
- Not A Wetland (incorrectly identified on NWI)
- Wetlands Study Areas
- 525 Water-Level Measurement Site with Elevation
- Potentiometric Contour
- Depression on Water Table Contour

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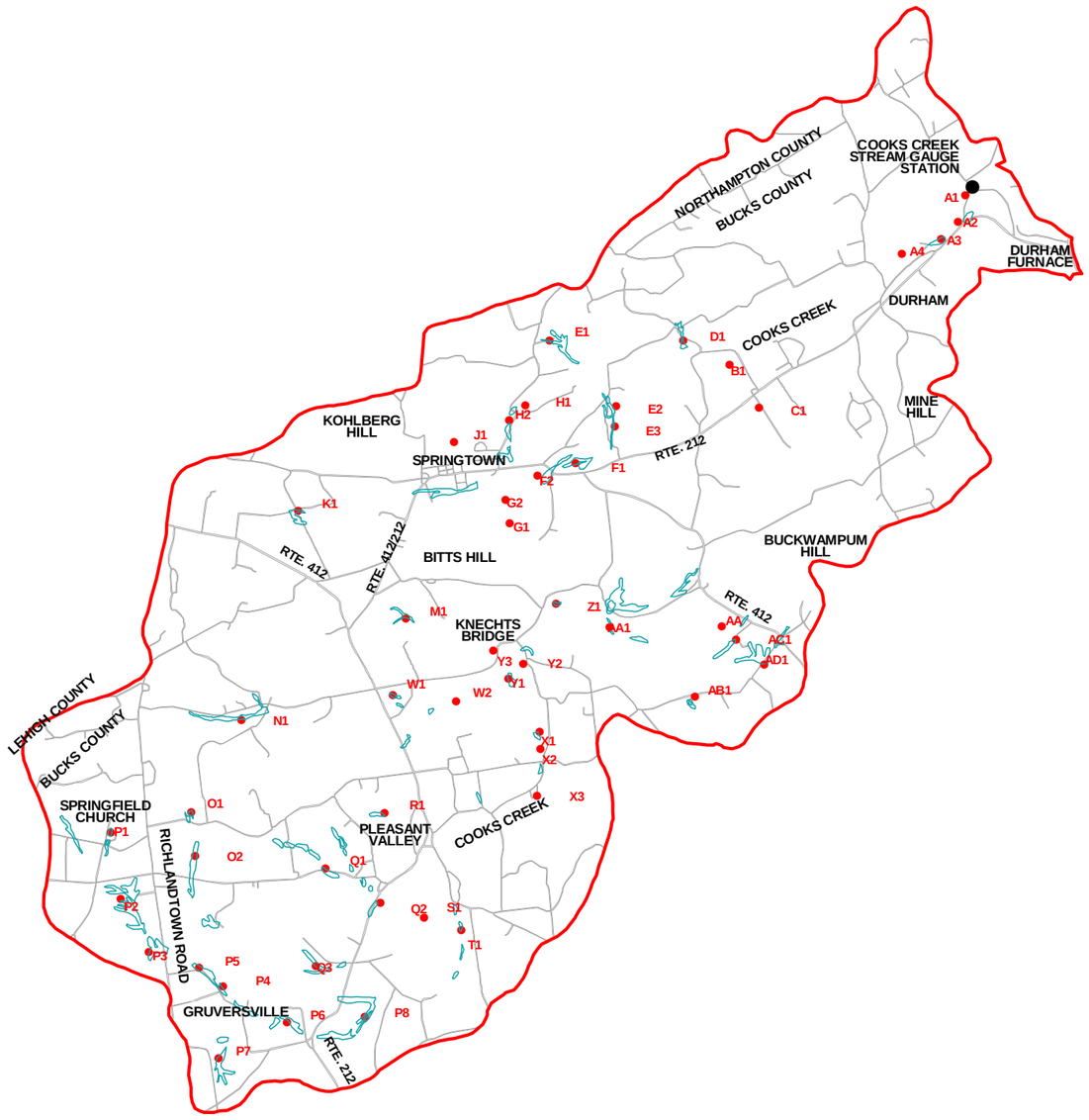

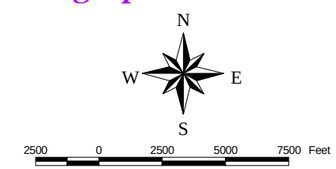

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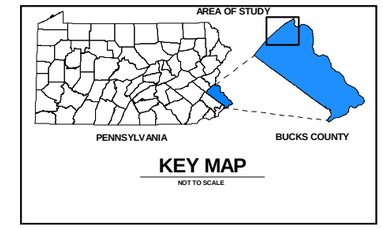

- Figure 8.1 -
Field Identified Wetlands

LEGEND

- Watershed
- Stream
- C1 Wetland Data Point
- Field Identified Wetlands

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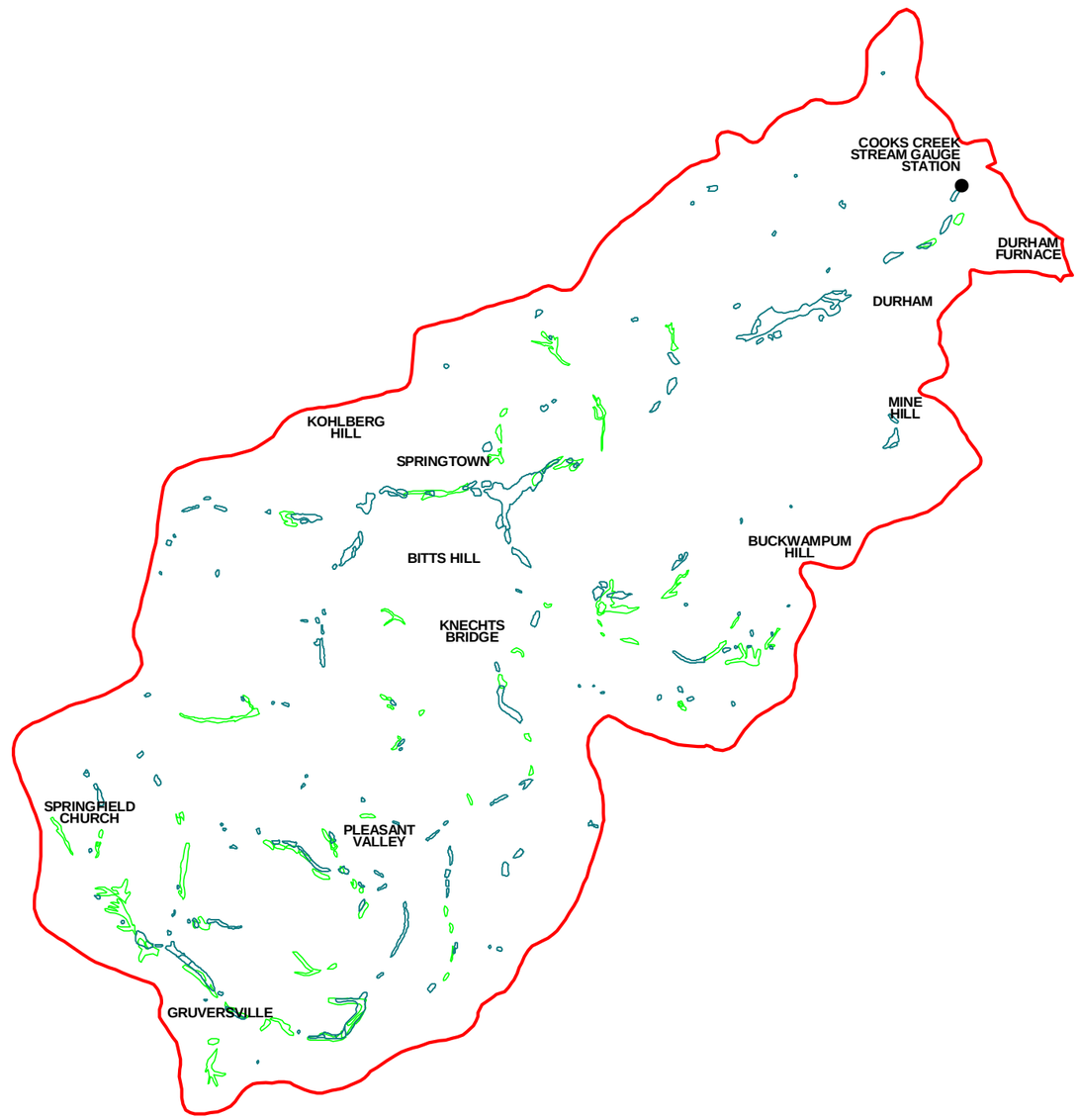

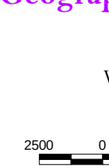

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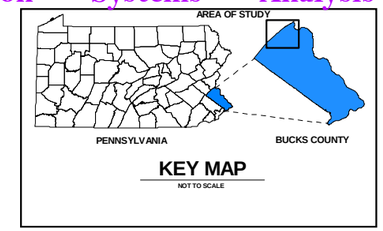

Figure 8.2 - Proposed Wetlands Overlay District

LEGEND

- Watershed
- National Wetlands Inventory
- Field Identified Wetlands

SOURCE

NATIONAL WETLAND INVENTORY MAPS, US FISH AND WILDLIFE SERVICES

FIELD IDENTIFIED WETLANDS, JUNE 1999

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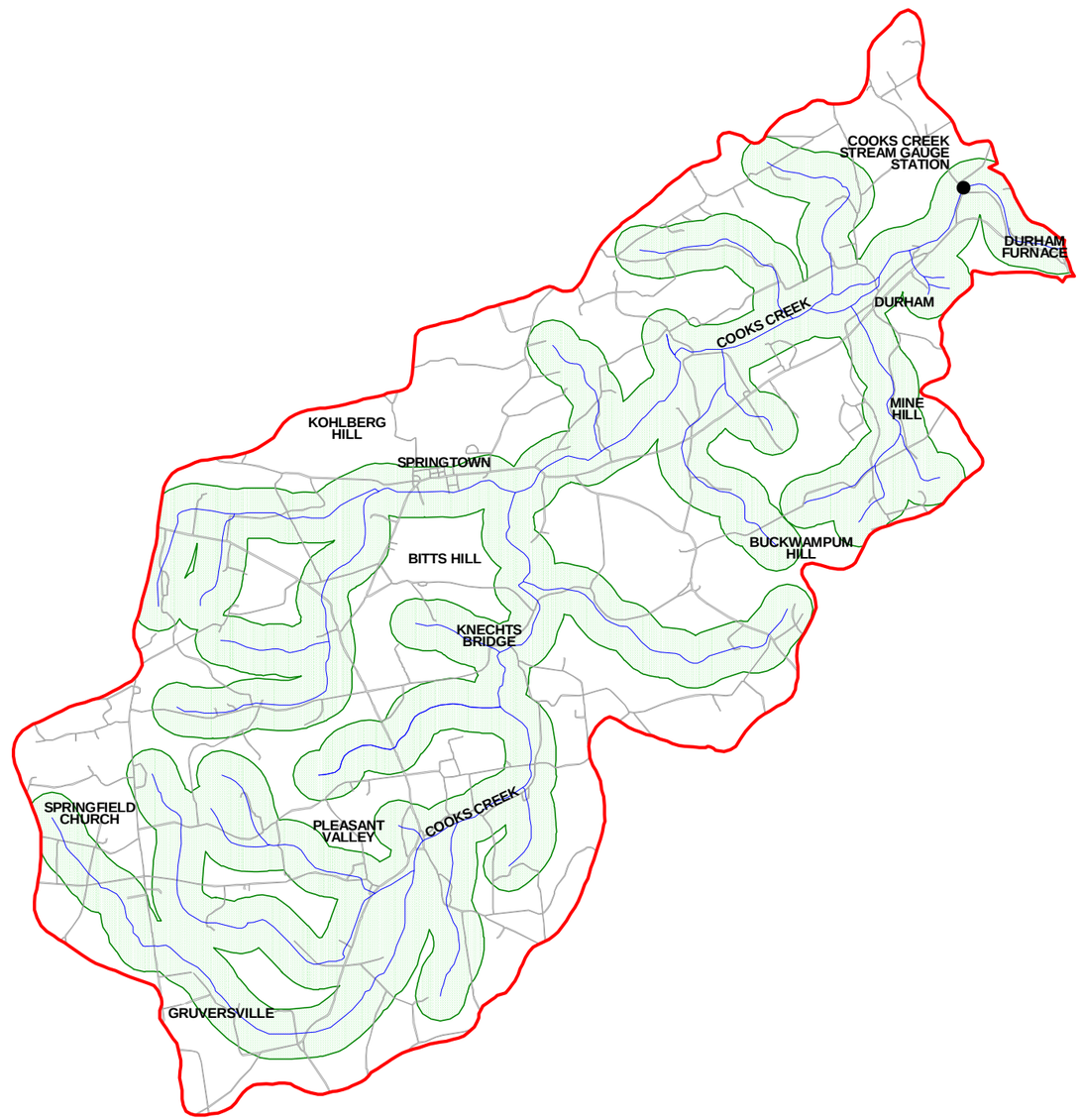
Geographic Information Systems Analysis



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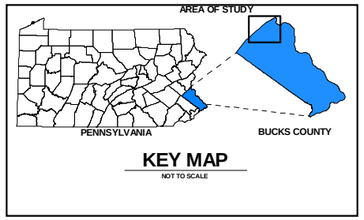

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LEGEND

- Watershed
- 1,000 Foot Stream Riparian Buffer
- Stream

MJE MJ Environmental Associates, Ltd.

Golder Associates

3e EEE Consulting, Inc. Environmental, Engineering and Educational Solutions

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Cooks Creek Watershed Monitoring and Planning Program

Cooks Creek Watershed Conservation Plan

Bucks County, Pennsylvania

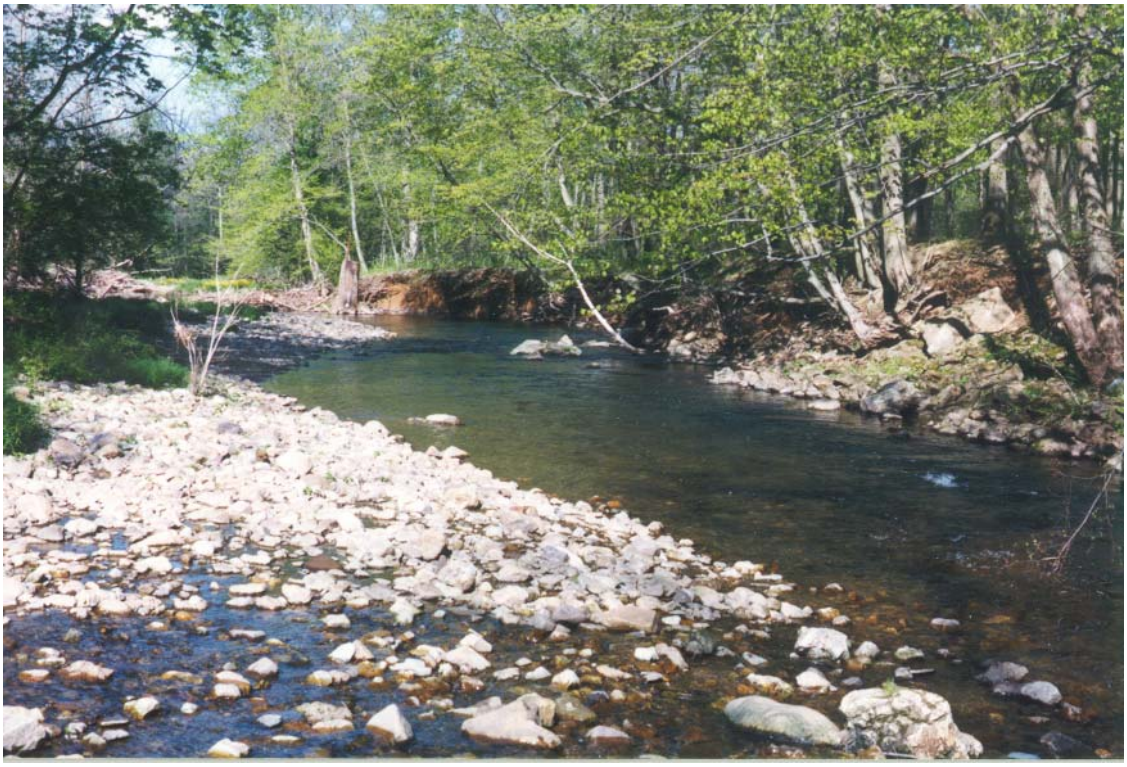
Funded through a grant from Pennsylvania Department of Conservation and Natural Resources

Prepared by

Durham Township Environmental Advisory Council

with the assistance of

MJ Environmental Associates
and
Wheeler Environmental Services



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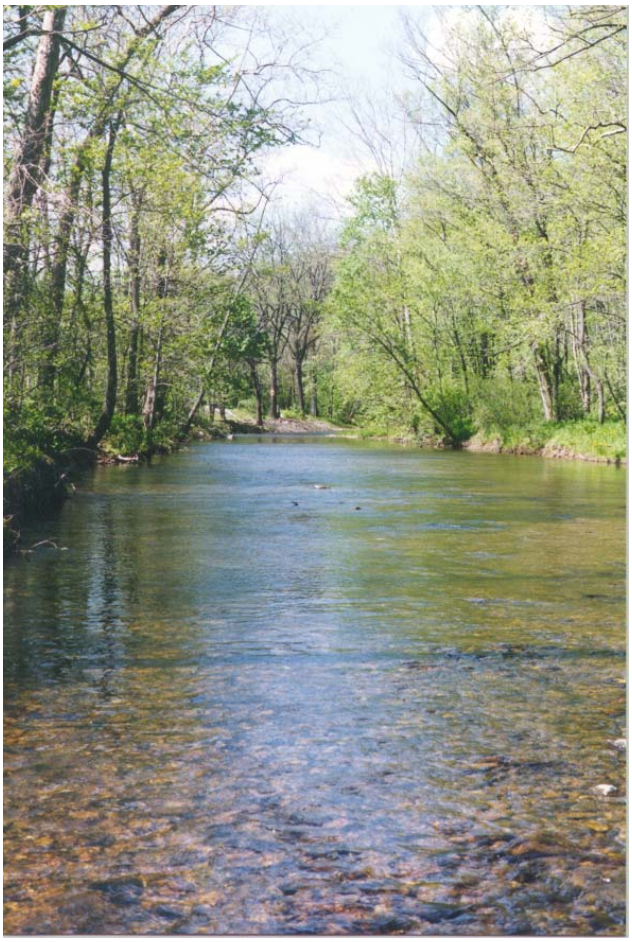

A CASE FOR PROTECTION OF THE COOKS CREEK WATERSHED

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Cooks Creek Watershed Conservation Plan
Bucks County, Pennsylvania

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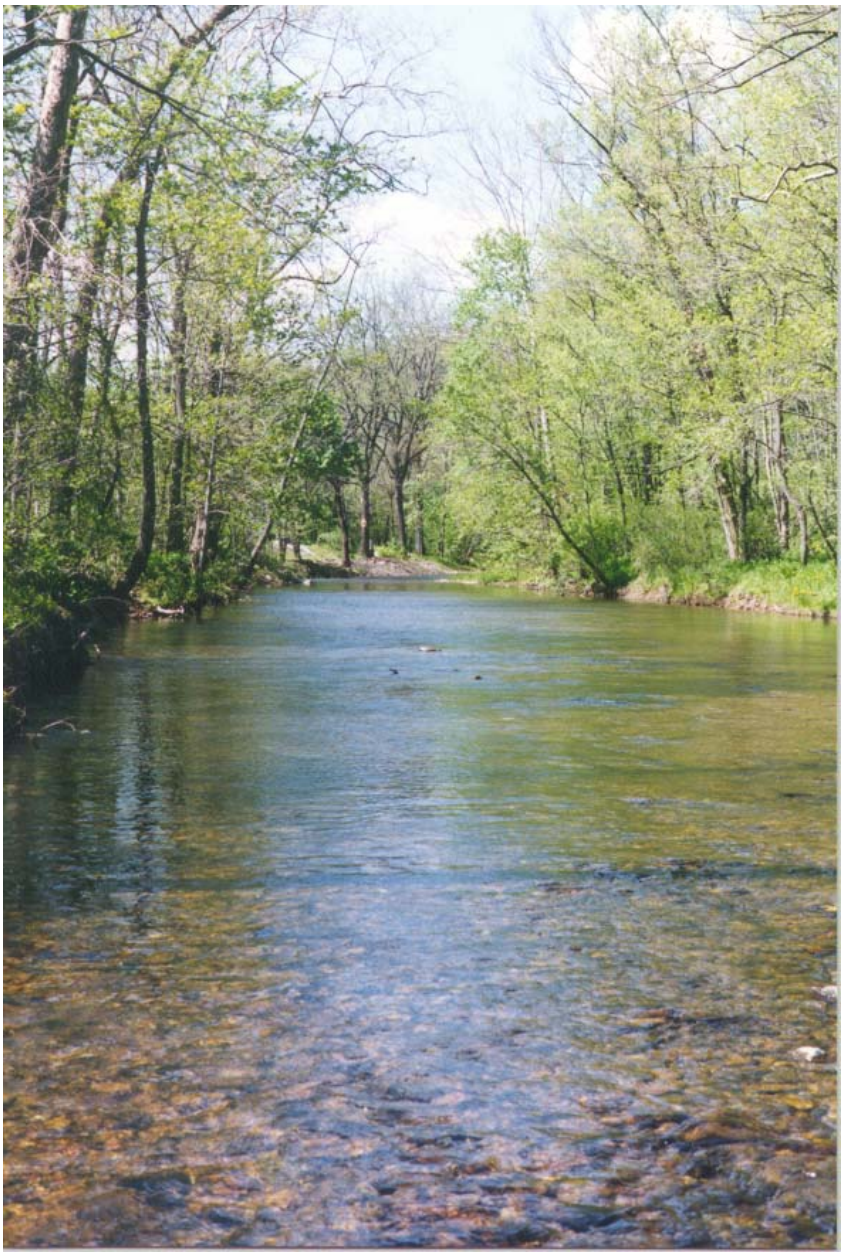

A CASE FOR PROTECTION OF THE COOKS CREEK WATERSHED

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Foreword

This Watershed Conservation Plan (WCP) is a compilation of numerous studies that have been conducted within the Cooks Creek watershed. These studies include: geologic and wetland surveys, well water level monitoring, stream gauge data collection, water quality chemistry, bioassessment surveys, stream corridor evaluations, and GIS database development. This WCP references all these studies and the appendices to this report include the results of many of the studies performed. The notable exception being the results of studies performed in support of the *Wetlands Management Plan* that was prepared for the USEPA (published under separate cover). Those wishing to obtain a copy of the Wetlands Management Plan should contact the Durham Township EAC. This WCP was funded in part from the Community Conservation Partnership Program, administered by the Bureau of Recreation and Conservation, Pennsylvania Department of Conservation and Natural Resources. Special thanks to the members of the Cooks Creek Watershed Association, the Durham Township Environmental Advisory Council, and the Springfield Township Environmental Advisory Council who provided hundreds of hours of volunteer time toward the development of this Plan.

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Executive Summary

Overview

This Watershed Conservation Plan is for the Cooks Creek Watershed, located primarily in the Townships of Durham and Springfield, Bucks County, Pennsylvania. This plan is based upon several years of intensive research and analysis of watershed conditions and was developed to provide the basis for plans and ordinances that will protect the resource value of the watershed for the residents of the area. A list of recommendations has been prepared to implement this plan consistent with the results of these studies.

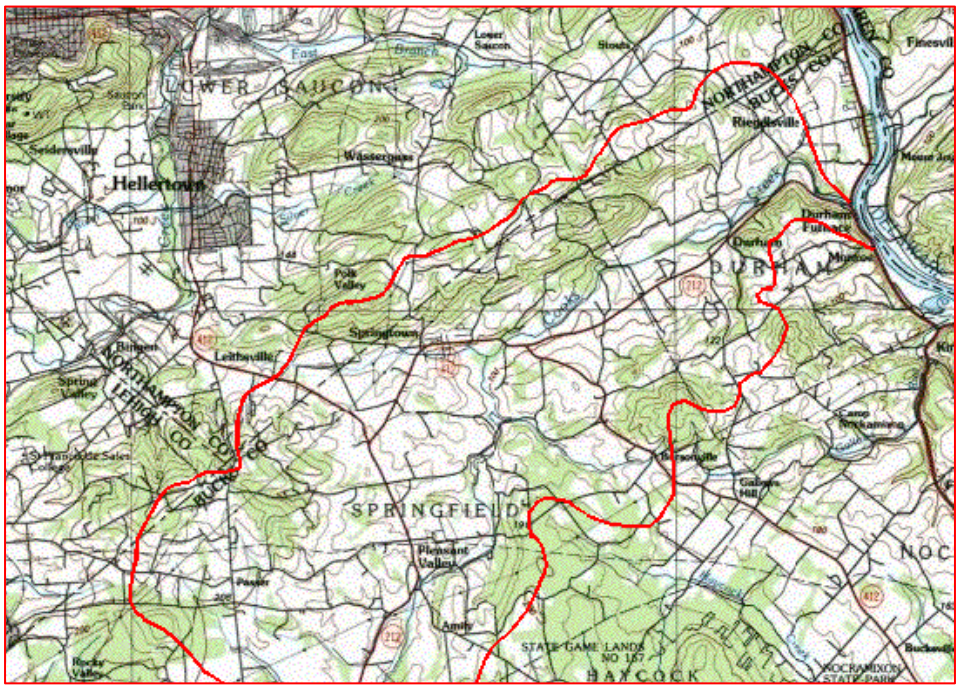

Figure ES1 - Cooks Creek watershed area.

The Cooks Creek Watershed is located in upper Bucks County, Pennsylvania and is a tributary to the Delaware River. Approximately 40 miles of stream corridor drain about 30 square miles of terrain primarily in the townships of Durham and Springfield, but also including small portions of Haycock and Richland Townships, as well as Upper SauconTownship, Lehigh County and both Lower Saucon and Williams Townships, Northhampton County.

The Cooks Creek Watershed corridor is comprised of scenic hills, valleys, and open areas where the waterways flow. Cooks Creek has a diverse watershed corridor. The watershed corridor is comprised of broad open valleys, valley bottoms, and gentle stream gradients

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dictated by the underlying geology of the area. Land use is primarily residential and agricultural, providing for a scenic and bucolic setting.

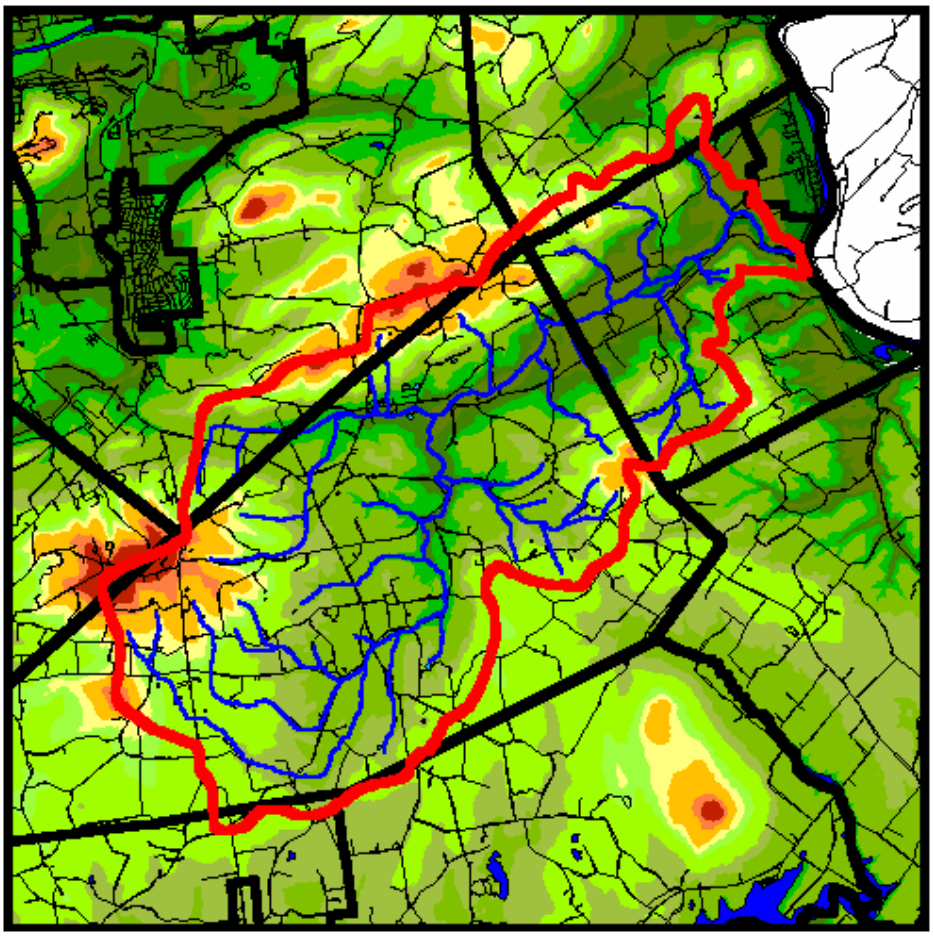

Figure ES2 – Watershed Topographic Map

Cultural/Historical

The Cooks Creek Watershed, positioned as it is in upper Bucks County, is an area steeped in colonial history. There are numerous colonial period homes, public houses, and inns still surviving and both Durham and Springfield Township have active historical societies. The Durham Iron Works and Mine in Durham Furnace, provided pig iron and iron products for the colonies and armaments for the Revolutionary Army. The mine entrance and airshafts on Mine Hill are still easily seen. In fact, the mine provides a refugee for the endangered Indiana Bat, resulting in the entrances being blocked to the public in 1995. The Durham Gristmill stands on the site of the original Durham Furnace, and is a fine illustration of the importance of waterpower to the colonists. Cooks Creek was diverted using a system of

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wing dams and raceways, still being maintained by Durham Township. The mill itself ceased operations only in recent years (1960s) but is no longer operational. Plans are in place to restore the building and water wheel. In addition to the iron, the area was well known as a good source of lime for agricultural purposes, and numerous limekilns, in various states of disrepair, can be found throughout. Although historically, the pervasive network of tributaries resulted in a host of covered bridges being built, only one of these quaint structures still remains. Fire and flood have taken their toll, but the Knecht's Bridge off Slifer Valley Road in Pleasant Valley still provides a touch of historic class to Springfield Township.

Geology

The geology of a region, while predominantly unseen, is the foundation for all the natural resources. Soils, groundwater, surface water and through these the flora and fauna of a region are all dictated on a fundamental level by geology. The underlying geology of the Cooks Creek Watershed is primarily of three types: crystalline (granite and schist) in the ridges to the north and south, diabase (red shale) in the headwaters, and a carbonate (limestone) central valley.

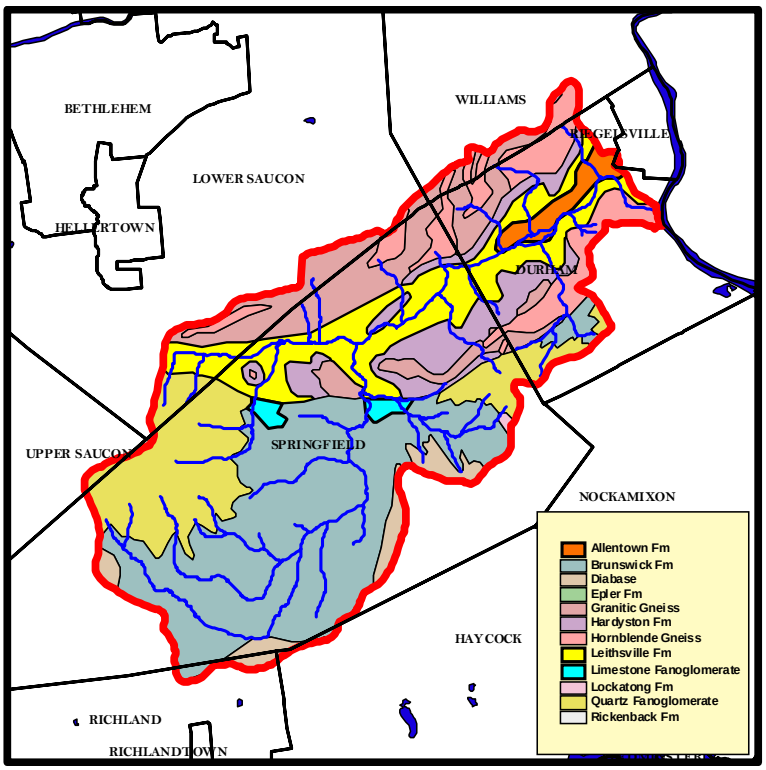

Figure ES3 – Geology Map.

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In order to fully understand the geology of the Watershed, professional geologists were commissioned to study the area. The geologists used a combination of aerial survey and field confirmations to develop geology overlays and three dimensional model depictions of the major geologic units.

The geologic units of the entire watershed were grouped into four geologic categories:

- Category I: Diabase
- Category II: Brunswick and Lockatong Formations; and Quartz Fanoglomerates
- Category III: Carbonate Rocks including Allentown and Leithsville Formations and Limestone Fanoglomerates
- Category IV: Crystalline Rocks including Hardyston Formation and Gneiss Formations

These classifications were used in determining groundwater contributions to the baseflow of the basins and/or sub-basins within the watershed. Sub-basins are the drainage areas of various tributaries to the main stem of Cooks Creek Watershed. This ranking of sub-basins was necessary for extrapolating water production yields from each sub-watershed area. This information was used to assess water balance and groundwater resource evaluations.

Hydrology

The unique geologic characteristics noted above dictate the surface water hydrology of the Cooks Creek Watershed. The 37 miles of Cooks Creek and its tributaries drain a watershed that is 30 square miles in size, approximately 9.5 miles long and 4 miles wide. Cooks Creek flows 18 miles in a southeasterly direction from Flint Hill to the Delaware River with a vertical elevation drop of 625 feet.

The watershed headwaters are primarily in the western portions of Springfield Township, where large, flat open farm fields are punctuated by springs. Emergent wetlands surround the streams, indicating their location to the observant and protecting the minute flows that eventually gather to become the Cooks Creek. The streambed in this area meanders through farm fields or mature secondary growth forests of oak, ash and walnut. Along the northern and southern boundaries of the watershed are the crystalline ridges of Buckwampum Hill, Mine Hill, Flint Hill and Steely Hill. Springs punctuate the ridges, bursting forth where the plates of limestone and crystalline rocks meet and rushing down to the limestone valley through mature hardwoods, often with steep slopes. Due to the small size of the watershed, however, none of these tributaries is very large, rarely exceeding 4 feet in width. Two (2) of these tributaries are of special note: Silver Creek in Springtown and Coon Hollow Run in Durham.

Understanding the hydrology of Cooks Creek was seen as a priority to being able to protect the stream's Exceptional Value (EV) status. There is a finite amount of water in the watershed, and a theoretical minimum required for the sustenance of the Creek, both for its beauty and as habitat for wildlife. The water in the Creek comes from two sources: storm water/snowmelt runoff and groundwater. While weather plays its hand as far as runoff is concerned, the groundwater comes from springs and seeps and is virtually continuous. This flow is termed the *baseflow*, and is the most important hydrologic characteristic of the watershed.

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In order to better understand the hydrology of Cooks Creek, the United States Geologic Survey (USGS) had installed a stream flow monitoring station, or stream gauging station at Red Bridge Road in Durham, but it was abandoned in 1993. The Durham Environmental Advisory Council (DTEAC) obtained the stilling well in 1995 and reactivated it with new equipment in May of 1999. The DTEAC plans to continuously monitor the flow in Cooks Creek for 10 years to better understand the baseflow of the Creek through development of a $Q_{7\text{-}10}$ statistic. The $Q_{7\text{-}10}$ is a hydrologic statistic representing the weekly average of the lowest flow expected during a 10-year period. This statistic has legal precedence for its use in the establishment of planning parameters for baseflow and wellhead protection. In addition to this station, which effectively monitors the entire watershed, a second station above the confluence of Silver Creek in Springtown is planned in order to more effectively characterize the diabase/sandstone headwaters portion of the watershed.

Groundwater hydrology or hydrogeology is the linkage between the geology and the groundwater of a watershed. As mentioned above, Cooks Creek is a complex, interdependent system that relies on groundwater for its baseflow. It is absolutely necessary to understand these linkages and the linkages between hydrogeology and hydrology fully before one can truly manage the available resources to ensure that there is adequate high quality drinking water for citizens as well as water for sustaining Cooks Creek.

To better understand the amount of water in the aquifers of the Watershed, DTEAC commissioned a field study to develop a groundwater contour map. This map is a synoptic picture of the groundwater level as measured through drinking water wells.

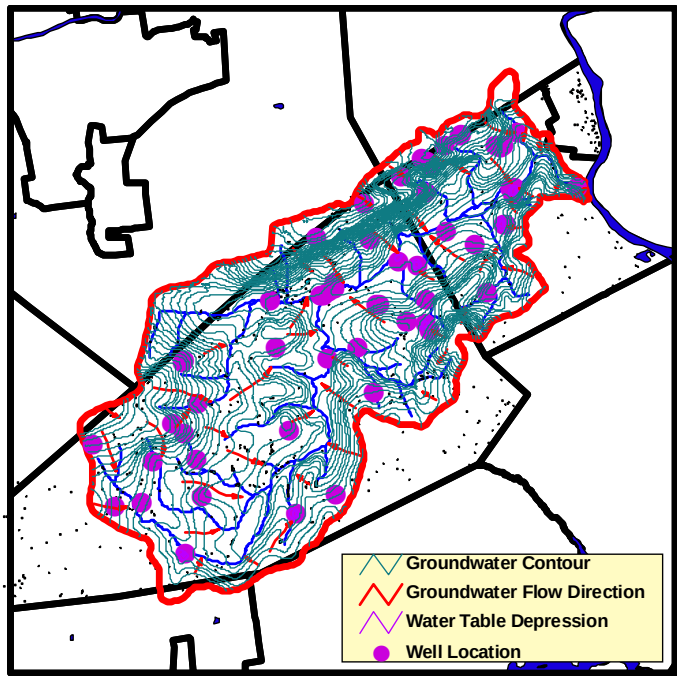

Figure ES4 – Groundwater Contour Map.

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Over 75 wells were surveyed in this study and a contour map developed. In order to understand how the aquifer responds over time, several locations throughout the area were monitored for water level on a monthly basis. This "dynamic range" illustrates how the aquifer responds to use and rainfall. When combined with data from the stream gauge, a complete picture of the hydrologic system of the watershed begins to appear.

It appears that current water withdrawals are not jeopardizing the baseflow of the Creek. However, additional modeling studies currently underway will enable managers to determine the amount of groundwater available for development that will not jeopardize this baseflow. It is important to note here that these calculations are based on assuming that water quality conditions remain constant. If water quality continues to be threatened by nutrients and erosion, additional baseflow may be needed in the Creek in order to maintain the necessary water quality during periods of low flow.

Water Quality

Cooks Creek boasts good to excellent water quality, a diverse macro-invertebrate benthic community, and a Class A wild brown trout (*Salmo trutta*) population. In addition, tributaries to Cooks Creek support both Class A wild brown trout populations and Class A native brook trout (*Salvelinus fontinalis*) populations. The entire Cooks Creek drainage basin is classified as an *Exceptional Value (EV) coldwater fishes (CWF)* waters. These standards are based upon the health of the biological communities present in the stream, the natural resources, and the scenic beauty of the watershed as well as the recognition of the local community as to their inherent value. Special status is granted only by petition to the Environmental Quality Board of the State of Pennsylvania.

The watershed is not without water quality issues, however. A literature search and a field survey revealed that both suspended sediments and nutrient runoff have contributed to apparent stress in various locations throughout the watershed. While the data collected to date do not indicate a definitive management action, they do indicate the need for a more detailed investigation into the reasons for their presence and to suggest appropriate management action.

Land Use

Land use issues are directly linked to the ways in which human impacts effect the hydrologic system of the watershed. Land use in the watershed varies tremendously from open unused forested lands to intensively residential village centers. One way to manage the diversity in this system is to divide the watershed into sub-watersheds based on tributaries. The Cooks Creek Watershed includes a total of 40 sub-watersheds. It is these watershed units that must be understood in order to maintain water quality and quantity in the watershed. Hydrologists will be using these sub-watersheds as the modeling of our watershed continues in the next several years. However, considerable effort must be made to better understand current land us and to characterize the land use in each of these sub-watersheds. In addition, the

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comprehensive plan and zoning ordinances should be developed utilizing the sub-watershed system to incorporate the results of this study in the most effective manner.

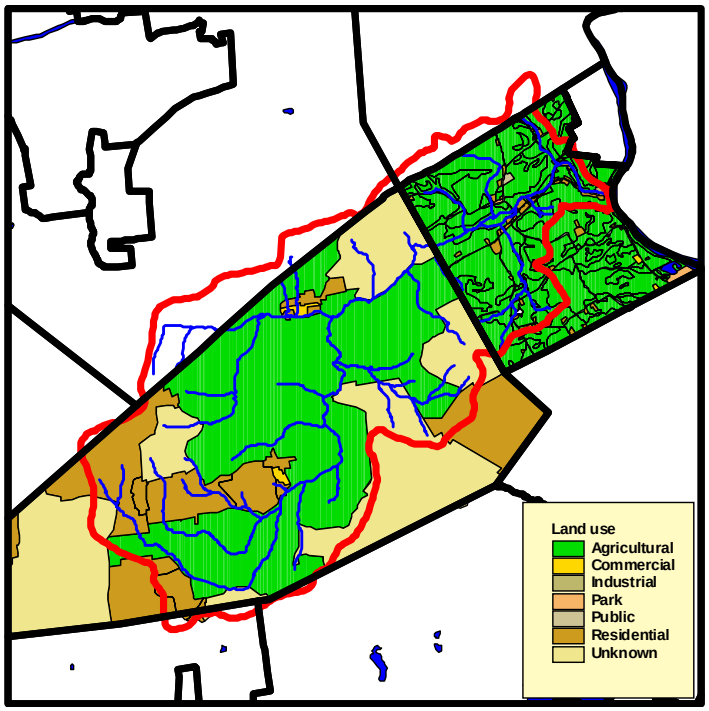

Figure ES5 – Existing Land Use Map.

While both Durham and Springfield townships have progressive land use regulations that take resource protection into account, these documents are outdated and have relatively weak scientific underpinning. There is an immediate need to bring the Comprehensive Plans and Zoning Ordinances up to date in both townships. This need has been recognized and is currently being acted upon. This Watershed Conservation Plan, and the information it contains, is envisioned to be an invaluable asset in the process of updating these documents.

Soils

The Cooks Creek Watershed boasts some of the finest agricultural soils in Bucks County, with over 65 % of the land considered prime agriculture. In addition, included are some highly sensitive shallow forest soils along the higher ridges as well as poorly drained hydric soils in the lowlands.

Soils are the link between the underlying geology and the surface features such as topography, stream morphology, surface water hydrology, vegetation, and land cover. Soils are not only the primary resource governing plant communities and agricultural productivity of the watershed, but they also control the permeability of surface runoff and are instrumental in recharging the groundwater that sustains the Cooks Creek. Soils also provide a critical

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biological filter for pollutants such as pesticides, hydrocarbons and nutrients that are the main threats to water quality.

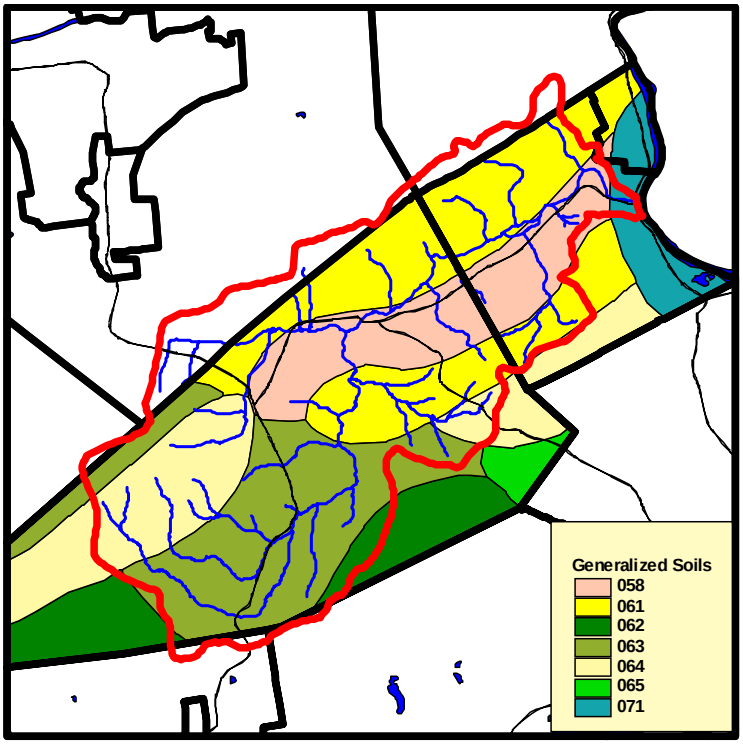

Figure ES6 - Generalized Soils Map for the Watershed.

Three main generalized soil groups exist in the Cooks Creek Watershed. These groups are:

- Deep soils that have a medium-textured surface layer and a medium textured or moderately fine-textured subsoil. (Associations: Allenwood Chester (061 and 064) , Duffield-Washington (058), and Towhee-Neshaminy-Mount Lucas (062));

- Deep soils that have a medium-textured surface layer and a firm friable, but mainly firm and compact, subsoil; shallow to deep over shale or sandstone. (Associations: Abbottstown-Readington-Reaville (065) and Penn-Klinesville (063)); and,

- Deep soils that have a medium-textured surface layer and a medium-textured or moderately coarse-textured subsoil (Association: Alton-Pope (071)).

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Recommendations and Management Options

The overall goal of this Cooks Creek Watershed Conservation Plan is two fold: 1) to formulate a management program that truly sustains water resource through utilization of Best Management Practices (BMPs) and 2) to highlight those characteristics or critical issues in the watershed that require further study. This can be achieved through projects conducted in cooperation with watershed associations, agricultural organizations, various governmental agencies and others. Management options will include maintenance, enhancement and restoration activities. The following management options and recommendations should be considered for protecting, enhancing, and preserving the Cooks Creek Watershed resources:

1. Develop a Water Management Plan

Using data developed from ongoing and future studies, develop a Sustainable Watershed Management Plan that provides for wellhead and baseflow protection in the Cooks Creek Watershed.

2. Monitoring Cooks Creek Flow

The critical baseflow condition $Q_{7\text{-}10}$ values are used in the Water Balance Model. The $Q_{7\text{-}10}$ has not been collected from the Cooks Creek Watershed using data from a ten-year period. Less than four years of data have been collected for this calculation. This equation requires the collection and use of 10 years of data, therefore, continued monitoring of the "Red Bridge Road" bridge location gauging station should be conducted to obtain the additional data required. The following maintenance actions should be conducted:

- *Maintenance of Red Bridge Gauge* – Continue to maintain and periodically download the computer at the Red Bridge Road monitoring station and upload into WAMOS;

- *Maintenance of the Rating Curve for the Red Bridge Road Gauging Station*. The Rating Curve requires annual riverbed profile measurements and periodic stream velocity measurements; and,

- *Install a Second Stream Gauging Station* – A second stream gauge station should be installed in the eastern edge of the watershed. Preferably this station should be upstream of the confluence of Silver Creek with the main stem of Cooks Creek, in the village of Springtown.

3. Monitoring Aquifer Levels

Water levels should be measured monthly at 4 to 6 residential wells. This data is used in groundwater storage and water budget calculations in WAMOS computer interface.

4. Generate an Upgraded Water Table Map.

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In this study approximately 75 residential wells were utilized to establish the water table map. An additional 30 residential wells are suggested to measure for depth to water to upgrade the water table map.

5. Expand the GIS Database

As more watershed related data becomes available, expand and incorporate all data into GIS and computer applications. Train municipal officials in the use and maintenance of GIS databases. Develop and maintain current land use maps.

6. Continue to Develop the Hydrologic Database managed using the computer interface WAMOS

As more hydrologic data becomes available, continue to incorporate, expand, and enhance the hydrologic database and facilitate its use in planning activities.

7. Develop a Nutrient Management Plan

Low level, chronic nutrient pollution has been observed in the watershed and has been shown to impact water and habitat quality. Perform a comprehensive nutrient balance to determine the sources and causes of nutrient enrichment in the Cooks Creek Watershed. Use this information to pinpoint appropriate management actions.

8. Develop a Township Level Storm water Management Plan

Extremely local erosion problems have been observed contributing to siltation in the streambeds. Given the sensitivity of the wildlife and fisheries of the watershed these problems should be carefully examined and controlled, if possible. Although a county-wide storm water management plan exists a specific township level plan should be developed to determine the locations and magnitude of storm water runoff in the watershed. Monitor erosion throughout the watershed and determine its causes. Develop a plan to manage both storm water and erosion and determine appropriate management actions.

9. Develop a Comprehensive Biological Inventory

Considerable biological resources exist in the watershed. In order to monitor the success of this plan and to alert officials to any future problems, work with local watershed groups to establish and monitor the health of the biological resources of the watershed including but not limited to:

- Fish population surveys;
- Rare and endangered species (flora and fauna);
- Wetland plant inventory;
- Bats of Mine Hill; and,

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- Benthic invertebrate diversity and health.

10. Expand and Maintain a Water Quality Monitoring Program

In order to expand water quality monitoring information and track improvement, the following community programs should be encouraged:

- Stream Watch Program (Philadelphia Academy of Sciences program or equivalent);
- Nutrient Survey and Management Plan; and,
- Visual assessment (Delaware River Basin Commission method or equivalent).

11. Educational Activities

Educational programs are necessary to change misconceptions regarding watershed resources and to encourage future protection and enhancement of Cooks Creek Watershed. The following educational programs or forums should be considered:

- Water Quality Seminars for Local Government Officials:
  - Maintaining current or limited ground water levels in order to protect against excessive groundwater drawdown that would result in adverse effects to wellheads and stream baseflows;
  - Suitability of soils for on-site septic systems including:
    - Soils feasible for conventional systems;
    - Soils feasible for alternative systems;
    - Soils not feasible for any type of on-site system;
    - Carbonate derived soils, not feasible in Bucks County for any on-site system; and,
    - Soils subject to flooding, not feasible for any on-site systems.
  - Minimization practices for point and non-point source pollutants; and
  - Improving riparian buffer management along tributaries.
- Public Workshops
  - Public awareness of non-point source pollution;
  - Implementation of animal nutrient management plans;
  - Improving farming practices especially with respect to livestock stream crossings and stream corridor livestock fencing initiatives; and,

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- School outreach.

12. Riparian Buffer Improvements

A complete assessment of current stream bank conditions should be conducted to determine priority sites within the watershed requiring riparian buffer enhancements. Riparian buffer improvement and management programs should be employed.

13. Ordinances and Planning Documents

Update the Comprehensive Plans for both Durham and Springfield Townships. Include the data in this plan, and referenced studies. Work to ensure that water quality and quantity are sufficient to support local vision for the future of the watershed.

The following critical areas should be considered for zoning ordinance and Comprehensive Plan preparation:

- Storm water management and erosion control;
- Wetlands protection;
- Baseflow protection;
- Conservation easements and open space;
- Endangered and/or threatened species habitat protection;
- Karst and sinkhole land development standards;
- Overlay districts of critical areas (first order sub-basins; wetland buffers; riparian (flood plain); and, lakes and ponds);
- Septic systems types based upon soil districts;
- Steep slopes;
- Stream or riparian buffers; and,
- Wellhead protection.

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We, the undersigned, in the interests of the citizens of Springfield and Durham Townships, will utilize the findings of this study to the best of our ability to effectively manage the resources of the Cooks Creek Watershed for the maximum benefit of all citizens:

Signed and attested, this _____day of _____, 2002

_____

Bartley Millett
Chairman, Durham Board of Supervisors

_____

Richard Johnson
Durham Board of Supervisors

_____

Manfred Marshewski
Durham Board of Supervisors

_____

Peter Lamana
Springfield Board of Supervisors

_____

James Hopkins
Springfield Board of Supervisors

_____

Rodney Weider
Chairman, Springfield Board of Supervisors

_____

Charles Halderman
Springfield Board of Supervisors

_____

Robert Zisko
Springfield Board of Supervisors

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A CASE FOR PROTECTION OF THE COOKS CREEK WATERSHED

A recent USGS publication stated, "As the Nation's concerns over water resources and the environment increase, the importance of considering groundwater and surface water as a single resource has become increasingly evident" (T.C. Winter, USGS -- Water Resources of the United States – Circular 1139). This certainly applies to the existing and future water supply and water quality issues in Pennsylvania. Whether the concern is source-water protection, drought management, wetland preservation, in-stream aquatic habitat, spring-water withdrawals, or total maximum daily loads (TMDL), an understanding of the interactions between groundwater and surface water is needed for resource management.

The issues surrounding growth patterns and overall water resources are not limited to municipal boundaries. The Pennsylvania Municipalities Planning Code enables water resources to be integrated into the overall land use and land management schemes. Individual municipalities within the Cooks Creek area (and elsewhere) have not been able to technically cope with matters that extend beyond their respective jurisdictions.

The geographical scope of the Cooks Creek Rivers Conservation Plan must be watershed-wide considering all aspects of water resources including: aquifers, quality and quantity, water supply, wastewater, and stormwater. It is the objective of this study to build on prior knowledge and formulate a resource management capability that sustains these resources for future use. Due to the unique and sensitive nature of the Cooks Creek system, it is important to manage and protect the creek, aquifer, springs, and wetlands as a whole. A holistic or watershed-based management approach is needed to address these concerns.

Watershed analysis is a unique approach that provides the basis for a sound understanding of watershed conditions and management options. Independent components influence watershed conditions, such as geology and climate. Within the confines of a watershed, the specific site geology may control vegetation, soils, hydrology, and stream morphology. Climate affects each of these variables, which in turn may affect watershed conditions. As land use and water consumption increase, the influence of man on the environment and watershed will be more profound and immediate.

In order to facilitate a holistic management plan, existing conditions within the Cooks Creek Watershed have been evaluated. Included in the evaluation were studies related to surface water quality, stream bank conditions and characteristics, groundwater availability and flow, geology, hydrogeology, and soil characteristics and types. A review of previous studies and assessments was also conducted.

The geology, hydrogeology, and soil study results were used to develop a management plan with respect to water use, stormwater and wastewater management, and to provide guidance for future development within the watershed.

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I. HISTORY

Durham Township

Durham Township comprises 6,410 acres and is one of the smallest of the 31 townships of Bucks County. It is located in the extreme northeast corner of the county. It is bounded northwest by Northhampton County, northeast by the Delaware River, southeast by Nockamixon Township, and southwest by Springfield Township.

Prior to its establishment as a township on June 3, 1775, it was a quasi-organization known as the Durham Tract. This land tract shares virtually the same boundary lines of the township today. Evidence points to settlement as early as 1698. Durham Tract was populated faster than surrounding counties due to the iron deposits located in the Durham Hills. Even though this area was growing at a fast pace, private ownership of the land by Durham Iron Company hindered its development into a “township”.

It was not until 1727 that a blast furnace was erected in the village of Durham. Power for the furnace was derived from the nearby Durham Creek. This historic landmark is preserved at the Mercer Museum in Doylestown, Pennsylvania. The Iron Works provided cannon shot for the Provincial government, presumably for the French and Indian War. The Continental Army was also supplied shot shells and cannon from Durham. The great chain stretching across the Hudson at West Point in the Revolution was made here. Each link weighed 250 pounds.

Little is know about the operations at Durham Iron Works. It began operations sometime in 1727 and on December 24, 1773, the owners of the company decided to partition the land. The partition divided the land into forty-four (44) tracts. One tract included the Durham Furnace itself and was apportioned to Joseph Galloway, his wife Grace, and daughter of Lawrence Growden. Mr. Galloway leased the iron works to George Taylor, who operated it from 1774 until 1780. During this time, Galloway had become the leader of the Tory side of the movement opposing Independence, and promptly sided with the British. He was accused of treason; his properties were seized and sold in 1779 to Richard Backhouse. Mr. Backhouse and his associates operated the furnace from 1780 through 1789. Thereafter, the furnace was not in operation and was sold to Judge William Long in 1819. The original furnace was demolished and replaced by a gristmill, which still stands.

In 1847 Joseph Whitaker and Company purchased the remaining 894 acres of the furnace tract. They built two (2) new blast furnaces located near the mouth of Durham Creek where it empties into the Delaware River. This company produced mainly pig iron and shipped their product by water and by train from Riegelsville, NJ. In 1864 the Whitakers sold the property to Edward Cooper and Abram Hewitt. Mr. Cooper was an engineer and inventor, who designed the hot blast stoves, double bell and hopper used at Durham.

After only 17 months, the property again changed hands and was deeded to Lewis Lillie & Son of Troy, NY. Lillie & Son then transferred their safe making operation to Durham. They enlarged the

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plant and derived power by damming the Durham Creek and digging a mile long race. Lillie & Son continued operating both blast furnaces in conjunction with local mines and quarries. Financial difficulties led to the take-over by creditors who operated the company under the name of The Lillie Safe and Iron Company. The Company was later sold to its previous owners, Cooper and Hewitt, on October 1, 1870. The new owners modernized the plant and added two (2) new blasts.

On December 27, 1901, the property was transferred to Col. John Jamison and Aaron F. Baker, who transferred the property in one (1) week to the newly chartered Durham Iron Company. This Company was in operation for approximately 7.5 years, prior to shutting down on June 23,1908. The plant was dismantled in 1912 and the real estate was later divided and sold. The history of the Durham Iron Works spanned 181 years, including suspensions. This company took its place in history from supplying shot in the Revolutionary War to discovery and invention of new metallurgy processes.

Other early industrial efforts throughout the region directly related to the agricultural economy. Scores of gristmills and sawmill operations were erected along the streams of the county that provided the necessary power for the mills. The great abundance of forests provided a natural lumber resource. The lumber was shipped downstream, where shipbuilding became an important industry in Philadelphia and other cities along the Delaware River. Robert Durham built the first Durham Boat in Durham Township, which was used to ship the iron product to Philadelphia. He is also credited with building the ship George Washington used in his famous crossing of the Delaware.

Durham Creek flows through the valley and is bounded on either side by high hills. There is a gradual ascent to the hills that permit cultivation of the land. There have been frequent discoveries of Indian relics in this area, suggesting the early occupation of the American Indian race.

The “Old Durham Furnace School”, erected in 1727, was the first school built in the Upper Bucks area. Children met in this small log house, located on the east side of the road leading from Easton to Philadelphia, approximately 100 yards north of Durham Creek. Many other schools were then built in the area, including the present-day Durham School built in 1865. The original school consisted of 2 rooms. In the 1920’s, two (2) more rooms and an all-purpose room were added.

Springfield Township

Springfield Township lies in the extreme northern area of Bucks County and borders Northampton and Lehigh counties, along Route 212. It is one of the largest and one of the least populous townships. In the southeastern portion of the township, the Indians settled a considerable hill, called “Buckwampum”. In this area near Stony Point, a great number of arrowheads and Indian implements have been found.

In 1735, William Penn's sons sold about 4,000 acres of their best land in southeastern Pennsylvania by lottery. These acres became known as the Lottery Lands of Springfield Township. Persons of German descent almost exclusively purchased the lottery tract. It is one of

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the last townships to be organized. It is assumed the early settlers found their way to this area during the time of settlement of the Durham Tract. Durham was an English settlement and the first purchasers of land in Springfield were of the same descent. It is recorded that some English settlers reached this area through the "Swamp" and "Richlands". The Germans followed the same route. Springfield Township is a valley where immigrants up the Delaware and Perkiomen Rivers met.

The earliest purchase of land in this area was in 1737, although settlers were in the area prior to this time. The land consisting of 651 acres on Cook's Creek was patented to William Byran.
One of the first German settlers, George Bachman, purchased 213 acres at the branches of the Tohickon and Saucon Creeks in the northwest part of the township. One of the oldest dwellings in the township can be dated to 1738.

A prominent citizen of Springfield Township was the Reverend A.R. Horne (1834-1902). The Reverend established the Bucks County Normal School at Quakertown, and remained in charge for five (5) years. He established *The National Educator* and was the proprietor and editor.

On June 16, 1743, the settlers of Springfield petitioned the court to permit their settlements to be "comprehended in a new township". The township was then surveyed and laid out immediately after this petition was filed. At this time there were 56 "dwellers", presumably heads of families. Springfield was given its name due to the vast number of springs and seeps that gushed out of its hillsides that formed brooks and creeks. The original boundary of the township did not extend quite to the line of the two Saucon Townships. The intervening strip of land was left between these three townships. This area was later added into Springfield Township borders, which closely resemble its borders today.

The first gristmill in Springfield was built by Stephen Twining in 1738. In 1861 Springfield's public school system was operational, comprising eleven (11) schools. The Springfield Church, known as Trinity, Reformed and Lutheran was established prior to 1745 and is one of the oldest in the northern townships of Bucks County. The first house was built of logs and served as both church and schoolhouse. The Mennonite congregation in Springfield built their first meetinghouse in 1780.

Several roads in Springfield were constructed dating to 1742. These roads connected key areas both in and around Springfield. Key areas included: Bethlehem, Houpt's mill, Durham, Strawns Tavern, and Fretz's gristmill. It is thought that the "Indian Walk of 1737" passed through Springtown. The post office was established here in 1823, with Joseph Afflerbach appointed as postmaster.

Today Springfield boasts many historic landmarks including: Springtown Hotel, Springfield Union Church, Liberty Bell Trolley, Pleasant Valley Bridge, and Pleasant Valley Grist-Mill.

Information gathered from various resources was used to create a map of the locations of historic significance throughout the watershed (Figure A). Current records reflect that:

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- 186 historic places or agricultural resources are located within Springfield Township;
- 13 historic places or agricultural resource areas worthy of further study are located within Durham Township;
- 19 sites within the watershed are eligible for placement on the National Register;
- 2 sites are National Historic Landmark sites; and,
- 15 sites are suggested for further study for their potential historical or cultural significance.

Several scenic roadways (19.5 miles) are also present within the watershed. These are also shown on Figure B.

Numerous colonial period homes, public houses, and inns still survive in both Durham and Springfield Townships. The Durham Gristmill stands on the site of the original Durham Furnace, and is a fine illustration of the importance of waterpower to the colonists. Cooks Creek was diverted using a system of wing dams and raceways, still being maintained by Durham Township. The mill itself ceased operations only in recent years (1960s) but is no longer operational. Plans are in place to restore the building and water wheel. In addition to the iron, the area was well known as a good source of lime for agricultural purposes, and numerous limekilns, in various states of disrepair, can be observed. Although historically, the pervasive network of tributaries resulted in a host of covered bridges being built, only one of these quaint structures still remains. Fire and flood have taken their toll, but the Knecht's Bridge off Slifer Valley Road in Pleasant Valley still provides a touch of historic class to Springfield Township.

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II. PROJECT AREA CHARACTERISTICS

Location

Cooks Creek Watershed is located in southeastern Pennsylvania, between 40 ° 23’ 13.90” and 40 ° 3 6' 24.20” north latitude and 75°11' 50.40” and 75°20' 57.00” west longitude. Cooks Creek is a tributary to the Delaware River and is located primarily in the northern part of Bucks County (Figure 1). Most of the watershed areas are located in Springfield (70.29%) and Durham (19.39%) Townships. Small portions of the watershed are located in the neighboring Townships of Richland (0.72%), Haycock (0.21%), and Riegelsville Borough (0.03%). Minor portions of the watershed basin are also located within Lehigh County (Upper Saucon Township, 0.28%) and Northampton County (Lower Saucon Township, 6.83% and Williams Township, 2.25%). The watershed has a vertical elevation drop of 625 feet from the headwaters to its confluence with the Delaware River.

Size

The stream originates along the southern slopes of Flint Hill in Springfield Township. Cooks Creek flows approximately 18 miles in a northeasterly direction to its confluence with the Delaware River at Durham Furnace. The entire Cooks Creek basin, including its 37 miles of unnamed tributaries, drains approximately 30 square miles of predominantly private lands.

Topography

The watershed is approximately 9.5 miles long and 4 miles wide with an elevation ranging from 140 feet above mean sea level (MSL) at the mouth to approximately 1,000 feet above MSL on Flint Hill along the northern boundary with Lehigh County. Approximately 36 % of watershed is too steep (15% or greater) for development according to the Bucks County Conservation District criteria.

In order to better understand the unique topographic characteristics of the watershed Figures 2, 3, and 4 have been prepared. Figure 2 presents the topographic contour map of the region. This map was digitized and compiled from the Riegelsville, PA-NJ, 1990, Hellertown, PA, 1992 Quakertown, PA, 1973, and Bedminster, PA, 1990 USGS 7.5 minute Quadrangle Maps. Figure 3 was developed to easily identify elevations within the watershed utilizing a Digital Elevation Model (DEM). Figure 4 illustrates the main tributaries of the Cooks Creek Watershed and the drainage pathways of the tributaries, utilizing hill-shaded rendering data. This presents a three-dimensional image of Cooks Creek Watershed, by simulating the sun on the northern horizon casting shadows on hills and valleys.

Major Tributaries

The Cooks Creek Watershed includes a total of 40 sub-watersheds that were delineated by the outline of the drainage basin divides pattern (Figure 5). Figures 5-1 through 5-7 present sub-basin identification information. The *stream order* of these sub-watersheds are important to note, as *first*

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order sub-watersheds account for 66% of the land surface in Cooks Creek Watershed. Based upon the geologic sub-basins, *first order* stream regions (Area 1, Area 3, Area 4, Area 6, and Area 7) and all higher order stream regions (Area 2 and Area 5) were established in this study (Figure 6.1 and Figure 6.2).

A *first order* stream is the original headwater tributary that flows from a spring or seep. This area is usually the steepest portion of the watershed and therefore can be severely impacted by the loss of vegetation. A perennial stream that flows year round is considered a *first order* stream, while an ephemeral or temporary stream (i.e., storm flow channels etc.) is not. When two *first order* streams converge, they form a segment known as a *second order* stream. Two *second order* streams merge to form a *third order* stream, and so on. *First* and *second order* headwater streams generally provide the greatest surface area of the watershed system and they also allow the greatest exposure to pollutants within the system.

It is also important to note that Pennsylvania Department of Environmental Protection (PADEP) has established a system for classifying streams in the State as specified in Chapter 93, Title 25 of the Pennsylvania Code. The standards are based on water uses which are to be protected and will be considered by PADEP in its regulation of discharges from sewage treatment plants, industrial plants, and stormwater management facilities. Current Water Quality Classifications for the Cooks Creek Watershed are shown on Figure 7.

The highest quality designations for a streams or watersheds are considered Cold Water Fishes (CWF). Cooks Creek Watershed has been designated a CWF. Additional classifications and uses of streams are summarized below:

- CWF – *Cold Water Fishes* – Maintenance and/or propagation of fish species including the family Salmonidae and additional flora and fauna which are indigenous to a cold water habitat.

- MF – *Migratory Fishes* – Passage, maintenance, and propagation of anadromous and catadromous fishes and other fishes which ascend to flowing waters to complete their life cycle.

- TSF – *Trout Stocking* – Maintenance of stocked trout from February 15 to July 31 and maintenance and propagation of fish species and additional flora and fauna, which are indigenous to a warm water habitat.

- WWF – *Warm Water Fishes* – Maintenance and propagation of fish species and additional flora and fauna, which are indigenous to a warm water habitat.

Chapter 93 also includes two categories of Special Protection Waters:

- HQ – *High Quality Waters* – A stream or watershed that has excellent quality waters and environmental or other features that require special water quality protection.

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- EV – *Exceptional Value Waters* – A stream or watershed which constitutes an outstanding national, State, regional, or local resource, such as waters of national, State, or county parks or forests, or waters which are used as a source of unfiltered potable water supply, or waters which have been characterized by the Fish Commission as "Wilderness Trout Streams", and other waters of substantial recreational or ecological significance.

The entire Cooks Creeks basin has been designated as an *Exceptional Values (EV) CWF* Waters.

The major tributaries to Cooks Creek are: Silver Creek (Silver Creek) and Hollow Coons Run.

Watershed Corridor

The watershed corridor consists of the tributaries and drainage channels that comprise the watershed as a whole. "Waters of the United States" or "Waters of the Commonwealth" include all wetlands, ponds, lakes, streams impoundments, and intermittent drainageways that can eventually be linked to interstate or foreign commerce. Almost all tributaries above the intermittent stage are considered "Waters of the United States".

The Cooks Creek Watershed corridor is comprised of the hills, valleys, and open areas where the waterways flow. Cooks Creek has a diverse watershed corridor comprised of broad open valleys, valley bottoms, and gentle stream gradients dictated by the underlying geology of the area.

The stream morphology or the characteristics, patterns, and profiles of the stream are typical of eastern Pennsylvania waterways. Land use along the corridor is a mixture of agricultural, residential and forested lands, with almost no industrial land use. The overall condition of the watershed corridor is good with the need for riparian buffer zones and stabilization in limited areas resulting from historical agricultural practices.

Climate

The region is part of the Eastern Broadleaf Forest Ecoregion (Bailey 1995). The climate of the area is classified as cool temperate, with an average growing season length of 160 days. The average annual precipitation of 42 inches occurs throughout the year, but precipitation rates are slightly higher in the summer months (Cuff et al. 1989).

Watershed Land Use

The Cooks Creek valley is predominantly rural/agricultural, in fact, 58 % of the Durham Carbonate Valley is used for agricultural purposes. Woodlands represent 15 % of the land area. The residential (15 %) and commercial, manufacturing, and institutional land uses (2 %) are located mainly along Route 212 and are concentrated in the villages of Springtown and Durham. The vacant undeveloped area of this valley comprises the remaining 10 % of the land area (Figure 8).

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Land Use Patterns and Trends (Bucks County)

The following natural features characterize the Cooks Creek Watershed. Future planning solutions for development and conservation can be derived from this information.

Historically, farms, villages, and country towns characterized Bucks County. However, the period just after World War II marked a mass migration from Philadelphia and the sub-urbanization of many parts of the county (especially in the lower Bucks County region). Since that time, Bucks County has been one of the fastest growing counties in the state. This can be attributed to several factors including: proximity to major metropolitan areas, accessibility to regional highway and transit systems, availability of developable land, extensive environmental and cultural resources, significant business and economic activity, and continued migration of population from cities to suburbia. Today, Bucks County is a diverse community with decentralized population and employment areas. Notwithstanding past growth, over half of the county currently consists of agricultural, rural residential, or vacant land uses (located primarily in the central and upper Bucks County regions).

Despite the continued high levels of growth during the past decade, land consumption for residential development generally appeared to be occurring at a slower pace. The reduced consumption of land can be attributed to: the slower rate of growth for housing development, the nearly built out stage of certain areas, and the trend for the concentration of the development of reduced lot size and cluster housing. The reduction in land consumption is reflected in the county's average acreage per dwelling unit statistics. These statistics indicate that land consumption reduced from 0.718 acres/unit in 1970 to 0.537 acres/unit in 1990. The consumption of land for non-residential development in the county has been steady over the past three decades, resulting mainly from construction of industrial parks, office parks, shopping centers and expansion of existing commercial areas.

As lower Bucks County approaches build out capacity, development pressures have crept into central Bucks County. This region is expected to receive the majority of future residential and non-residential growth. Central Bucks County is expected to grow at a faster pace than in previous decades, with Upper Bucks County following close behind.

The Upper Bucks County region is the most rural area of the county. The total land area for the region is approximately 263 square miles or roughly 43% of the total county area. With the exception of several small areas of concentrated development in and around the nine existing Boroughs and numerous villages, it has the highest percentages of rural residential (64%) and vacant land (52%) use in the county.

A significant portion of this region contains natural resources, which may limit development, including: steep slopes, wetlands, floodplains, and soils with shallow depths to bedrock. In addition, recreation and tourism constitute a significant portion of the region's vitality and provides visitors with an ample supply of recreational land and numerous historic inns. In fact, this region has the highest concentration of park and recreational acreage, and State Game Lands in the

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county. The Pennridge and Quakertown planning areas of the region have public water and wastewater systems throughout its Boroughs and adjacent areas under development. In contrast, all of the Palisades planning area within the watershed, including Durham and Springfield Townships are serviced by on-lot sewage treatment systems. Springfield Township does provide wastewater treatment for the village of Zion Hill, however, this area is not in the watershed. Finally, the region is served by the Quakertown, Palisades, and Pennridge School Districts.

Various townships and municipalities other than Durham and Springfield have limited lands within the watershed. These lands account for a minimal area of the watershed, therefore, only the Springfield and Durham Township zoning districts have been included within this study.

Zoning -- Durham Township

The Durham Township Natural Resources Plan identifies the township as prime agricultural land, forest, steep slopes, scenic areas, wetlands, streams, floodplains and ponds (Figure 9).
Agricultural land is most valuable to society when it is cultivated. It is crucial that it be preserved in parcels large enough to permit efficient farm operations and to allow adequate separation or buffer from non-farm activities. If prime agricultural soils are to remain productive, their extreme low tolerance to extensive development must be recognized. Agricultural lands comprised 36% of the Township land in 1994 (Bucks County Continuum, Bucks County Planning Commission, January 1994).

Other natural resources such as forests, steep slopes, scenic areas, wetlands, streams, floodplains, and ponds have evolved over time and are a part of the ecologic systems of the region. They also represent the areas of the greatest aesthetic beauty within the Township. Individually and collectively these natural resources are highly interdependent. The destruction of any one resource could have far reaching effects, not only on the natural systems in Durham Township, but in surrounding municipalities as well.

The following is a list of primary zoning districts within Durham Township (Zoning Ordinance, December 1992):

- *Resource Protection (RP).* The land in this district is identified in the Durham Township and Bucks County Comprehensive Plans. These lands contain important resource features and historic areas. The two-fold purpose of this ordinance is to: 1) maintain the agricultural industry and preservation of farmland and 2) to protect the valuable natural resources.

- *Village Center (VC).* This area is designed to preserve the character and integrity of Durham Village. Specific development and construction criteria must be maintained in order to protect the historic nature of the Village.

- *Development Districts.* These areas are designed to accommodate the anticipated growth within the Township. The purpose of development areas is to control and regulate development in order to coordinate the provision of public services. Residential

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development is encouraged in these concentrated areas, which will promote the most efficient use of land. The two development districts are outlined below.

- *Rural Residential Area (RR).* The purpose of this district is to accommodate all types of residential structures to ensure a balanced community. The district encourages continued development of Riegelsville Borough as the regional center.

- *Planned Industrial-Commercial Area (PC-I).* This area is designed for planned industrial and commercial uses in an appropriate location with access to arterial highways and public services. The intent of this area is to encourage high quality industrial and commercial development. This development enhances the employment opportunities within the Township. These areas are designed with adequate road access and public utilities to minimize adverse impacts on the surrounding natural resources and residential areas.

- *Limestone Region*. This is not a separate zoning district but it is an area that extends through various districts within the Township. Careful consideration during design and construction is required to protect against future damage or destruction (i.e. sinkholes, fissures, etc.).

- *Floodplain Conservation District*. The purpose of this area is to prevent the loss of property and life through restrictive zoning. It also provides for flood protection and relief.

- *Steep Slope Areas*. This area provides for permitting uses of steep slopes in areas which are compatible with preservation of natural conditions and which maintain stable soil conditions.

Zoning -- Springfield Township

The zoning ordinance for Springfield Township was reviewed (Zoning Ordinance, August 1990). A brief description of these areas is presented in the following list of primary zoning districts:

- *Agricultural District (AD).* The purpose of the Agricultural District is to recognize and protect the area designated as a significant agricultural area by Bucks County in its Natural Resources Plan and the areas of the Township where farming predominates.

- *Watershed District (WS).* This district is designed to protect the existing watershed. It provides for low intensity development compatible with the natural features of the watershed.

- Res*ource Protection District (RP).* The purpose of this district is to protect areas consisting largely of natural features such as: forest, steep slopes, scenic areas, wetlands, streams, floodplains, and ponds.

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- *Rural Residential District (RR).* The purpose of this area is to preserve the rural character of the Township. This area provides for the residential growth of the Township. All types of residential uses are permitted at various densities according to the underlying geology of the site. Development will relate to the natural physical characteristics such as waterways, woodlands, topography, and soils in order to protect and preserve these natural features and the open character of the countryside. Areas underlain with limestone must employ development practices and designs that will not adversely affect the structural integrity of the underlying strata.

- *Development District (DD).* This area is established to accommodate anticipated growth of the township. These areas are served by public sewers and include high-density housing.

- *Village Commercial District (VC).* Village centers are specifically structured to accommodate municipal, retail, and institutional uses considered to be essential to the function of residential neighborhoods. The village center is located within a limestone region; therefore, appropriate siting of sewage disposal systems is mandatory to prevent pollution of groundwater sources.

- *Planned Industrial District (PI).* This area is designed for planned industrial and commercial uses in an appropriate location with access to arterial highways and public services. The intent of this area is to encourage high quality industrial and commercial development. This development enhances the employment opportunities within the Township. These areas are designed with adequate road access and public utilities to minimize adverse impacts on the surrounding natural resources and residential areas.

- *Highway Commercial District (HC).* This district was specifically designed to provide for highway commercial uses along Route 309. The Route 309 corridor is not within the boundaries of the Cooks Creek Watershed.

- *Floodway Protection Overlay (FP).* This area is an overlay district and as such it adds to existing regulations in the district affected. This area provides for the protection of stream corridors subject to flooding.

- *Scenic District Overlay.* The purpose of this district is to protect the unique visual character of the township. It is designed to minimize adverse visual impacts.

Socioeconomic Profile

Population Centers

The information was derived from the Bucks County Planning Commissions Municipal Demographic Profile of Bucks County (February, 2000) and the Bucks County Continuum (January, 1994). These records were used to illustrate changes in population over time. Population and housing unit projections are important as they help to identify future water needs.

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Durham and Springfield Townships and Riegelsville Borough were utilized to demonstrate the growth rates and the socioeconomic profile of the watershed. The watershed is relatively undeveloped, with pockets of urbanization along the Silver Creek and Cooks Creek Valleys.

Durham Township and Riegelsville Borough experienced a population growth of less than 100% from the period of 1930 through 1990, while the surrounding municipalities, including Springfield, experienced a population growth of 100 to 499% for the same time frame. In fact Riegelsville has experienced a decrease in the population.

Adjustments to municipal population projections were based upon potential growth scenarios and stages of development of each municipality. Population projections for the three areas show a steady increase in the numbers of residents for the area. The table below presents these projections.

	Population 2000	Projected Population 2020	% Growth
Durham Township	1,420	1,970	38.7%
Springfield Township	5,660	7,760	37.1%
Riegelsville Borough	1,020	1,240	21.6%

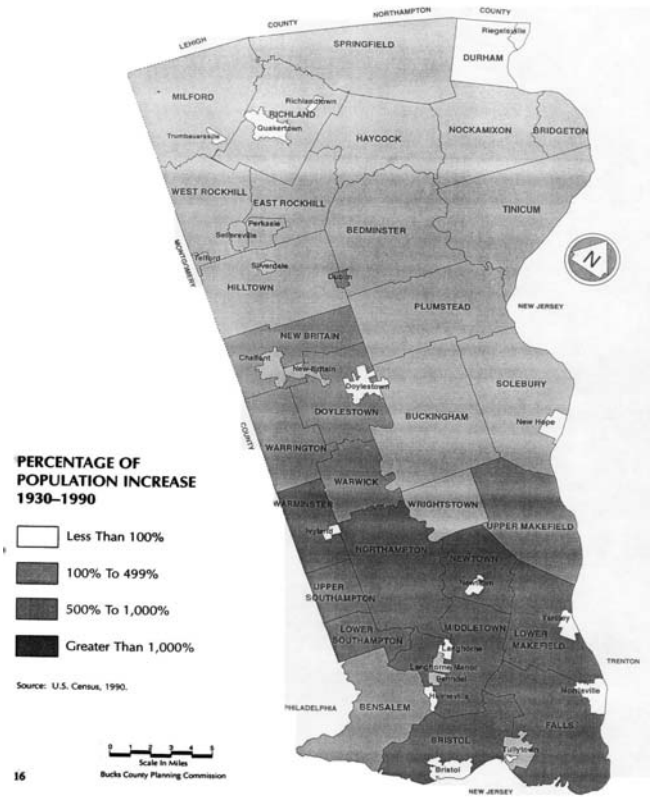

Figure 10. Percentage of population increase 1930 – 1990.

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Housing projections were developed for the county as a whole and served as a control total for municipal projections, which were produced separately. By the year 2020 housing units in the three major municipalities within the watershed are expected to increase. The table below presents the projections in housing units for the watershed.

	Housing units 2000	Projected units 2020	% Growth
Durham Township	~600 units	720 to 810 units	20 to 35%
Springfield Township	~2,220 units	2,530 to 2,860 units	14% to 29 %
Riegelsville Borough	~430 units	440 to 500 units	2% to 16%

These projections are designed as tools to plan for what may occur if the demographic characteristics and trends remain constant to the year 2020. The projections for specific areas are discussed below. The Cooks Creek Watershed is primarily within the *Palisades Area.*

Palisades Area Profile

The Palisades planning area, which includes Durham and Springfield Townships, is predominantly rural and constitutes approximately 38% of the region and 16% of the total county land area. The area contains a high concentration of natural resources including: streams, the Delaware River, floodplains, wetlands, steep slopes, significant agricultural areas, and woodlands. Significant geologic features such as Ringing Rocks, Durham Caves, High Rocks, and Nockamixon Cliffs are located in the planning area. There are several high quality streams in this area, including Cooks Creek and portions of Rapp and Tinicum Creeks. The planning area also contains several county parks, various state game lands, and approximately one third of the Delaware Canal State Park. Water and sewer facilities are almost exclusively on-lot.

Palisades Area Development Trends

In the past, growth in the upper Bucks region was slow, with only limited residential and non-residential subdivision and land development located predominately in or around the existing boroughs. Currently agricultural, vacant, and rural residential land uses constitute approximately three quarters of the total regional land area. The densest development is centered around Quakertown Borough and the corridor between and including Telford, Perkasie, and Sellersville boroughs. The upper Bucks region is projected to grow at a faster pace than in previous decades. The economic stability created by public water and wastewater systems and the strong commercial and industrial presence makes the Quakertown and Pennridge planning areas very attractive for future growth. Improved access to Route 611, Route 309, and Interstate 78 may facilitate increased growth pressure throughout the region.

Durham Township Development Trends

The Bucks County Housing Plan projected that Durham Township will need an additional 1,820 housing units to reach its full development capacity. The county presented two alternative approaches that the Township could take in planning for future growth. One alternative is the

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comprehensive plan with the traditional zoning techniques. The other alternative is the Development Area concept. Both provide for the same degree of development, but each utilizes a different approach.
The traditional approach divides the entire township into different use districts, (i.e., residential, commercial or industrial, etc.). In this approach development is controlled by the availability of adequate roads, sewers or other essential facilities necessary for development. This approach encourages scattered, sprawling development patterns and does not preserve open space or agricultural land. The Development Area concept, allows for farmland and open space preservation by realizing that most development should occur in areas where services already exist or where they can be reasonably provided.

Transportation Facilities

Transportation access to employment centers throughout upper Bucks region is relatively good through highway access. These highway systems include: Routes 113, 212, 309, 313, 663, 412, 413, 611 and the Northeast Extension of the Pennsylvania Turnpike. Primary transportation access to the Cooks Creek Watershed is gained from Routes 212, 611, and 412.

Three airports are located in the region, however there are no airports within the watershed.

Historically, rail access was important to the mining and metallurgy industries of Durham Township. While the remains of several trestles exist within the bed of Cooks Creek and historical railbeds can be seen along the Creek, there are no functioning railways in the Watershed.

Major Sources of Employment

According to the Bucks County Continuum (January, 1994) and the Municipal Demographic Profile of Bucks County (February, 2000), the major sources of employment within the area are: mining and manufacturing (34 to 35%), service industry (28 to 31%), and wholesale/retail trade (17 to 23%). Labor force and employment estimate projections also show a steady increase over time within the area of the watershed. However, there are no specific businesses that have a significant impact on the watershed, nor are any businesses located in the watershed itself that employ significant numbers of people.

Outstanding or Unique Features

Cooks Creek boasts good to excellent water quality, a diverse macro-invertebrate benthic community, and a Class A wild brown trout (*Salmo trutta*) population. In addition, tributaries to Cooks Creek support both Class A wild brown trout populations and Class A wild brook trout (*Salvelinus fontinalis*) populations. The entire Cooks Creek drainage basin is classified as an *Exceptional Value (EV) coldwater fishes (CWF)* waters. These standards are based upon the health of the biological communities present in streams and rivers.

The main stream is a moderately alkaline, well-buffered limestone stream that supports excellent aquatic macro-invertebrate populations and a Class A wild brown trout population. Class A wild

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trout populations are also present in Silver Creek and Coon Hollow Run (tributaries to Cooks Creek). The wild brown trout populations in the Cooks Creek basin are unique in Bucks County. The wild brook trout population in Coon Hollow Run is not only unique in Bucks County, but is also very rare in the Pennsylvania Fish and Boat Commission (PFBC) fisheries management region Area 6. Surface and groundwater resources in the basin, upon which the Class A wild trout populations depend are very susceptible to contamination due to the underlying limestone geology.

The wild brown trout populations in Cooks Creek are probably limited by two factors: seasonal elevations in water temperatures and restricted physical habitat. Cooks Creek was divided into three sections, describing stream characteristics influencing the wild trout population (Figure 11).

- **Section 1** of Cooks Creek (headwaters section) lies upstream from the major limestone influences. Relatively poor physical habitat combines with a lack of riparian buffers in many areas (resulting in warming of the water). These characteristics make this part of the watershed unsuitable for supporting a wild trout population.

- **Section 2** of Cooks Creek (middle section) supports a Class A biomass and has somewhat restricted physical habitat for adult trout.

- **Section 3** (located toward the mouth of the creek) has less physical habitat than Section 2, and therefore supports less biomass.

Wild trout populations in Sections 2 and 3 are probably at their physical carrying capacities. Electro fishing in both sections, particularly in Section 3, detected adult trout. The PADEP should continue to protect the EV-CWF status of the Cooks Creek basin. This is necessary to protect the uniqueness of this area and its' scenic and historical qualities.

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III. Issues, Constraints, and Opportunities

This section identifies recommendations from previous studies and investigations performed for assessing watershed conditions and/or resources that will aid in the protection and management of watershed resources. In addition, a summary of existing data gaps which may require further study or investigation to address watershed concerns is presented.

Previous watershed investigations performed by PADER (1990), PA Fish and Boat Commission (1992 & 1993), Township of Durham (1995), Symbiosis Environmental (1998), Morris Arboretum (1999), and DTEAC / MJE (2000) on Cooks Creek Watershed have been reviewed. The following is a list of the recommendations made based upon this literature review. See Appendices A for a summary of each report.

Recommendations presented in the PADER 1990 Report

- Based on the Department's evaluation of the Cooks Creek Watershed, a change in the basin's water use designation to EV status is appropriate. Justification for a basin wide EV designation, include:
    - The excellent water quality of Cooks Creek and its tributaries have better than applicable standards. The limestone influenced water quality and associated aquatic biota of Cooks Creek are rare in this part of the state.
    - Redesignation as EV would provide a degree of protection for this water source.
    - Due to the carbonate lithology, a number of geologic formations found in the basin have been identified by the Department as having aquifers that are easily contaminated. The association of surface water and groundwater typically found in limestone influenced streams, makes the protection of groundwater quality highly dependent upon the protection of surface water quality. This is especially important due to the widespread use of groundwater for domestic use.
    - Local planning agencies have documented their desire to preserve the unique resources found within the Cooks Creek Watershed. Local zoning is compatible with and would be complemented by an EV designation.
    - Naturally reproducing brook and brown trout populations, as well as the migratory American eel (*Anguilla rostrata*), have been documented in the Cooks Creek basin by both the PFBC and the Bureau of Water Quality Management.
    - The Cooks Creek Watershed, because of its juxtaposition to the Delaware River corridor, is utilized by a number of migratory avian species. Not only are resident species dependent upon the continued excellent water quality, but also so are migratory species, which utilize the basin as an important stopover point during the spring and fall.
    - Cooks Creek is a 1-A candidate in the Scenic Rivers System Inventory. The basin provides a variety of outdoor recreational opportunities which do not require modification of the existing natural setting including fishing, hunting, birding, horseback riding, cross country skiing, hiking, and sight-seeing.

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- More than 150 delineated wetland areas exist in the Cooks Creek basin. At least one wetland in the basin is of exceptional ecological significance, supporting numerous rare and endangered wildlife and plant species.
- Ten species of special concern in Pennsylvania have been recorded in the Cooks Creek Watershed. The Nature Conservancy has documented the current existence of several endangered herpetofaunal species within the basin, including the bog turtle (*Clemmys muhlenbergii*), the eastern mud salamander (*Pseudotriton montanus*), and the red-bellied turtle (*Chrysemys rubriventris).*

Recommendations presented in the PA Fish and Boat Commission (PFBC) 1992 Report

- The Pennsylvania Department of Environmental Resources (PADER) should continue to protect the entire Cooks Creek basin with the EV-CWF designation.
- The Bucks County Conservation District (BCCD) should investigate the sources of the moderate siltation of Cooks Creek, noted by the PFBC and pursue corrective actions. These areas are described in Section 01 of the report. They include: the area downstream from the State Road 4067 bridge, the downstream side of a private farm road bridge in Gruversville vicinity, the area downstream from the Township Road 485 bridge, and the area downstream from the State Road 4069 (Slifer Valley Road) bridge.
- Bank erosion in a pasture immediately upstream from the village of Pleasant Valley was noted. Measures should be taken to correct this problem.
- Best management practices on farmlands upstream from Springtown should be implemented to better control surface runoff into tributaries and the main stem.
- The BCCD should investigate the PADER report that livestock have free access to unnamed tributaries within the Cooks Creek basin and pursue corrective actions.
- The PFBC should continue to manage the wild trout populations in Sections 02 and 03 (downstream from the State Road 212/State Road 412 bridge to the mouth of the creek at the Delaware River) with conventional, statewide angling regulations.
- The Springtown Rod and Gun Club should restrict plantings of adult trout in Cooks Creek. Plantings should be restricted to the sections upstream from Springtown and downstream from Durham, contingent upon landowner permission.
- If interested, the Bucks County Chapter of Trout Unlimited should pursue habitat improvement projects in Section 03 (downstream of Red Bridge Road bridge) of Cooks Creek.
- The PFBC Area 6 Fisheries Management staff should reconnoiter Section 03 of Cooks Creek to determine whether or not the site's habitat was representative of the entire area. If not, a second, more representative site for a trout population estimate should be selected.
- Township officials should consider enacting ordinances that will prevent future development from denuding stream banks of trees and natural vegetation. Trees and vegetation provide the necessary shade to maintain cold-water habitat for Cooks Creek's trout population and will protect against further bank erosion. Bank erosion contributes sediments to the stream, which negatively impact fish and aquatic insects, resulting in the stream becoming wider and shallower.

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Recommendations presented in the PFBC 1993 Report

- The BCCD should investigate the sources of heavy siltation in Coon Hollow Run and take corrective action. Probable sources are from agricultural and dirt road run-off.
- Local land use planning agencies should recognize the unique and sensitive nature of Coon Hollow Run in Bucks County. Township officials should enact zoning laws and other restrictions that will protect the stream from degradation.
- The PFBC should continue to manage Coon Hollow Run under conventional, statewide angling regulations.

Recommendations presented in the Symbiosis Environmental 1998 Report

- Both Coon Hollow Run and Cooks Creek appear to be in excellent health and continue to be worthy of their EV status.
- The benthic communities within Coon Hollow Run and Cooks Creek are sensitive to low flow conditions, and should be considered carefully when planning water usage within the Township. This can be accomplished by: restricting over-utilization of groundwater and surface water resources, avoiding permanent degradation of the stream ecosystem, and increasing regulation of land use practices.
- The PFBC 1993 report mentions siltation in the downstream reaches of Coon Hollow Run, and that this siltation is likely due to the presence of an unpaved road crossing the stream. Siltation can result in decreased habitat for benthic invertebrates and decreased sites for trout spawning. In an effort to protect the sensitive benthic and fish communities, the Township may wish to consider streamside erosion management at the Coon Hollow Road crossing.

Recommendations presented in the Morris Arboretum 1999 Report

- Several stream valleys including Cooks Creek were deemed as high-priority sites due to their high quality aquatic resources. Township managers should continue to strive to protect these areas with open space protection areas.
- The regions continuous forest cover and unusual geology should be protected. This area provides a habitat for birds and other species that are dependent upon extensive tree-covered areas.

Recommendations presented in the DTEAC / MJE 2000 Wetlands Conservation Plan Report

- Possible actions for the maintenance and preservation of the wetlands and the unique natural resources within the Cooks Creek Watershed include:

    - *Watershed Management*. Because of the unique and sensitive nature of the Cooks Creek system, it will be important to manage and protect the creek, aquifer, springs, and wetlands as a system. A holistic management approach that recognizes the connections between various elements and uses a number of different approaches is recommended.

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- *Comprehensive Plan, Environmental Element*. One important step is to develop an element of the Comprehensive Plan that discusses the valuable social and environmental benefits of the Cooks Creek Watershed. This is important because the Comprehensive Plan serves as the blueprint for Township decisions on land use and development. A thorough discussion of environmental considerations should be included in the Comprehensive Plan. The Environmental Element should include a discussion on the natural resources inventory as well as goals, objectives, and strategies for protecting valuable environmental resources.

- *Cooks Creek Overlay District or Environmental Ordinance*. One option to consider is an "overlay" ordinance for Cooks Creek that would require new development projects to identify sensitive resources, and use best management practices to protect these resources. An overlay district is a special designation within the Zoning Ordinance that contains additional requirements beyond those required by current zoning, focusing on protecting special resources. Overlays are typically used for valuable river systems, public water supply reservoirs, historic areas, etc. As an alternative, a Township-wide environmental ordinance could be developed that has similar requirements to the overlay district. Some of the basic features included in such ordinances are described below:
    - Identification or inventory of sensitive resources such as karst or aquifer recharge areas, wetlands, springs, steep slopes, highly erodible soils, highly permeable soils, and 100-year floodplains within the overlay zone.
    - Inclusion of a vegetated buffer within the overlay zone. This buffer of vegetation extends landward (approximately 100 feet) from streams and creeks. This vegetated buffer is important for the protection of water quality because it traps some of the pollutants that would otherwise be transported into the stream with stormwater.
    - A requirement for evaluation of the impacts to sensitive resources and water quality (surface water and groundwater) from proposed development. This approach can be broadened to require an analysis of the natural, physical and socio-economic environment for new development projects anywhere in the jurisdiction. For example, Tinicum Township has an ordinance that requires an Environmental Impact Assessment Report with similar broad ranging requirements for new development.
    - Mitigation steps to avoid, minimize, or mitigate for the impacts to sensitive resources described above.

- *Growth Management*. Other planning tools that could be considered include growth management ordinances that promote cluster development, preservation of open space and riparian corridors, and transfer of development rights to protect rural areas.

- *Education*. Continue to expand public outreach efforts that emphasize the public benefits of environmental stewardship and watershed management. This approach

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could involve seminars or newsletters for residents, industries, and farmers on the importance of protecting the watershed and how they can help.

- *Water Monitoring Program*. Consider developing a water quality-monitoring program of the stream and the primary water supply aquifer. Several stream monitoring programs have been implemented elsewhere including one developed by the PADEP and a nationwide program by the Isaac Walton League, which relies on citizen efforts. A similar program has been developed by the Alliance for the Chesapeake Bay, within the Chesapeake Bay Watershed. One option is to consider a program that uses remote sensing to track the health, type, and extent of wetlands in the watershed and water quality. Such programs have been implemented in other important watersheds such as the Everglades and Chesapeake Bay. Remote sensing has the ability to cost-effectively identify many water quality problems, drought stress in vegetation, and plant community changes. This effort would require a source of funding or a collaborative effort with a research institution or consultant with the capability to perform such analysis.

- *Funding*. Consider seeking additional funds to develop a watershed approach for management and preservation of the Cooks Creek natural resources, water quality, and groundwater resources.

- *Protection of Sensitive Areas and Vulnerable Wetlands*. Promote the protection of sensitive segments of the watershed (i.e. riparian zones) and wetlands through fee simple acquisition, use of conservation easements, and re-establishment of vegetated buffers. The focus of this effort should be wetland areas that are important to aquifer recharge, wetlands that are disturbed or impacted, springs and seeps that contribute base flow to the stream and wetlands, and habitats that support rare species, and headwaters segments of the Cooks Creek tributaries. The following wetland areas should be targets of this effort:
  - Wetlands within karst-prone geologic formations;
  - Wetlands with potentially suitable habitat for endangered and threatened species such as Area D, Area P, Area X, Area Y, Area AA, Area AC, Area AD; and,
  - Disturbed wetlands included in Area J, Area M, Area T, Area W, and Area X.

Other Critical Issues for the Watershed

- Nutrient pollution;
- Stream bank erosion;
- Loss of stream bank cover;
- Outdated planning documents and accompanying zoning ordinances;
- Baseflow loss (stream water level decreases);
- Loss of habitat for flora and fauna especially threatened and/or endangered species;
- Karst topography related issues.

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Data Gaps

Additional studies or investigations required to aid in the protection, preservation, and enhancement of the watershed may include:

- Development of a comprehensive watershed management tool for Cooks Creek Watershed;
- Stream watch – volunteer stream monitoring program;
- Conducting ongoing groundwater elevation contour mapping for the watershed;
- Further refinement of the water table data with additional monitoring point(s) to improve the water table maps and more fully understand the hydrology of the watershed;
- Stream water quality sampling for continued evaluation of water resources;
- Permeabilities, transmissivities, storage coefficients, hydrochemical characteristics and the characteristics of the water table (piezometric surface) should be assessed;
- A watershed wide nutrient management plan to protect the exceptional value status of the watershed;
- Zoning ordinances that are consistent with comprehensive plans to protect vital resources and high-risk areas (i.e., karst, hydric soil, steep slopes, etc.)
- Preparation of updated land use maps to evaluate current conditions and management strategies within the watershed;
- Watershed wide stormwater management plan;
- Watershed wide stream bank evaluation and erosion control plan to assess conditions and provide stream bank restoration management plans;
- Maintenance of the GIS database and Township development of the GIS as an implementation tool to assist in planning and protection of the resources (e.g. streams, karst, hydric soils, etc.) within the watershed;
- Wellhead protection scheme for public and private wells; and,
- Karst geology protection plan for the limestone valley.

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IV. Land Resources

Geology

The geology of a region, while predominantly unseen, is the foundation for all the natural resources. Soils, groundwater, surface water and the flora and fauna of a region are all dictated on a fundamental level by geology. The underlying geology of the Cooks Creek Watershed is primarily of three types: crystalline (granite and schist) in the ridges to the north and south, diabase (red shale) in the headwaters, and a carbonate (limestone) central valley.

In order to fully understand the geology of the Watershed, professional geologists conducted studies of the area. The geologists used a combination of aerial survey and field confirmations to develop geology overlays and three dimensional model depictions of the major geologic units.

The geologic units of the entire watershed were grouped into four geologic categories:

- Category I: Diabase
- Category II: Brunswick and Lockatong Formations; and Quartz Fanoglomerates
- Category III: Carbonate Rocks including Allentown and Leithsville Formations and Limestone Fanoglomerates
- Category IV: Crystalline Rocks including Hardyston Formation and Gneiss Formations

These classifications will be used in determining groundwater contributions to the base flow of the basins and/or sub-basins within the watershed (Refer to Figure 5). Sub-basins are the drainage areas of various tributaries to the main stem of Cooks Creek Watershed. Figure 12 depicts the sub-basin geology for the entire Cooks Creek Watershed. The sub-basins were grouped into seven areas determined of the dominant local geology.

Figures 12-1 through 12-7 provide in-depth detail of the geology of each sub-basin area (Areas 1-7). Each area is again divided into sub-watersheds. The designations are identified as: Cooks Creek (CC), Silver Creek (SC), Tributary (T), North (N), South (S), while numbers identify each individual sub-watershed, with *first order* streams labeled as “a”. This ranking of sub-basins is necessary for extrapolating water production yields from each sub-watershed area. This information is used later to assess water balance and groundwater resource evaluations.

The topography of Cooks Creek drainage basin is defined by geologic characteristics of harder, more resistant rocks, which occupy highlands. These highlands may rise to elevations as high as 300 feet above the lowlands. The softer, less-resistant rocks tend to erode easily and occupy the lowlands as broad open valleys, valley bottoms, or gentle stream gradients. With harder, more resistant rocks, the valleys are narrower and steeper. Many of the streams draining the ridges surrounding the valley of Cooks Creek flow down more resistant rocks that underlie the ridge crest and mid slopes. These streams occupy steeper and narrower valleys. Cooks Creek occupies the broad, open, lowland valley bottomlands called the Durham Carbonate Valley (Figure 13). Much of this land is currently under agricultural use. The natural diversity of Cooks Creek basin is due largely to the fact that the watershed spans two physiographic provinces: the Reading Prong and the Piedmont.

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Reading Prong

The northern portion of the basin is part of the New England Geologic Province, locally known as the Reading Prong. Separated from the Triassic formations to the south by the Monroe Border Fault; the Reading Prong is composed of parallel ridges of Precambrian gneiss separated by a Cambrian limestone valley.

The northern portion of Cooks Creek basin, along Kohlberg-Steelys-Bougher Hills, has narrow ridges of granite gneiss, and Hardyston Quartzite. Rugged terrain with steep slopes precludes much development. This area is predominantly forested. Local streams occupy steep and narrow valleys that serve as the discharge areas for groundwater.

The southern portion of Cooks Creek basin from Bitts Hill to Mine Hill is a highland. It consists of a series of stacking thrust fault bounded blocks of Hardyston Quartzite and granite gneiss. This area is above the Musconetcong Thrust Fault. Steep slopes have precluded development and the area remains forested. The gentler sloped areas of the area are farmed.

Piedmont

The southern half of the Cooks Creek basin lies within the Piedmont Geologic Province. This area is in the Triassic Lowlands, a region of gentle rolling ridges and alternating bands of sedimentary Triassic shale, sandstone, argillite, and conglomerate of the Brunswick, quartz Fanoglomerate and Lockatong Formations. The shales and sandstones produce good to excellent agricultural soils and which are farmed. Only stream valleys, steep slopes, poorly drained areas, and scattered farm woodlots remain forested.

Buckwampum Hill and Flint Hill contain massive sills and dikes of diabase rock. This was formed when molten magma intruded during the late Triassic or early Jurassic period formations. Subsequent erosion has produced a series of ridges and hills. A boulder-strewn landscape with numerous perched wetlands is common. The rocky landscapes created by diabase intrusions have remained mostly forested due to their ruggedness and unsuitability for agriculture.

Flint Hill ridge occurs as a broad, plateau-like upland that serves as the western drainage divide for Cooks Creek basin, while the prominent ridge of Buckwampum Hill serves as the southeastern drainage divide. Both of these areas are utilized for agriculture.

Karst-prone Areas

Karst-prone areas consist of closely spaced sinks or sinkholes including caverns. These sinks are the result of exceptionally soluble rocks, where sinks and caverns form. In this type topography, the drainage pattern is irregular and/or streams disappear abruptly into the ground. These sinks are a direct result of solubility of carbonate rock, such as limestone. Karst-prone areas are mature karst systems of limestone bedrock in which old sinkholes are masked by extensive soil coverage.

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Most of the carbonate rocks in Durham Carbonate Valley are dolomitic, therefore, they would be less likely to have large sinkhole occurrences and massive cavern networks that may exist in areas with calcitic carbonate rock such as those found in Florida, Kentucky, and Missouri. Nevertheless, as shown by the number of sinkholes occurrences, there is obviously a need for concern (Figure 14). Figure 15 depicts the karst-prone areas of the watershed.

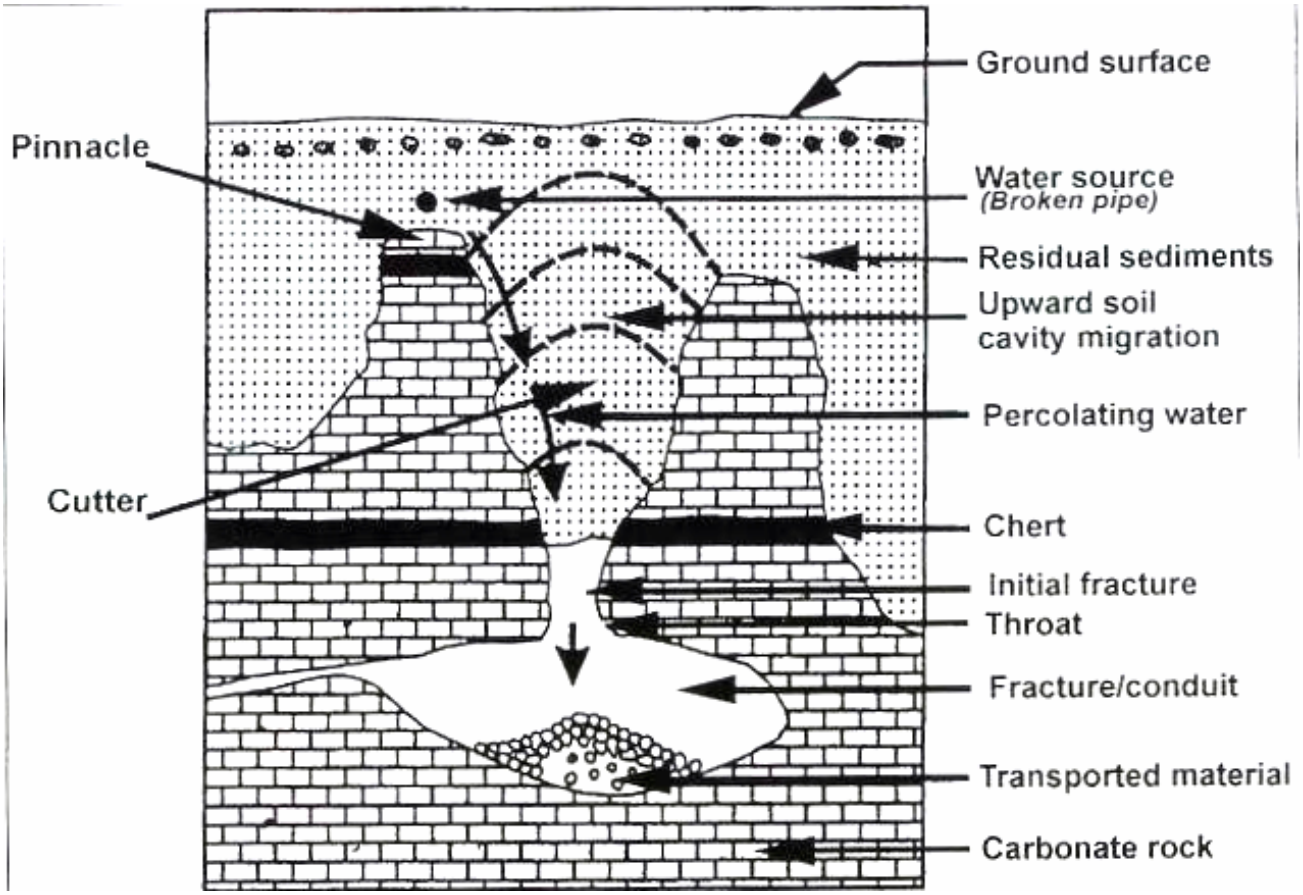

Figure 16. Conceptualization of Sinkhole Formation (Foundation Engineering Problems and Hazards in Karst Terranes, Fact Sheet 11, Maryland, Geologic Survey, Figure 4)

Karst prone areas present many challenges to the watershed. Current mapping of the karst geologic topography reveals numerous areas within the watershed that must be properly evaluated and protected to avoid loss of property and life.

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Soils

Soils are formed over thousands of years from weathering bedrock and decaying plant growth or organic matter. Soils are the link between the underlying geology and the surface features such as topography, stream morphology, surface water hydrology, vegetation, and land cover. Soils control the permeability of surface runoff and the recharge within the watershed. Soils also control the plant communities and agricultural productivity of the watershed. Prime agricultural areas are typically established in deep soils along valley bottoms. Forested areas typically exist where thin soils are encountered.

Soils are important in the filtering of pollutants that may affect the water quality of the watershed. This is especially important when considering the placement of on-site septic systems within the watershed. The correlation between the soils and septic system type and placement are discussed in greater detail in Appendix E.

Three main generalized soil groups exist within the watershed. These groups are:

- Deep soils that have a medium-textured surface layer and a medium textured or moderately fine-textured subsoil. (Associations: Allenwood Chester, Duffield-Washington, and Towhee-Neshaminy-Mount Lucas);
- Deep soils that have a medium-textured surface layer and a firm friable, but mainly firm and compact, subsoil; shallow to deep over shale or sandstone. (Associations: Abbottstown-Readington-Reaville and Penn-Klinesville); and,
- Deep soils that have a medium-textured surface layer and a medium-textured or moderately coarse-textured subsoil (Association: Alton-Pope).

Figure 17 presents the Generalized Soils Map for the watershed. As shown on Figure 17, the area near the Delaware River is comprised of Alton-Pope Association soils. These are nearly level to gently sloping, well-drained soils on terraces or floodplains. The central portion of the watershed consists of Duffield-Washington and Allenwood Association soils. These are gently sloping, well drained upland soils. On either side of the Duffield–Washington Association soils are the Chester soils. Chester Association soils contain nearly level to moderately steep, well-drained upland soils. On either side of the Allenwood soils are the Penn-Klinesville Association soils. Penn Klinesville Association soils are comprised of nearly level to moderately steep, shallow and moderately deep, well-drained upland soils. Figure 18-A and Figure 18 presents the entire watershed soil types.

Natural constraints resulting from soil related issues include: poor water recharge areas, high groundwater table, steep slope soils (Figure 18B), shallow soils and highly eroded soils. Figures 18-1 through 18-7 present the soils maps for Areas 1-7 that were digitized for the watershed during this project. Specific soil types are mapped and utilized later in the report to outline areas of concern with respect to septic system design and placement within the watershed. For instance, Towhee-Neshaminy-Mount Lucas soils are typically found over diabase. These soils are rated as having moderate to severe limitations for on-site septic systems due to their shallow depth to bedrock and low water yields. Consideration should be given when existing groundwater wells and water quality require protection.

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Hydric soils are present in the watershed especially along the stream corridors in Springfield Township. These soils are shown on Figure 19. Hydric soils are generally associated with wetland areas and as such should be considered critical areas that should be protected. Hydric soils are not suitable for on site septic use.

Prime agricultural soils should also be considered areas that require special protection and/or preservation. Dwindling farmland resources within southeast Pennsylvania highlight the need for consideration of the prime agricultural soil regimes.

Land Ownership

Land ownership is based upon the information supplied in the Bucks County Continuum (January, 1994). Land ownership and use, based upon the 1990 data, reflect that the majority of the land is privately owned. In the table below the three major municipalities within the watershed were again used for calculating watershed wide data.

	Acres	Private	Commercial	Institutional
Durham Township	5,882	4,457	26	212
Springfield Township	19,699	14,630	248	720
Riegelsville Borough	634	385	7	122

Critical Areas

Based upon the Cooks Creek Wetlands Management Plan desktop study (MJE et al. May, 2000) and field reconnaissance, it appears that the wetlands and streams are largely undisturbed and unstressed. There are, however, certain areas that are critical to water quality protection, the potable water supply, and the continued existence of rare and/or threatened species. These areas include:

- Wetlands and the streams located in karst-prone formations that may serve as groundwater recharge areas. Spatial analysis was performed for identifying critical areas related to karst issues within Cooks Creek Watershed. The following "Karst Overlay Zones" were outlined using GIS methods**:**
    - Durham Carbonate Valley and Tax Map Parcels, Figure 13
    - Sinkholes and Tax Map Parcels, Figure 14, and,
    - Karst-prone areas and Tax Map Parcels, Figure 15.
- Headwater segments of the tributaries, which are vulnerable to disturbance and development.
- Springs and seeps, especially along the base of the channel banks. These groundwater discharge areas contribute cool, high quality base flow water to Cooks Creek.

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- Habitats that support or potentially could support threatened and endangered species (Wetland Areas: D, P, X, Y, AA, AC, and AD).

  - *Area D*: *Potential bog turtle habitat*. This includes a small tributary to Cooks Creek that drains from the north of the main channel along Haupts Bridge Road. A palustrine-forested wetland was identified in this area. Relatively steep slopes, springs/seeps, and potential habitat for the bog turtle characterize the area. Development has encroached within about 300 feet of the site. The wetlands and waters of the US in this area are located in a rock unit that is prone to karst formation.

  - *Area P* – This area includes several segments that are located near the headwaters of the main stem of Cooks Creek. It includes waters of the US, plus numerous fringe wetlands scattered along the channel. Wetland types included predominantly palustrine forested, with smaller areas of palustrine emergent and palustrine scrub/shrub. Many of these field-identified wetlands are not depicted on the National Wetland Inventory (NWI) maps. One potential wetland mitigation site was identified near the southern end of this wetland. Some recreational use, and disturbance of wetlands from mowing and livestock grazing were noted. Development ranged from 200 to 2,000 feet away from the site. Some potential bog turtle habitat was observed.

  - *Area X* – This area includes a 4,000-foot section of the main channel of Cooks Creek along Springhouse Lane. The area is predominantly waters of the US, although several fringe wetlands (palustrine scrub/shrub and palustrine emergent) were located along the length of the channel. Three wetlands were field identified that are not shown on the NWI maps. Some of the area was cleared and a power line crosses the area. No significant water quality problems were noted although algae blooms were observed. One area had potential bog turtle habitat.

  - *Area Y* – This area includes about a 2,000-foot segment of Cooks Creek near Sliffer Valley and Knechts Bridge Roads. Several field-identified wetlands were discovered along the length of two small intermittent tributaries to Cooks Creek. These areas had riverine, and palustrine emergent wetlands. The area had habitat that would support bog turtles.

  - *Area AA* – This area includes segments of two unnamed tributaries and their confluences. The area is located near Walnut Lane and Sliffer Valley Road. Drainage channels that would be considered waters of the U.S dissect it. One large palustrine-forested, one fairly large palustrine emergent, and one large palustrine open-water wetland were accurately depicted on the NWI map. The field reconnaissance identified a large palustrine forested wetland and several small palustrine forested fringe wetlands. Bog turtles have been reported in this area, but none were observed. The hydrology of the area has been modified by construction of an old dam.

  - *Area AC* – This area is within the headwaters of an unnamed tributary to Cooks Creek near Bursonville Road. The area includes palustrine scrub/shrub, palustrine emergent and palustrine open-water wetlands. The area had potential habitat for bog turtles.

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- *Area AD* – This area is within the headwaters of a *first order* tributary of Cooks Creek located near Harrow Road. A fairly extensive palustrine scrub/shrub and palustrine emergent wetlands were identified. Several small areas of palustrine open-waters were correctly mapped on the NWI map. A spring was identified in the headwaters of the tributary. The area had potential habitat for special status species.

- Segments near developed areas primarily Springtown, Pleasant Valley and the eastern portion of Durham Township. These areas are stressed by road crossings.

- Disturbed wetlands included in Area J, M, T, W, and X (Figure 20). These areas are described below:

  - *Area J* - This area includes a small tributary of Cooks Creek that extends northward through Springtown. A spring was noted at the headwaters of this tributary, as were several seeps along the course of the stream. Some segments of this stream were located in close proximity to residences. The area appeared to be used for recreation and water supply. There was evidence of stream alteration through channelization, small check dams, culverts, and water withdrawal by pumping.

  - *Area M* – This area includes the headwaters of a *first order* stream near Springtown Road. Several small ponds were identified in the headwaters along with a palustrine emergent wetland that was not depicted on the NWI maps. The ponds supported ducks, blue heron, and a wide variety of songbirds. Some areas of wetland areas were mowed and used for recreation.

  - *Area T* – This area includes about a 3,000-foot segment of an unnamed tributary to Cooks Creek near Amity. The channel was determined to be waters of the US. The area includes several NWI mapped palustrine open-water and emergent wetlands scattered along the stream. Two additional fringe wetlands were identified in the field. In many places, wetlands and riparian areas were mowed to the edge of the channel. Development averaged about 200 feet away from the channel.

  - *Area W* – This area includes the headwaters of two *first order* tributaries of Cooks Creek near Old Bethlehem Road and Sliffer Valley Road. Waters of the US (riverine wetlands) and small areas of palustrine emergent and palustrine open-water wetlands characterize the area. The area has several horse trails, a debris pile, and is mowed.

  - *Area X* – This area includes about a 4,000-foot section of the main channel of Cooks Creek along Springhouse Lane. The area is predominantly waters of the US, although several fringe wetlands (palustrine scrub/shrub and palustrine emergent) were scattered along the length of the channel. Three wetlands were field identified that are not shown on the NWI maps. Some of the area was cleared where a power line crossed the area. No significant water quality problems were noted although algae blooms were observed. One area has potential bog turtle habitat.

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Hazard Areas

Hazard areas are shown on Figure 21.

Landfills

There are no landfills in Durham or Springfield Townships.

Waste Management Sites

There are two waste management sites in Springfield, the Delguerico Waste Transfer Station and the Gemstar Tires used tire storage facility. The Gemstar Facility has been closed and the tires removed, however there has been no evaluation of historical impacts (if any). Visual assessment conducted was not proximal to this facility (Figure 21) nor to the DelGuerico facility as part of this study However, given the nature of these activities, the proximity to the Cooks Creek, and the sensitivity of the Cooks Creek system to water quality impacts, additional survey work should be conducted in these areas to determine if any potential threat to water quality exists.

Abandoned Mines--Quarries

The information regarding the history, location, and use of mining resources within the watershed was gleaned from the Durham Resource Inventory Plan (June, 1995) and Place Names in Bucks County (MacReynolds, 1995. pages 144-145).

An iron ore mine was developed along a spur of South Mountain at Mine Hill in as early as 1698. Another mine was opened in 1851, which was considered the largest and best of the Durham Mines.

The abandoned Durham Mine, near Durham Furnace. has become an important bat hibernaculum, the second largest in Pennsylvania with 8,000 -10,000 bats recorded in a 1997 survey. A rare fresh water invertebrate, Prices' Cave Isopod, also has been found in the mine. In 1994, the Pennsylvania Game Commission and Heritage Conservancy collaborated to install specially designed gates to exclude humans but allows the bats to enter and leave freely. Problems involving vandalism of the gates have occurred, requiring continual monitoring and repairs.
A quarry is also located in the same general region as the mines within the watershed. There is also evidence of historic quarrying activity on the east side of Drifting Drive just north of Route 212/412 in Springfield Township and in the vicinity of the confluence of Cooks Creek with the Delaware River in Durham Township. There are currently no ongoing quarrying activities in the Watershed.

Sinkholes

Previous evaluations of Cooks Creek Watershed geological data (Conservation and Management Practices For Buckingham and Durham Carbonate Valleys, February 1985; Wetlands

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Management Plan, May, 2000; and, this report) presented specific areas in the Durham Carbonate Valley zone that are prone to sinkhole formation or disappearing streams.

The field delineation of karst-prone areas (MJE & Golder, April, 2000, Wetlands Management Plan, and MJE & Golder, June, 2000) was performed using industry standard methods (Figure 15). These methods include: correlation of topographic flat areas with stressed vegetation using topographic maps and aerial photographs.

The sinkholes shown on geologic maps were delineated in various phases of geologic field survey, performed by USGS (Drake, A. A., 1969), and during an environmental assessment for on-lot sewage system suitability in the carbonate valleys of Bucks County (Roy F. Weston, Inc. 1978).

The following "Karst Overlay Zones" were outlined using GIS tools (i.e. intersections and buffering):

- Durham Carbonate Valley zone – Figure 13;
- Known Sinkholes zone – Figure 14; and,
- Karst-prone areas zone – Figure 15.

Mismanagement practices in areas underlain by limestone can induce opening of older sinkholes or result in new sinkhole formations. No information about "Disappearing Streams" or "Blind Valleys" in Durham Carbonate Valley was available for the watershed. The limited information obtained was gathered during desktop studies including reviews of existing reports, aerial photographs, USGS Quadrangle maps, and similar information.

A thorough inventory of the stream system for the entire watershed was completed during field survey tasks for this project (*Seepage Runs and Creek Reconnaissance* and *Karst-Prone Areas Reconnaissance Completion*). When landowners limited access, the stream inventory was completed by visual observations from nearby public roads.

The "Karst-Prone Areas" that were delineated are considered to be at high risk for sinkhole development. The general lack of many active sinkholes, the presence of mostly mantled sinkholes (i.e. sinkholes formed by collapse of a mantle of soil above bedrock), and the general absence of exposed bedrock in the topographically lowest portions of the valley, suggest that the Cooks Creek karst is a mature system. Mature karst systems of limestone bedrock within the watershed are masked by extensive soil coverage (Figure 16).

Consequently, karst hydrologic definition and assessment is difficult for the following reasons:

- Many of the features of concern lie underground and are inaccessible or accessible only by drilling.
- Carbonate rock terrain in Cooks Creek drainage basin generally occur in lowlands. Outcrops of the underlying bedrock are masked by overlain soils including alluvium and other material washed in from the surrounding highlands.

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- The discharge point or points of a drop of water falling in a karst watershed can only be assigned a probability.
- Discharge points in karst can change periodically as plugging and unplugging of conduits (caverns, voids, etc.) occur with varying storm intensities.
- Drainage in karst watersheds tends to be three dimensional, flowing laterally across the surface, as well as vertically underground.

Sinkholes provide direct recharge routes to groundwater; therefore, water quality in wells, caves, and springs may be affected by discharge of runoff from developed sinkhole areas. Consequently, any sinkhole evaluation must address potential impacts of proposed development on receiving groundwater, and must consider water quality management measures to mitigate any resulting impacts. The nature of site-specific karst conditions should be evaluated on a site-by-site basis within the identified karst-prone areas. These evaluations should be performed by a licensed geologist familiar with karst.

Sinkholes can also directly impact engineered structures in their proximity by causing instability or even collapse. Engineered structures include not only homes and businesses, but bridges and roadways as well. Care must be taken to guard against inappropriate development in areas where the expected land use will result in sinkhole formation near proposed or existing engineered structures.

These sinkhole evaluation reports performed for new developments shall identify whether the site lies within a critical area or a sensitive area based upon the following classifications.

- Areas within 100 feet of private water supply wells.
- Areas within 1,000 feet of public water supply wells.
- Areas within 500 feet of springs used for public or private water supply.
- Areas within 1,000 feet of caves, providing habitat to rare or endangered species.

The Durham and Springfield Township Engineers may at their discretion wish to change the distances listed above, where the recharge areas for a well, spring, or cave have been independently evaluated by site-specific studies conducted by a qualified engineer or geologist.

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V. Water Resources

The aquifers underlying an area comprise its groundwater system. Hydraulically, the system serves two functions:

- It stores water (dictated by the porosity); and,
- It transmits water from recharge areas to discharge areas.

Thus, a groundwater system serves as both a reservoir and as a transmitting medium. Water enters the groundwater system in recharge areas and moves through the system to the discharge areas. The rate of movement of groundwater from recharge areas to discharge areas is dependent upon the hydraulic conductivity and hydraulic gradients.

A groundwater map is a graphical representation of the occurrence and distribution of groundwater within a geographical locale. Hydrogeological maps divide groundwater into four broad categories, depending on their basic content and/or principal purpose. These categeories are:

- *Geological Groundwater Map.* This type of map shows the extent to which the geology of an area may provide indications of the occurrence, distribution, and movement of groundwater. This type of map presents an essentially static picture of what in nature is a dynamic system. It implies a closer relationship between geological formations and groundwater occurrence than what actually exists (Figure 12, and Figures 12-1 through 12-7). These figures depict the geologic formations throughout the watershed.

- *Hydraulic Groundwater Map.* This type of map utilizes the classification of rocks and formations according to the conditions under which water normally occurs within them. The geological formations are defined by their hydraulic and closely related characteristics, such as porosity, permeability, degree of fracturing, and shape of the aquifer. Hydraulic groundwater maps show limits of artesian and watertable conditions, groundwater divides, distribution of hydraulic characteristics, and the elements of geological structure, which influence groundwater occurrence (Figures 22-1 through 22-7). These figures depict the hydrogeologic or water-bearing units within the watershed. Each geologic formation has common characteristics with respect to its water-bearing capacity. Information supplied by Pennsylvania Groundwater Information System Database (DCNR, July, 1998) was used to illustrate the formation and yield for individual wells.

- *Groundwater Resource Map.* This type of map is widely used to indicate groundwater yield and characteristics of water quality (i.e., domestic, municipal, agricultural and industrial use). Groundwater resource maps generally do not show groundwater hydraulics and dynamics. In this report the Hydraulic Groundwater and Groundwater Resource Maps are combined in Figure 23, and Figures 22-1 through 22-7.

- *Groundwater Contour Map.* This type of groundwater mapping and assessment, utilizes concepts based upon the mapping of hydrological properties and classical geological

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characteristics. The information presented on the map may include the ability of the subsurface rocks to transmit and store water, as well as their permeabilities, transmissivities, storage coefficients, hydrochemical characteristics and the characteristics of the water table (Figure 23).

- Hydrologic information of precipitation, evaporation, and water level measurements are used to estimate the general direction of groundwater flow, the location of recharge and discharge areas, and the connection between aquifers and surface water systems. Water chemistry data can be used to infer flow directions, identify sources and amounts of recharge, estimate groundwater flow rates, and define local, intermediate, and regional flow systems.

Major Tributaries

The Cooks Creek Watershed includes a total of 40 sub-watersheds that were delineated using the GIS technique to outline the drainage basin divides. Tributaries provide the essential quantity and quality of water for the larger stream systems, and are most vulnerable to the impacts of land disturbance and development. Land use issues are directly linked to the potential adverse impacts upon the watershed (Figures 12, and Figures 12-1 through 12-7).

It should be noted that two small tributaries CC20a and CC22a, located in Area 5 in the southwestern portion of the watershed, have not been classified as *second-order tributaries*. (Figure 5-5). These streams and their smaller tributaries are classified as *direct local drainage of the headwaters area*, thus showing the special importance of *first order* streams.

Watershed Water Quality Sampling

As part of the Water Quality Subtask, a Water Quality Survey of Cooks Creek and its tributaries were conducted. Twenty-seven (27) locations were surveyed within the Cooks Creek Watershed (Figure 24). Field parameters tested include: alkalinity, carbon dioxide, ambient air temperature, water temperature, pH, specific conductivity, turbidity, and dissolved oxygen. In addition, laboratory chemical analyses were conducted to supplement the field survey work. Twelve stream samples were analyzed for phosphates and nitrates, and 8 samples were analyzed for fecal coliform. These parameters and their importance to water quality are discussed below. This information was obtained from the Delaware River Basin Commission (DRBC) website.

Alkalinity: Alkalinity is important for fish and aquatic life because it protects or buffers against pH changes (keeps the pH fairly constant) and makes water less vulnerable to acid rain. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates may also contribute to alkalinity.

Limestone is rich in carbonates, so waters flowing through limestone regions generally have high alkalinity -- hence its good buffering capacity. Conversely, granite does not have minerals that contribute to alkalinity. Therefore, areas rich in granite have poor buffering capacity.

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Water Temperature - Water temperature is an important environmental factor for fish and other aquatic life. Many species can only tolerate specific temperature variations. Of particular importance to Cooks Creek is maintaining temperature suitable for maintaining the wild and native trout populations.

pH pH is a measure of the acid/alkaline relationship in a water body. pH values range on a scale of 0 to 14, with 7 being neutral. Since pH is logarithmic, a one-notch change in pH (e.g., from 6 to 7) represents a 10-fold increase.

A pH of about 6 to 9 is generally favored by aquatic life, especially fish. Chemicals released from industry, mining, acid rain, and other man-made sources can adversely impact in-stream pH levels. Natural sources such as limestone deposits in bedrock and tannic acid (produced by certain vegetation) can also influence pH.

Conductivity - Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids, such as chloride, nitrate, sulfate and phosphate **anions** (i.e., ions that carry a negative charge) or sodium, magnesium, calcium, iron and aluminum **cations** (i.e., ions that carry a positive charge). Organic compounds like oil do not conduct electrical current very well therefore they have a low conductivity.

Conductivity is useful as a general measure of stream water quality. Each stream tends to have a relatively constant range of conductivity that, once established, can be used as a baseline for comparison with regular conductivity measurements. Significant changes in conductivity could then be used as an indicator that a discharge or some other source of pollution has entered a stream. For example, a failing wastewater plant would raise the conductivity because of the presence of chloride, phosphate and nitrate. On the other hand, an oil spill would lower conductivity.

Turbidity In simple terms, turbidity answers the question, "How cloudy is the water?" Light's ability to pass through water depends on how much suspended material is present. Turbidity may be caused when light is blocked by large amounts of silt, microorganisms, plant fibers, sawdust, wood ashes, chemicals, and coal dust. Any substance that makes water cloudy will cause turbidity. The most frequent causes of turbidity in lakes and rivers are plankton and soil erosion from stormwater runoff

Dissolved Oxygen Dissolved oxygen (DO) is oxygen that is dissolved in water. It is produced through diffusion from the surrounding air; aeration of water that has tumbled over falls and rapids or as a by-product of photosynthesis. The amount of dissolved oxygen present is affected by temperature. Cold water generally contains more DO than warm water.

Nitrate and Phosphate - Nitrate and phosphate are necessary for aquatic plant growth, which support the rest of the aquatic food chain. An appropriate level of nutrients is one of the driving forces of the aquatic ecosystem. Both of these nutrients are derived from a variety of natural and artificial sources, including decomposition of plant and animal materials, man-made fertilizers,

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and sewage. Rainfall also can be a significant source of nitrates. Excessive nutrients might cause undesirable plant growth, which negatively impacts water quality.

Determining the optimum levels of nitrates and phosphates in water is extremely complex. Their levels often fluctuate considerably because they are constantly being taken up and released by aquatic life, being exchanged with stream bed sediments, and undergoing various other transformations.

In natural unpolluted water, phosphate levels are generally very low. Phosphorus, which combines with oxygen to form phosphate, is most often the limiting factor for plant production in streams. Nitrogen uptake by algae is generally in the nitrate form if nitrate is available. However different types of fresh water algae can utilize either organic nitrogen or inorganic nitrogen in the form of ammonia, depending on which is available (Stumm and Stumm-Zollinger, 1972). Algae typically require phosphorus in an inorganic form, usually as orthophosphate ion (Kormondy, 1969).

Fecal Coliform - Fecal coliform is the measure of the amount of human or animal waste in the water. The amount of fecal coliform affects the health of the stream and determines the ability of the stream to support aquatic life.

Results of Water Quality Monitoring (Field Parameters)

Two (2) sediment samples were collected, one upgradient and one downgradient of the dam at Paper Mill Facility. One water sample was collected near downgradient of the dam. Sediment samples are designated with the letter ”S” and numbered sequentially. The sediments samples (S1 and S2) were analyzed in a laboratory for toxic metals, pesticides and herbicides. Stream water samples were designated with the letters “SW” and numbered sequentially. The stream water sample (SW1) was analyzed for toxic metals, pesticides, herbicides, phosphorus and nitrates. Twelve (12) samples were collected and analyzed for phosphate and nitrates. Fecal coliform was also analyzed from 8 field locations. These field survey results did not reveal any indication of chemical contamination. Sampling sites were established at locations within the watershed where appropriate base line stream characterization could be calculated. A summary of the results is shown on Table 1.

USEPA National Watershed Characterization, dated September 1999, indicates less than 5 % of water quality samples collected exceed maximum contaminant levels (MCLs) for groundwater and surface water within the watershed. MCLs are the highest amount of contaminant the USEPA permits in drinking water. MCLs were established to ensure drinking water posed no short or long-term health based risks to the general public. This particular finding is, therefore, an indication of relatively good drinking water quality throughout the watershed.

The watershed is not without water quality issues, however. A literature search and a field survey revealed that both suspended sediments and nutrient runoff have contributed to apparent stress in various locations throughout the watershed. Nutrient levels up to 1 mg/L and elevated phosphorous concentrations suggest a concern within the watershed. Evidence of blue-green algae in Silver Creek, near the firehouse on the south side of Route 412, reflects the results of such water quality issues. While the data collected to date do not indicate a definitive management action, they do indicate the need for a more detailed investigation into the reasons for their presence and to suggest appropriate management action.

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Field parameter screening was conducted at the 27 stream quality assessment locations. These results are summarized in Table 2. The following list presents the range of results noted during this investigation:

- Water temperature 13.8˚C to 23.9˚C,
- pH 7.5 to 8.88 standard units,
- Conductivity 0.136 to 0.298 mS/m
- Turbidity 0.0 to 17.0 NTU
- Dissolved Oxygen 5.02 to 11.2 mg/L

These results indicate a varying degree of water quality within the watershed. Field parameter graphs are shown in Appendix B, Attachment B1.

Stream Visual Assessment

The Delaware River Basin Commission (DRBC) protocol was utilized to visually assess the stream conditions in the watershed. The same 27 water quality sample locations were visually assessed in conjunction with the water quality sampling. As part of the visual assessment the following factors were assessed: instream cover, fine particle sediments, flow patterns, stream bank conditions, disturbances to the riparian buffer, riparian zone vegetative width, litter, and overall assessment (Table 3).

The visual assessment revealed that several stream segments within the watershed would be classified with the qualifiers of *marginal* and *poor* conditions according to this assessment protocol. The majority of these *marginal* and *poor* sites are located at road crossings (SW8, SW11, SW14, SW15, SW16, SW17, SW21, SW22, SW23, and SW25).

No other areas showing specific mismanagement with respect to surface water were found during this study; however, Springfield Township may wish to consider periodic assessment of the downstream locations from the trash transfer station and the used tire yard. Similar areas are often a source of stream contamination, therefore, these areas may warrant close attention.

Stream Morphology Assessment (Rosgen Classification Technique)

Morphology is the study of the form and structure of a biological system. Stream classification is key in understanding and predicting natural stream response to restoration and predicting patterns and conditions of stream flow. Natural self-stabilizing tendencies have proven to be much more successful in channel restoration than engineering control practices. Understanding the natural morphologic features of an un-impacted stream can serve as a basis for achieving natural stability, rather than attempting to employ rigid engineering controls (i.e. gabion channels, etc.). Letting “nature take its course” can be beneficial when planning and implementing stream restoration or enhancement. Watershed management is enhanced through the proper classification and basic understanding of stream morphology.

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Rosgen developed a *Field Guide For Stream Classification* (1998) that has become a widely accepted methodology to classify streams. The effective classification of a stream requires objective, quantifiable data or criteria that yields consistent results from varying individuals (e.g. two people in two separate evaluations yield the same results from the same method). A method like this can provide uniform, reproducible, reliable, and comparable classification of streams.

Rosgen effective classification of streams is shown in Appendix B, Attachment B2.

Rosgen's Method was used to classify seven (7) areas or transects within the watershed. Figure 25 depicts the location of these transects, while Table 4 shows the results of the classification. Attachment B2 includes the classification key for single thread natural rivers, established in Rosgen's *Field Guide For Stream Classification*, (1998).

Point Source Pollution

In order to maintain the watershed's EV status, protection against stream water quality degradation is crucial. *Point source* pollution is pollution that can be traced to a single source, such as a discharge pipe from an industry. Industrial plants and sewage treatment plants in the watershed are the main sources of *point source* pollution. Sewage treatment effluent discharges nutrients and phosphorous from human waste and household chemicals into the watershed. Industrial wastewater may have more pollutants related to manufacturing processes. A total of approximate 2,200 *point source* discharges exist as septic systems within the watershed (Figure 26).

Historically there was one known solvent spill, within the Cooks Creek Watershed on January 17, 1987. This area is known as the Durham Township Drum Site. Emergency response activities took place on February 4, 1987. The enforcement removal administrative record file is available at USEPA Region 3 –HSCD, Incident Notification Report, Case No. PA87251

Non-Point Sources

Non-point source pollutants are those pollutants that do not come from a pipe or single source, but rather from a wide area or diffuse source. Typically, nonpoint pollution results from chemicals carried in stormwater runoff. Nonpoint source pollution can also come from the atmosphere or move through groundwater. For the Cooks Creek Watershed, minimizing nonpoint source pollution is the single most important act that can be done by residents to maintain water quality.

Examples of sources of *non-point source* pollution are:

- Roads
- Parking lots,
- Lawns,
- Cultivated fields and livestock maintenance areas,
- Construction sites, and,
- Stormwater management control systems.

Examples of non-point source pollution are:

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- Siltation
- Nitrates and Phosphates
- Petroleum Hydrocarbons
- Trace Metals (lead, cadmium, chromium)
- Pesticides and Herbicides
- Bacteria

Proper public education and information dissemination can greatly reduce the impact from *non-point source* pollution.
Impervious surfaces are relatively low within the watershed. Index of Watershed Indicators (IWI) data (EPA, 2001) indicates Cooks Creek watershed as a watershed with Less Serious Water Quality Problems. For Overall Watershed Characterization maps generated based on IWI data and DRBC maps are shown in Appendix B, Attachment B3.

Stormwater Management

New impervious surfaces (i.e. areas where water no longer penetrates the ground surface such as paved surfaces) result in significantly reduced groundwater infiltration and aquifer recharge since water or wastewater resources are exported from the watershed system. Reduced recharge results in lowering the water table with a corresponding reduction in stream base flow. As base flow decreases during dry periods, crucial first-order tributaries and existing shallow wells may dry up resulting in drastic ecological consequences.

Conversely, the impervious surfaces that reduce infiltration result in increased stormwater discharge. Even with careful design, the use of detention basins for stormwater management increases the total volume of stormwater discharged. This is due to the fact that such detention basins only control the peak rates of stormwater discharge.

As detention basins multiply throughout a watershed, adverse downstream impacts may result. These adverse impacts include: flooding, increased runoff volumes, stream bank and channel erosion, and altered stream morphology. Water pollutants resulting from increased stormwater runoff is also an important concern.

This water quality impact includes wet weather discharges or "mass loads" of *non-point source* pollution from these new impervious areas, containing hydrocarbons (petroleum product residuals), metals, biological/chemical oxygen demand (BOD/COD), and a host of other pollutants. Stormwater pollution also is generated from large areas of chemically maintained landscapes, such as lawns and gardens, as well as agricultural fields and livestock maintenance areas. These areas generate nutrients, sediment, COD, pesticides and herbicides. During dry weather, *non-point source* water quality impacts include malfunctioning on-site septic systems and other small but significant wastewater flows.

Efforts should be taken to minimize additional *non-point source* pollutant inputs into surface waters. Surface water *non-point source* pollution in particular, erosion and sedimentation, and lack

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of groundwater recharge are, perhaps, the greatest concern with respect to stormwater management. Stormwater management ordinances should be consistent with guidelines presented in *Pennsylvania Handbook of Best Management Practices for Developing Areas* (1998) or in the *PADEP Erosion and Sediment Pollution Control Program Manual* (2000). For instance, the 2-year storm or one that produces 3.2 inches of rain in a 24-hour period of time, is the most frequent storm resulting in erosion and flooding. Comprehensive ordinances should incorporate provisions to protect against the impacts from such events.

Wetlands

General Description

Possible wetland areas were first identified with the use of U.S. Fish and Wildlife Service NWI maps, aerial and color infrared photography followed by onsite reconnaissance. The Cooks Creek Watershed supports a great abundance and diversity of wetlands. Figure 27 shows the approximate location, classification, extent of wetlands, and waters of the U. S. that were field identified in June and July of 1999 by the EEE and classified on the NWI maps. As previously mentioned, a Wetlands Management Plan was developed from this study.

The NWI maps depict 337 acres of wetlands within the watershed. A total of 259 acres of wetlands were field investigated in 1999. Of the 259 acres, only 158 acres had been previously shown on the NWI maps. This suggests that there may be considerably more wetland areas within the watershed than previously interpreted. Based upon this information all developments along the Cooks Creek corridor should require a wetland evaluation prior to development to protect against the loss of these resources.

Springs and Seeps

Numerous springs or seeps were found in the watershed, particularly in the headwaters. Most springs and seeps are located within 500 feet of a first-order stream (Figure 28). The springs and seeps are critical to the continued existence of nearby wetlands, special status species and the trout populations. This is due to the fact that the discharge from springs and seeps provide year-round base flow and contribute cool, high quality water that is vital to the survival of these populations.

The numerous springs or seeps from the base of slopes found in the area, are most vulnerable to the impacts from land use, land disturbance, and development. Special consideration should be given to the protection recommendations in this study.

Wetland Threats

Wetlands within the watershed do not appear to be significantly stressed due to hydrological modification, development, or human activities. Groundwater discharge and stream flows provide the crucial water source for most wetlands. If these hydrologic sources are modified, the wetlands

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may be at risk. In addition, increased or intense development in close proximity to wetlands could adversely affect them.

Wetland Functions and Values

According to the Wetland Evaluation Techinque (WET II) analysis, wetlands in the Cooks Creek Watershed are highly effective in providing groundwater recharge, groundwater discharge, flood-flow alteration, wildlife migration and wintering, aquatic diversity, and recreation.

Riparian Buffer Areas

A riparian area is defined as the area within 75 to 100 feet from the edge of both banks of the stream. Simply defined, riparian buffers are streamside plant zones. These buffers have a variety of functions, including: absorption of excess nutrients; shading and cooling waters; reducing the speed and volume of runoff entering a stream; and providing stream bank stabilization. These buffer zones provide an important phase of protection against *non-point source* discharges such as sediment, nutrients, and pollutants. The roots of trees and vegetation secure soils and therefore, reduce flooding and stream bank erosion. Littoral waste or leaves, twigs, branches, and other organic debris that fall in streams and waterways, decay and become an important part of the food web for micro and macro organisms within the stream. Trees and herbaceous plants provide shade along tributaries and maintain cooler water temperatures necessary for natural aquatic organisms, including brook and brown trout.

A 75-foot wide cover on each side of a tributary is typically recommended in southeastern Pennsylvania's local zoning ordinances. This maximizes the benefits to a stream's health and sustains conservation of watershed resources. Reforestation efforts, although generally effective may not provide the best habitat for "native" flora and fauna. While vegetative cover is recommended along tributaries, it may be beneficial to have scrub/shrub or herbaceous plant species rather than woody plants and trees. "Riparian Buffer Easements" or a landowner's voluntary agreement to maintain the stream corridor, have been found to be one of the most efficient ways to maintain and/or restore stream riparian buffers.

It should be noted, that a common misconception is that the riparian buffer zone can be reduced in size as one nears the headwaters of a stream. This is due to the fact that the headwater channels are smaller in size. Headwater channels may include ephemeral channels including streams, ditches, or swales that flow only during storm events. These areas are the most vulnerable to adverse impacts from *non-point source* discharges and, therefore, should have *the same or greater* width of protection through riparian buffer zones.

GIS maps were used to evaluate these areas. A total of 1,607 acres of riparian buffer zones were found Figure 28. The majority of the buffer is deciduous forestland (45 %) and farmland (43 %). The remaining buffer consists of: herbaceous rangeland, scrub/shrub rangeland, mixed rangeland and coniferous forest each comprising 3 % or less of the riparian buffer. Further evaluation

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regarding riparian buffer zone quality should be conducted within the watershed, to ensure continued protection of watershed resources.

Lakes and Ponds

Most of the lakes and ponds currently within the watershed cannot be considered naturally occurring. The watershed area was not influenced by glacial activity from the most recent Wisconsin Ice Age. Thus, the lakes and ponds within the watershed were not created by glacial scouring, but were created by human activity. There are approximately 95 lakes and ponds within Cooks Creek Watershed. Seventy-eight (78) are associated with area wetlands. The high percentage of wetland-associated ponds and lakes, stresses the importance of wetland protection in the watershed (Figure 29). Some ponds were constructed for use in mill processes and farming purposes.

Floodplains

Flooding has not been a serious problem in the Cooks Creek Watershed even though significant amounts of stormwater runoff reach the streams. The 100-year floodplain is mapped on the hydrologic resource map (Figure 30). Adverse effects from impervious surfaces are relatively low within the watershed; therefore, floodplains are still somewhat undeveloped. Impacts from flood-related concerns experienced in heavily suburbanized areas have not been felt in this region. The cumulative effects from flooding impacts due to conventional stormwater management systems can be avoided through proper planning and zoning.

Recent flooding experienced in other areas of the state, such as in the Darby Creek Watershed reflect the need for appropriate protection of floodplains and flood-prone areas. Floodplains provide the storage capacity for storm water events that occur within any given watershed. The Federal Emergency Management Agency (FEMA) administers the National Flood Insurance Program. This program enables property owners to purchase insurance coverage against losses resulting from flooding. In areas not mapped by FEMA, PADEP has established jurisdiction over all activities occurring within 50 feet from the top of bank of a watercourse.

Critical Areas Related to Water Quality

Spatial analysis performed during the wetland management study that identified critical areas related to the surface water to groundwater interconnection issues within Cooks Creek Watershed produced the following *overlay zones* in need of special attention:

- First-Order Sub-basins,
- Wetlands Buffer,
- Riparian (Floodplain) Map, and,
- Lakes and Ponds.

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Water Supply

Most of water supply is private residential potable water wells.

Public

The community of Springtown in Springfield Township is serviced by a public water supply. The water is collected from a spring located near the Cooks Creek Watershed divide near Springfield Township's boundary with Lower Saucon Township. This public water supply system also includes production wells. The area served by the public water supply is shown on Figure 31. This public water service covers approximate 750 acres with approximately 230 customers.

Private

The total number of private residential wells is approximately 500 in Durham Township and 1700 in Springfield Township

Water supply is typically groundwater-based, pumped from the aquifers with corresponding reductions in stream base flow. Water use can be considerable for different land uses and activities. Water consumption increases during the warmer weather months when stream flow is already at its lowest point.

The concept of Sustainable Watershed Management (*Sustainable Watershed Management at the Rapidly Growing Urban Fringe*, T. H. Cahill, et al., Watershed 96 Proceedings) utilizes fundamental resource management objectives to: 1) measure the tolerance limits of the natural system, and 2) balance the human use of land and water resources in order that the carrying capacity of these natural systems are not exceeded. The following management objectives have been established based on this concept, with modeling methodologies developed to achieve these objectives:

- Maintain stream base flow, and, in particular, during drought periods (Utilizing $Q_{7\text{-}10}$ methodology). In the Cooks Creek Watershed additional information is necessary to evaluate the $Q_{7\text{-}10}$; therefore, further data collection is required.

- Maintain groundwater levels in order to protect existing/future wells.

- Assure that stream flooding is not increased.

- Prevent groundwater contamination, particularly from nitrate.

Well Head Protection Areas

The depth to the water table is highly variable and ranges from zero to hundreds of feet below the ground surface. Usually, the depth to the water table is shallow near permanent bodies of surface water such as streams, lakes, and wetlands. An important characteristic of the water table is that its configuration varies seasonally and from year to year.

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Although typically only wells that are screened near the water table are used for establishing a groundwater map, all accessible water wells were used in order to obtain a sufficient number of data points. The depth to the water table was determined by measuring it from the ground surface with a water level meter. Water levels are referenced to a common datum generally sea level. This allows one to configure the water table and provide an indication of the approximate direction of ground-water flow. Arrows drawn perpendicular to water table contours indicates the direction of ground-water flow along the upper surface of the ground-water system (Figure 23). The water table is continually adjusting to changes in the recharge and discharge patterns of the groundwater; therefore, water level measurements were made at approximately the same time, and the resulting map is representative only of that specific time (November 12-15, 1999).

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VI. BIOLOGICAL RESOURCES

Wildlife

Overview

The wildlife habitat within Cooks Creek Watershed has been assessed several times since the Division of Water Quality (DWQ) has developed water quality standards designating Cooks Creek as "Exceptional Value". These habitat evaluations targeted specific wildlife habitats (i.e. streams, lakes, wetlands, bogs), in various areas of the watershed. Appendix A presents findings and interpretations of various habitat evaluation reports completed from 1990 to present. Research relating to the wildlife resources of the watershed include: *Natural Areas Inventory of Bucks County, Pennsylvania* (June, 1999), *Bucks County Natural Resources Plan (*March, 1999*)*, and *The Pennsylvania Department of Conservation and Natural Resource*s *Database.*

According to the U.S. Fish and Wildlife Service (USFWS), the Cooks Creek supports several populations of bog turtles (*Clemmys muhlenbergii*), which is listed as a federally threatened species. Bog turtles inhabit shallow, spring-fed fens (marshes), sphagnum bogs, swamps and pastures that have an open-canopy and are characterized by soft muddy bottoms and clear cool water that is usually ground-water fed. According to the USFWS, occasional transient species that are federally threatened or endangered may visit the Cooks Creek Watershed as well. A list of these species is included in Appendix C. The Pennsylvania Department of Conservation and Natural Resources database showed that the following state-threatened or endangered species have been recorded within or near the watershed:

Species	Status
Spreading Globeflower (*Trollius laxus Salisb.*)	State endangered
Red-bellied turtle (*Pseudemys rubriventris*)	State threatened
Least bittern (*Ixobrychus exilis*)	State threatened
Peregrine falcon (*Falco peregrinus)*	State endangered
Sedge wren (*Cistothorus platensis*)	State threatened
Bog turtle (*Clemmys muhlenbergii*)	State endangered

Information concerning the habitat, natural history, management practices, and identifying characteristics for each of these species is included in Appendix C. According to the Nature Conservancy, the bog-turtle and other special status species including the red-bellied turtle and the eastern mud salamander (*Pseudotriton montanus*) have been documented at one site within the watershed (Bureau of Water Quality Management, 1991).

The Bureau of Water Quality Management (1991) fish surveys within Cooks Creek Watershed reveal a diverse population of primarily cold-water fishes including:

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Common Name	Scientific Name
Brown trout	*Salmo trutta*
Brook trout	*Salvelinus fontinalis*
Rainbow trout	*Oncorhynchus mykiss*
Rock bass	*Ambloplites repestris*
Redbreast sunfish	*Lepomis auritus*
Bluegill	*Lepomis macrochirus*
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*Lepomis gibbosus*
Largemouth bass	*Micropterus salmoides*
Smallmouth bass	*Micropterus dolomieui*
Longnose dace	*Rhinichthys cataractae*
White sucker	*Catostomus commersoni*
Blacknose dace	*Rhinichthys atratulus*
Common shiner	*Luxilus cornutus*
Swallowtail shiner	*Notropis procne*
Spotfin shiner	*Cyprinella spiloptera*
Silvery minnow	*Rhinichythys falactus*
Bluntnose minnow	*Pimephales notatus*
Cutlips minnow	*Exoglossum maxillingua*
Creek chub	*Semotilus atromaculatus*
Margined madtom	*Noturus insignis*
Tesselerated darter	*Etheostoma olmstedi*
Slimy sculpin	*Cottus cognatus*

Avian Species

The avian (bird) population within the county includes 135 nesting species and 117 transient or occasional visitors. Species, which have been lost or suffered the greatest declines are those associated with wetland habitats and grasslands. In recent years the Peregrine falcon (*Falco peregrinus*), a federal endangered species, has been noted nesting on bridges along the Delaware River corridor.

The Audubon Society utilizes a number of locations within the Cooks Creek Watershed during its Annual Christmas Bird Count, including sampling points located along stream corridors. At least 196 avian species have been recorded within the basin. Using a feeding guild classification system, 39 of these species are directly dependent upon water for survival. The Cooks Creek Watershed, because of its proximity to the Delaware River corridor, is utilized by a number of migratory avian species. Numerous resident species are dependent upon the continued excellent water quality. This is an example of how the benefits of the EV status extend far beyond the physical boundaries of the watershed.

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Terrestrial Species

Ten species of turtles including at least one population of bog turtle have been observed in Bucks County. The Red-eared slider (C*hrysemys scripta*), an introduced species, is well established in many areas of the county. Fifteen (15) snake species are present in Bucks County, one of which is poisonous, the Copperhead. Eleven (11) amphibian species (frogs and toads) are present within Bucks County. Twelve (12) salamander and two (2) lizard species are also present.

Several mammal species such as raccoon (*Procyon lotor)*, opossum (*Didelphis virginiana)*, cottontail rabbit (*Sylvilagus floridanus)*, groundhog (*Marmota monax)*, striped skunk (*Mephitis mephitis*), chipmunk (*Tamias striatus*), and gray squirrel (*Sciurus carolinensis*) are common, abundant, and have adapted to humans. Red squirrels (*Tamiasciurus hudsonicus*) and flying squirrels (*Glaucomys volans)* are less common. The red fox (*Vulpes fulva*) has become increasing abundant, but the native gray fox (*Urocyon cinereoargenteus)* is rare. Beaver (*Castor Canadensis)* have become fairly common after being extirpated around the turn of the century and subsequently reintroduced from farther west. Muskrats (*Ondrata zihethicus)* are abundant throughout the region.

The Virginia white-tailed deer (*Odocoileus virginianus)* is the only large herbivore that thrives in this area. Small mammals include five shrews (*Cryptotis)*, three voles (*Microtus*), two native mice (*Pitymys*), and three mole (*Scalopus)* species. Although rarely seen, weasel (*Mustela frenata)*, ermine (*Mustela erminea)*, and mink (*Mustela vison)* are also present. The introduced Norway rat (*Rattus nervegicus*) and house mouse (*Mus musculus*) are common in areas adjacent to human activity but do not generally occur in natural habitats (*Natural Areas Inventory of Bucks County Pennsylvania*, 1999).

Large carnivorous mammals have declined in diversity throughout Pennsylvania due to the systematic early eradication of the Gray wolf (*Canis lupus)*, Wolverine (*Gulo luscus)*, Cougar (*Felis concolor)*, and Lynx (*Lynx Canadensis*). Coyotes (*Canis latrans)* are occasionally spotted in Bucks County. An occasional river otter (*Lutra Canadensis)* has been seen in Upper Bucks County and occasionally individual black bears (*Ursus americanus*) are spotted foraging in the region but none are known to frequent the area. Durham Mine in northern Bucks County is the second largest bat hibernaculum in Pennsylvania, housing 8,000-10,000 bats when last surveyed in 1997.

The interspersion of forest and agricultural lands, along with numerous wetlands located along stream channels, provides habitat for a variety of woodland, farmland, and wetland wildlife species. Game species include gray squirrel, raccoon, fox, ruffed grouse (*Bonasa umbellus)*, wild turkey (*Meleagris gallopavo)*, pheasant (*Phasianus colchicus)*, white-tailed deer, eastern cottontail rabbit, muskrat, weasel, and mink. Non-game species include numerous small mammals, reptiles, shore birds, raptors, and various songbirds. Many of these species are dependent on forested, agricultural, and wetland areas for food and cover.

Currently there has been no comprehensive evaluation of the wildlife fauna of the Cooks Creek Watershed, in spite of the recognition that the area has received from wildlife managers. In order to ensure that valuable habitat for wildlife is protected, this evaluation should be performed, focusing on those areas already identified as having the potential to support wildlife, particularly protected species.

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Aquatic Species

Throughout the last century, fish diversity has declined in Southern Bucks County due to water pollution, habitat degradation, and the detrimental impact of introduced species. However, the Cooks Creek Watershed still maintains a diverse and natural complement of aquatic life.

Biological investigations of Cooks Creek by the Pennsylvania Fish Commission (PFC) and the Bureau of Water Quality Management (BWQM) reveal diverse, well-balanced, functional benthic macro-invertebrate communities. Sampling conducted by the BWQM in 1990 indicates a moderately high taxa count (ranging from 14 to 19 species). Samples were dominated by a number of mayfly, stonefly, and caddisfly genera. These are positive indicator species that reflect good to excellent water quality conditions within the sampling areas. An extensive evaluation of the benthic invertebrate communities in Cooks Creek was performed by the Durham Township EAC in 1997 and 1998 (Symbiosis, 1998). Overall, the invertebrate communities are typical of the high water quality present in the surface waters of the Cooks Creek Watershed, but are sensitive to low flow conditions. It is unknown if this is due to the reduced flow itself or from increased concentrations of low level nutrient pollution that comes with reduced flow.

Fish population studies confirm Cooks Creek and its tributaries are dominated by naturally reproducing brown trout and other fishes indigenous to a cold-water habitat. Fish species typical of warm/cool water habitats (e.g., green sunfish, bluegill, largemouth and smallmouth bass, and carp) have also been collected from Cooks Creek. These species were most likely transient individuals migrating from the Delaware River or introduced species from fish producing farm ponds. American eels (*Anguilla rostrata)* have also been noted in Cooks Creek Watershed.

Electro fishing by the PFC and the BWQM confirms natural population of brown and brook trout in Cooks Creek. Brook trout are established in a number of the unnamed tributaries. Brown trout biomass is highest in the tributary, which flows through Springtown and the main stem reach below their confluence. As described in the Surface Water section of this report, numerous limestone springs augment the main stem flow of Cooks Creek in this region. The naturally high fertility of these limestone springs in association with their effects on habitat stability (stable flows and temperature) supports a valuable cold-water fishery. BWQM personnel observed numerous brown trout between 12 and 18 inches during the March 13, 1990 survey.

Vegetation

General habitat types found in the Cooks Creek basin include old-field, pasture and cultivated lands (30 to 40 %), hardwood forest (30 to 40 %), wetlands, and riparian areas. Within woodlands, timber composition is primarily mixed oak, with American elm (*Ulmus Americana)* and red maple (*Acer rubrum)* present in the stream valleys.

Cooks Creek Watershed has a diversity of naturally occurring plants with 2,038 different species recorded. Prior to European settlement 1,393 native species were present. An additional 645 plant species were introduced.

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Some introduced plants have become nuisance species such as: purple loosestrife (*Lythrum salicaria*), multiflora rose (*Rosa multiflora*), and lesser celandine (*Ranunculus ficaria*). These compete with native plant species. It is not known at this time the extent of infiltration of these species in the watershed or their impact on native flora. Another major threat to the native flora is the overpopulation of white tail deer, which over browse herbaceous species. This over browsing has resulted in the depletion of low-growing vegetation including native wild flowers, shrubs, tree seedlings, and saplings. Forest regeneration is threatened since there are no young tree seedlings and saplings to replace existing aging forest cover. Furthermore, erosion of steep slopes has resulted from loss of vegetative cover.

Natural Areas Inventory/PNDI Species

The Natural Areas Inventory is a program funded in part by PADCNR and sponsored by The Nature Conservancy. The purpose of these inventories is to provide the most complete compilation of data available regarding local flora and fauna. In addition the inventories include state or federally listed rare, threatened or endangered plant or wildlife species. The Pennsylvania Natural Diversity Inventory (PNDI) compiles inventories describing rare and significant natural resources within the Commonwealth of Pennsylvania.

Endangered and Protected Species were identified on the following sites. The numbering system of these sites is based upon *Natural Areas Inventory of Bucks County, Pennsylvania* (June, 1999) (Figure 32).

- **Durham Mine, Mine Hill and Rattlesnake Hill - "Site 6"--** The abandoned mine has become an important bat hibernacula, the second largest in Pennsylvania with 8,000 -10,000 bats recorded in a 1997 survey. Six species of bats have been identified at the mine, including two species of special concern in the state. The 150 to 175-acre forest that covers the northern and eastern slopes of Mine Hill and Rattlesnake Hill provides a link between the mine and the Cooks Creek and Delaware River corridors which is of significance for the bats and also provides habitat for 62 bird species including 10 rare breeders.

- **Buckwampum Mountain - " Site 55" --** This site includes approximately 320 acres of forested slopes and hilltop; it straddles the boundary between Durham and Springfield Townships. Headwaters streams of Gallows Run and Cooks Creek originate in seeps and wetlands on the slopes of Buckwampum Hill. Fifty-eight species of birds have been recorded including 7 rare breeders.

Important Habitats

Several important habitats were assigned priority ranking. Six sites were ranked as priority 1, 2 or 3 as determined through information available at the time of this report (Figure 32).

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Priority 1 Sites

Cooks Creek – Site No. 4 ***Springfield Township, Durham Township***

Cooks Creek (also known as Durham Creek) originates in the Triassic diabase and quartzite hills of western Springfield Township and flows in a northeasterly direction through Brunswick Formation shales into a limestone valley at Springtown. From there it follows a course through the Cambrian limestones of Springfield and Durham Townships to its confluence with the Delaware River below Riegelsville. The main stem of Cooks Creek is approximately 15 miles in length, the tributaries total an additional 37 miles. The creek has been designated an Exceptional Value (EV) stream by the PADEP. It supports a native brown trout population.

Headwaters of the main channel of Cooks Creek are on the lower slopes of The Lookout (see site # 35 below). Most of the land along the creek is agricultural, although extensive sedge meadows are present in several locations. Industry borders the creek near its mouth in the vicinity of Durham Furnace, the site of an early iron forge.

Cooks Creek is an outstanding aquatic resource. Protection efforts should extend from the headwaters downstream to the mouth at the Delaware River.

Notable features include:

- Tussock sedge marsh
- Red maple - scrub/shrub palustrine woodland
- Sugar maple - basswood forest
- Red oak - mixed hardwood forest
- Tulip tree - beech - maple forest
- Silver maple floodplain forest
- Red maple - scrub/shrub palustrine woodland

Durham Mine, Mine Hill, and Rattlesnake Hill – Site No. 6 ***Durham Township***

This site consists of extensive north-facing forested slopes extending for about two miles along Route 212 from Mine Hill Road to the intersection with Route 32 south of Riegelsville. The ridge represents a spur of the Reading Prong and is composed of Hardyston quartzite and Byram gneiss separated from the main mass of the Reading Prong by the limestone valley encompassing Cooks Creek. The early forge at Durham was supplied iron ore from Mine Hill. In 1851 a larger mine was opened to the east in Rattlesnake Hill, which supplied the nearby Durham Iron Works with ore.

The abandoned mine has become an important bat hibernacula, the second largest in Pennsylvania with 8,000 -10,000 bats recorded in a 1997 survey. Six species of bats have been identified at the mine, including two species of special concern in the State. Due to the importance of the hibernacula, in 1994

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the Pennsylvania Game Commission and Heritage Conservancy collaborated to install specially designed gates to exclude humans, but allow bats to enter and leave freely. Problems involving vandalism of the gates have occurred, requiring continual monitoring and repairs. Increased monitoring of the gates is urgently needed to protect the bats, which are very vulnerable to disturbance, especially during hibernation. A rare fresh water invertebrate, Price's cave isopod, also, has been found in the mine.

The 150-175 acre forest on the northern and eastern slopes of Mine Hill and Rattlesnake Hill provides a link between the mine and the Cooks Creek and Delaware River corridors. This forest is important for the bats and also provides habitat for 62 bird species including 10 rare breeders.

Notable features:	Threatened and/or Endangered Status		
❖ Bat hibernacula housing 8,000-10,000 bats;			
❖ Red oak-mixed hardwood forest;			
❖ Eastern small-footed myotis Myotis leibii;	G3	S 1	PT
❖ Northern myotis-Myotis septentrionalis;	G4	S2S3	CR
❖ Price's cave isopod Caecidotea pricei;	G3	S2S3	
❖ 62 bird species, including 10 rare breeders.			

Priority 2 Sites

Cressman Hill – Site No. 27 ***Springfield Township***

This site consists of approximately 300-forested acres of slopes and flat uplands on diabase. It is contiguous with additional forested land comprising the Dimple Creek watershed, which extends into Haycock Township and includes Lake Towhee County Park. To the north Cressman Hill is part of the Cooks Creek Watershed. The forest is continuous except for utility right-of-ways and several roads that bisect it. It is a typical boulder-strewn diabase forest, ranging from moist to wet. Dominant canopy species include: tuliptree (*Liriodendron tulipifera*), red maple (*Acer rubrum*), red oak (*Quercus rubra*), white oak (*Q. alba*), swamp white oak (*Q. bicolor*), and shagbark hickory (*Carya ovata*). The herbaceous flora is rich and diverse.

Notable features:

- ❖ Tuliptree – beech – maple forest;
- ❖ Red maple terrestrial forest;
- ❖ Headwaters of tributaries of Cooks Creek, Three Mile Run and dimple (Kimbles) Creek; and,
- ❖ Large forested expanse.

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The Lookout – Site No. 49 ***Springfield Township***

This site consists of a forested diabase hill (part of the Haycock diabase sheet) that rises more than 150 feet above the surrounding countryside to a maximum elevation of 911 feet. It is surrounded by approximately 300 acres of mixed deciduous forest with a rich herbaceous layer extending from Richlandtown Pike west to Salem Road. There is a large abandoned quarry on the southeast slope. An electrical power transmission right-of-way crosses The Lookout from north to south. The surrounding forests include old stonewalls, vernal ponds, and other varied habitat. Headwater streams of both Cooks Creek and the Tohickon Creek originate on The Lookout fed by springs on the lower slopes. The site is identified as an outstanding scenic geological feature of Pennsylvania (Geyer and Bolles 1979).

Notable features:

- Outstanding scenic geologic feature;
- Headwaters of Cooks Creek including springs on lower slopes of The Lookout;
- Red oak-mixed hardwood forest; and,
- Sugar maple-basswood forest.

Priority 3 Sites

Buckwampum Mountain – Site No. 55 ***Springfield Township, Durham Township***

This site includes approximately 320 acres of forested slopes and hilltop; it straddles the boundary between Durham and Springfield Townships. Headwater streams of Gallows Run and Cooks Creek originate in seeps and wetlands on the slopes of Buckwampum Hill. Fifty-eight species of birds have been recorded including 7 rare breeders. The county owns several parcels on the hill including a communications tower. Residences are scattered along the lower slopes on a dirt road, which leads to the top on the south side. Deer browsing is moderate to severe throughout the area. Geology is Triassic shale and quartzite and the site lies immediately adjacent to the Monroe Border Fault. A description of the forest composition approximately 100 years ago is provided by the journals of two local botanists, John and Harvey Ruth (White and Rhoads 1996).

Notable features:

- Headwaters of tributaries of Gallows Run and Cooks Creek;
- Red oak-mixed hardwood forest;
- Red maple-blackgum-palustrine forest; and,
- 58 bird species including 10 rare breeders.

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Chestnut Hill – Site No. 57 ***Durham Township***

This site consists of extensive wooded slopes with scattered houses tucked into the woods. The entire area is heavily browsed by deer and consequently lacks shrub and under story canopy layers. Herbaceous species are also sparse. Chestnut Hill is composed of Triassic shale and quartzite and is adjacent to the Monroe Border Fault. Surveys by the Bucks County Audubon Society have identified 63 bird species on Chestnut Hill including 10 rare breeders.

Notable features:

- Immediately adjacent to the Monroe Border Fault;
- Red oak - mixed hardwood forest; and,
- 63 birds species including 10 rare breeders.

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VII. CULTURAL RESOURCES

Durham Township

Durham Township has limited cultural resources. There is one small un-named municipal park located in the vicinity of Dogwood Lane. Local residents identify this park as the *Durham Township Park*, although no official name has been designated. This park consists of a baseball field, basketball court, and small playground for younger children. No privately owned athletic facilities are in existence within the Township. No hiking or biking trails are available at this park or in any other area of the Township. (Janet Davis, August 2001, personal communication)

In spite of Cooks Creek trout population, public fishing is difficult, as all the land adjacent to Cooks Creek is privately owned. Residents gain access to the Creek from areas adjacent to public roads or from bridges. No open space is currently designated by the Township; however, an application is being prepared for submission. An Open Space Plan has been approved and a parcel on Red Bridge Road is being pursued at this time. In addition, it should be noted that several farm land parcels are held under agricultural preservation and conservation easements.

Springfield Township

The following information was obtained via a telephone interview with Jeffery Mease, Springfield Township Zoning Officer, August 2001. Springfield Township has no municipally owned parks, hiking, or biking trails. There is discussion with officials pertaining to the construction of a hiking trail between Durham and Springfield Townships.

Fishing throughout the Township is similar to Durham, where all land adjacent to Cooks Creek is privately owned. Admittance to fishing areas is limited to public road or bridge access. Springtown Village is the home of a privately owned Athletic Association equipped with tennis courts, basketball courts and baseball fields primarily used for little league baseball. Playground areas are available for use under limited conditions at public school buildings.

No municipally held land is designated for open space. The Township is actively investigating the opportunities for the purchase of land or development rights for open space use. The Springfield Township Open Space and Farmland Preservation Plan identifies the following privately held properties within Springfield Township:

- The Heritage Conservancy owns 63.7 acres dedicated for open space,
- The Haycock Camping Ministries owns 160.78 acres, and
- The Silver Creek Recreation Area holds 31.83 acres for private recreation.

This plan further identifies the following conceptual recreational trails (Figure 33):

- Silver Creek Athletic Association to Durham Athletic Association;
- Walnut Street, Springtown to Springtown Rod and Gun Club;
- Springfield School to Silver Valley Conservation Area;

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- Quarry Road to Ebert Road for access to Passer Community Association;
- Active/Passive Recreation Area on PP&L Property on Wrecsics Road; and,
- Route 212 Richlandtown Borough to Funks Mill Road/Old Bethlehem Road.

Cooks Creek Watershed

Cooks Creek Watershed Association

The Cooks Creek Watershed Association (CCWA) is a private not for profit corporation providing a forum for public education and advocacy for the Cooks Creek Watershed. The CCWA was founded in 1974 and has membership ranging from a few dozen to a few hundred concerned citizens. The Association adopted the following as its goal. "To protect, preserve and improve the quality of water, land and life in the Cooks Creek Watershed."

In the years since its founding CCWA has done much to further this lofty goal. Environmental camps have been conducted jointly CCWA and other nearby environmental education groups almost every year from 1975 to 1995. Camps have explored topics ranging from life in ponds and wetlands, forest ecology, Native Americans, and included night-time owlings. Recently, these outreach activities have been reinvigorated through the CCWA participation in the Rivers Conservation program.

In 1975, Cooks Creek was classified as a "warm water fishery" suitable for trout stocking. The CCWA recognized that the water quality was much higher than warm water fishery since Cooks Creek supported reproducing populations of brown and brook trout, had abundant macro invertebrates and had many other small fishes. In 1976 CCWA initiated the first stream reclassification effort and saw Cooks Creek's classification raised to "cold water fishery." In the late 1980's, after much work on the part of the members of CCWA the classification was again raised, this time to "exceptional value waters."

Stream Improvement was a very important part of CCWA during the 1980's. Starting in 1977 when its first gabion was placed to divert the storm flow away from an eroding bank until 1991 when the program was completed CCWA members worked with the Soil Conservation District, the Fish Commission and Trout Unlimited to reduce soil erosion and flooding.

Water Quality has been a driving force of CCWA since the first reclassification of the waters of Cooks Creek in 1976. CCWA has tested the stream at varying places and times. In 1975, testing for *E. coli* bacteria was started and continued until 1977. The Fish Commission has surveyed the stream with shock treatments and the Delaware River Keepers Network has tested the waters for dissolved oxygen, pH, temperature, nitrates and phosphates. CCWA has joined the River Keeper and is now testing for these five parameters at four sites in the watershed. CCWA was asked to assist the U.S. Geologic Survey in measuring the groundwater levels and flows in the Cooks Creek Watershed. CCWA members participated for two years, measuring rainfall and recording meteorological events. The 1990's saw CCWA help broker a deal that involved the donation of a 64-acre tract of land to the Heritage Conservancy.

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In addition to the CCWA, the watershed also has two functioning Environmental Advisory Councils (Durham and Springfield Townships). There is also a movement underway to establish a private land conservancy.

Bucks County

Limited cultural and recreational resources are available within Durham and Springfield Townships; however, access to numerous resources within Bucks County is available. These facilities are in close proximity to Cooks Creek Watershed, and can be enjoyed by all watershed residents. A brief description of Bucks County's cultural and recreational resources follows.

The Bucks County Department of Parks and Recreation and Bucks County.com web sites identify the following park and recreation areas within the County:

- Seven (7) Parks: These parks offer: playgrounds, picnicking, hiking, ball fields, horseback riding trails, boating, fishing, camping, swimming, ice skating, nature areas, and rest rooms,
- Two (2) State Parks: These are: Delaware Canal State Park and Nockamixon State Park,
- Two (2) Nature Centers: These centers offer educational recreation,
- Two (2) Boat Rental Facilities, and
- One (1) Wildflower preserve.

Three environmental organizations are based in Bucks County. Each offers services for the protection, restoration, and enhancement of Bucks County's natural resources. These are: Delaware Riverkeeper Network in Washington Crossing, The Heritage Conservancy in Doylestown, and The Raymond Proffitt Foundation in Langhorne.

The area also boasts numerous Bed and Breakfast Inns throughout the region. Tourists are attracted to this region as it offers antique shopping, specialty stores, outdoor fun, and historic sites. These historic sites include: Washington Crossing Historic Park, The Pearl S. Buck House, The Fonthill Museum, The Moravian Pottery & Tile Works Museum, The Mercer Museum, and the Michener Art Museum.

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VIII. WATER BUDGET

A water budget can be compared to financial budget. A financial budget is used to maintain a balance between a persons' income and their outgoing cash flow or debt. A water budget can be considered much the same way. In other words, to maintain a balance in the ecological system one must account for the *income* (sources of water) and *outgoing* (water losses in the system) water resources. A water budget is used to manage growth and development within a community, and to guarantee that a sustainable supply of water remains consistent over time. This is also called the carrying capacity of the groundwater system. The quality and quantity of surface and groundwater sources, would be limiting factors with respect to growth density and siting for development. Careful planning should prevent exceeding the carrying capacity of the watershed.

The water budget takes into account the water cycle, evapotranspiration, groundwater and surface water supplies, and interbasin (import and export) transfers of water. A water budget is important to understand since it provides crucial information regarding the carrying capacity of the land with regard to water resources.

Aspects of the Water Budget

The Hydrologic Cycle or Water Cycle is the complex naturally occurring cycle or movement of water through evaporation, wind transport, stream flow, percolation, and other related processes. This cycle links the relationship between:

1. *Surface water* including: streams, run-off, and discharges; and,
2. *Groundwater* including: recharge, geologic formation yield potential, soil storage capacity, and aquifers.

The cycle describes how water circulates through the natural process. This system begins with the sun evaporating ocean and surface water. The evaporated water vapor enters the earth's atmosphere and moves with the flowing winds. Some of the water condenses into water droplets and is precipitated as rainfall and snow. The precipitation runs off the land surface and eventually flows back to the ocean completing the cycle. The cycle is generally limited by the local climate and the amount of precipitation. The cycle can also be influenced, to some degree, by human activities.

The water budget is dependent upon this cycle and the influences upon it. Understanding the geology and hydrogeology of the underlying formation of the watershed helps assess the potential for groundwater yield. Soil matrix, topographic relief (i.e., slope), and vegetative cover are other factors that may affect stream base flow and thus water quality and quantity. All of these are factors that affect the *income* of the budget.

Development activities can affect the water budget since they can alter groundwater recharge and stream flow. Clear cutting forests, drilling residential wells, plowing or displacing soils, construction of impervious surfaces, and stormwater control systems all may adversely affect the

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natural hydrologic cycle through altered uptake and additional usage of water resources. These may result in *outgoing* losses to the budget.
The challenge is to understand how to sustain and maintain the water quality and quantity in light of current and future development trends. Current water demands should be compared with future water demand projections to evaluate the potential carrying capacity of the watershed.

Base flow analysis calculated from Cooks Creek stream gauge data indicate that the watershed basin has a large storage capacity sustaining up to 92.29 % of stream flow during dry seasons. Analysis of the stream flow data from 1990 through 1999 further indicates that groundwater attributed to an average of 68.24 % of the base flow to Cooks Creek (Appendix D).

It should be noted, data gaps exist in the data collected between 1992 and 1999. Ongoing stream flow monitoring is being conducted. Data pertaining to the ongoing work up to the date of this report is included in Appendix D. Currently there are four (4) types of data being collected that can be used to assess the water budget of the watershed including:

1) Cooks Creek flow monitoring collected at the former USGS gauging station. An additional monitoring point is planned at the confluence of Spring Creek and Silver Creek;

2) Monthly residential observation well water level monitoring (at four (4) locations);

3) Collection of water levels data from residential wells to upgrade the existing groundwater contour mapping; and,

4) Water quality analytical sampling events within various locations of the watershed.

The calculation of a hydrologic budget is relatively simple, involving the subtraction of total outflow from total inflow, plus or minus the change in storage within the region. Of all the variables affecting the water budget, evapotranspiration (or transpiration) estimates pose the greatest problem. Evaporation refers to water losses directly through the air, while transpiration is defined as the water given off from plants and trees directly into the air. These factors are extremley difficult to measure and predict.

Numerous empirical methods of calculating evapotranspiration have been developed. The most common is that of Thornthwaite and Mather (1957) where potential evapotranspiration (PET) is estimated solely from climatological measurements. PET is defined as the amount of water that would be removed from the land surface by evaporation and transpiration processes. Table 5 presents the results of the PET determination for the Cooks Creek Watershed. With this data the actual evapotranspirartion (AET) can be calculated to provide the basis for determining deficits or surpluses in the overall water budget equation.

Water Budget calculations are shown in greater detail in Appendix D.

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IX. WATER BALANCE

The hydrologic equation, which is basically a statement of the law of conservation of matter, as it applies to the hydrologic cycle, defines the water balance. It states that in a specific period of time all water entering an area must either go into storage within its boundaries, be consumed therein, be exported from, or flow out either onto the surface or underground.

Groundwater is an integrated dynamic system based upon a combination of climatic, hydrologic, geologic, topographic, ecologic and soil-forming factors that collectively form a regime. These factors are interrelated in such a way that each provides some insight to the function of the system as a whole. Each factor can serve as an indicator of specific conditions present in the availabilty of groundwater. It is possible, therefore, to calculate the potential of an area for groundwater development by assessing as many of the factors listed above as possible. These factors are then compared or interpreted against known relationships among the factors and their effect on the groundwater regime.

A water balance input or *income* can be generated, in part, by calculating the potential groundwater yield from the geologic formations underlying the watershed. Varying geologic formations have been determined to yield specific quantities of groundwater. Geologic formations are comprised of hydrogeologic units. Data collected from these hydrogeologic units, have been used to determine the amount of groundwater each formation typically yields. For example, limestone formations are expected to yield a predictable quantity of groundwater, while crystalline formations yield an entirely different amount.

The area (size) of the 40 sub-watersheds was first determined using GIS based information. Next, the area of the geologic formations within each sub-watershed was calculated. The hydrogeologic units within each formation were then calculated to establish base flow contributions to the groundwater yield estimates (Table 6). The groundwater estimates were determined by taking the percentage of geologic units in each sub-watershed and multiplying the expected groundwater yield from each hydrogeologic unit. The expected groundwater yield was calculated for the following geologic categories, (1) Brunswick Group and Lockatong Formation, (2) the diabase, (3) carbonate rocks, and (4) crystaline rocks (Figure 22.1 through Figure22.7).

Each of the 40 sub-watersheds experience some amount of water use, primarily based upon residential use, which is expressed in "equivalent dwelling units" (EDUs). Based upon assumptions with respect to the number of dwelling units in each sub-watershed (estimated from the GIS database for population and households from the 1990 census) the consumptive use of water per dwelling unit was calculated at 300 gallons per day (GPD) (Table 7).

One statistic available to define the critical base flow condition is the Q7-10. The Q7-10 is the lowest consecutive 7-day average of stream flow, having the probability of occurring no more than once in a 10-year period. The recorded data for Cooks Creek flow-measurement station (12/12/1990 to 02/20/93, 05/11/1999 to 08/29/1999, and 12/18/1999 to present) indicates a critical base flow of 222 GPD/acre.

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Due to the limited stream gauge data available for Cooks Creek, yield ratios for the various rock aquifers were estimated from annual base flow for the 2, 5, 10, 25, and 50 year recurrence intervals at stream flow-measurement stations on Brandywine and Neshaminy Creek Basins (USGS Water-Resources Investigations Report 96-4127).

Analyzing the current and future hydrologic balance for each of the 40 sub-watersheds required the application of the Water Balance Model (WBM). This conceptual model considers the dynamics of water movement from precipitation through the soil and then into the groundwater reservoir, with eventual discharge as stream base flow. The WBM can be thought of as a bookkeeping process that accounts for the dynamics of the water cycle by considering each sub-watershed under stress conditions. The stream base flow is used as the net result of all limiting factors, including evaporation, transpiration and human intervention, so that existing uses and conditions are taken into consideration. The WBM has been applied and compiled for the entire watershed to identify potential stress conditions in the system to protect the resource (Table 7).
The water balance equation is: The quantity of precipitation (P) is equal to the stream flow (SF) plus evapotranspiration (PET), plus groundwater pumpage (GP), plus increase in groundwater storage (IGWS). $P = SF + PET + GP + IGWS$

Examples of Water Use Based upon Existing Conditions within the Watershed

Sub-watershed **CC1** is 2,643 acres and should yield 222 GPD/acre in drought conditions. Establishing the consumptive loss limit at 50% for the base flow reflects that 305,852 GPD would be evaporated. The 409 existing dwelling units in the sub-watershed, all of which are assumed to use on-site wastewater systems, will cumulatively lose approximately 24,540 GPD. This is only 4% of the Q7-10 stream flow; therefore, base flow is not affected.

Nitrate loading resulting from residential on-site septic systems are of concern. These on-site septic systems may generate nitrate loading to the groundwater, which may eventually negatively impact the aquifer. The nitrate loading is estimated in the last column of Table 7. This estimate was evaluated assuming the background concentration is 2 mg/1 within groundwater. Calculations performed reflect concern since all drainage areas detected Nitrate limits in excess of the Nitrate load.

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X. BEST MANAGEMENT PRACTICES

Best Management Practices (BMP) is considered to be the "best" guidelines and/or practices under current technology and understanding. BMPs can be initiated in the planning and design phases of projects in order to obtain the most benefit. BMPs have been prepared for numerous facets of development including: watershed management and protection; water quality protection; flora and fauna habitat protection; as well as residential well, septic system, and storm water control system design, construction and maintenance and/or monitoring.

Many publications have been prepared regarding BMPs. The primary sources widely used at the local or municipal level are:

- Pennsylvania Association of Conservation Districts, Inc. et.al. Pennsylvania Handbook of Best Management Practices for Developing Areas. Prepared by CH2MHill. Spring 1998.

- The National Farm *A* Syst / Home *A* Syst Program. Home *A* Syst – An Environmental Risk Assessment Guide for the Home. Natural, Resource, Agriculture, and Engineering Service (NRAES). April 1997.

- Commonwealth of Pennsylvania, Department of Environmental Protection. Erosion and Sediment Pollution Control Program Manual. DEP 363-2134-008, March 2000.

- Commonwealth of Pennsylvania, Department of Environmental Protection. Erosion and Sedimentation Control Plan Development Checkilists, Standard Worksheets, Details and Notes. A Companion to the Pennsylvania Erosion and Sediment Pollution Control Program Manual. January 1996.

- Commonwealth of Pennsylvania, Department of Environmental Protection. Summary Report of Urban Stormwater Nonpoint Source Pollution Controls and Practices. Prepared by Bureau of Watershed Conservation, 1998.

- Natural Resource Conservation Service. Pennsylvania Soil and Water Conservation Technical Guide, Part G, Section IV, Standards/Specifications. March 1983, revised October 1986.

- Pennsylvania State University. The Argonomy Guide. College of Agricultural Sciences. 1996 or most recent section.

- Commonwealth of Pennsylvania, Department of Transportation. Specifications. Publication 408M. 1996.

Appendix E provides copies of several BMP documents referencing wells, septic, and storm water systems. BMPs should be used when developing zoning ordinances or when passing local municipal codes with respect to the land use. Guiding Growth – Building Better Communities and Protecting Our Countryside, (Pennsylvania Environmental Council, September 1993), should be

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used as a planning guide to establish the framework for sound development and growth within Pennsylvania municipalities.

Utilizing GIS soil information from this report, detailed mapping was prepared showing the correlation between soil types and the “best” septic system design for the soil classification within a given parcel (Figures 36-41). This is an example of employing BMPs with the use of soil classifications when selecting various on-lot septic or conventional sewer systems available within the Cooks Creek Watershed.

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XI. MANAGEMENT OPTIONS AND RECOMMENDATIONS

The overall goal of this Cooks Creek Watershed Conservation Plan is two fold: 1) to formulate a management program that truly sustains water resource through utilization of Best Management Practices (BMPs) and 2) to highlight those characteristics or critical issues in the watershed that require further study. This can be achieved through projects conducted in cooperation with watershed associations, agricultural organizations, various governmental agencies and others. Management options will include maintenance, enhancement and restoration activities. The following management options and recommendations should be considered for protecting, enhancing, and preserving the Cooks Creek Watershed resources:

1. Develop a Water Management Plan

Using data developed from ongoing and future studies, develop a Sustainable Watershed Management Plan that provides for wellhead and baseflow protection in the Cooks Creek Watershed.

2. Monitoring Cooks Creek Flow

The critical baseflow condition ($Q_{7\text{-}10}$) values are used in the Water Balance Model. The $Q_{7\text{-}10}$ has not been collected from the Cooks Creek Watershed using data from a ten-year period. Less than four years of data have been collected for this calculation. This equation requires the collection and use of 10 years of data, therefore, continued monitoring of the "Red Bridge Road" bridge location gauging station should be conducted to obtain the additional data required. The following maintenance actions should be conducted:

- *Maintenance of Red Bridge Gauge* – Continue to maintain and periodically download the computer at the Red Bridge Road monitoring station and upload into WAMOS;

- *Maintenance of the Rating Curve for the Red Bridge Road Gauging Station*. The Rating Curve requires annual riverbed profile measurements and periodic stream velocity measurements; and,

- *Install a Second Stream Gauging Station* – A second stream gauge station should be installed in the eastern edge of the watershed. Preferably this station should be upstream of the confluence of Silver Creek with the main stem of Cooks Creek, in the village of Springtown.

3. Monitoring Aquifer Levels

Water levels should be measured monthly at 4 to 6 residential wells. This data is used in groundwater storage and water budget calculations in WAMOS computer interface.

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4. Generate an Upgraded Water Table Map.

In this study approximately 75 residential wells were utilized to establish the water table map. An additional 30 residential wells are suggested to measured for depth to water to upgrade the water table map.

5. Expand the GIS Database

As more watershed related data becomes available, expand and incorporate all data into GIS and computer applications. Train municipal officials in the use and maintenance of GIS databases. Develop and maintain current land use maps.

6. Continue to Develop the Hydrologic Database managed using the computer interface WAMOS

As more hydrologic data becomes available, continue to incorporate, expand, and enhance the hydrologic database and facilitate its use in planning activities.

7. Develop a Nutrient Management Plan

Low level, chronic nutrient pollution has been observed in the watershed and has been shown to impact water and habitat quality. Perform a comprehensive nutrient balance to determine the sources and causes of nutrient enrichment in the Cooks Creek Watershed. Use this information to pinpoint appropriate management actions.

8. Develop a Township Level Storm water Management Plan

Extremely local erosion problems have been observed contributing to siltation in the streambeds. Given the sensitivity of the wildlife and fisheries of the watershed these problems should be carefully examined and controlled, if possible. Although a county-wide storm water management plan exists a specific township level plan should be developed to determine the locations and magnitude of storm water runoff in the watershed. Monitor erosion throughout the watershed and determine its causes. Develop a plan to manage both storm water and erosion and determine appropriate management actions.

9. Develop a Comprehensive Biological Inventory

Considerable biological resources exist in the watershed. In order to monitor the success of this plan and to alert officials to any future problems, work with local watershed groups to establish and monitor the health of the biological resources of the watershed including but not limited to:

- Fish population surveys;
- Rare and endangered species (flora and fauna);
- Wetland plant inventory;

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- Bats of Mine Hill; and,
- Benthic invertebrate diversity and health.

10. Expand and Maintain a Water Quality Monitoring Program

In order to expand water quality monitoring information and track improvement, the following community programs should be encouraged:

- Stream Watch Program (Philadelphia Academy of Sciences program or equivalent);
- Nutrient Survey and Management Plan; and,
- Visual assessment (Delaware River Basin Commission method or equivalent).

11. Educational Activities

Educational programs are necessary to change misconceptions regarding watershed resources and to encourage future protection and enhancement of Cooks Creek Watershed. The following educational programs or forums should be considered:

- Water Quality Seminars for Local Government Officials:
  - Maintaining current or limited ground water levels in order to protect against excessive groundwater draw down that would result in adverse effects to wellheads and stream baseflows;
  - Suitability of soils for on-site septic systems including:
    - Soils feasible for conventional systems;
    - Soils feasible for alternative systems;
    - Soils not feasible for any type of on-site system;
    - Carbonate derived soils, not feasible in Bucks County for any on-site system; and,
    - Soils subject to flooding, not feasible for any on-site systems.
  - Minimization practices for point and non-point source pollutants; and
  - Improving riparian buffer management along tributaries.
- Public Workshops
  - Public awareness of non-point source pollution;
  - Implementation of animal nutrient management plans;

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- Improving farming practices especially with respect to livestock stream crossings and stream corridor livestock fencing initiatives; and,
- School outreach..

12. Riparian Buffer Improvements

A complete assessment of current stream bank conditions should be conducted to determine priority sites within the watershed requiring riparian buffer enhancements. Riparian buffer improvement and management programs should be employed.

13. Ordinances and Planning Documents

Update the Comprehensive Plans for both Durham and Springfield Townships. Include the data in this plan, and referenced studies. Work to ensure that water quality and quantity are sufficient to support local vision for the future of the watershed.

The following critical areas should be considered for zoning ordinance and Comprehensive Plan preparation:

- Storm water management and erosion control;
- Wetlands protection;
- Baseflow protection;
- Conservation easements and open space;
- Endangered and/or threatened species habitat protection;
- Karst and sinkhole land development standards;
- Overlay districts of critical areas (first order sub-basins; wetland buffers; riparian (flood plain); and, lakes and ponds);
- Septic systems types based upon soil districts;
- Steep slopes;
- Stream or riparian buffers; and,
- Wellhead protection.

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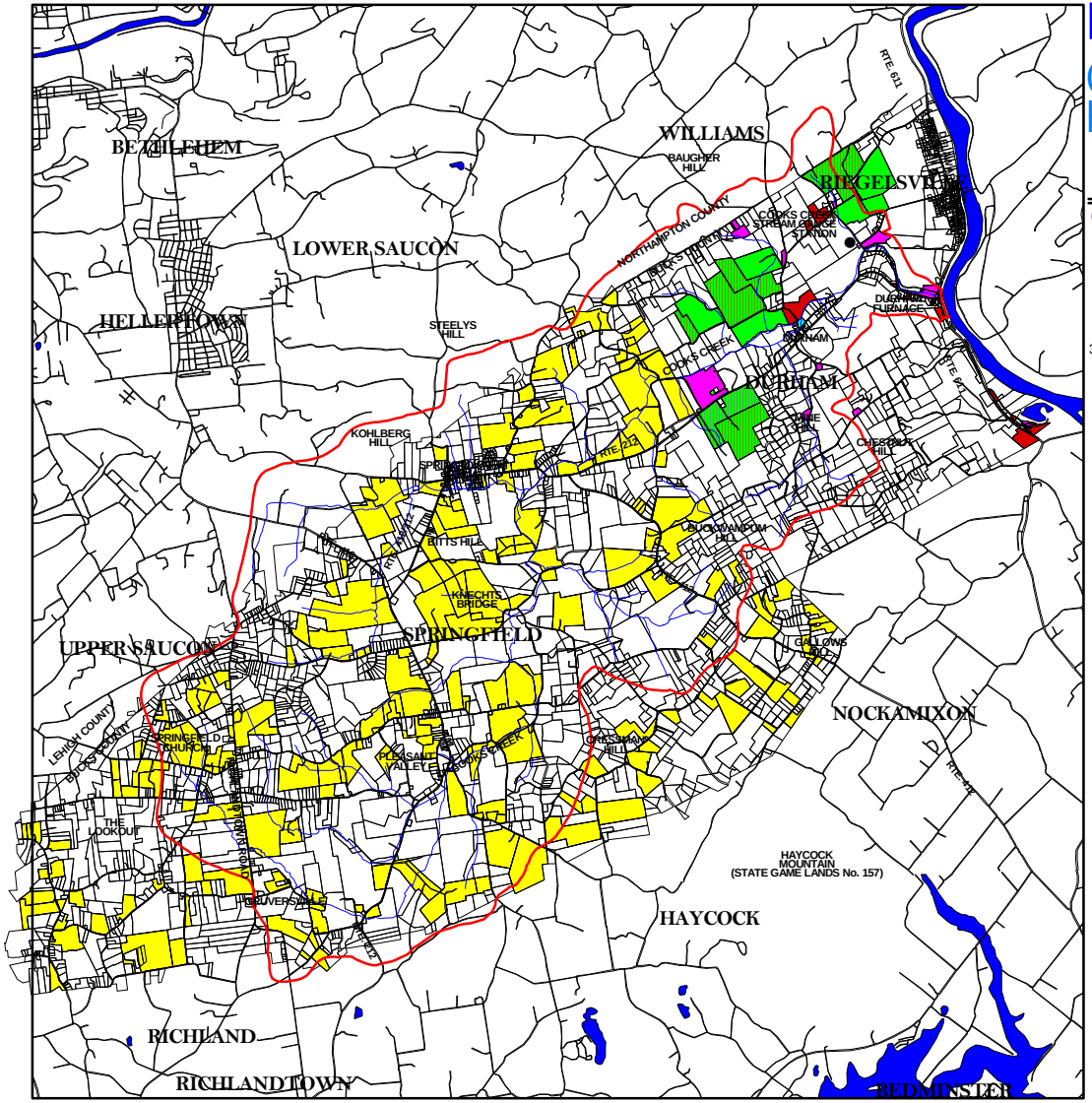

DTEAC- PaDCNR

COOKS CREEK WATERSHED RIVERS CONSERVATION PLAN

DURHAM AND SPRINGFIELD
BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis

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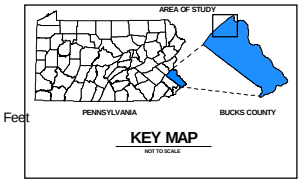
AUGUST 2001



- Figure A -
Cultural and Historic Resources Map

LEGEND

- Watershed Boundary
- Roads & Railroads
- Waterways
- Tax Map Parcels
- Historic Places - Springfield

Historic Places - Durham:

- Sites worthy of future study - may contribute to a multiple resource. Property nominated for agriculture
- National Register eligible sites
- National historic landmark sites - Sites on National Register
- Sites worthy of future study - Individual
- Sites worthy of future study - may contribute to a multiple resource. Property nominated for industry

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Environmental Advisory Council
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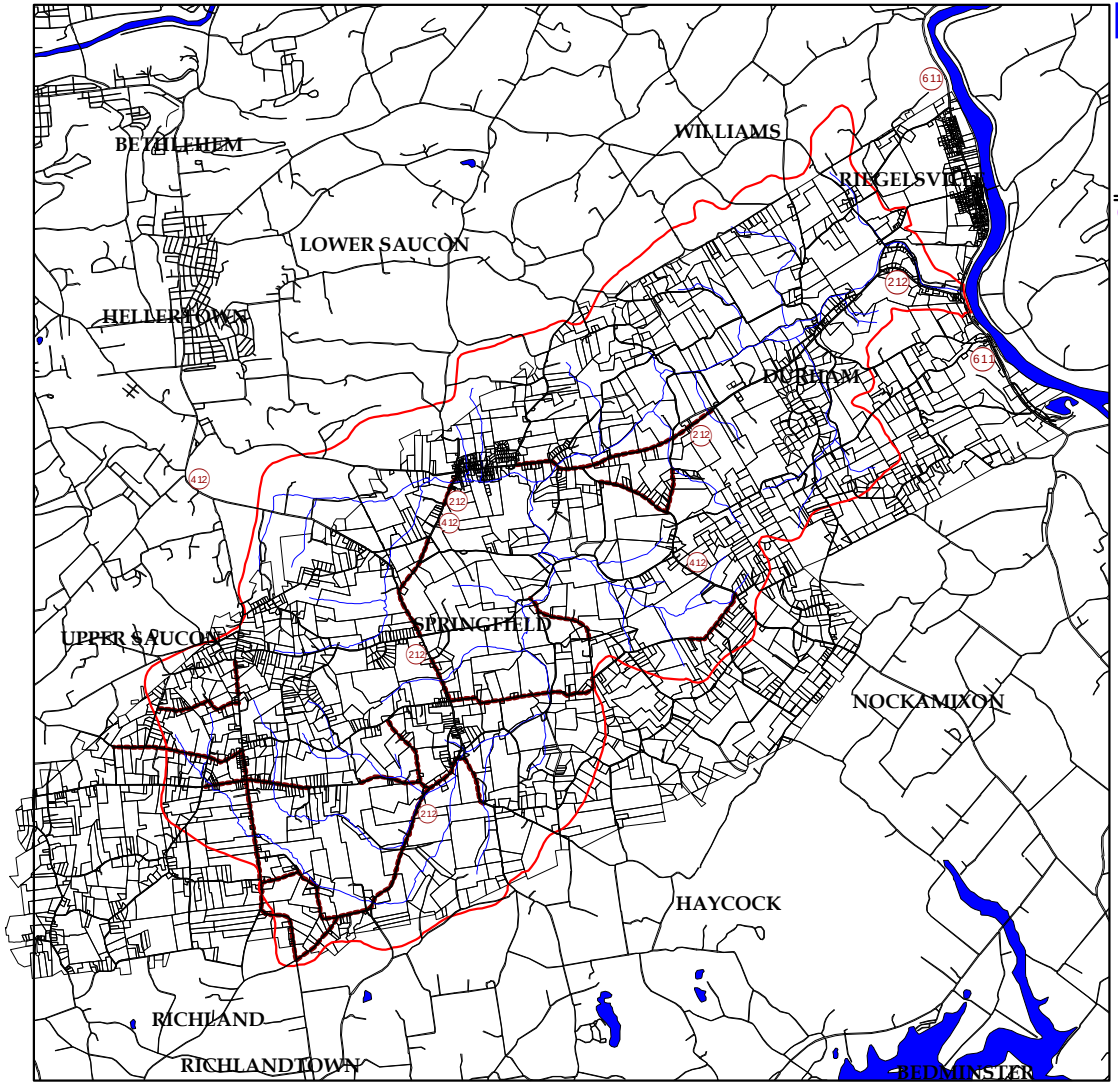

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BUCKS COUNTY, PENNSYLVANIA

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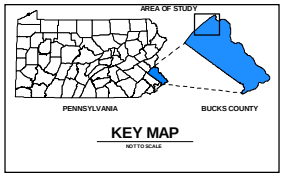

- Figure B - Scenic Roadways Map

LEGEND

- Watershed Boundary
- Roads & Railroads
- Waterways
- Tax Map Parcels
- Scenic Roadways

SOURCES:1) Springfield Township Open Space and Farmland Preservation Plan, Bucks County Planning Commission, July 1999.
2) DTEAC, Durham Resource Inventory Plan, 1994
3) Final Report & Data Analysis, Durham Township, Bucks County Historic Resource Survey, Bucks County Conservancy, October 1, 1992.

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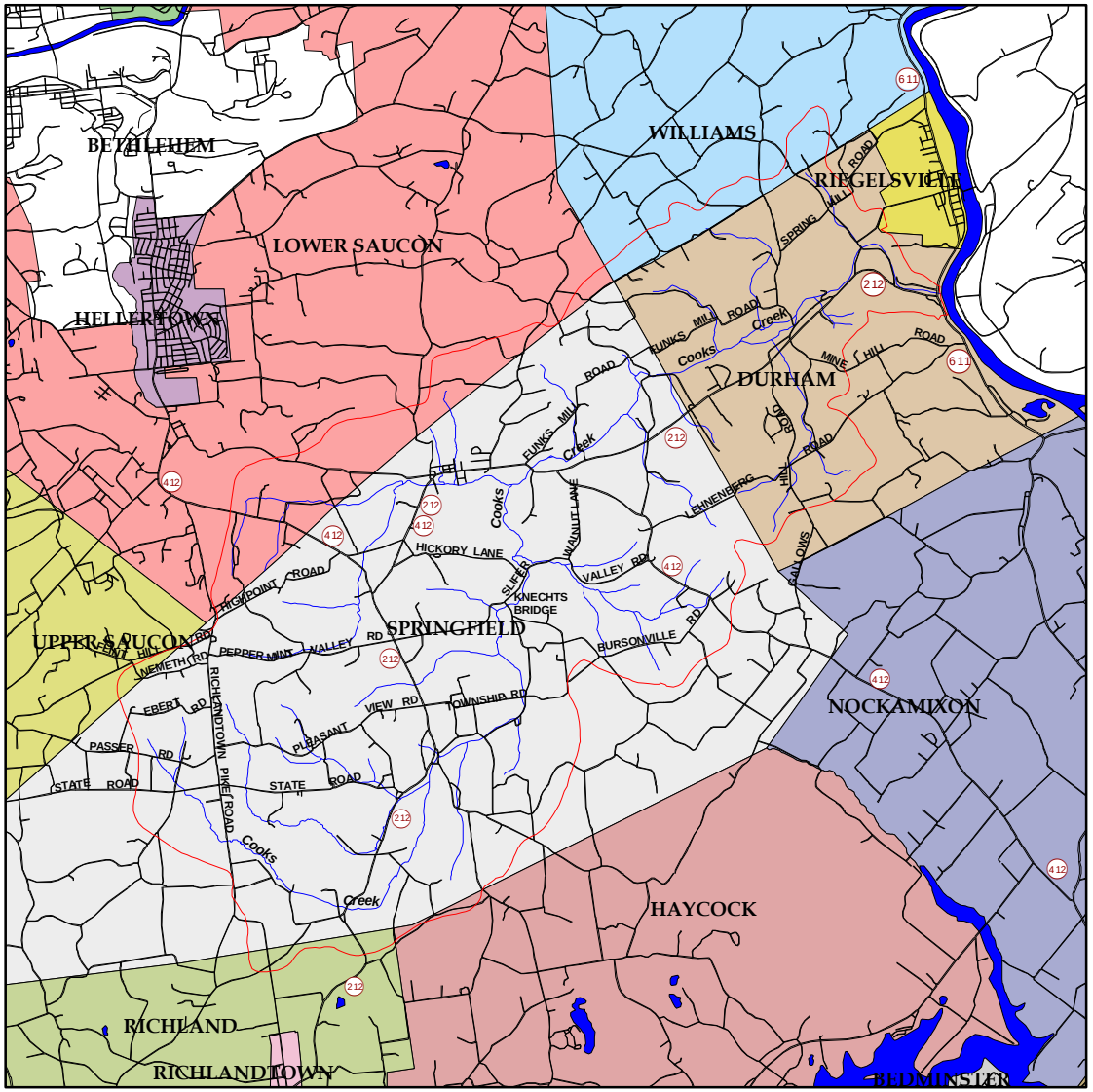

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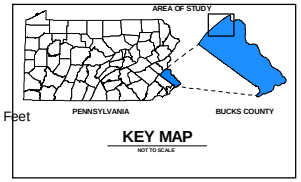

- Figure 1 -
The Base MAP

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Municipal Boundaries

- BEDMINSTER
- BETHLEHEM
- DURHAM
- FREEMANSBURG
- HAYCOCK
- HELLERTOWN
- LOWER SAUCON
- NOCKAMIXON
- RICHLAND
- RICHLANDTOWN
- RIEGELSVILLE
- SPRINGFIELD
- TINICUM
- UPPER SAUCON
- WILLIAMS

SOURCES: 1) GIS Data Depot (The GIS Data Depot and and GeoCommunity are houses data in support of GIS industry. The majority of the data provided has been downloaded from a wide range of GIS Web sites located on the Internet), Translation, attribution and analysis by MJE.

2) DTEAC , MJE , Wetlands Management Plan, Watershed digital map, 1999

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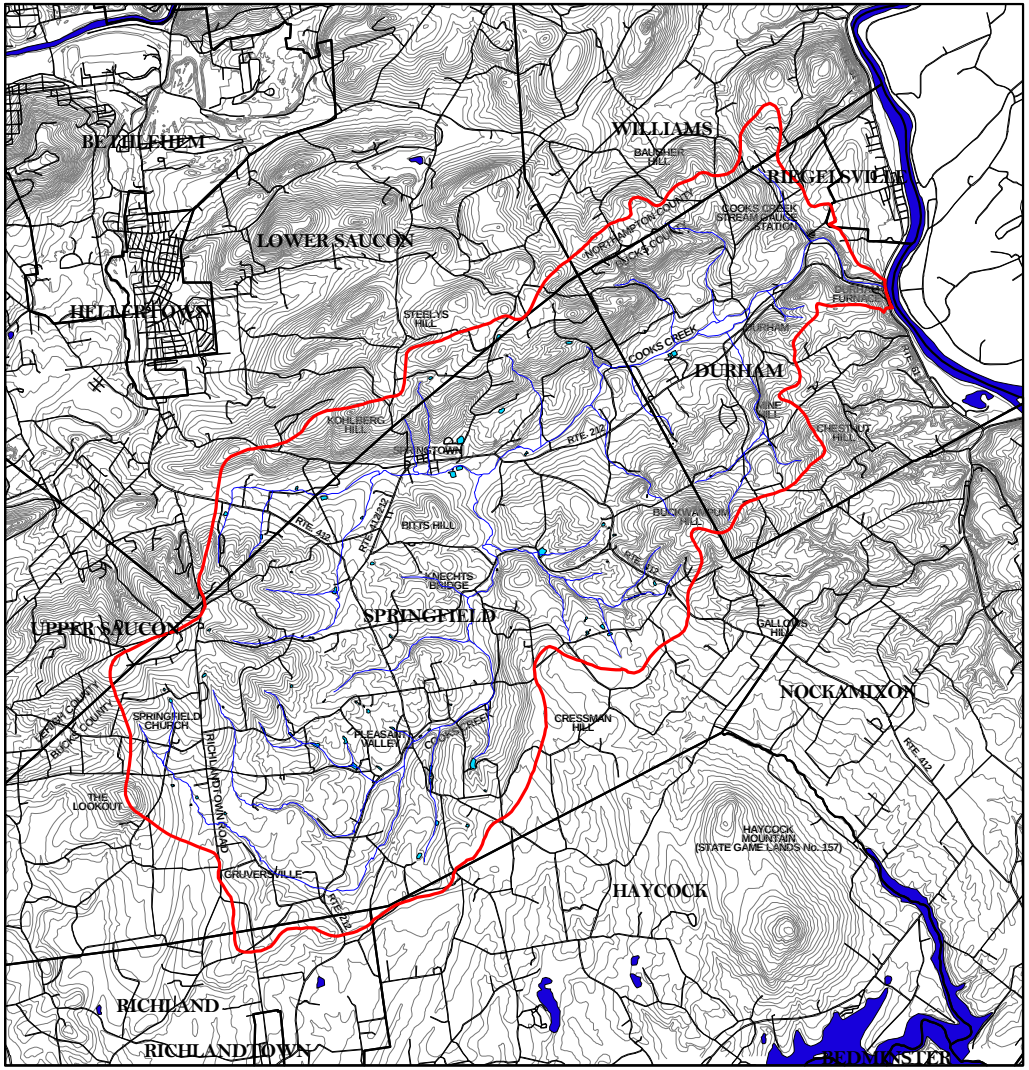

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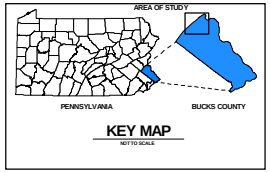

- Figure 2 - Topographic Map

LEGEND

- Watershed Boundary
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Ground Surface Contour

SOURCES:1) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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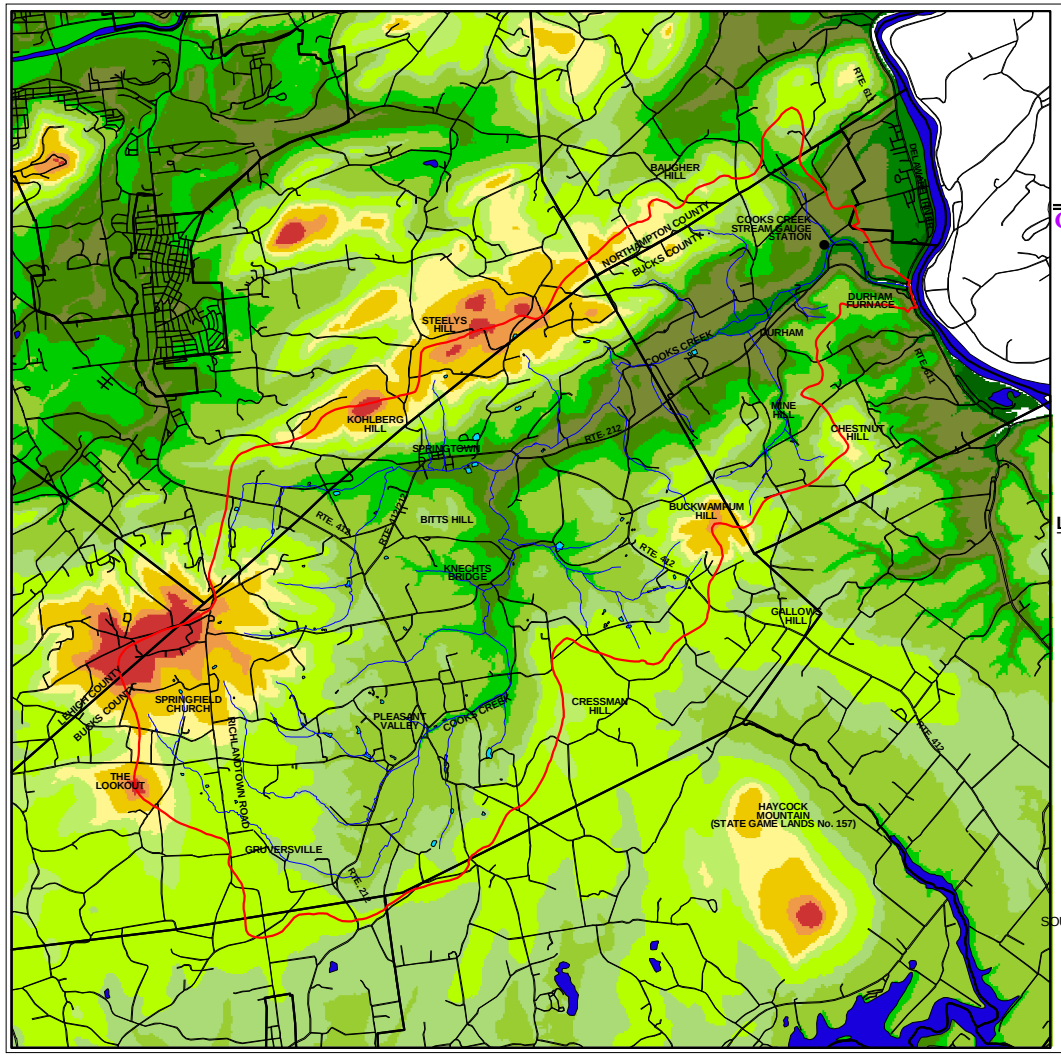

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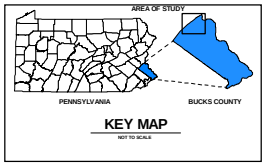

- Figure 3 - Topographic Map - DEM

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds

Elevation MSL (feet)

- 98 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- 300 - 350
- 350 - 400
- 400 - 450
- 450 - 500
- 500 - 550
- 550 - 600
- 600 - 650
- 650 - 700
- 700 - 750
- 750 - 800
- 800 - 850
- 850 - 900
- 900 - 950
- 950 - 1100
- No Data

SOURCES:1) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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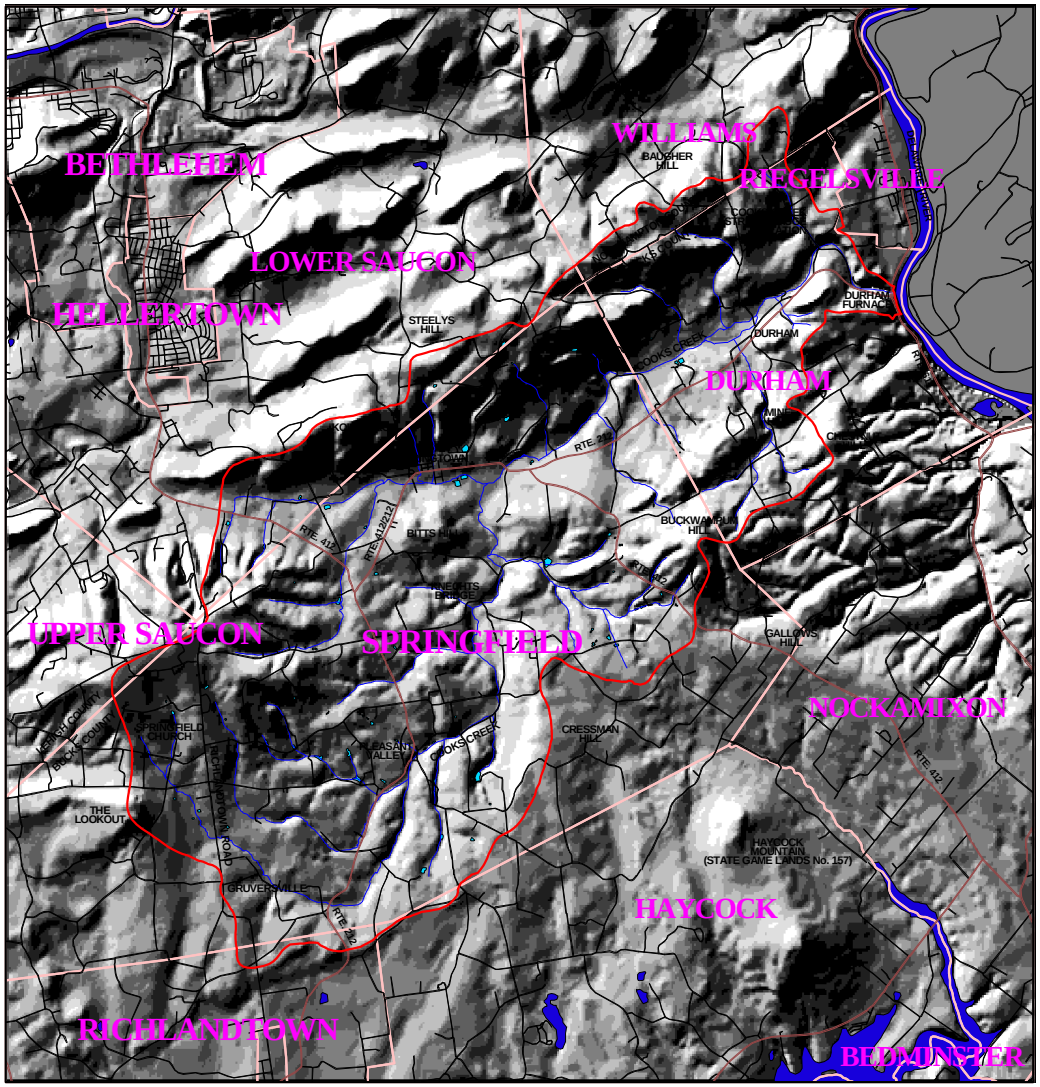

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BUCKS COUNTY, PENNSYLVANIA

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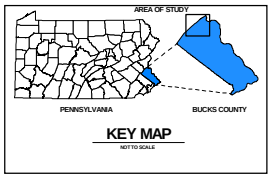

- Figure 4 - Hillshade View of the Cooks Creek Watershed

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds

SOURCES:1) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, digitize, translation, attribution and analysis by MJE, August 2000.

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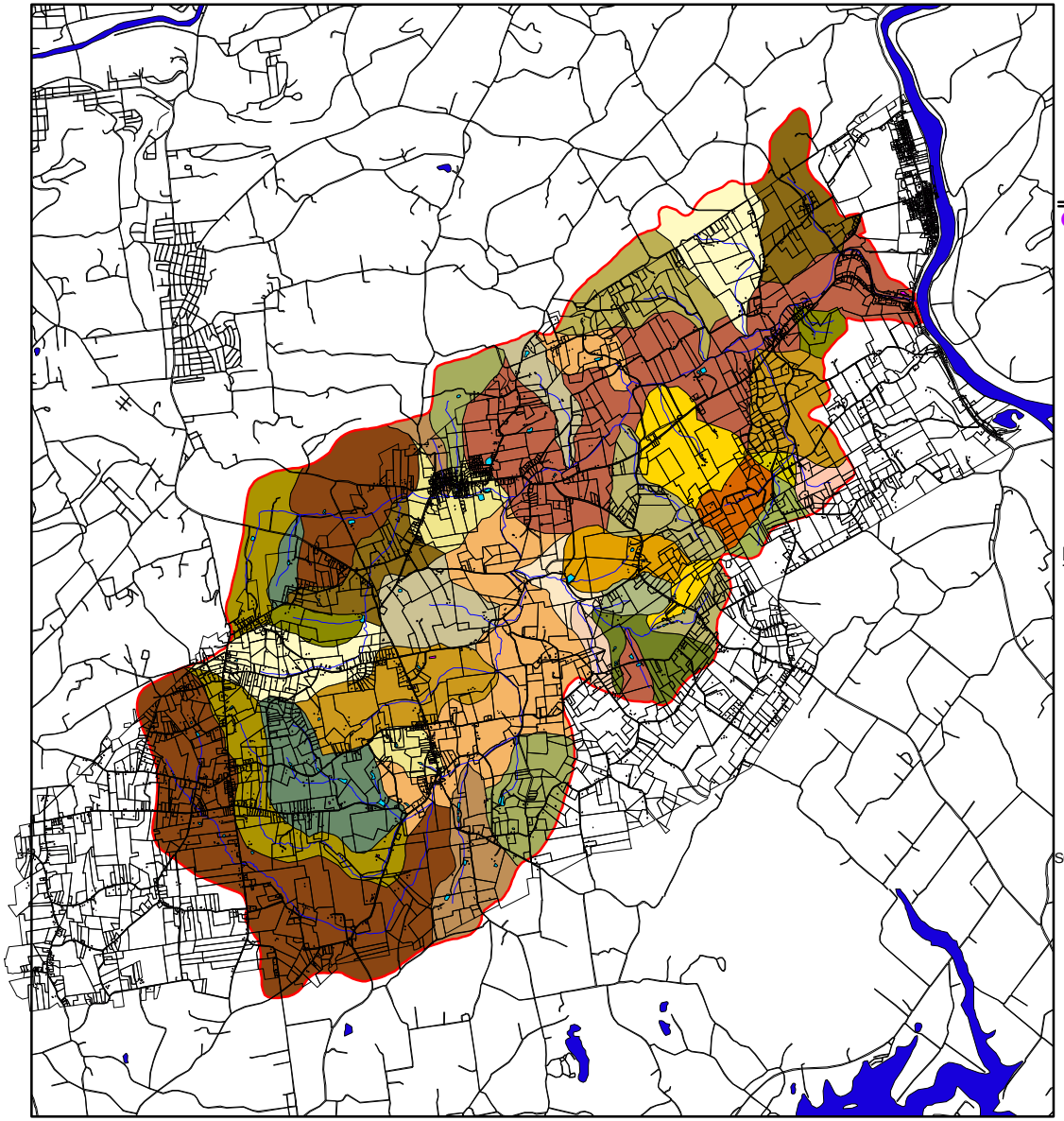

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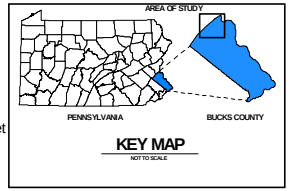

- Figure 5 - Cooks Creek Watershed Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Sub-basins
- Tax Map Parcels

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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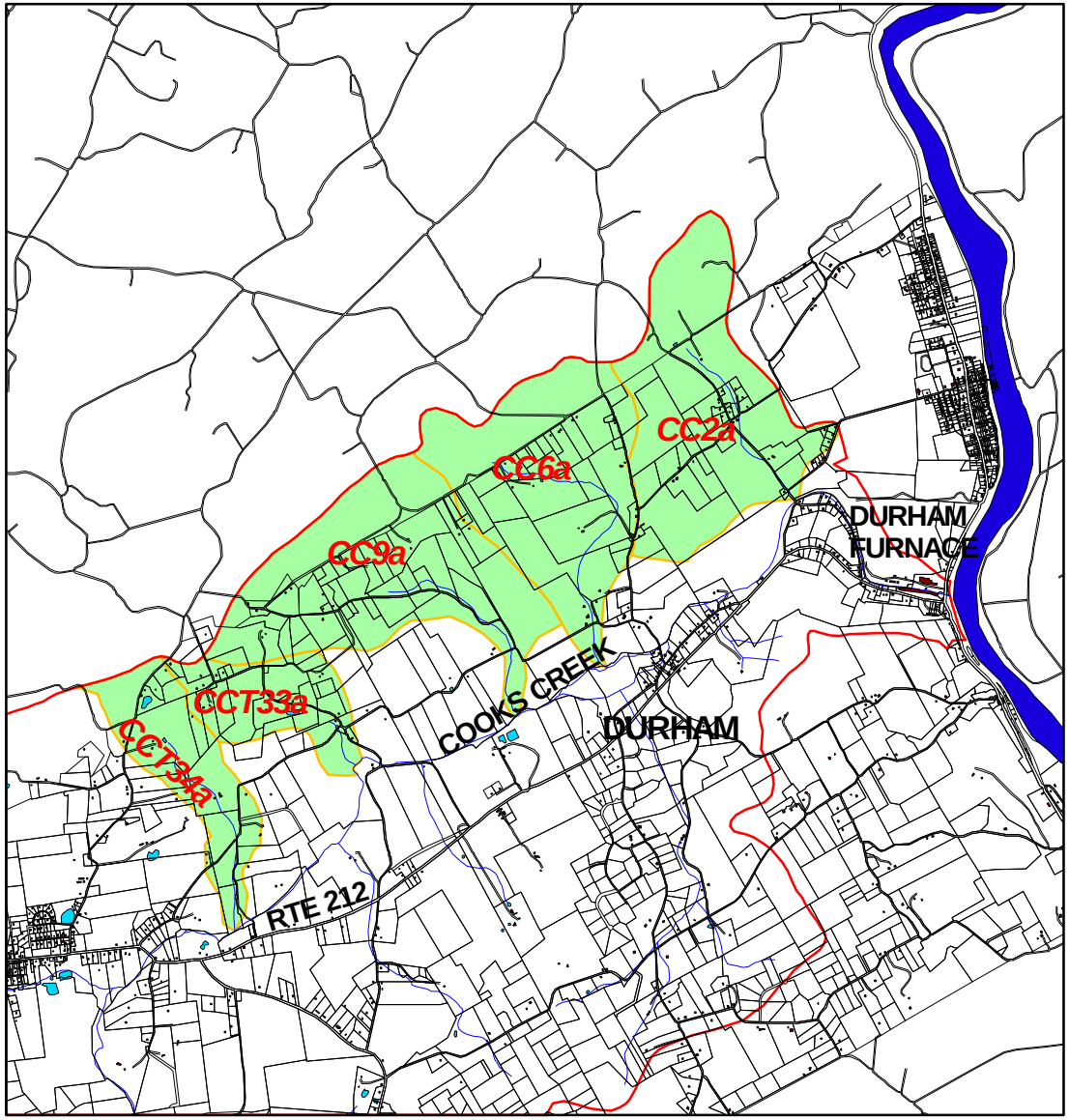

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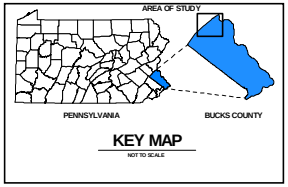

- Figure 5.1- Area 1 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- First Order Sub-basins
- Tax Map Parcels

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

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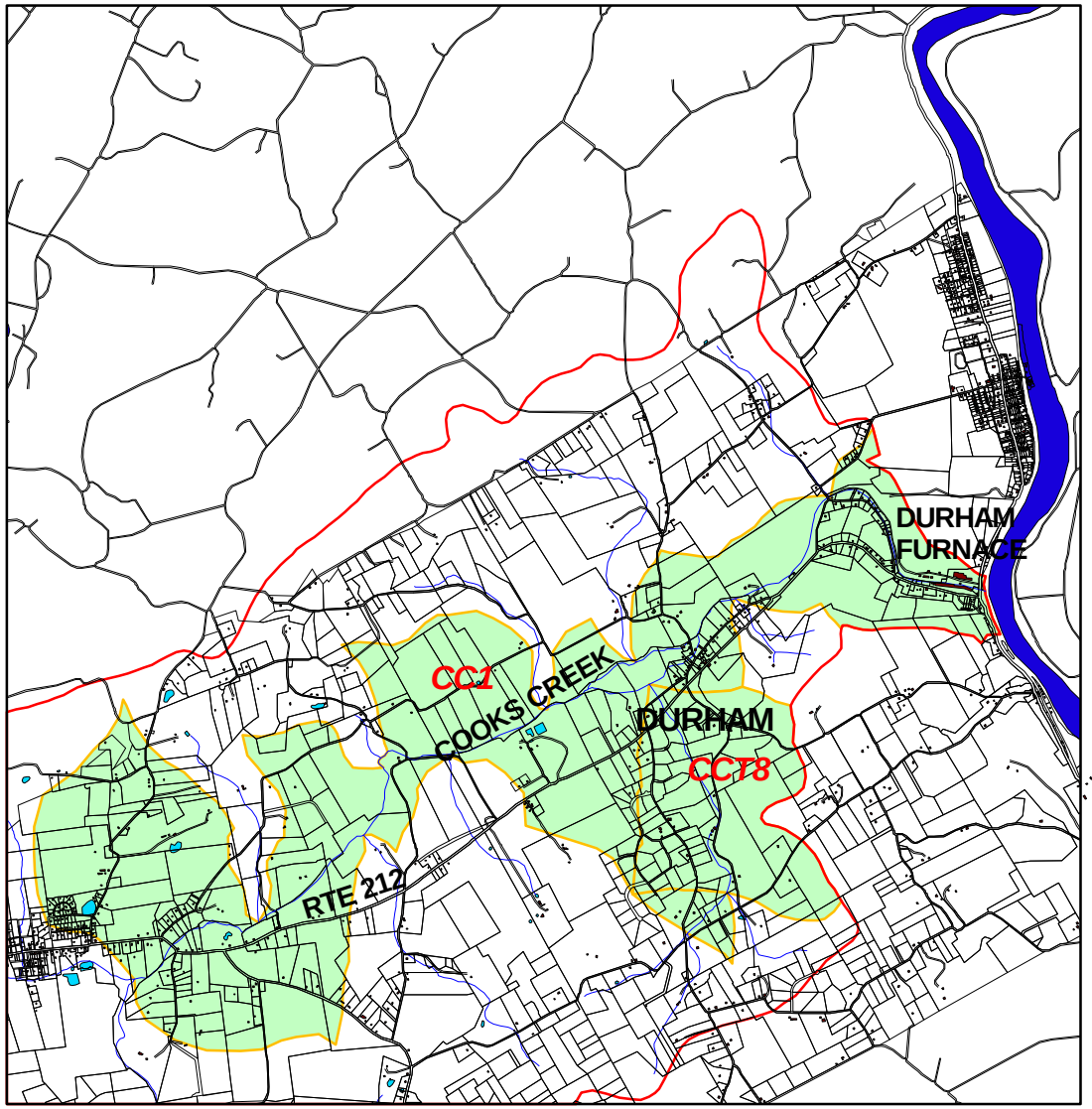

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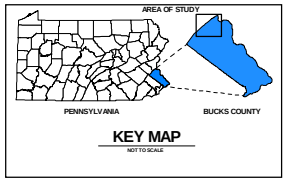

- Figure 5.2- Area 2 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Second Order Sub-basins
- Tax Map Parcels

SOURCES:
1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.
2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
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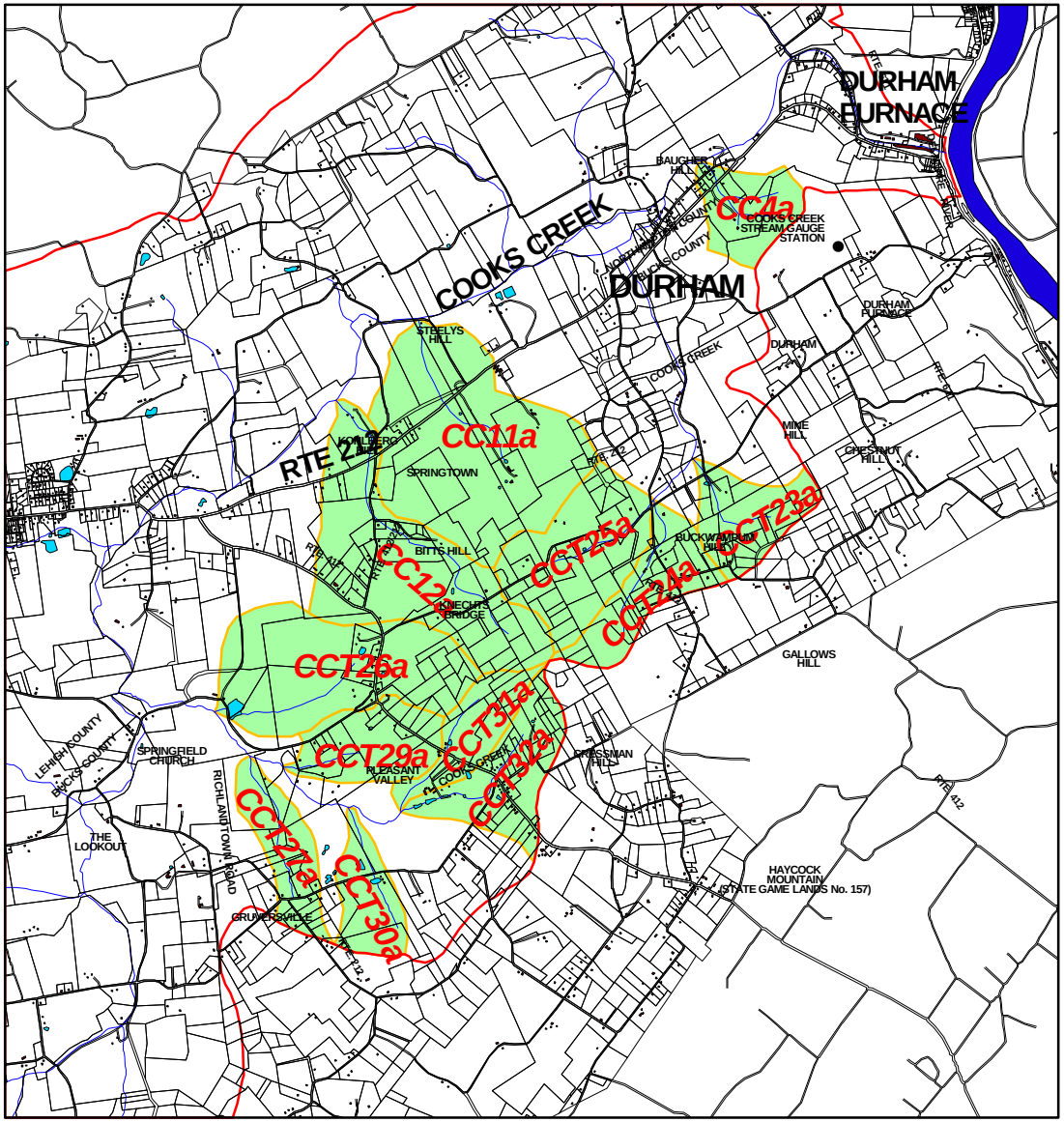

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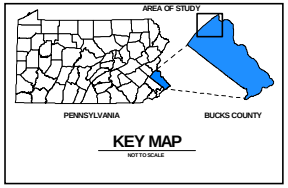

- Figure 5.3- Area 3 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- First Order Sub-basins
- Tax Map Parcels

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

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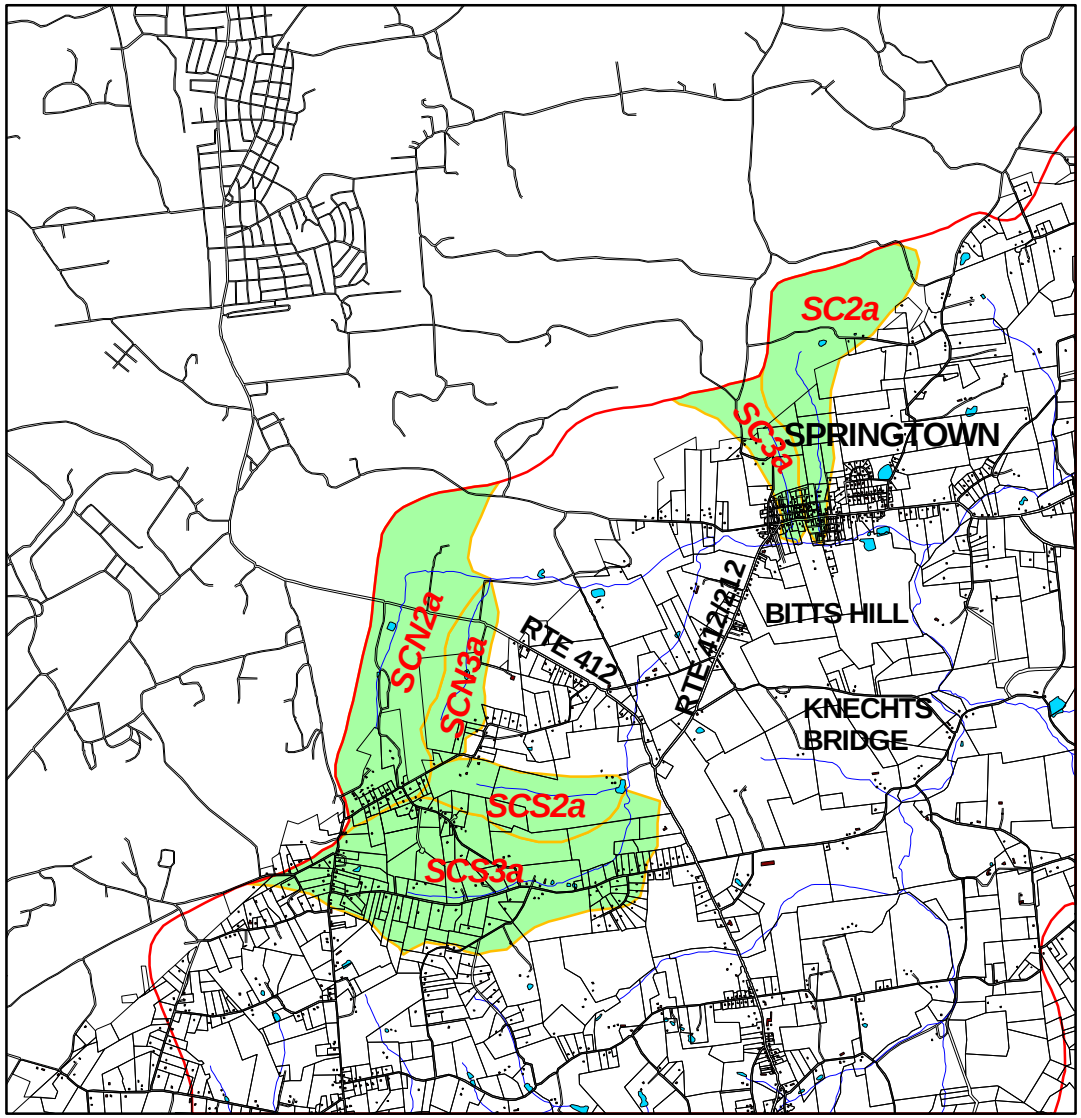

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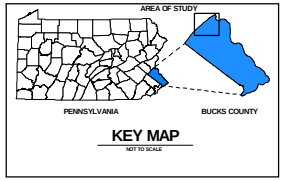

- Figure 5.4- Area 4 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- First Order Sub-basins
- Tax Map Parcels

SOURCES:
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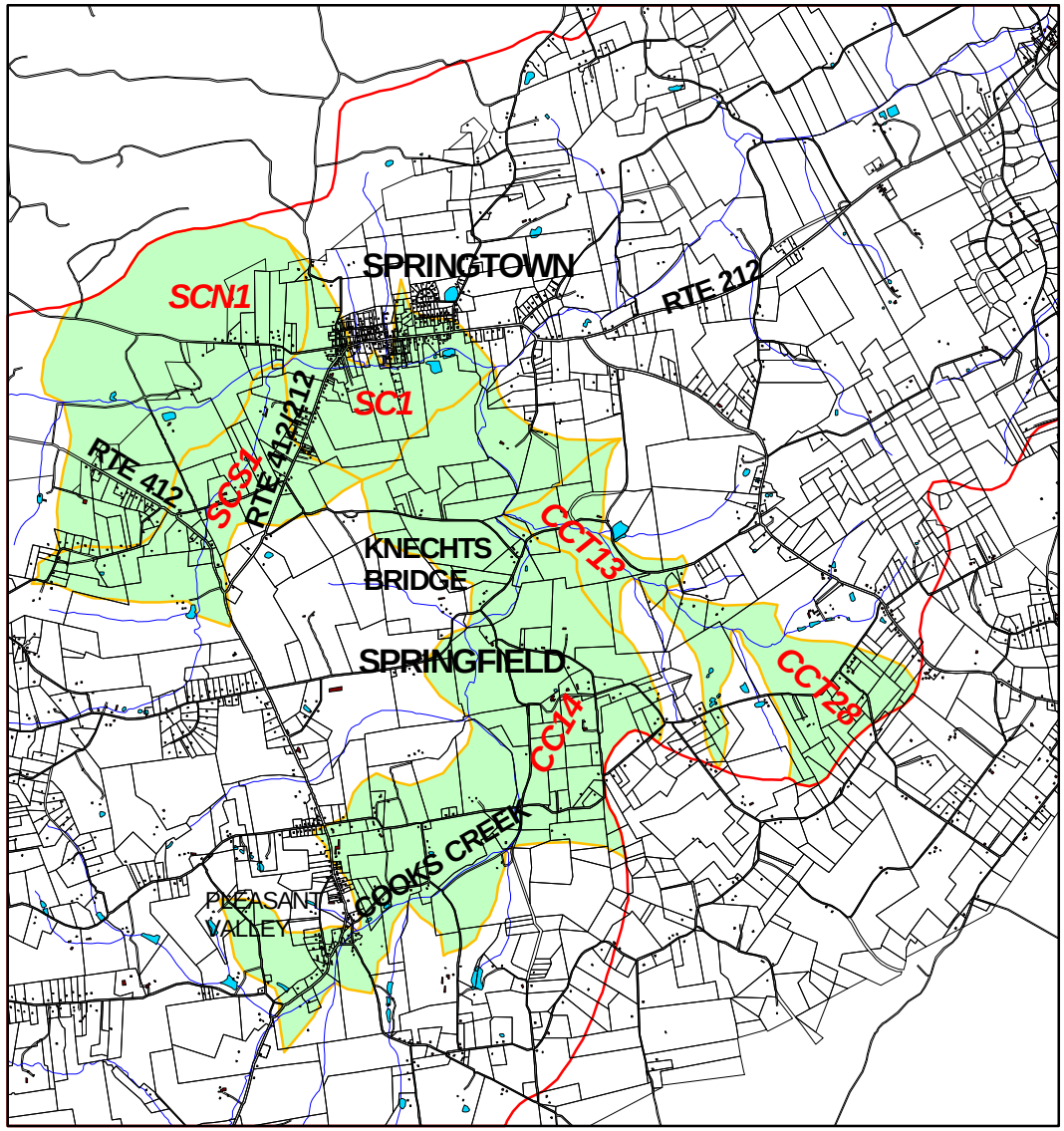

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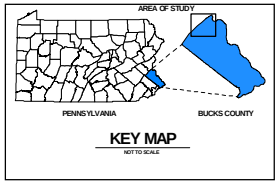

- Figure 5.5- Area 5 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Second Order Sub-basins
- Tax Map Parcels

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

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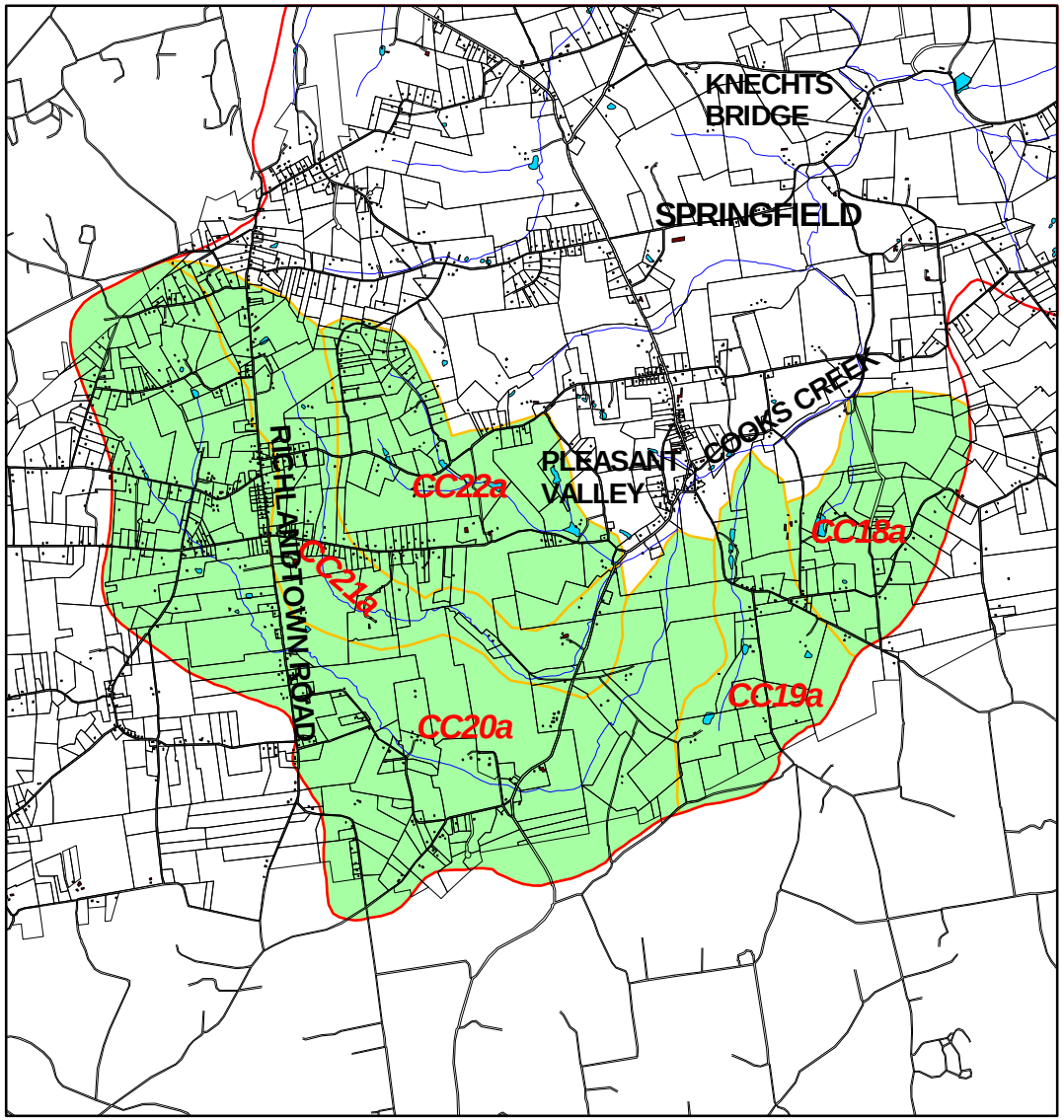

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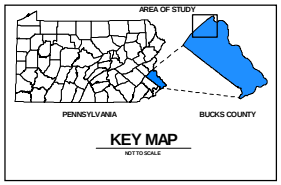

- Figure 5.6- Area 6 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- First Order Sub-basins
- Tax Map Parcels

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

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3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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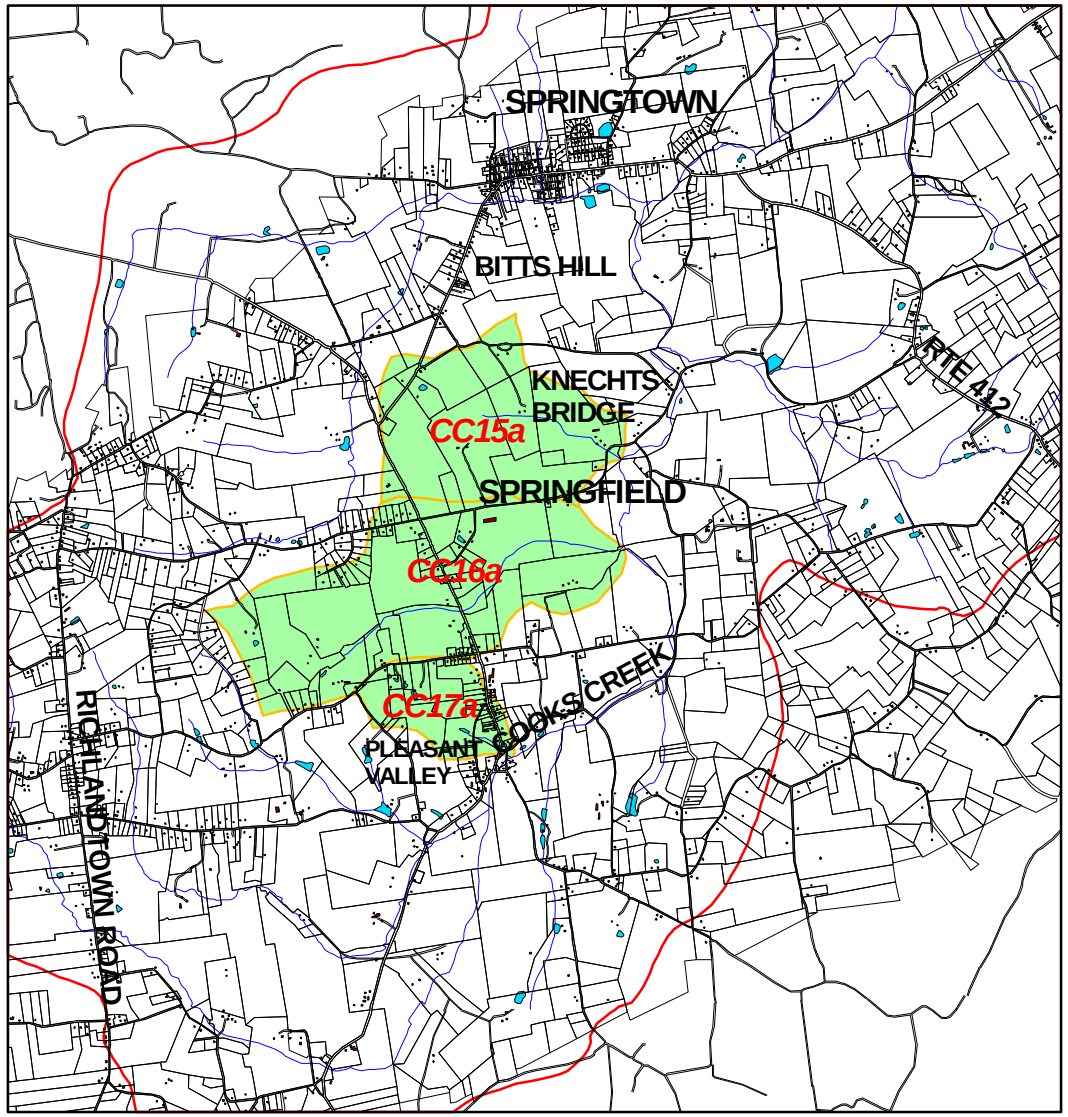

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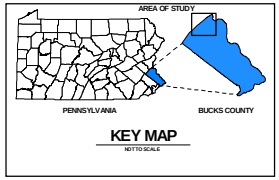

- Figure 5.7- Area 7 Sub-basins Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- First Order Sub-basins
- Tax Map Parcels

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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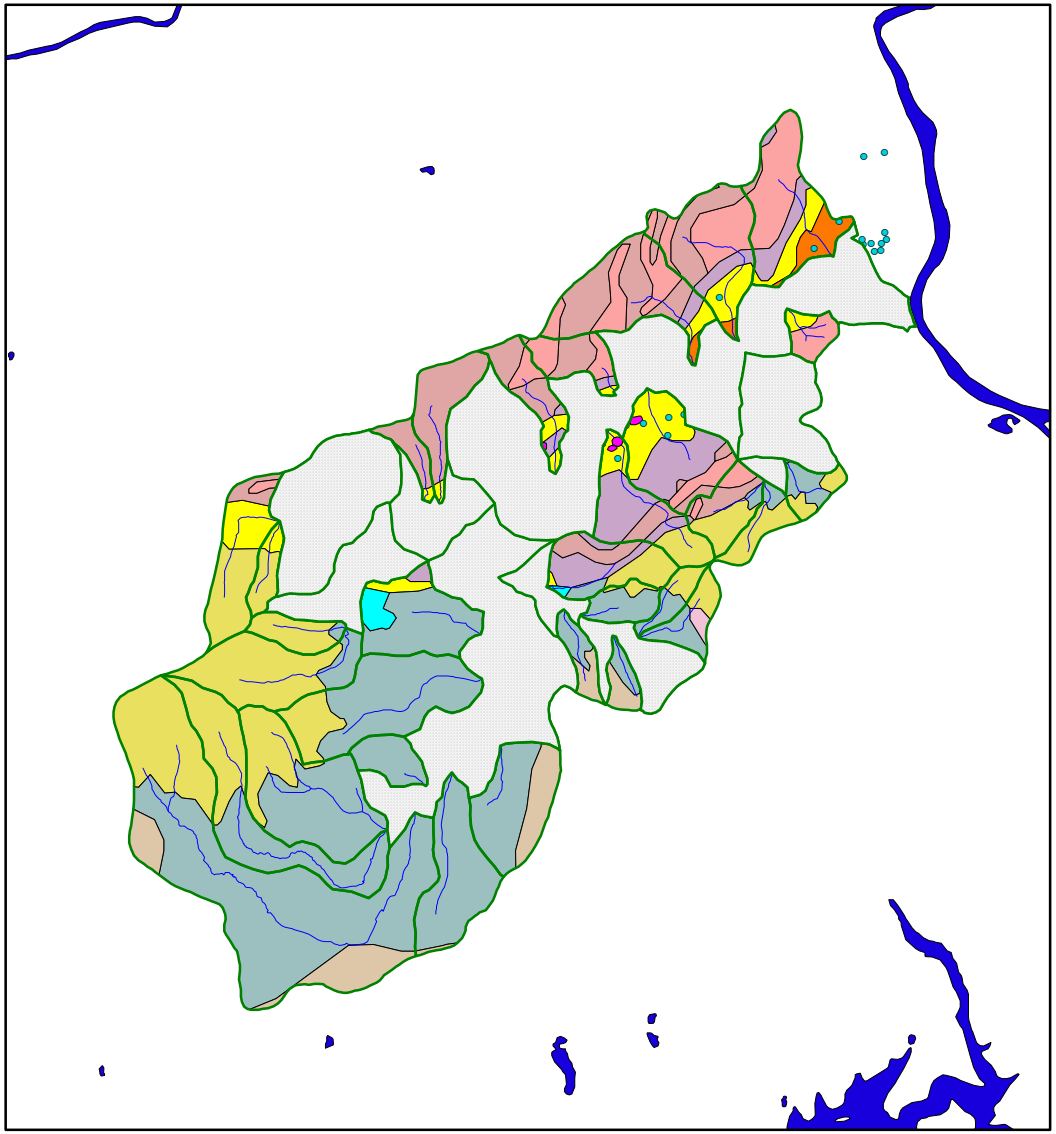

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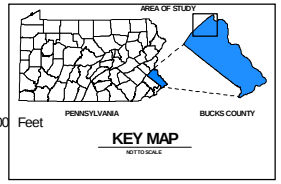

- Figure 6.1 -
First Order Sub-basin Geology Map

LEGEND

- Watershed Boundaries
- Waterways
- Lakes and Ponds
- Areas Susceptible to Karst Dissolution Features
- Sinkholes
- First Order Sub-basin
- Second Order Sub-basin
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

  (Brunswick Formation, Lockatong Formation, Quartz Fanoglomerate, Limestone Fanoglomerate: Passaic Formation (Undifferentiated))
- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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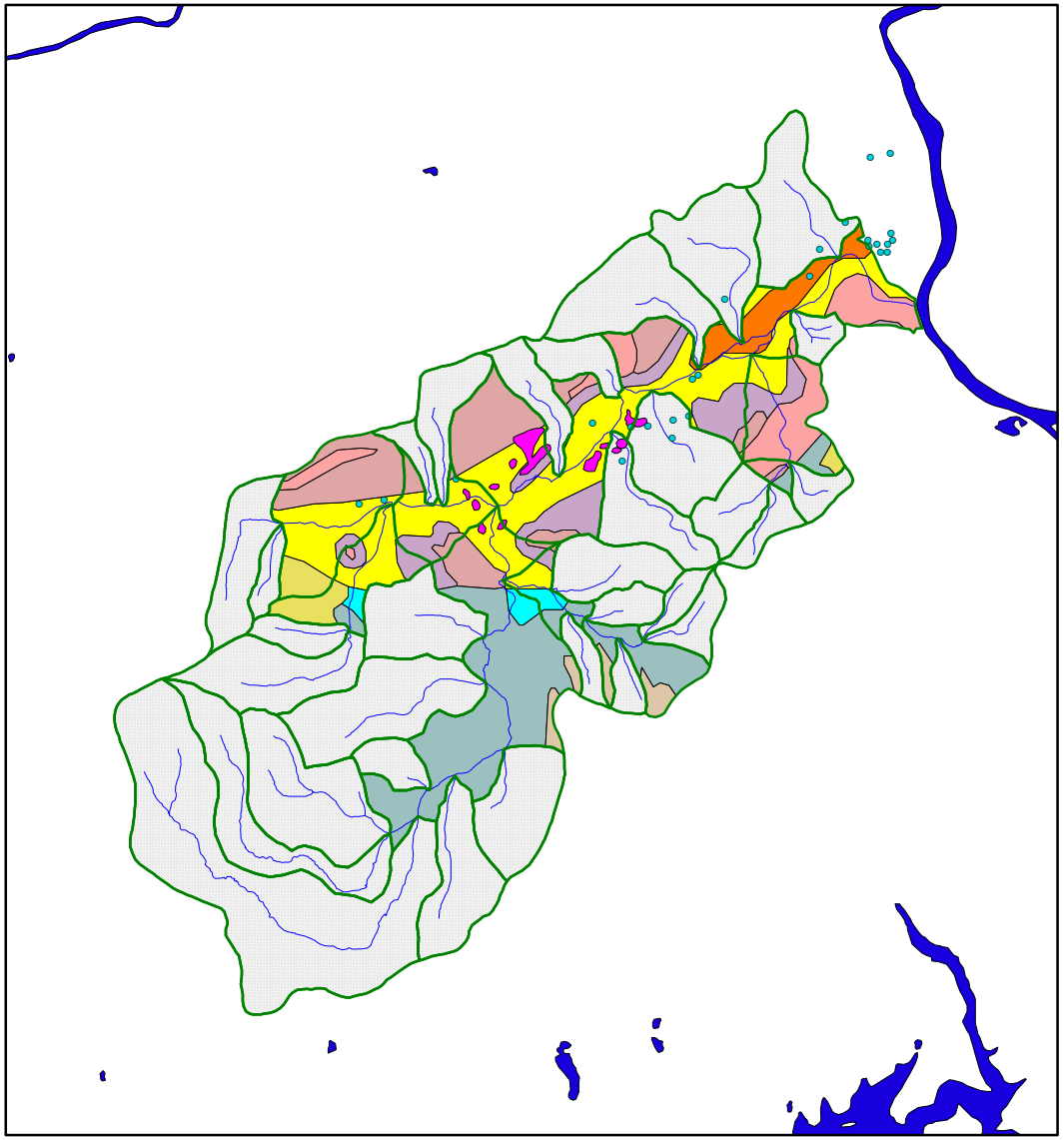

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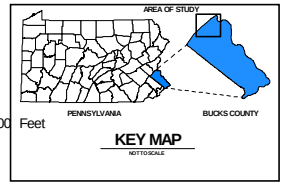

- Figure 6.2 - Second Order Sub-basin Geology Map

LEGEND

- Watershed Boundaries
- Waterways
- Lakes and Ponds
- Areas Susceptible to Karst Dissolution Features
- Sinkholes
- First Order Sub-basin
- Second Order Sub-basin
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *
- Passaic Formation (Undifferentiated)
- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

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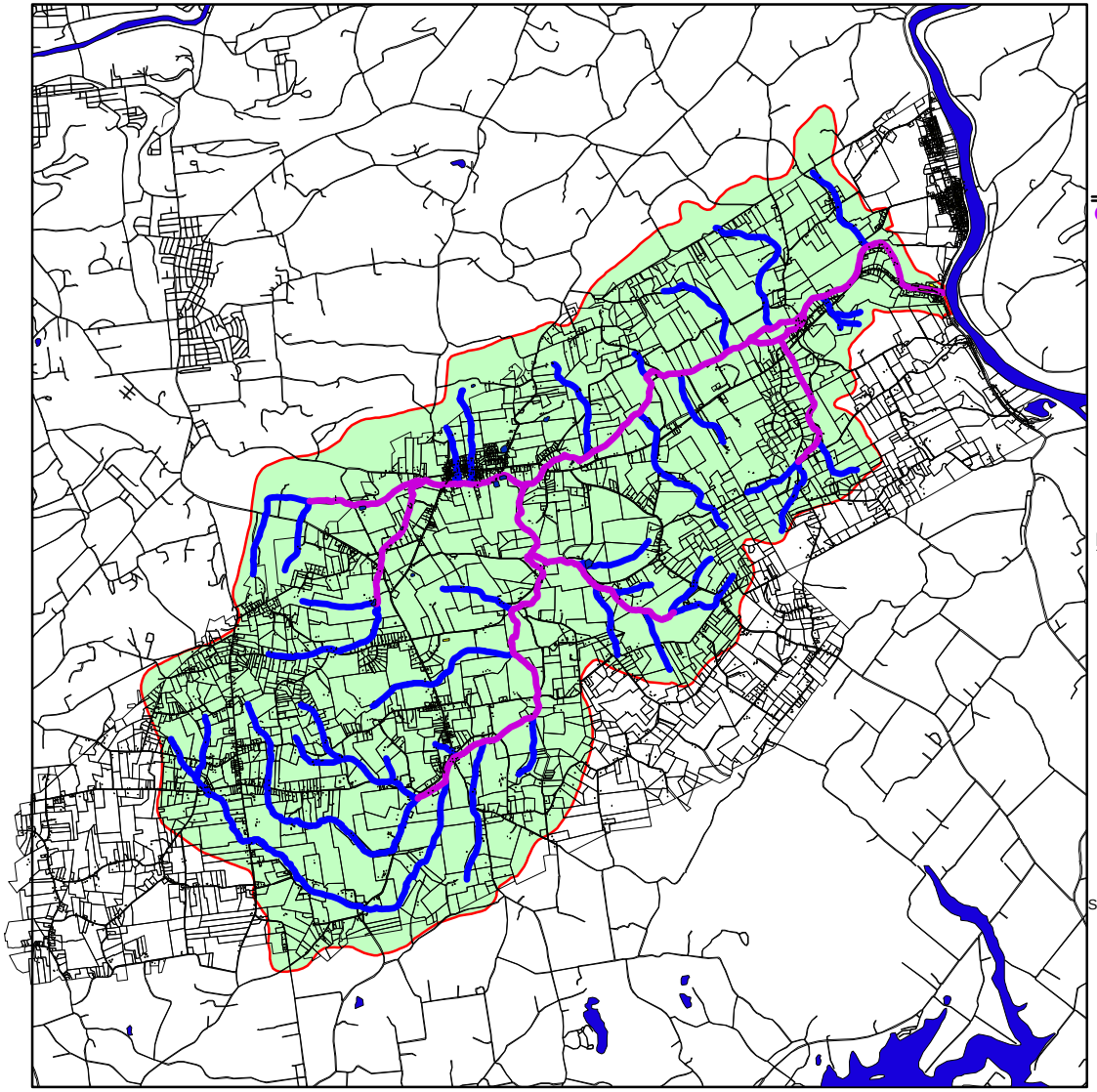

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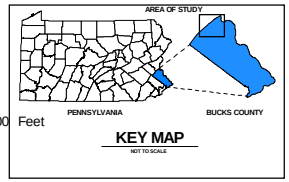

- Figure 7 -
Current Water Quality Classifications

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- Water Quality Designation: Cold Water Fishes (CWF)
- Special Protection Waters under Chapter 93: High Quality Waters (HQ)

Stream Order Delineation

- First Order Stream
- Second Order or Higher

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

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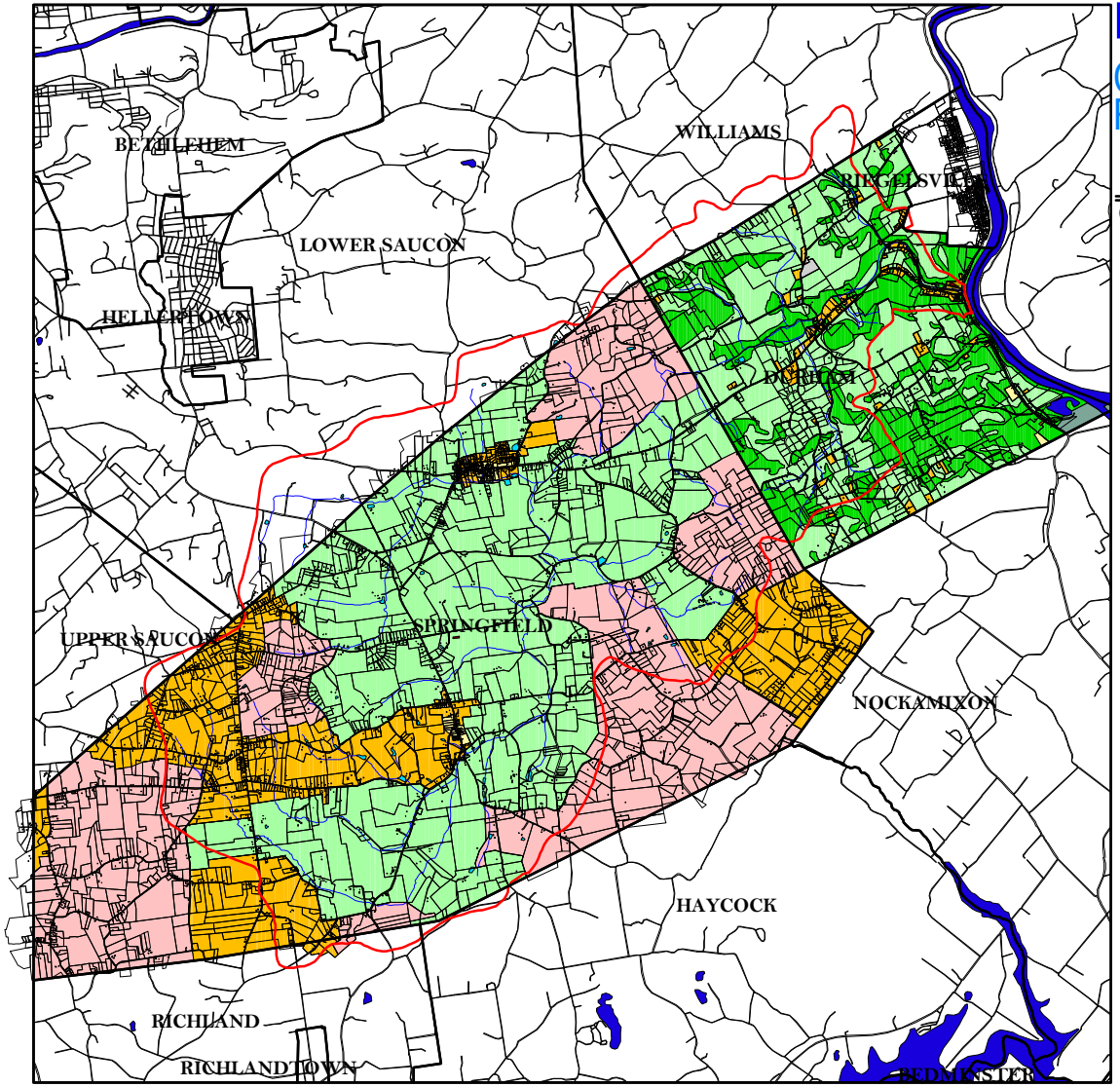

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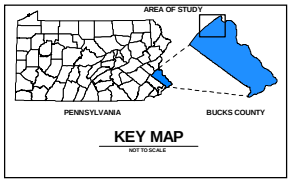

- Figure 8 - Land Use

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels

Land Use

- Agricultural
- Commercial
- Industrial
- Park
- Public
- Residential
- Unknown
- Prime Agricultural

SOURCES: 1) Durham Township Amendments to Comprehensive Plan, Adopted February 1, 1977

2) Springfield Township Comprehensive Plan, 1988

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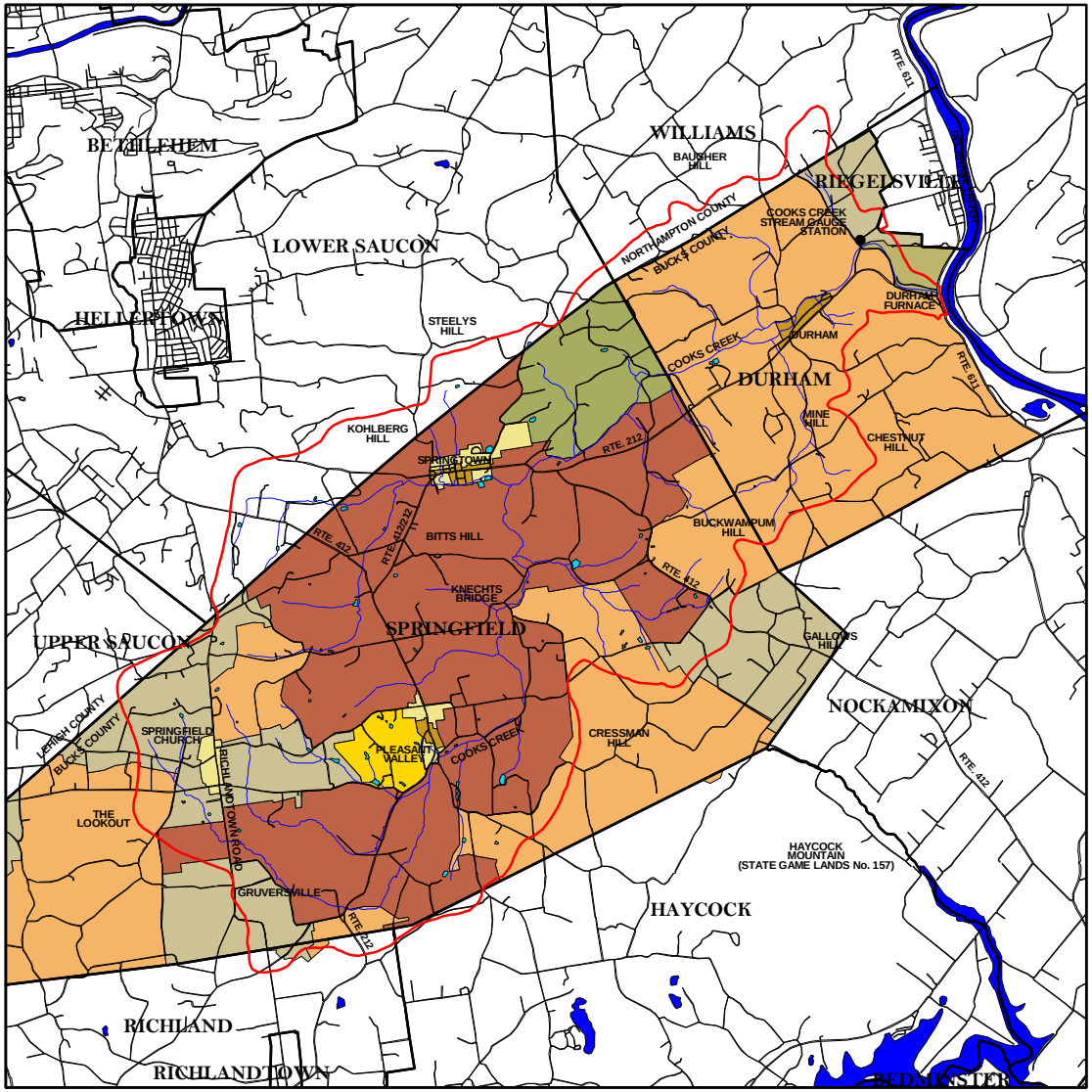

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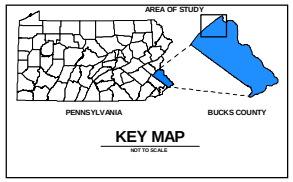

- Figure 9 - Existing Zoning Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds

Zones
- AD - Agricultural District
- DD - Development District
- PC-I - Planned Industrial-Commercial
- RP - Resource Protection
- RR - Rural Residential
- VC - Village Commercial
- VR- Village Residential
- WS - Watershed District

SOURCES:1) Durham Township Zoning Ordinance, December 9, 1992.
2) Springfield Township Open Space and Farmland Preservation Plan, July 1999.

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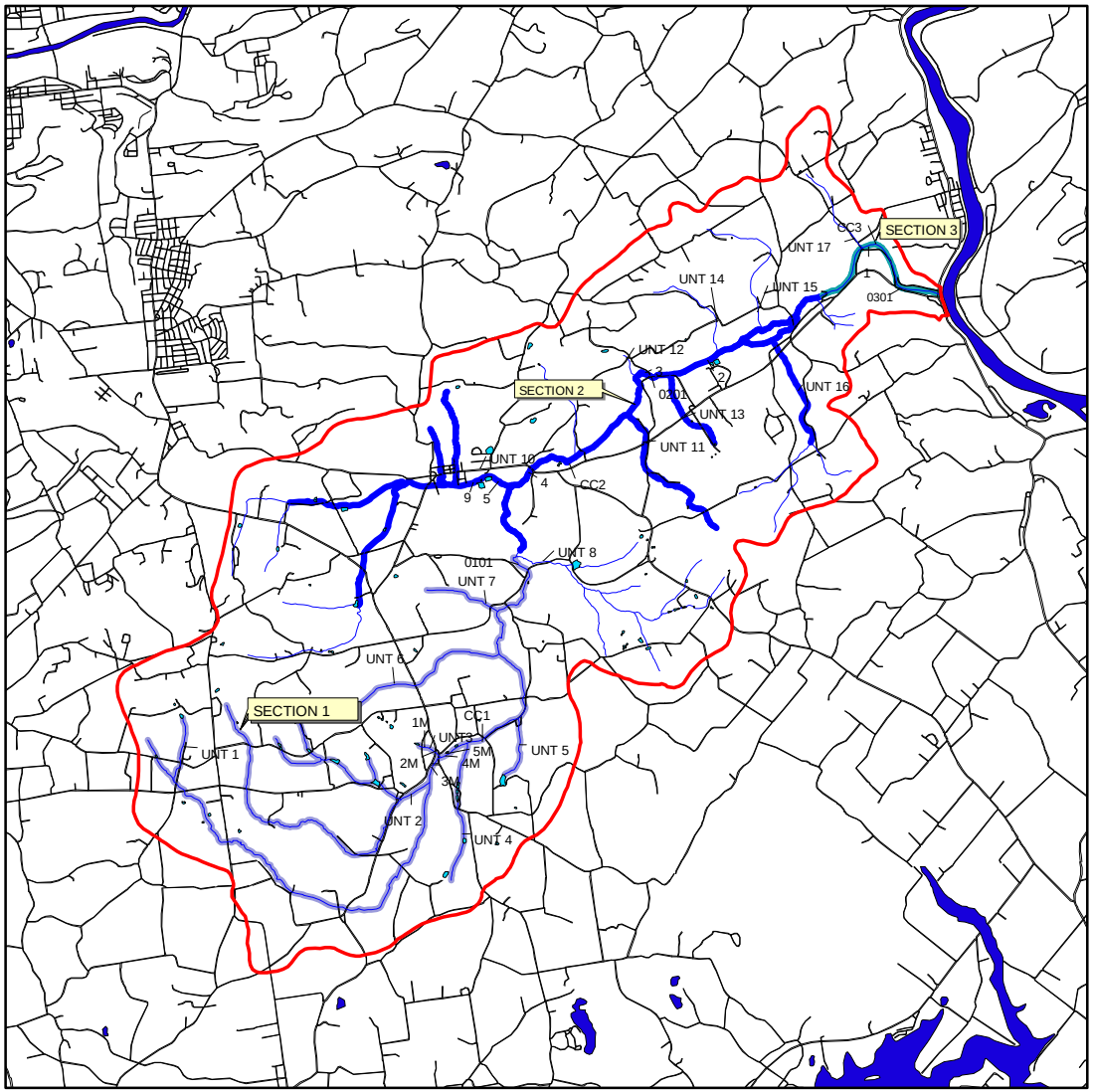

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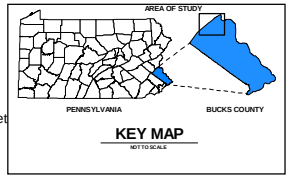

- Figure 11- Sections Map for Wild Trout Population

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings

Stream Characteristics for Wild Trout Population:

- Section 1 - Poor physical habitat contributes to warming of the water.
- Section 2 - Somewhat restricted physical habitat for adult trout supports a Class A biomass.
- Section 3 - Supports less biomass than section 2 due to less physical habitat.

Sample Locations:

1 - PFC Stream Survey Report Station (AUG 1973)

0101 - PFC Stream Inventory Station (AUG 1976)

1M - PFC Macroinvertebrate Evaluation Station (Feb 1986)

UNT 1 - DER BWQM Water Quality Station on Unnamed Tributary (Nov 1989)

CC1 - DER BWQM Special Protection Evaluation Station (March 1990)

SOURCES: 1) Cooks Creek - Special Protection Evaluation Report Water Quality Standards Review. Quality Assessment Unit Division of Water Quality Bureau of Water Quality Management Departament of Environmental Resources. July, 1990.

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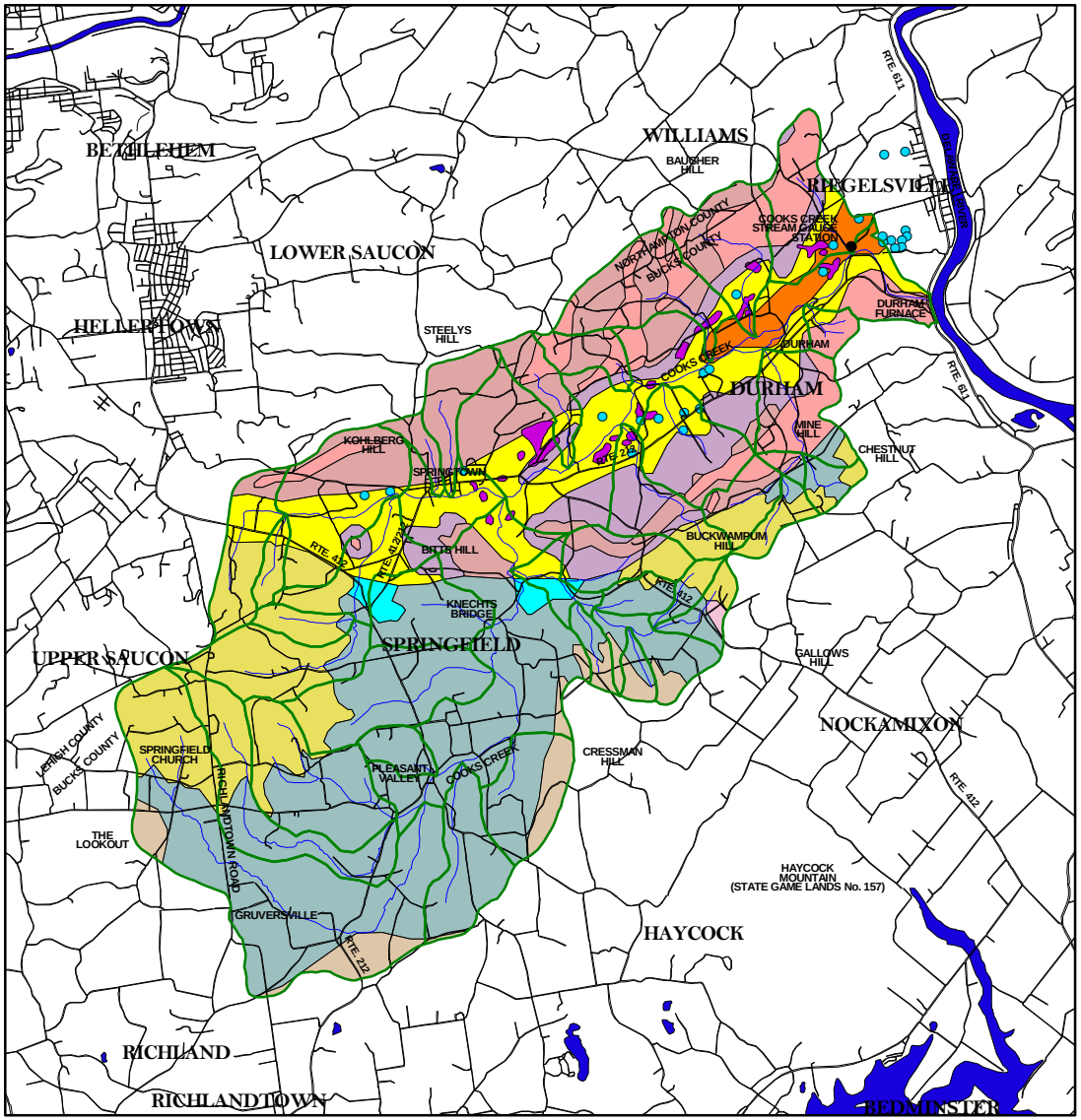

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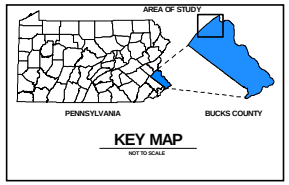

- Figure 12 - Geologc Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Areas Susceptible to Karst Dissolution Features
- Sinkholes
- Sub-basin
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

  Passaic Formation (Undifferentiated)
- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

NOTE: * denote karst-prone formations

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) Conservation and Management Practices for Buckingham & Durham Carbonate Valleys, Bucks County Planning Commission, February 1985
3) Spruance Lybrary of The Mercer Museum, Doylestown, Aerial Photos, 1950, 1958.
4) DTEAC , MJE , Wetlands Management Plan, Areas susceptible to karst, 1999

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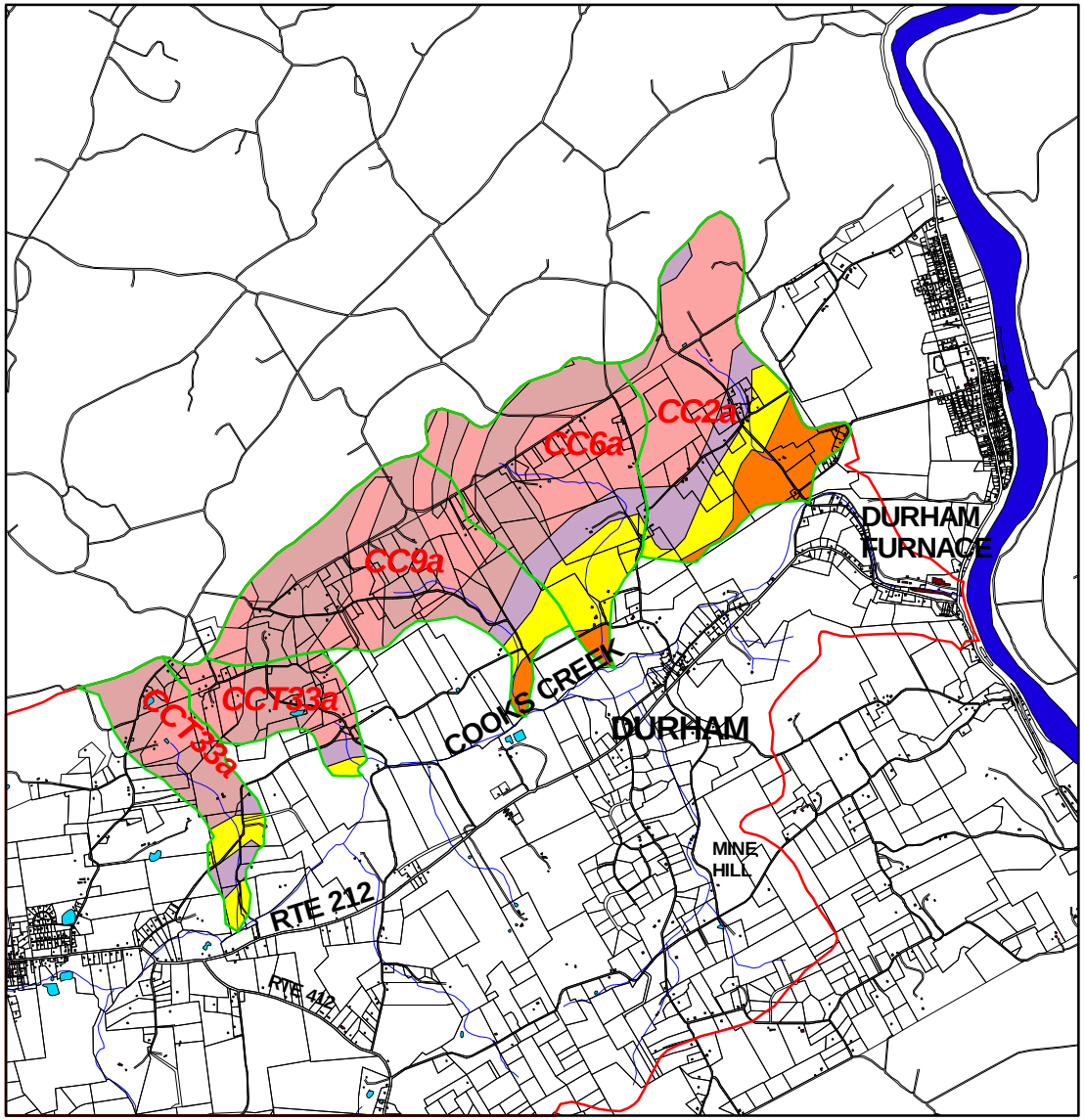

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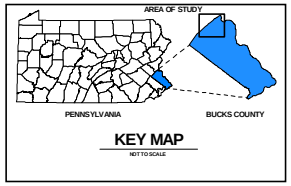

- Figure 12.1- Area 1 Sub-basin Geology - First Order Sub-basins -

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- First Order Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

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3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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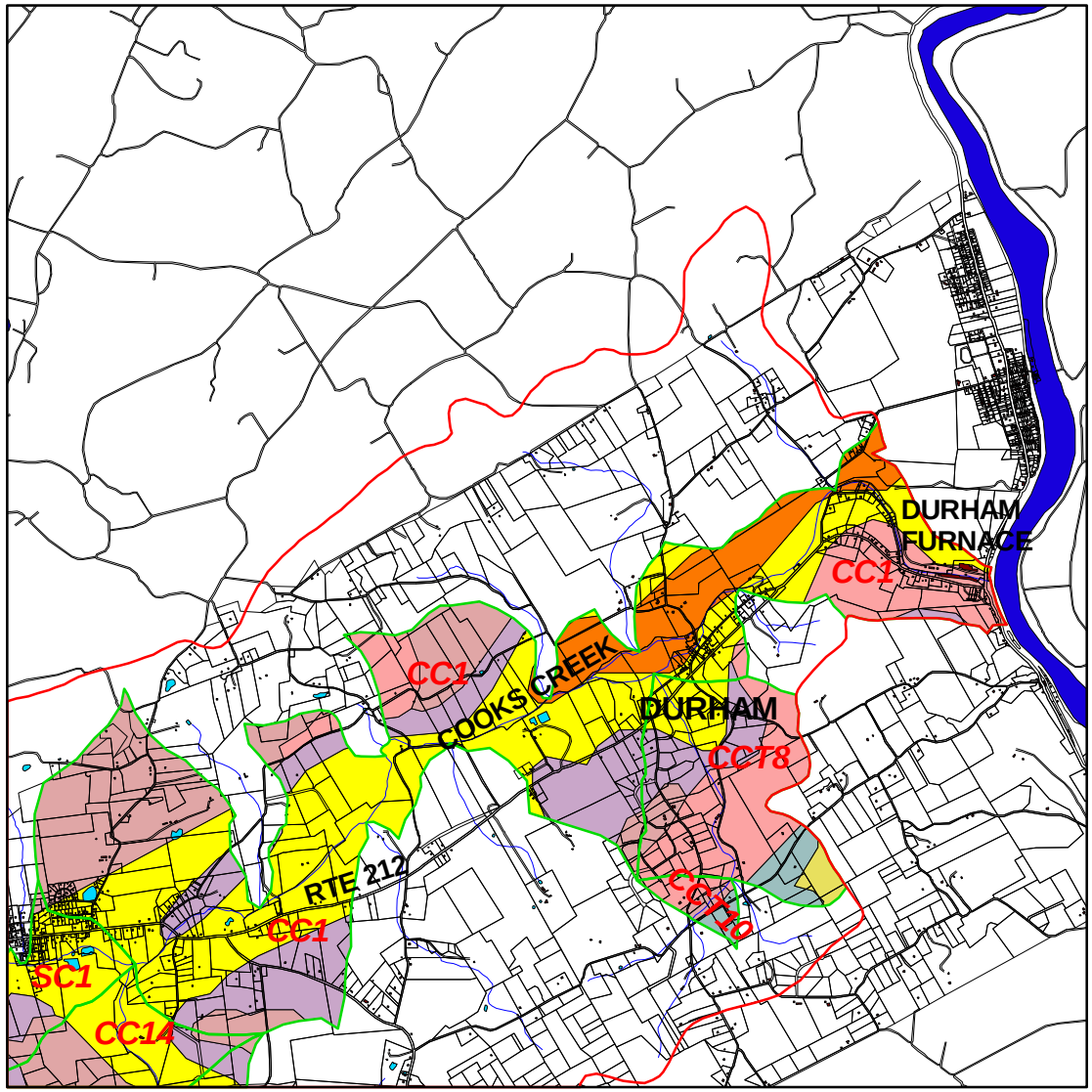

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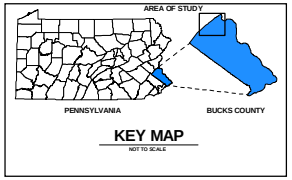

- Figure 12.2- Area 2 Sub-basin Geology - Second Order Sub-basins -

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- Second Order Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

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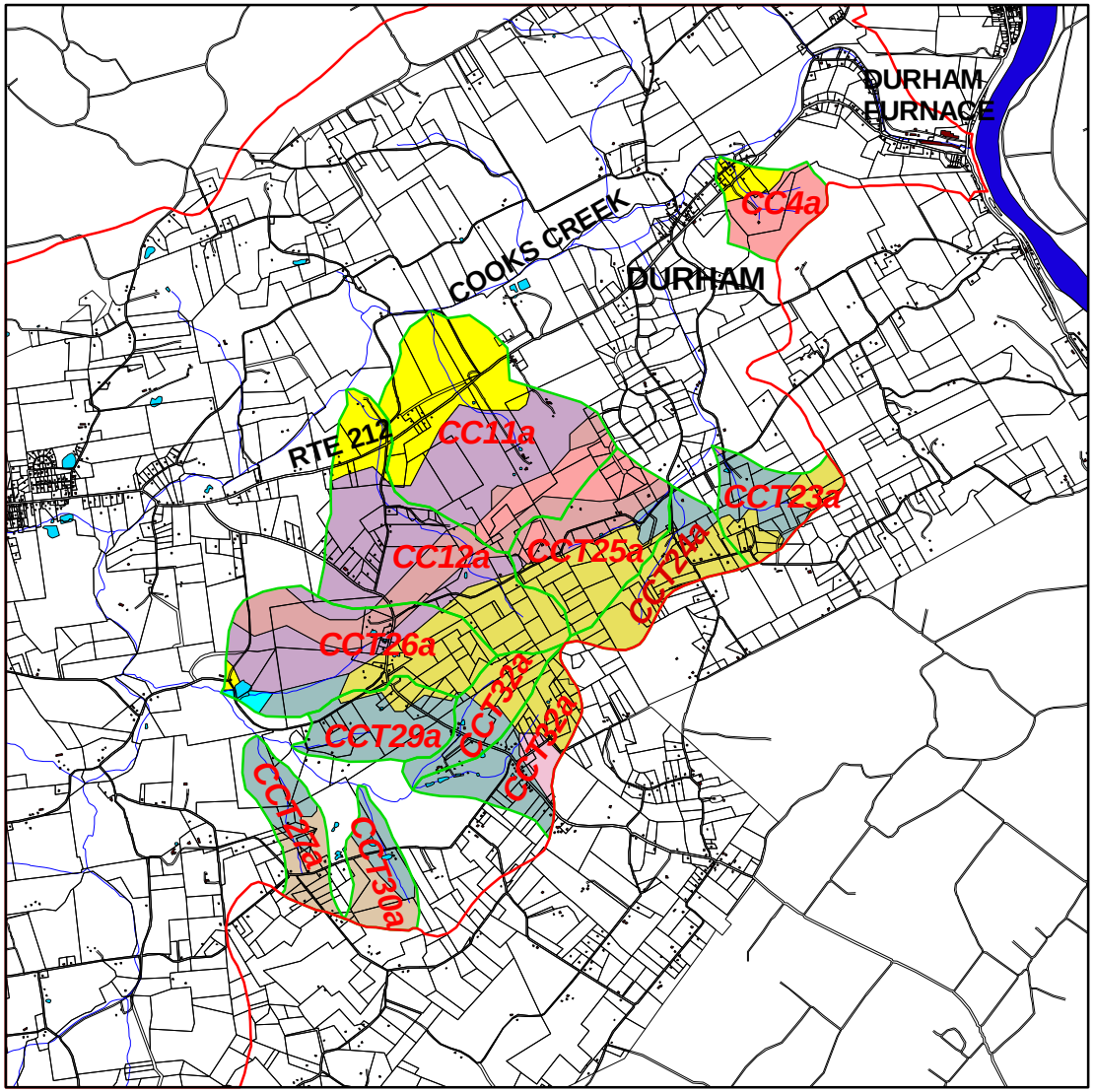

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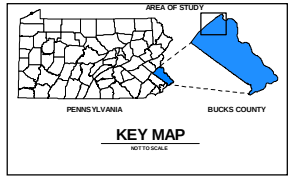

- Figure 12.3- Area 3 Sub-basin Geology - First Order Sub-basins -

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- First Order Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

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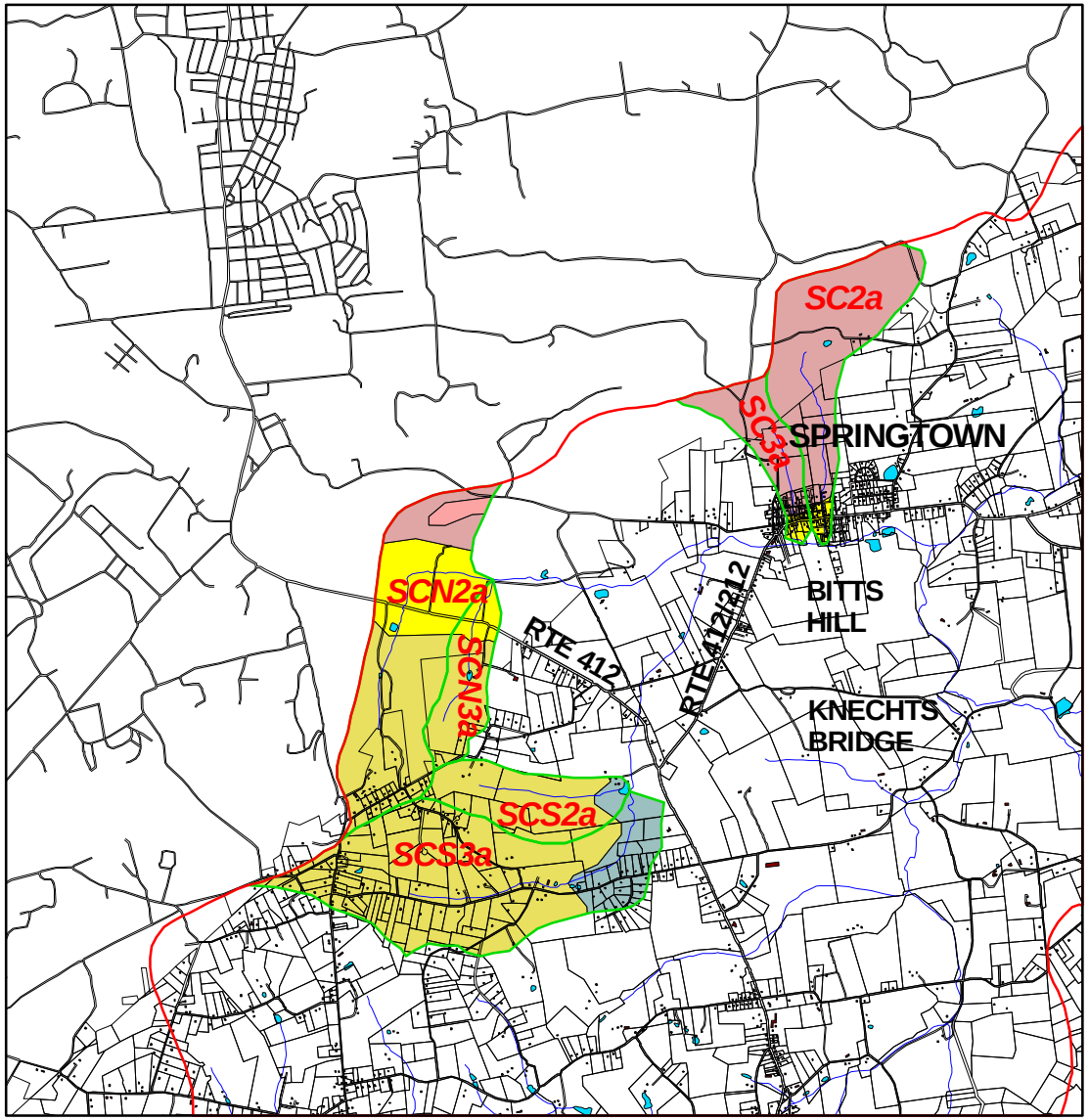

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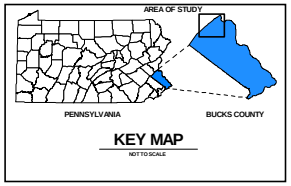

- Figure 12.4- Area 4 Sub-basin Geology - First Order Sub-basins -

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- First Order Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

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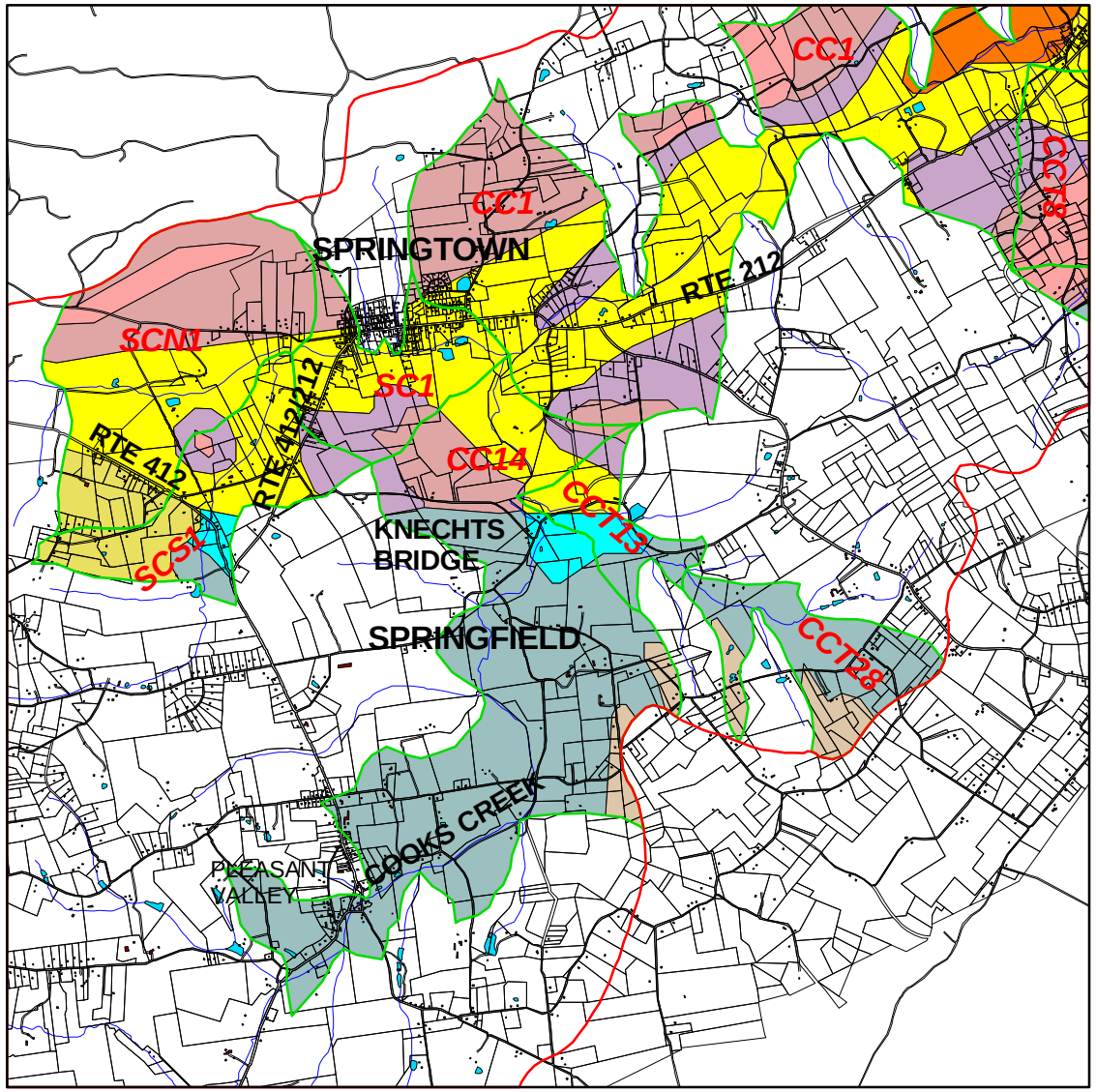

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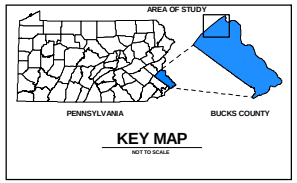

- Figure 12.5- Area 5 Sub-basin Geology - Second Order Sub-basins -

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- Second Order Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

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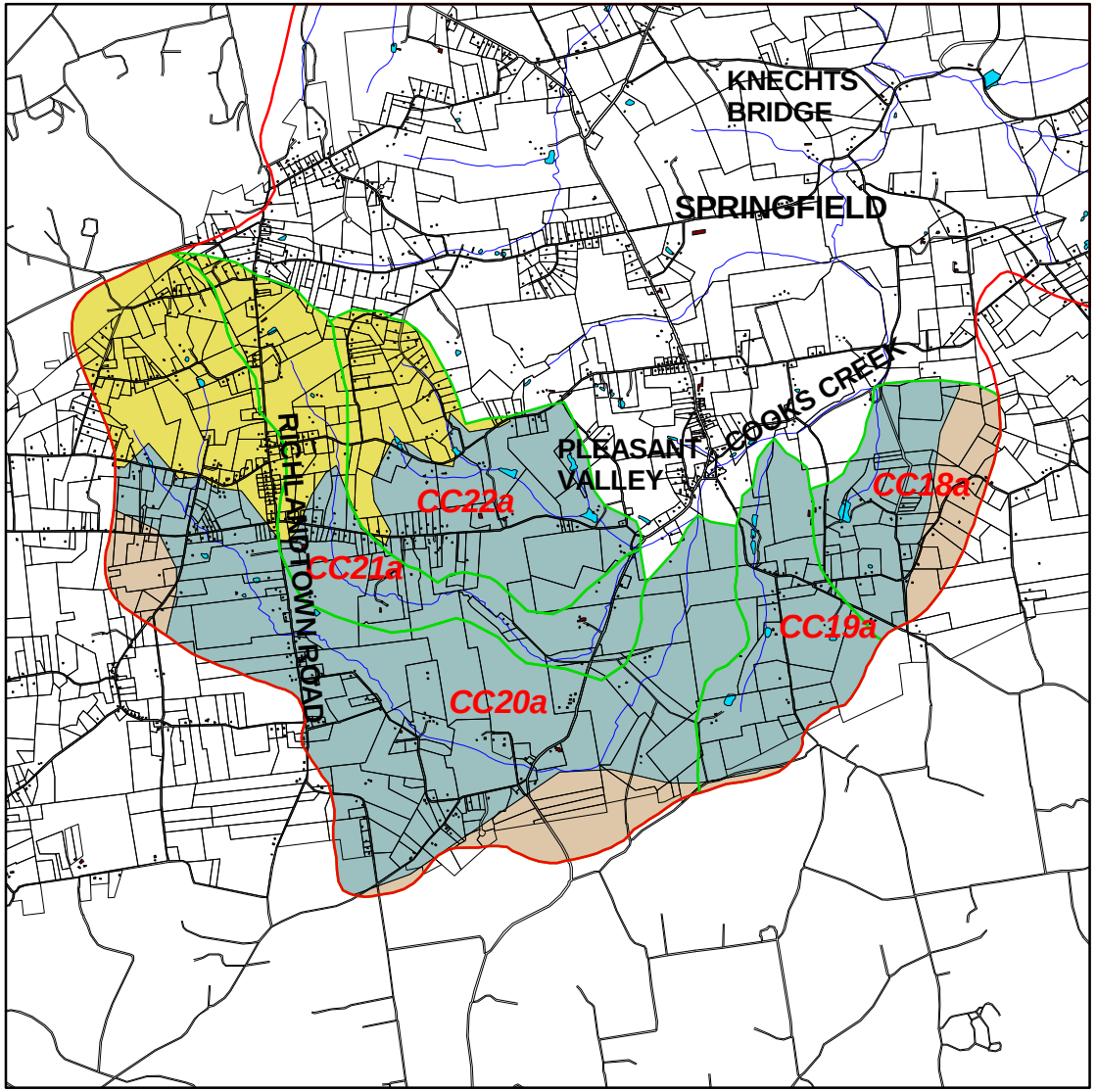

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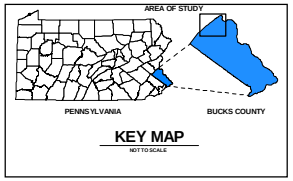

- Figure 12.6- Area 6 Sub-basin Geology - First Order Sub-basins -

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- First Order Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

Passaic Formation (Undifferentiated)

- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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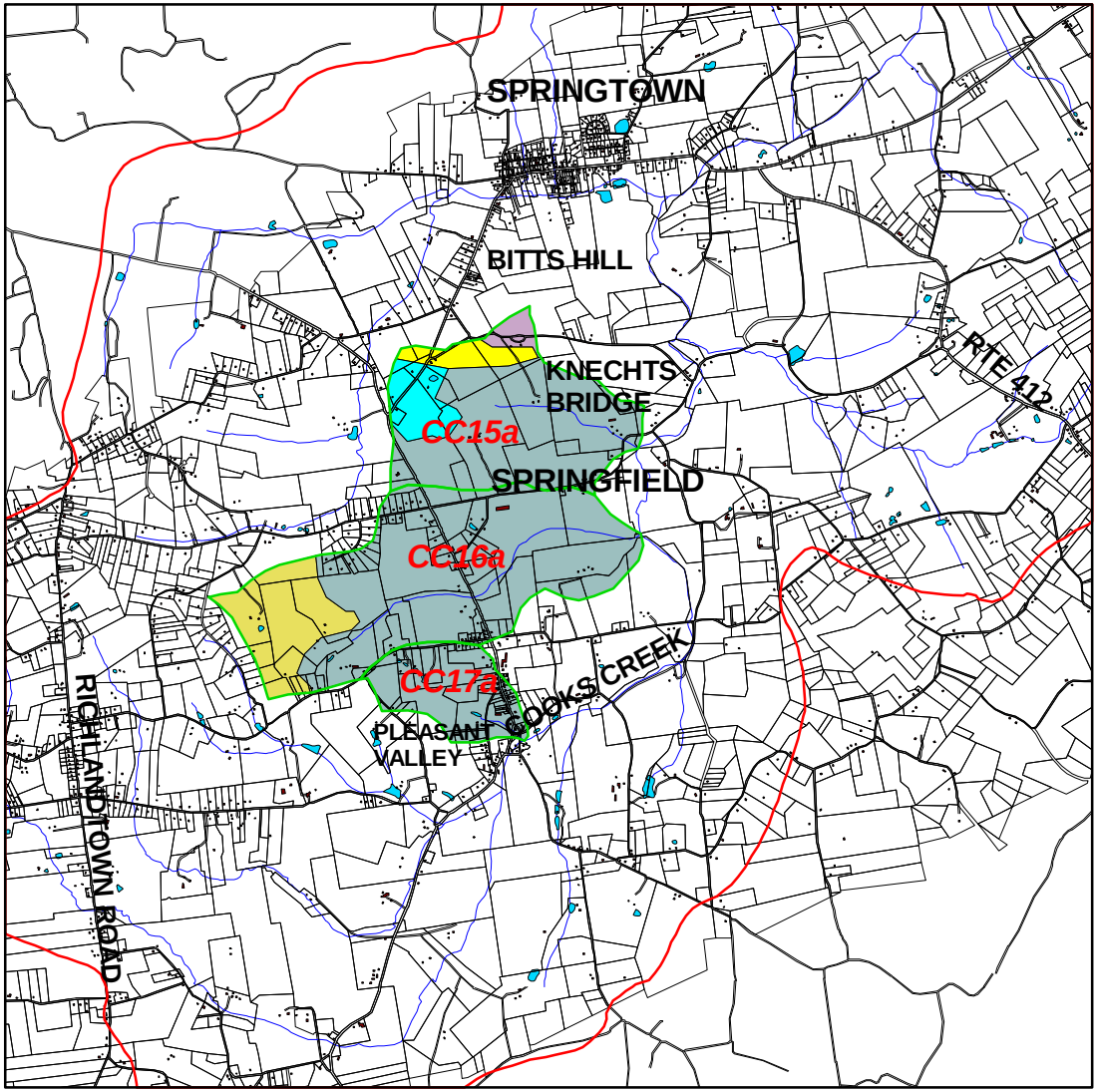

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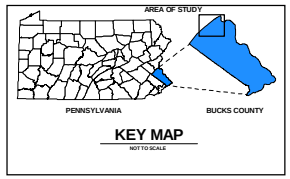

- Figure 12.7- Area 7 Sub-basin Geology

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Buildings
- Tax Map Parcels
- Sub-basins
- Diabase
- Brunswick Formation
- Lockatong Formation
- Quartz Fanoglomerate
- Limestone Fanoglomerate *

  (Passaic Formation (Undifferentiated))
- Allentown Formation *
- Leithsville Formation *
- Hardyston Formation
- Hornblende Gneiss
- Granitic Gneiss

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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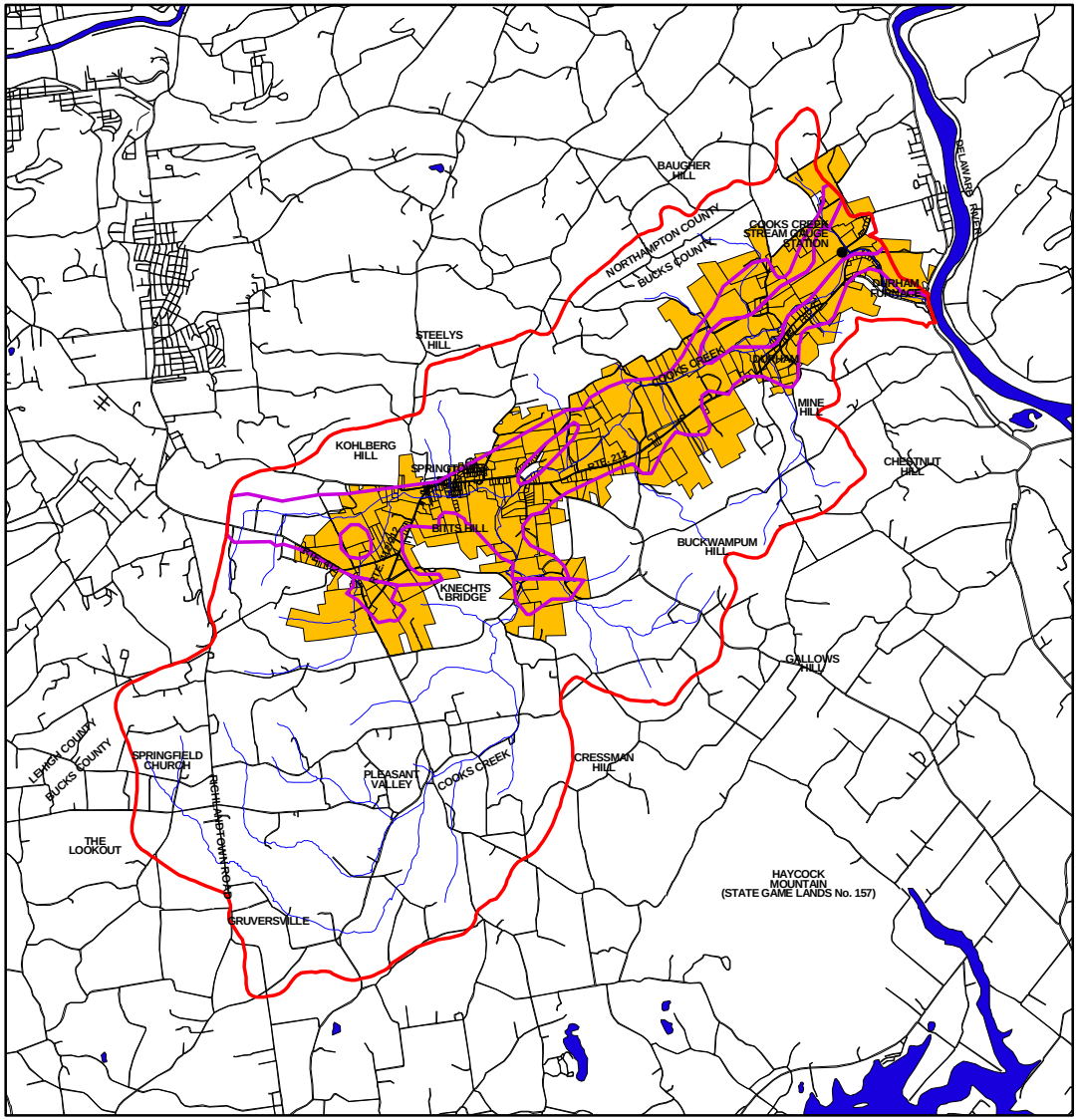

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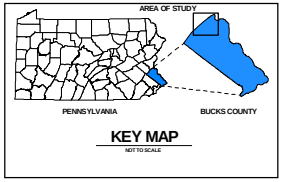

- Figure 13- Durham Carbonate Valley Parcels

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Durham Carbonate Valley - Geologic Contact
- Durham Carbonate Valley - Parcels

SOURCES: 1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.

2) Conservation and Management Practices for Buckingham & Durham Carbonate Valleys, Bucks County Planning Commission, February 1985

3) Spruance Lybrary of The Mercer Museum, Doylestown, Aerial Photos, 1950, 1958.

4) DTEAC , MJE , Wetlands Management Plan, Areas susceptible to karst, 1999

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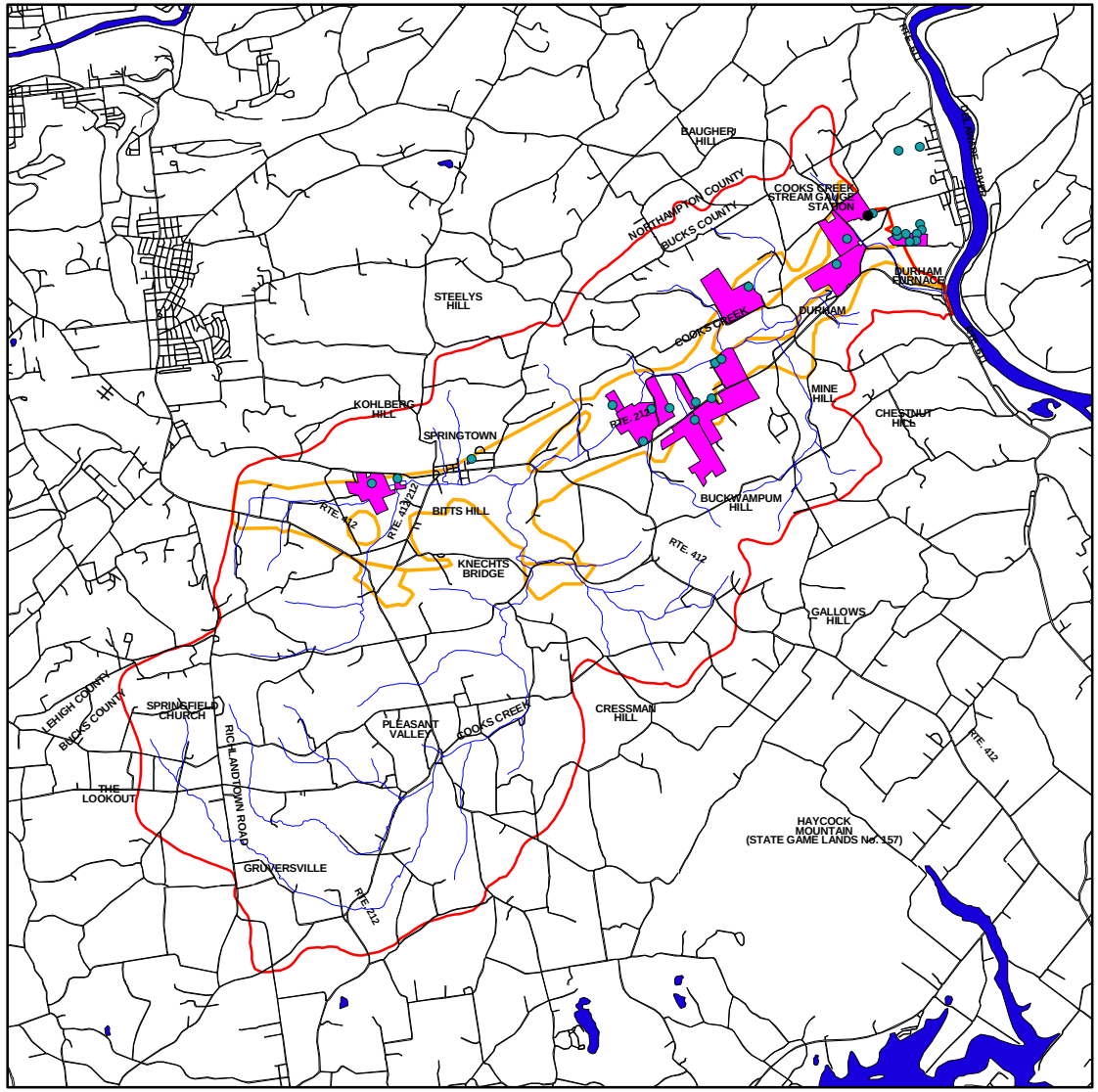

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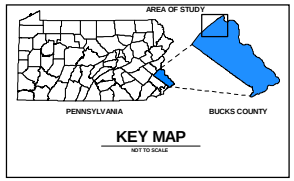

- Figure 14 - Parcels with Sinkholes

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Parcels with Sinkholes
- Durham Carbonate Valley - Geologic Contact
- Sinkholes

SOURCES: 1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.

2) Conservation and Management Practices for Buckingham & Durham Carbonate Valleys, Bucks County Planning Commission, February 1985

3) Spruance Lybrary of The Mercer Museum, Doylestown, Aerial Photos, 1950, 1958.

4) DTEAC , MJE , Wetlands Management Plan, Areas susceptible to karst, 1999

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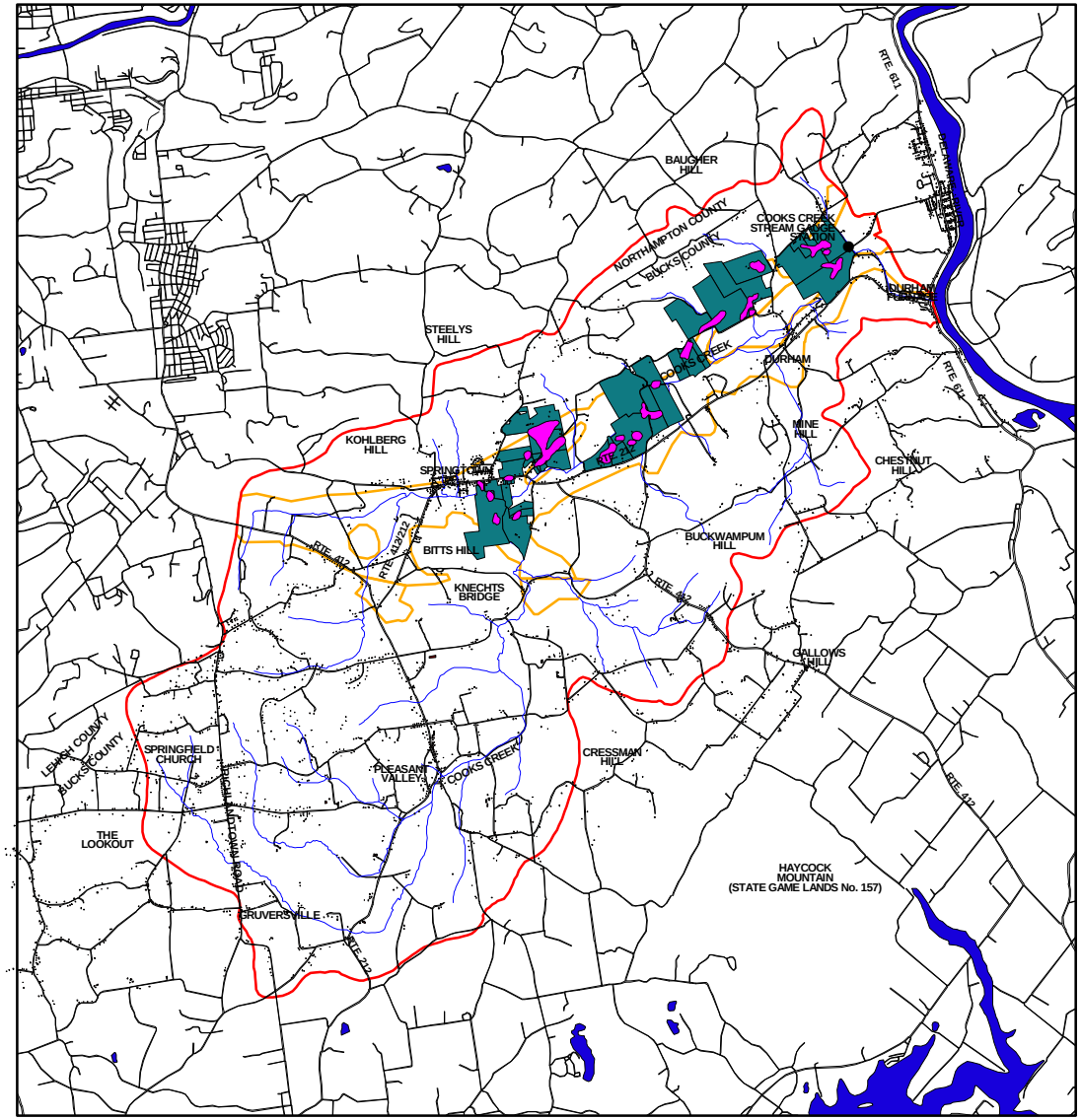

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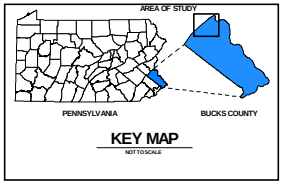

- Figure 15 - Karst-Prone Areas Parcels

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Buildings
- Karst-Prone Areas Parcels
- Durham Carbonate Valley - Geologic Contact
- Areas Susceptible to Karst Dissolution Features

SOURCES:1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.

2) Conservation and Management Practices for Buckingham & Durham Carbonate Valleys, Bucks County Planning Commission, February 1985

3) Spruance Lybrary of The Mercer Museum, Doylestown, Aerial Photos, 1950, 1958.

4) DTEAC , MJE , Wetlands Management Plan, Areas susceptible to karst, 1999

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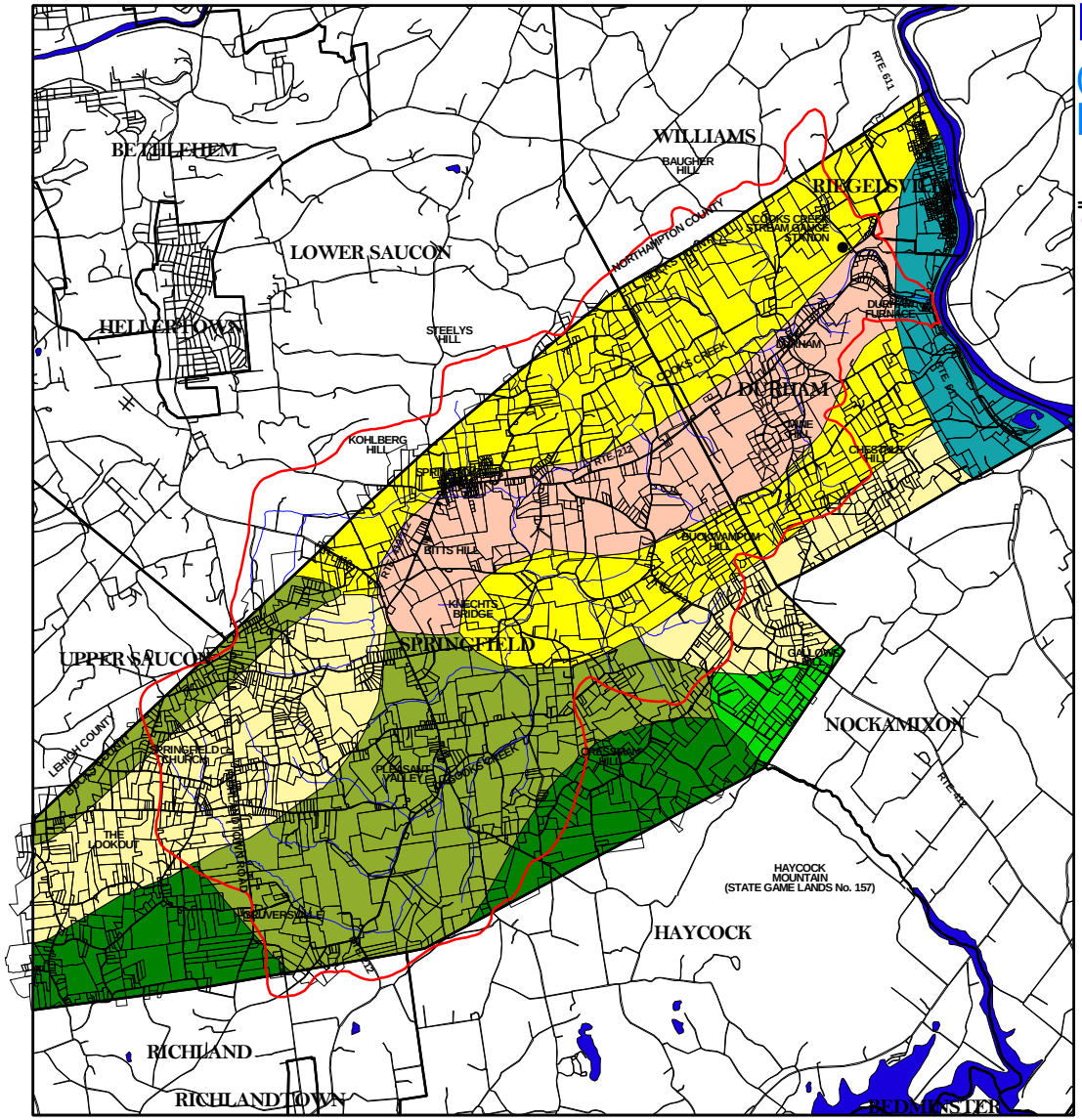

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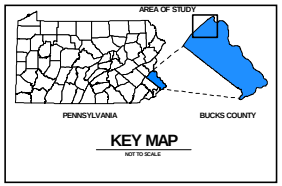

- Figure 17 - Generalized Soils Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Generalized Soils

DEEP SOILS THAT HAVE A MEDIUM TEXTURED SURFACE LAYER AND A MEDIUM TEXTURED OR MODERATELY FINE TEXTURED SUBSOIL:

- 061 - Chester association: Nearly level to moderately steep, well drained soils on uplands.
- 064 - Allenwood association: Gently sloping to moderately steep, well-drained soils on glacially influenced uplands.
- 062 - Towhee-Neshaminy-Mount Lucas association: Nearly level to moderately steep, poorly drained to well drained soils on uplands
- 058 - Duffield-Washington association: Gently sloping and sloping, well drained soils in upland valleys

SOILS THAT HAVE A MEDIUM-TEXTURED SURFACE LAYER AND A FIRM TO FRIABLE, BUT MAINLY FIRM AND COMPACT, SUBSOIL; SHALLOW TO DEEP OVER SHALE OR SANDSTONE:

- 065 - Abbottstown-Doylestown-Reaville association: Nearly level and gently sloping, moderately deep and deep, poorly drained to moderately well drained soils on uolands
- 063 - Penn-Klinesville association: Nearly level to moderately steep, shallow and moderately deep, well drained soils on upland.

DEEP SOILS THAT HAVE A MEDIUM TEXTURED SURFACE LAYER AND A MEDIUM TEXTURED OR MODERATELY COARSE TEXTURED SUBSOIL:

- 071 - Alton-Pope association: Nearly level and gently sloping, well-drained soils on terraces and flood plains.

SOURCES: 1) Pennsylvania Spatial Data Access system (PASDA is Pennsylvania's official geospatial information clearinghouse and the Commonwealth's node on the National Spatial Data Infrastructure (NSDI)), Translation, attribution and analysis by MJE, 1999.
2) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

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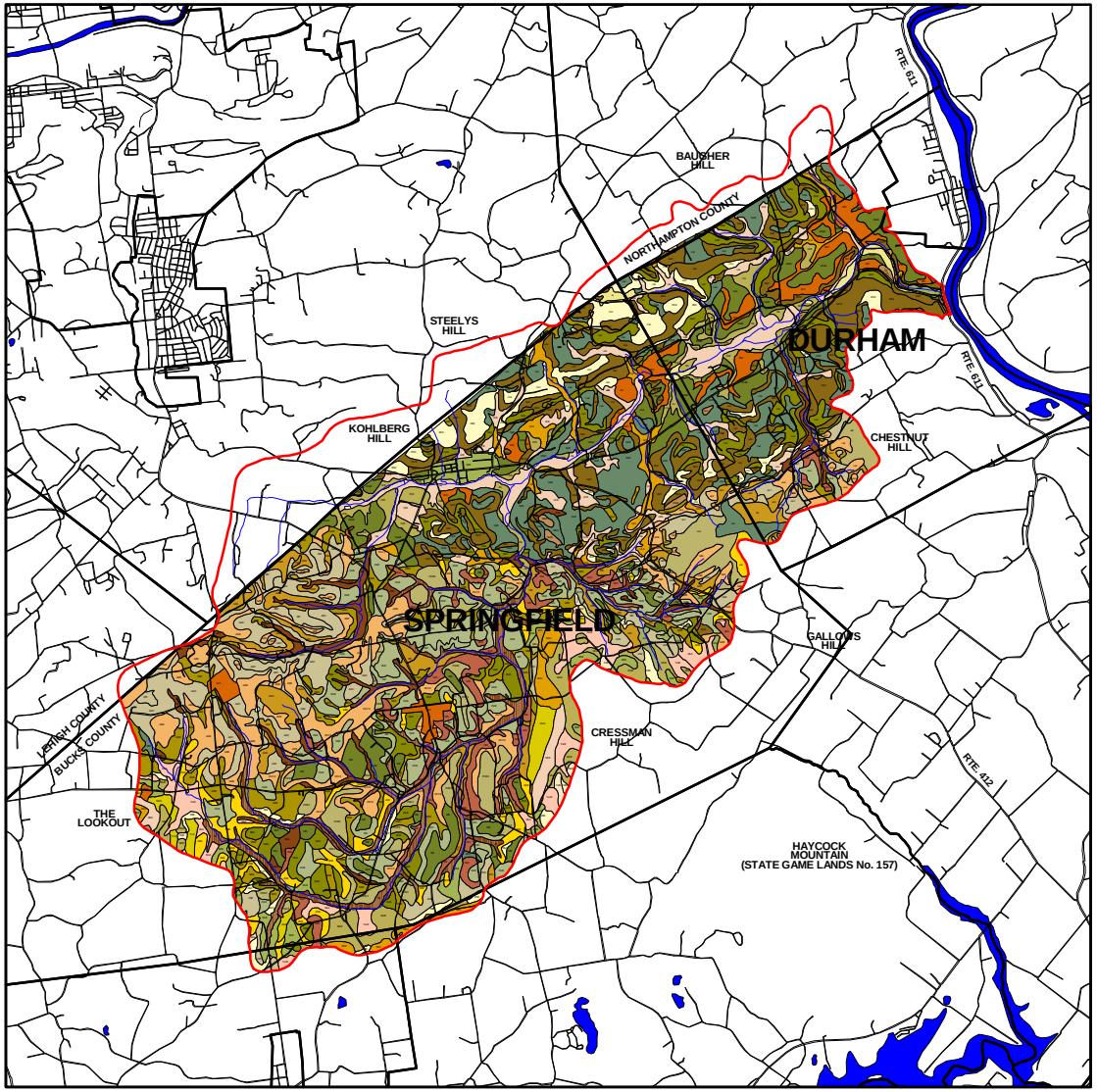

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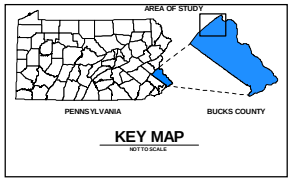

- Figure 18 - Soil Series Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soil Series and Map Symbols

AbA	DoB	MlA	PpA
AbB	DtC	MlB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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Figure 18.A- Soil Series Maps Legend

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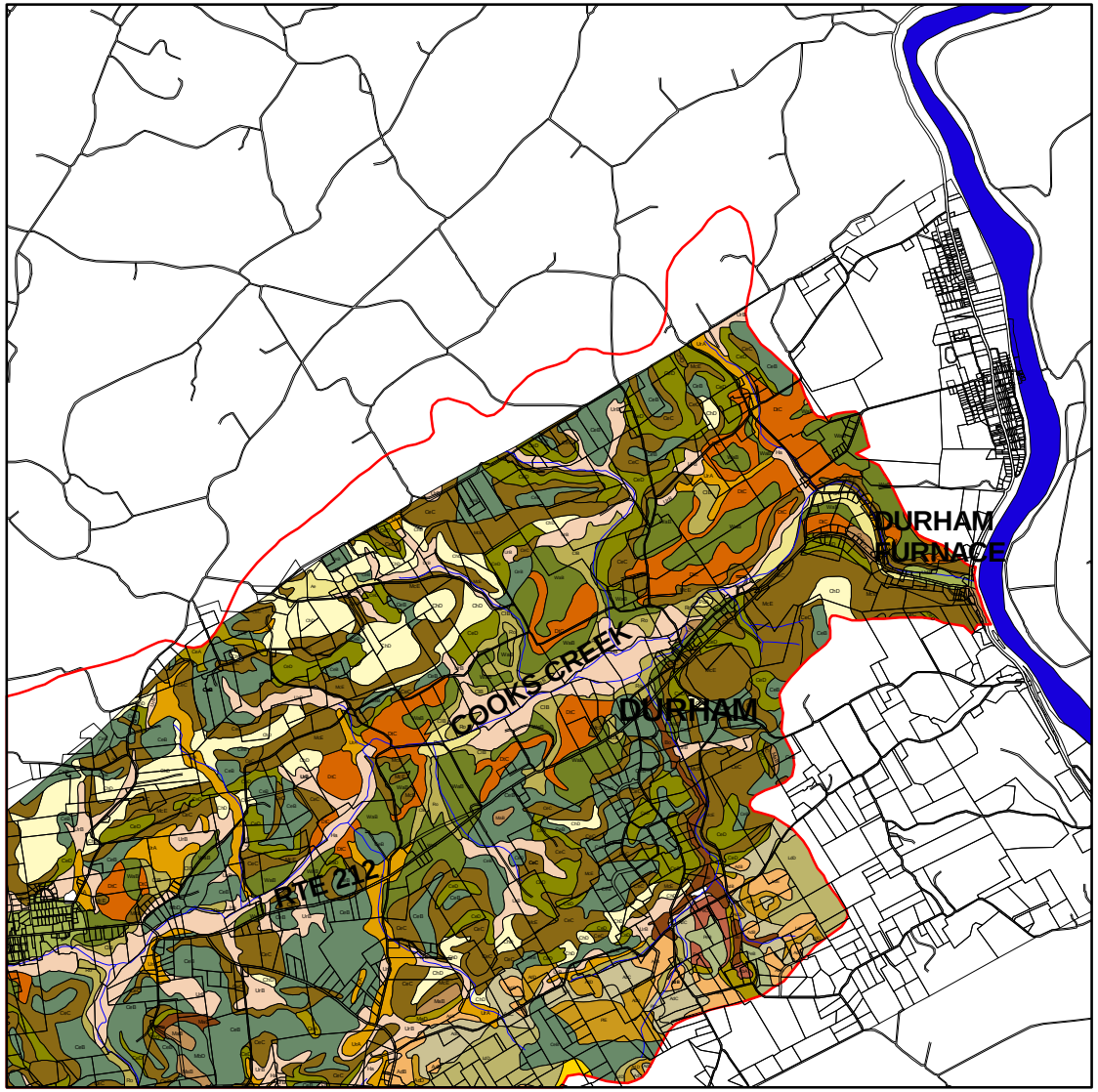
Geographic Information Systems Analysis

- AbA - Abbottstown silt loam 0 to 3 percent slopes
- AbB - Abbottstown silt loam 3 to 8 percent slopes
- AbC - Abbottstown silt loam 8 t0 15 percent slopes
- AdB - Allenwood gravelly silt loam, 3 to 8 percent slopes
- AdC - Allenwood gravelly silt loam, 8 to 15 percent slopes
- AdD - Allenwood gravelly silt loam, 15 to 25 percent slopes
- Ae - Alluvial land
- AgB - Alton gravelly loam, 3 to 8 percent slopes
- AlA - Alton gravelly loam, flooded, 0 to 5 percent slopes
- Bo - Bowmansville silt loam
- CeA - Chester silt loam, 0 to 3 percent slopes
- CeB - Chester silt loam, 3 to 8 percent slopes
- CeC - Chester silt loam, 8 to 15 percent slopes
- CeD - Chester silt loam, 15 to 25 percent slopes
- ChD - Chester extremely stony loam, 8 to 25 percent slopes
- ClB - Clarksburg silt loam, 2 to 6 percent slopes
- CwB - Culleoka - Weikert shaly silt loams, 3 to 8 percent slopes
- CwC - Culleoka - Weikert shaly silt loams, 8 to 15 percent slopes
- DoA - Doylestown silt loam, 0 to 3 percent slopes
- DoB - Doylestown silt loam, 3 to 8 8 percent slopes
- DtC - Duffield and Washington soils, 8 to 20 percent slopes
- Gravel Pit
- Ha - Hatboro silt loam
- KlB - Klinesville very shaly silt loam, 3 to 8 percent slopes
- KlC - Klinesville very shaly silt loam, 8 to 15 percent slopes
- KlD - Klinesville very shaly silt loam, 15 to 25 percent slopes
- LdB - Lansdale extremely stony loam, 0 to 8 percent slopes
- LdD - Lansdale extremely stony loam, 8 to 25 percent slopes
- LdE - Lansdale extremely stony loam, 25 to 50 percent slopes
- LhB - Lehigh channery silt loam, 0 to 8percent slopes
- LhC - Lehigh channery silt loam, 8 to 18 percent slopes
- LhD - Lehigh channery silt loam, 18 to 25 percent slopes
- LlD - Lehigh estremely stony silt loam, 8 to 25 percent slopes
- MaB - Manor loam, 3 to 8percent slopes
- MaC - Manor loam, 8 to 15 percent slopes
- MaD - Manor loam, 15 to 25 percent slopes
- MbD - Manor extremely stony loam, 8 to 25 percent slopes
- McE - Manor and Chester extremely stony loams, 25 to 50 percent slopes
- MlA - Mount Lucxas silt loam, 0 to 3 percent slopes
- MlB - Mount Lucas silt loam, 3 to 8 percent slopes
- MoB - Mount Lucas extremely stony silt loam, 0 to 8 percent slopes
- MoD - Mount Lucas extremely stony silt loam, 8 to 25 percent slopes
- NeB - Neshaminy channery silt loam, 3 to 8 percent slopes
- NeC - Neshaminy channery silt loam 8 to 15 percent slopes
- NhB - Neshaminy extremely stony silt loam, 0 to 8 percent slopes
- NhC - Neshaminy extremely silt loam, 8 to 15 percent slopes
- NhD - Neshaminy extremely stony silt loam, 8 to 25 percent slopes
- NhE - Neshaminy extremely stony silt loam, 25 to 50 percent slopes
- PeA - Penn silt loam, 0 to 3 percent slopes
- PeB - Penn silt loam, 3 to 8 percent slopes
- PeC - Penn silt loam, 8 to 15 percent slopes
- PeD - Penn silt loam, 15 to 25 percent slopes
- PhB3 - Penn - Klinesville shaly silt loams, 3 to 8 percent slopes, eroded
- PkC3 - Penn - Klinesville complex, 8 to 15 percent slopes, eroded
- PlD - Penn - Klinesville extremely stony silt loams, 8 to 25 percent slopes
- PlE - Penn - Klinesville extremely stony silt loams 25 to 50 percent slopes
- PoA - Pope loam, 0 to 5 percent slopes
- PpA - Pope loam, terrace, 0 to 3 percent slopes
- Quarry
- RdA - Readington silt loam, 0 to 3 percent slopes
- RdB - Readington silt loam, 3 to 8 percent slopes
- RdC - Readington silt loam, 8 to 15 percent slopes
- ReA - Reaville shaly silt loam, 0 to 3 percent slopes
- ReB - Reaville shaly silt loam, 3 to 8 percent slopes
- ReC - Reaville shaly silt loam, 8 to 15 percent slopes
- Ro - Rowland silt loam
- ToA - Towhee silt loam, 0 to 3 percent slopes
- ToB - Towhee silt loam, 3 to 8 percent slopes
- TwB - Towhee extremely stony silt loam, 0 to 8 percent slopes
- UdB - Urban land - Chester complex 0 to 8 percent slopes
- UlC - Urban land - Lansdale complex, 8 to 15 percent slopes
- UrA - Urbana silt loam, 0 to 3 percent slopes
- UrB - Urbana silt loam, 3 to 8 percent slopes
- WaB - Washington gravelly silt loam, 3 to 8 percent slopes
- WcD - Weikert - Culleoka shaly silt loams, 15 to 25 percent slopes



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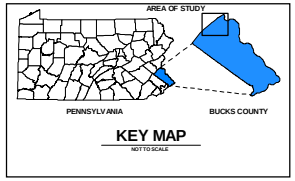

- Figure 18.1- Soil Series Map (Area 1)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MlA	PpA
AbB	DtC	MlB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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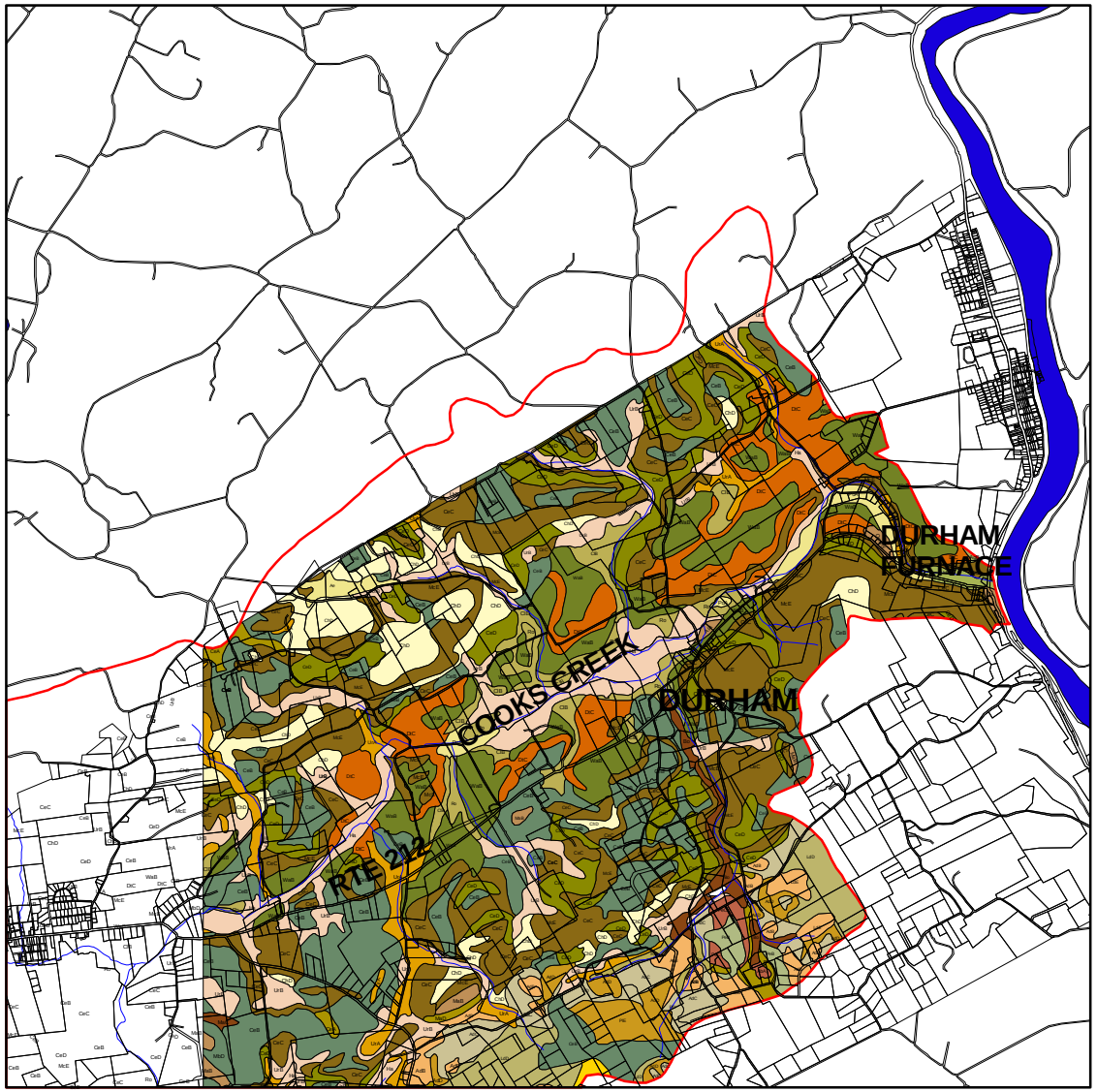

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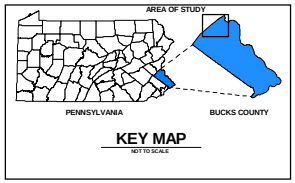

- Figure 18.2 - Soil Series Map (Area 2)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MiA	PpA
AbB	DtC	MiB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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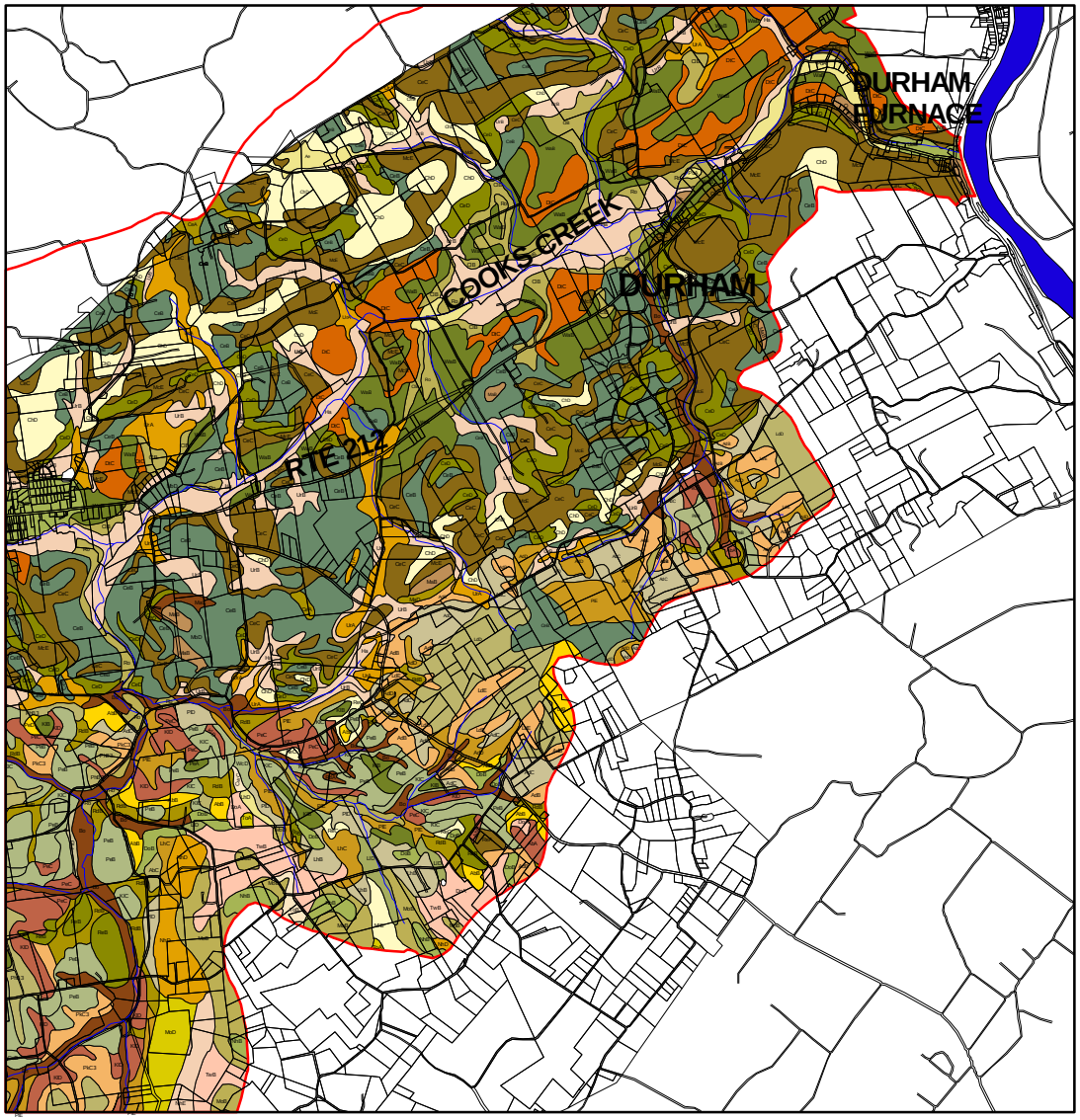

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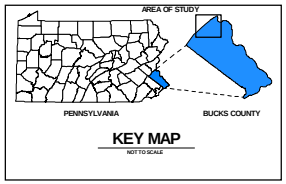

- Figure 18.3- Soil Series Map (Area 3)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MlA	PpA
AbB	DtC	MlB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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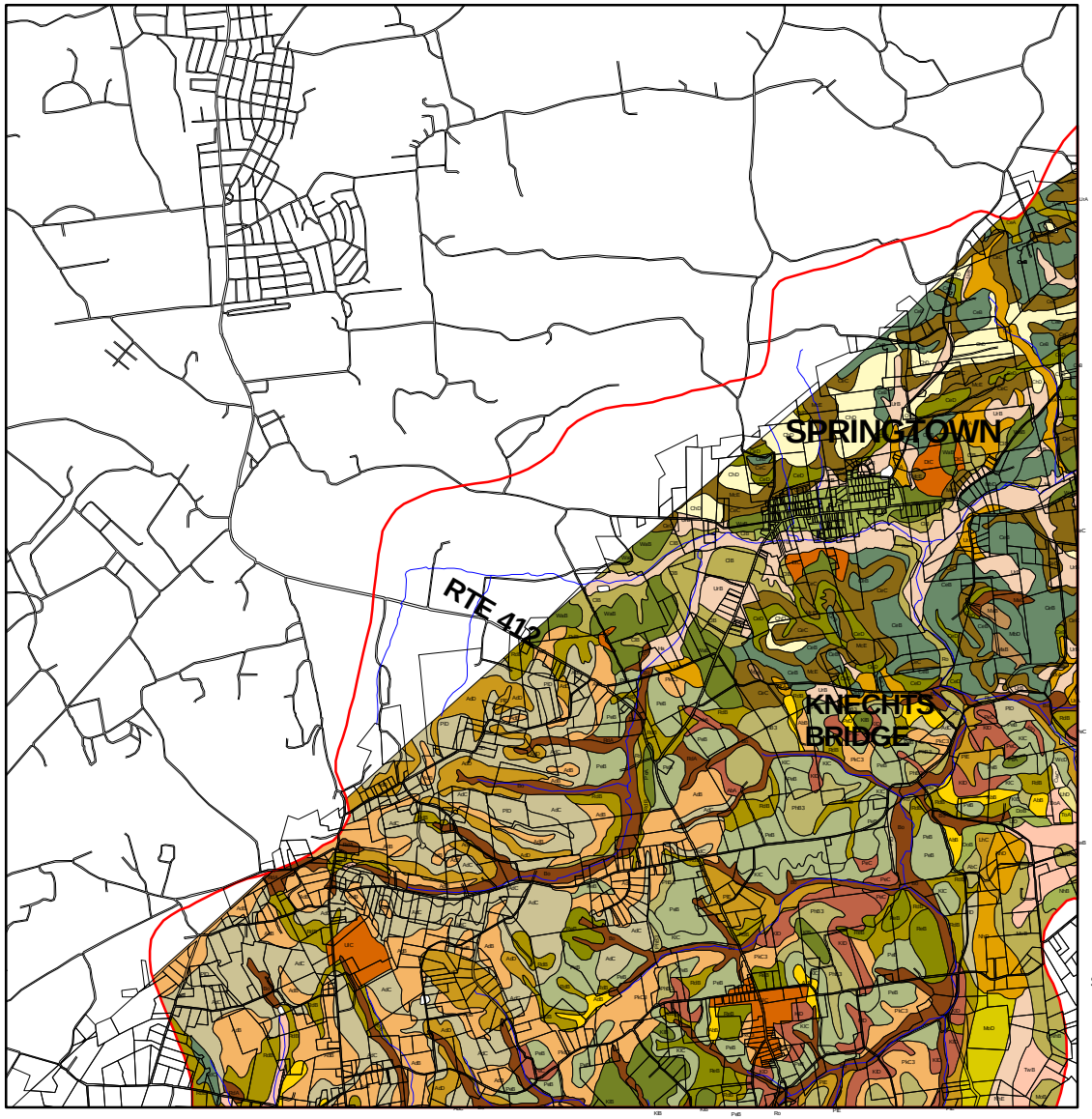

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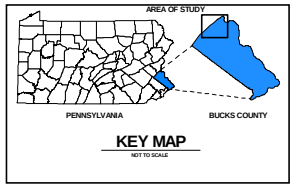

- Figure 18.4 - Soil Series Map (Area 4)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MIA	PpA
AbB	DtC	MIB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UkA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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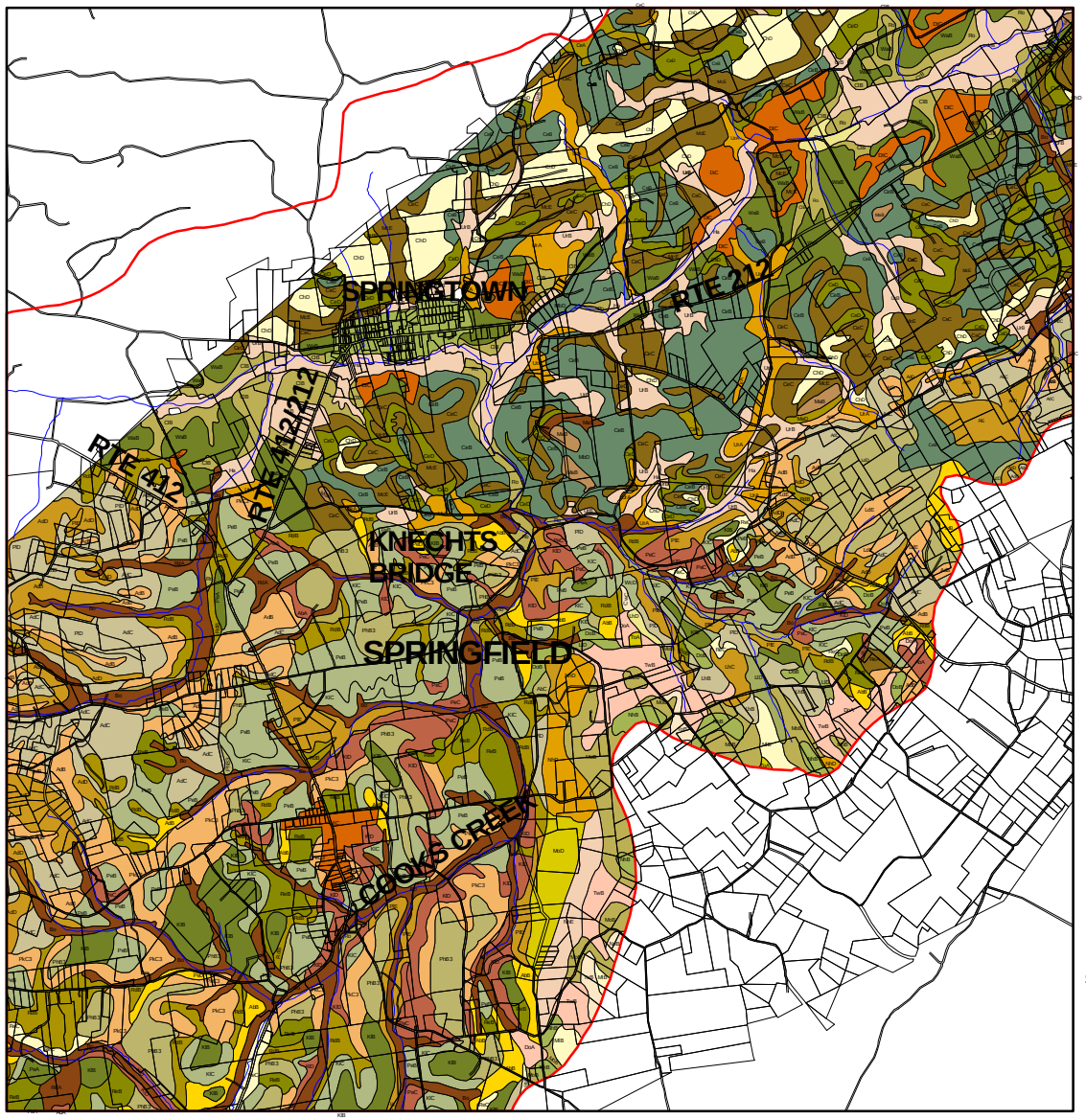

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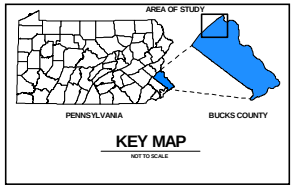

- Figure 18.5 - Soil Series Map (Area 5)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MIA	PpA
AbB	DtC	MIB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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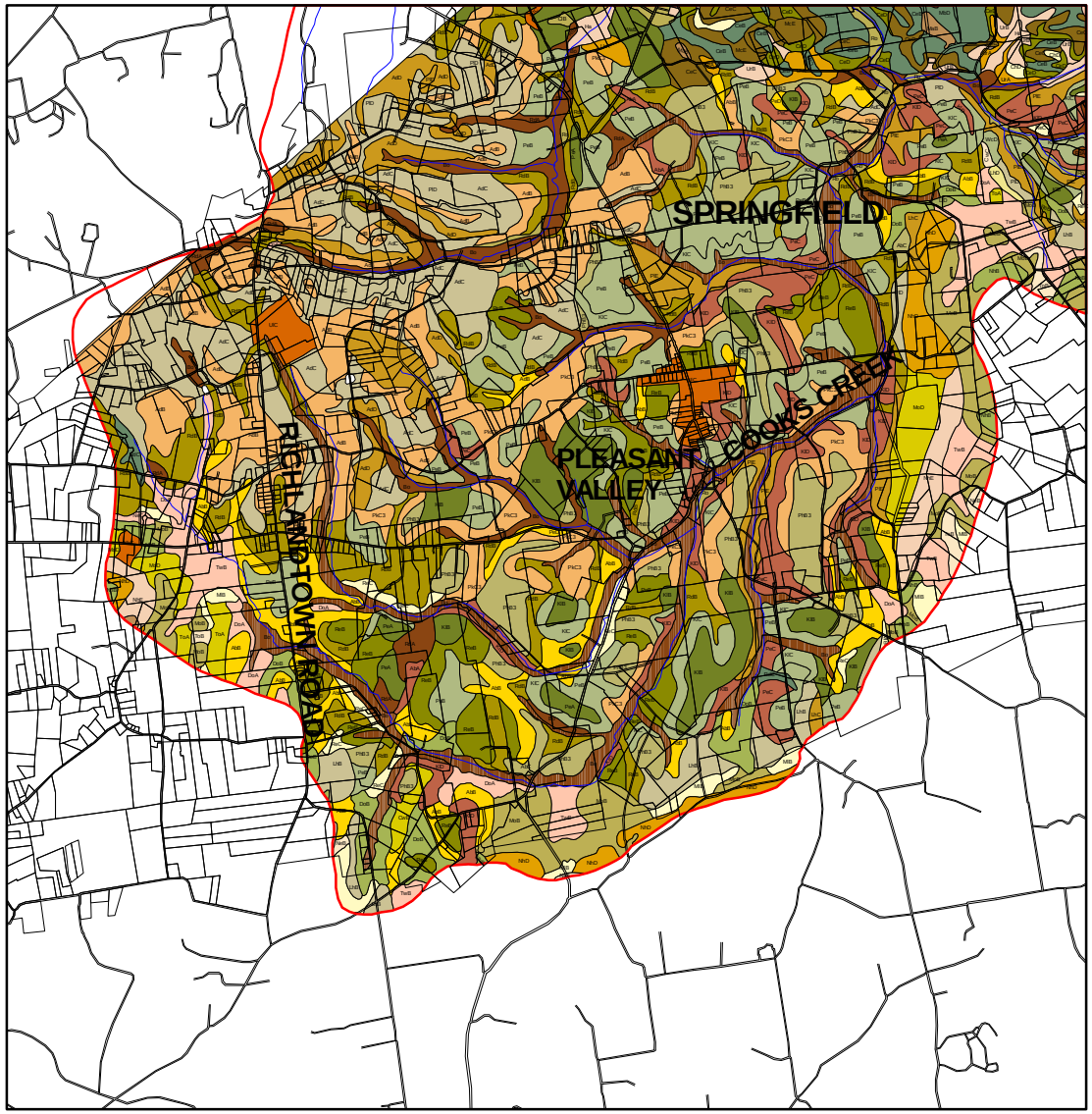

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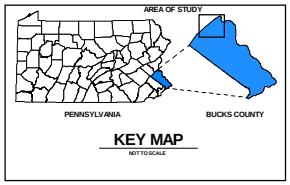

- Figure 18.6 - Soil Series Map (Area 6)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MlA	PpA
AbB	DrC	MlB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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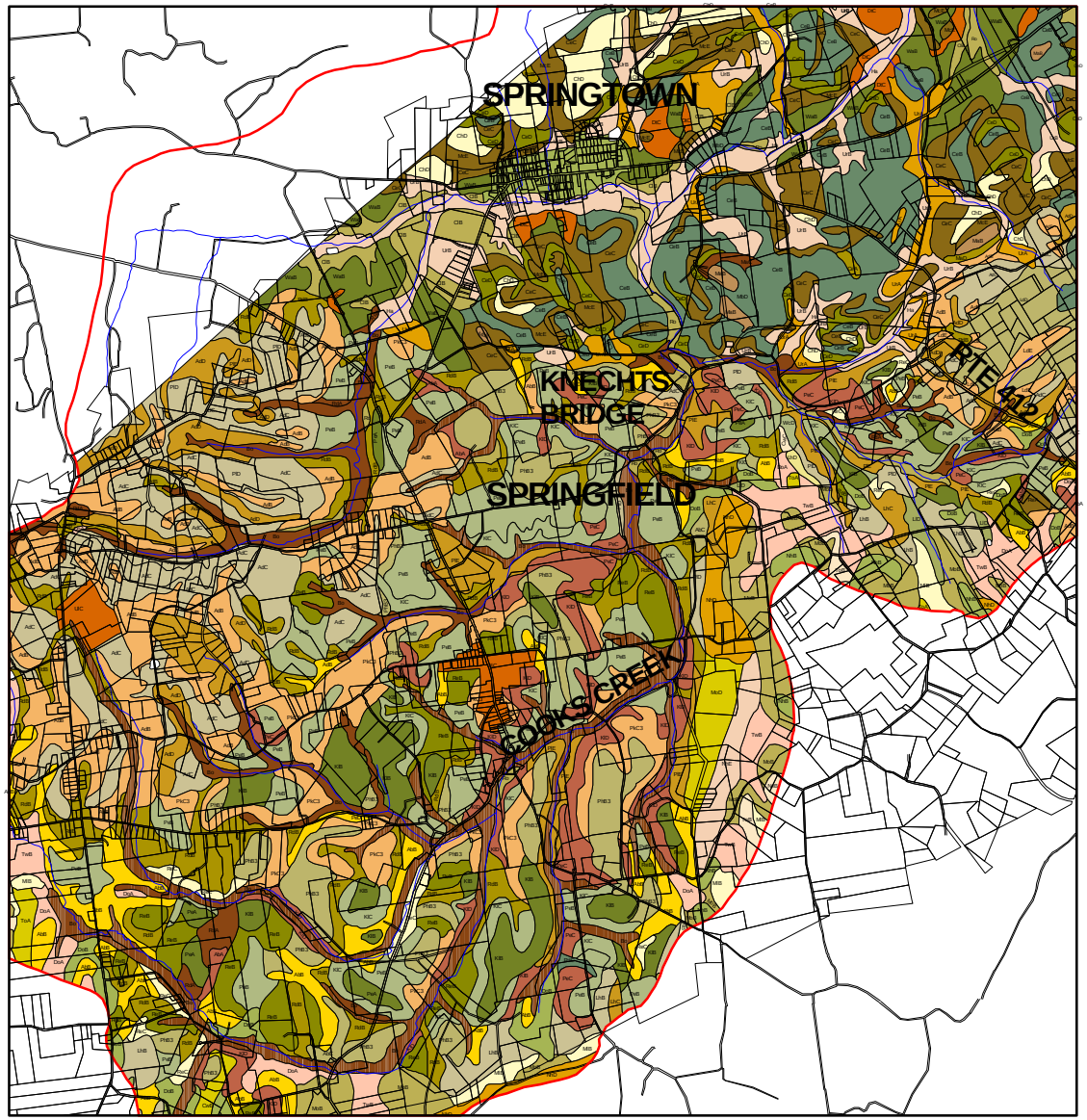

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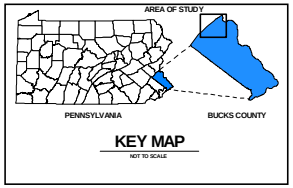

- Figure 18.7 - Soil Series Map (Area 7)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Series and Map Symbols

AbA	DoB	MlA	PpA
AbB	DtC	MlB	Quarry
AbC	Gravel Pit	MoB	RdA
AdB	Ha	MoD	RdB
AdC	KlB	NeB	RdC
AdD	KlC	NeC	ReA
Ae	KlD	NhB	ReB
AgB	LdB	NhC	ReC
AlA	LdD	NhD	Ro
Bo	LdE	NhE	ToA
CeA	LhB	PeA	ToB
CeB	LhC	PeB	TwB
CeC	LhD	PeC	UdB
CeD	LlD	PeD	UlC
ChD	MaB	PhB3	UrA
ClB	MaC	PkC3	UrB
CwB	MaD	PlD	WaB
CwC	MbD	PlE	WcD
DoA	McE	PoA	

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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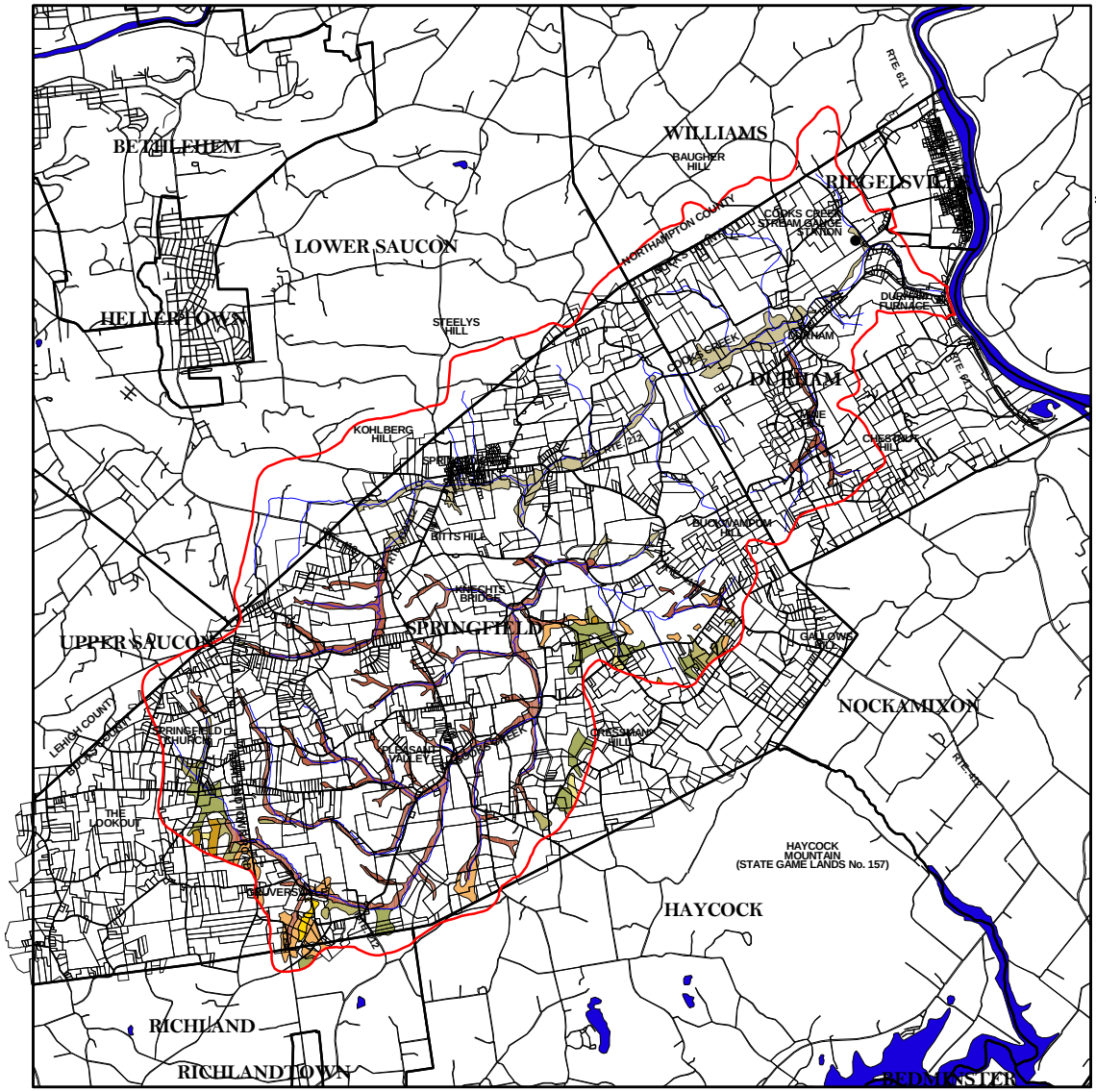

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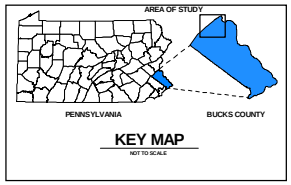

- Figure 19 - Hydric Soils Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Hydric Soils

- Bo (Bowmansville silt loam)
- CwB (Culloka-Weikert shaly silt loam, 3 to 8 percent slopes)
- CwC (Culloka-Weikert shaly silt loam)
- DoA (Doylestown silt loam, 0 to 3 percent slopes)
- DoB (Doylestown silt loam, 3 to 8 percent slopes)
- Ha (Hatboro silt loam)
- ToA (Towhee silt loam, 0 to 3 percent slopes)
- ToB (Towhee silt loam, 3 to 8 percent slopes)
- TwB (Towhee extremely stony silt loam, 3 to 8 percent slopes)

Note: The first capital letter is the initial one of the soil name. A second capital letter, A, B, C, D, or E, shows the slope. Most symbols without a slope letter are those of nearly level soils, but some are for soils and land types that have a considerable range of slope.

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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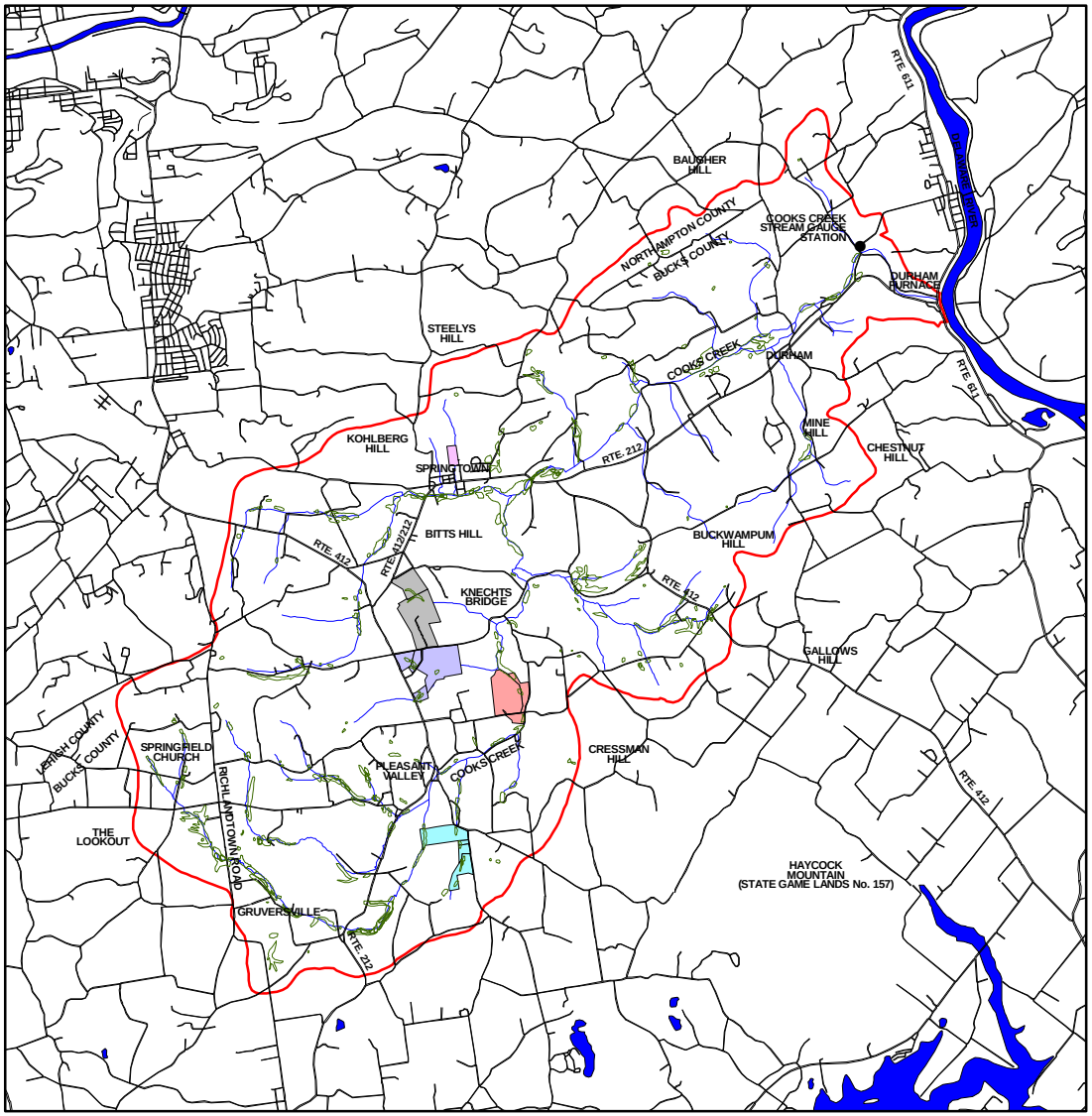

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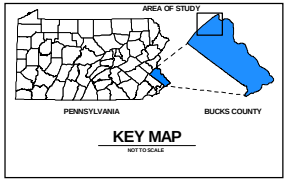

- Figure 20 - The Parcels Map with Disturbed Wetlands

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Wetlands
- Disturbed Wetland J
- Disturbed Wetland M
- Disturbed Wetland T
- Disturbed Wetland X
- Disturbed Wetland W

SOURCES: 1) Wetlands Management Plan, DTEAC, MJE et al., May 2000.

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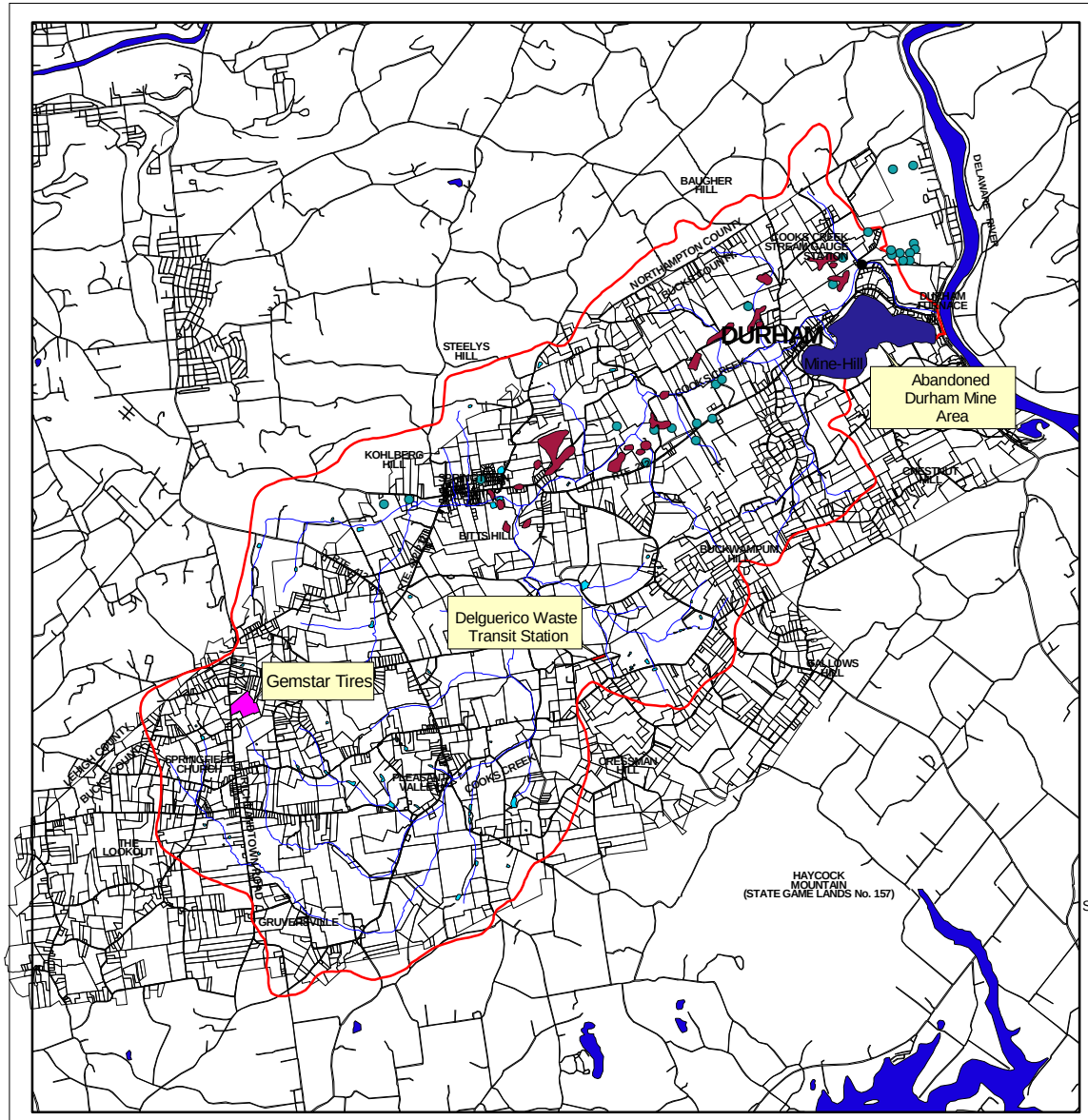

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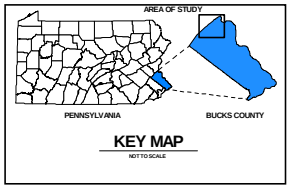

- Figure 21- Hazard Areas Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Stream
- Waterways
- Lakes and Ponds
- Karst-Prone Area
- Delguerico Waste Transit Station
- Gemstar Tires
- Abandoned Durham Mine Area
- Sinkholes

SOURCES: 1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.

2) Conservation and Management Practices for Buckingham & Durham Carbonate Valleys, Bucks County Planning Commission, February 1985

3) Spruance Lybrary of The Mercer Museum, Doylestown, Aerial Photos, 1950, 1958.

4) DTEAC , MJE , Wetlands Management Plan, Areas susceptible to karst, 1999

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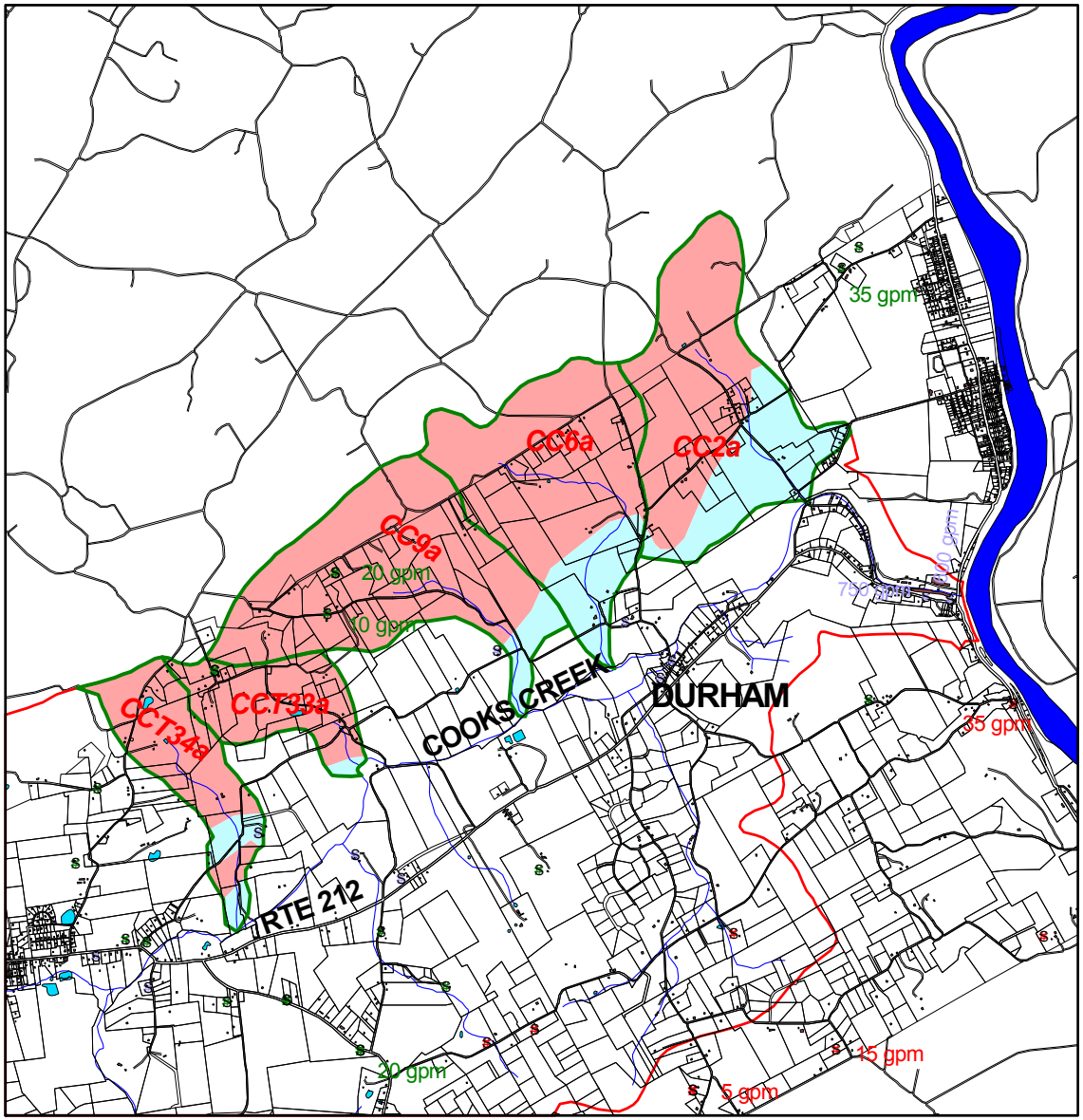

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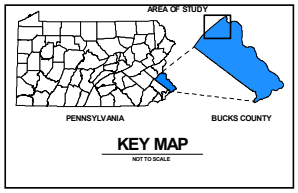

- Figure 22.1 - Sub-basin Hydrogeologic Units Map (Area 1)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basins
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS:
- Limestone
- Crystalline

FIRST ORDER SUB-BASINS ID:
- *CC2a*
- *CC6a*
- *CC9a*
- *CCT33a*
- *CCT34a*

TAPED HYDROGEOLOGIC UNIT FOR PaGWIS DATABASE WELLS:
- S Limestone
- S Brunswick
- S Crystalline
- S Diabase
- 35 gpm Maximum Recorded Yield

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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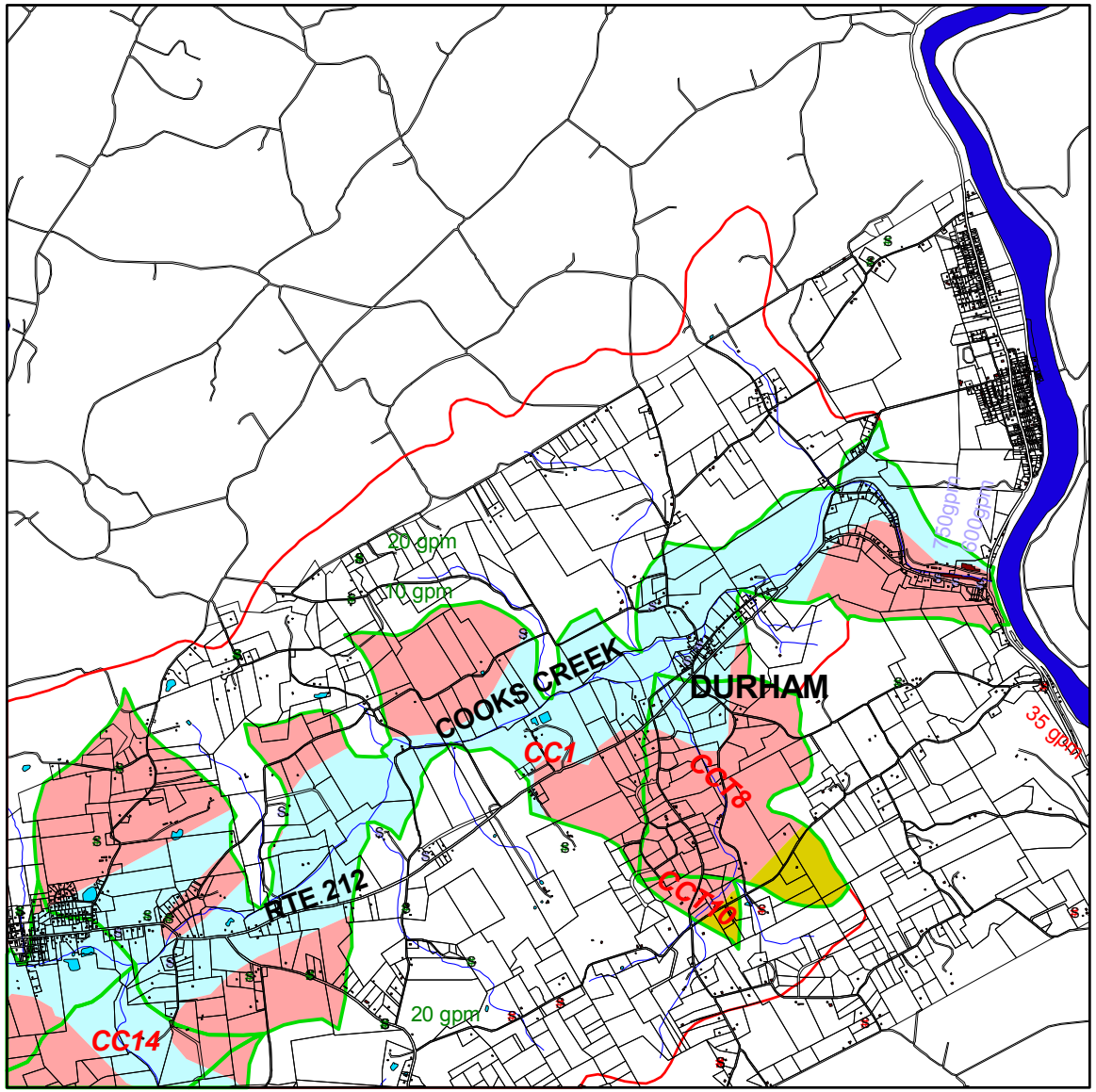

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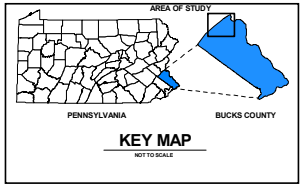

- Figure 22.2 - Sub-basin Hydrogeologic Units Map (Area 2)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basins
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS:
- Limestone
- Crystalline
- Brunswick

SECOND ORDER SUB-BASINS ID:
- *CC1*
- *CC14*
- *CCT8*
- *CCT10*

TAPED HYDROGEOLOGIC UNIT FOR PaGWIS DATABASE WELLS:
- S Limestone
- S Brunswick
- S Crystalline
- S Diabase
- 35 gpm Maximum Recorded Yield

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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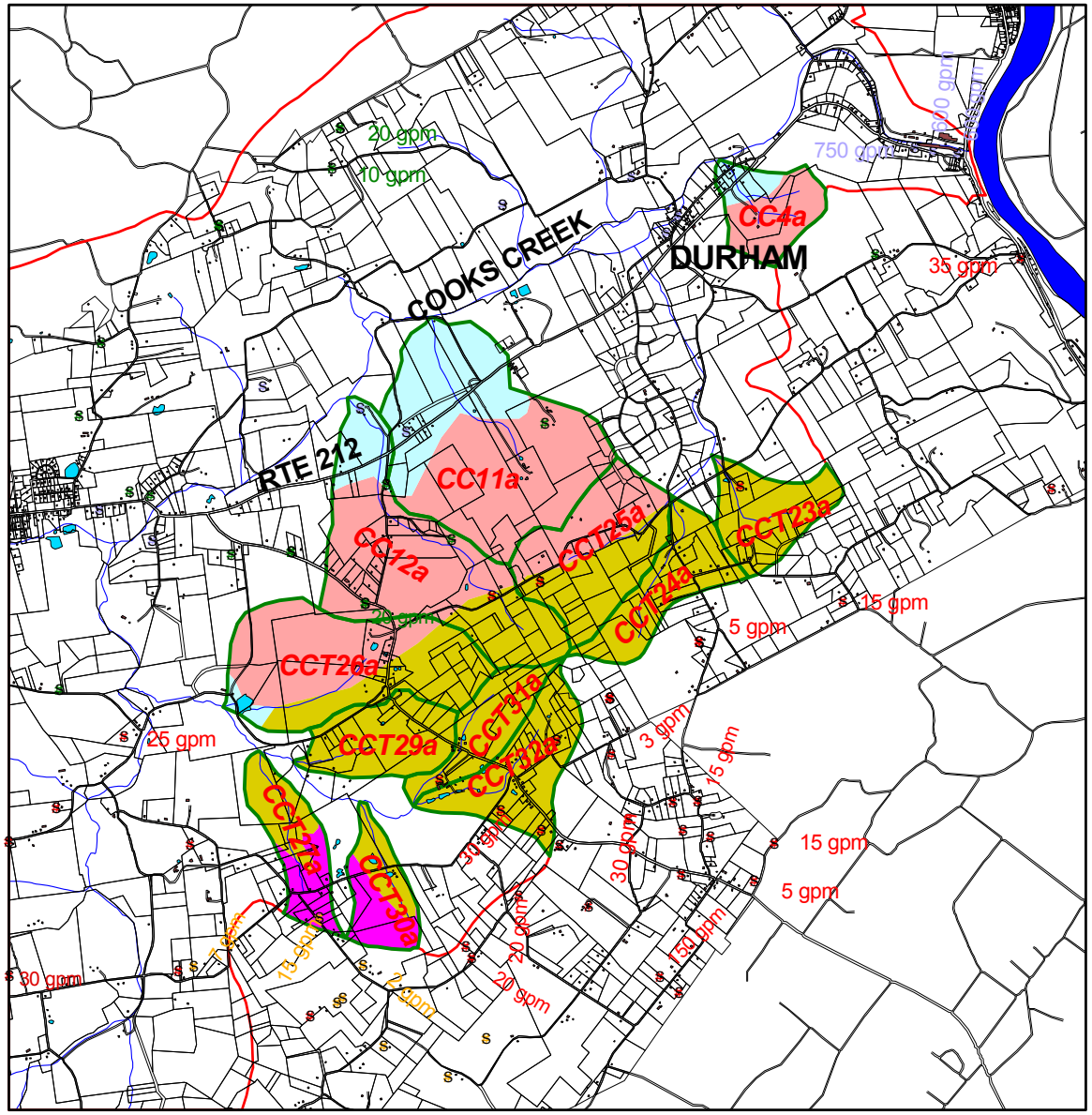

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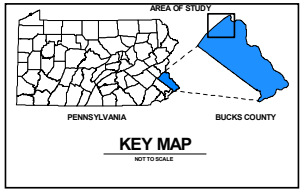

- Figure 22.3 - Sub-basin Hydrogeologic Units Map (Area 3)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basins
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS:
- Limestone
- Brunswick
- Crystalline
- Diabase

TAPED HYDROGEOLOGIC UNIT FOR PaGWIS DATABASE WELLS:
- S Limestone
- S Brunswick
- S Crystalline
- S Diabase
- 35 gpm Maximum Recorded Yield

FIRST ORDER SUB-BASINS ID:

CC4a	CCT23a	CCT29a
CC11a	CCT24a	CCT30a
CC12a	CCT25a	CCT31a
CCT21a	CCT26a	CCT32a

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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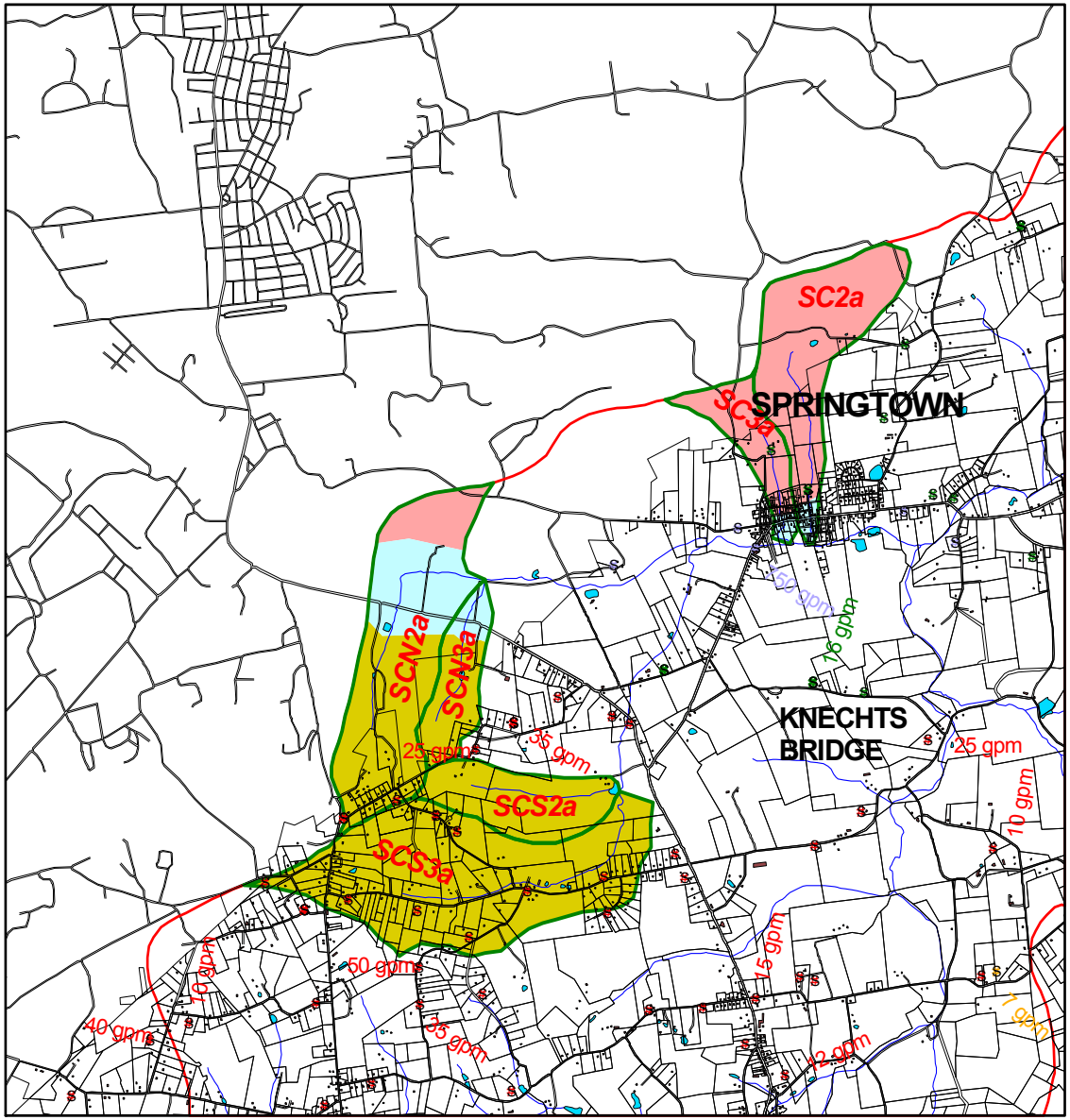

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COOKS CREEK WATERSHED RIVERS CONSERVATION PLAN

DURHAM AND SPRINGFIELD
BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis

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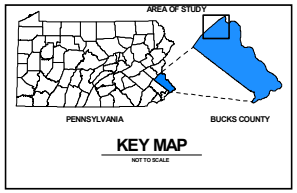
JANUARY 2001



- Figure 22.4 - Sub-basin Hydrogeologic Units Map (Area 4)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basins
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS
- Limestone
- Brunswick
- Crystalline

FIRST ORDER SUB-BASIN ID:

SC2a	SCN3a
SC3a	SCS2a
SCN2a	SCS3a

TAPED HYDROGEOLOGIC UNIT FOR PaGWIS DATABASE WELLS:
- S Limestone
- S Brunswick
- S Crystalline
- S Diabase
- 35 gpm Maximum Recorded Yield

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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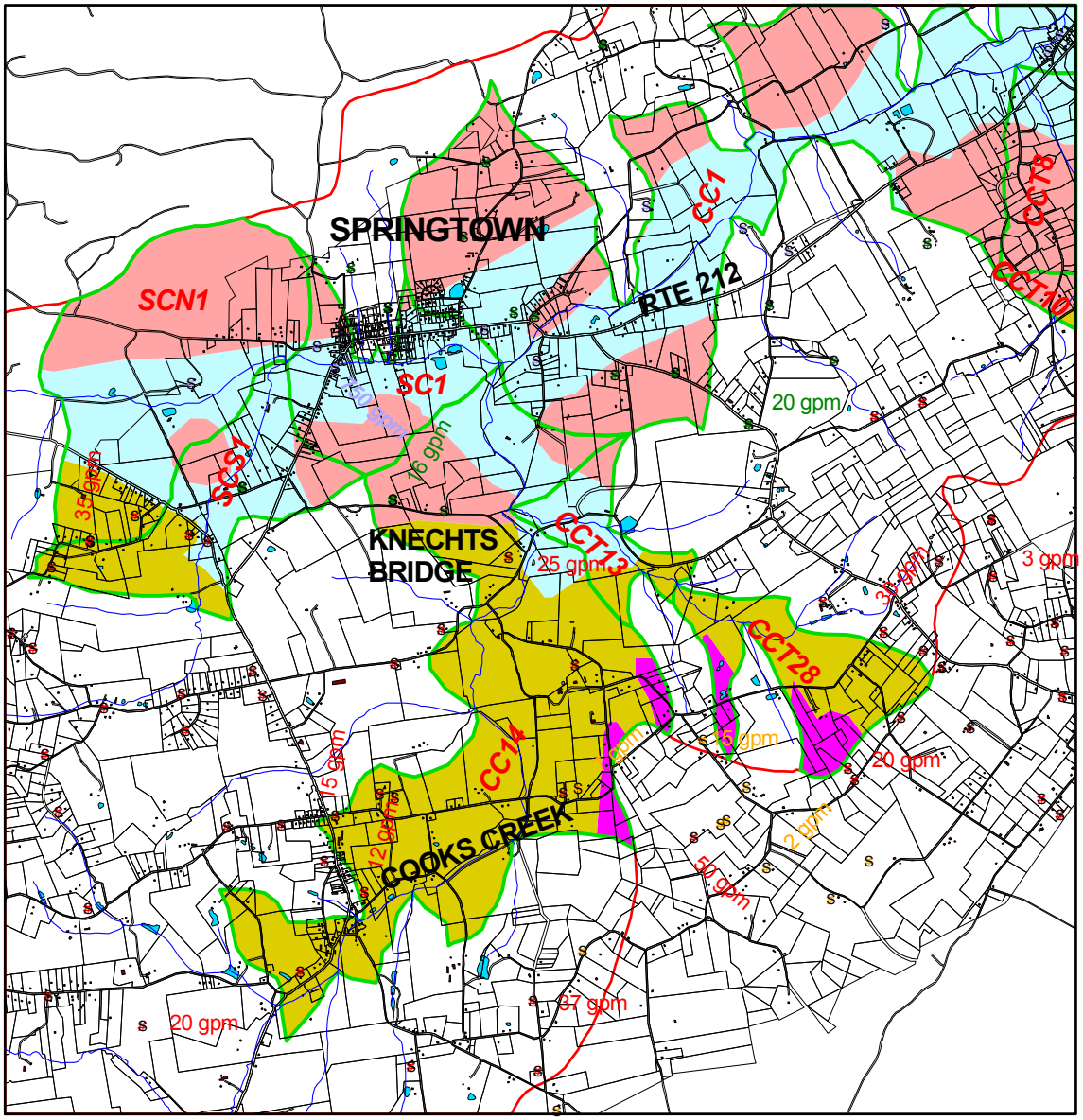

DTEAC- PaDCNR

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DURHAM AND SPRINGFIELD
BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis

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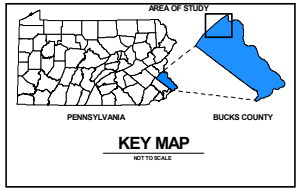

- Figure 22.5 - Sub-basin Hydrogeologic Units Map (Area 5)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basins
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS

- Limestone
- Crystalline
- Brunswick
- Diabase

S Limestone
S Brunswick
S Crystalline
S Diabase

35 gpm Maximum Recorded Yield

SECOND ORDER SUB-BASIN ID:

CC1 SCN1 CCT10
CC14 SCS1 CCT28
SC1 CCT8

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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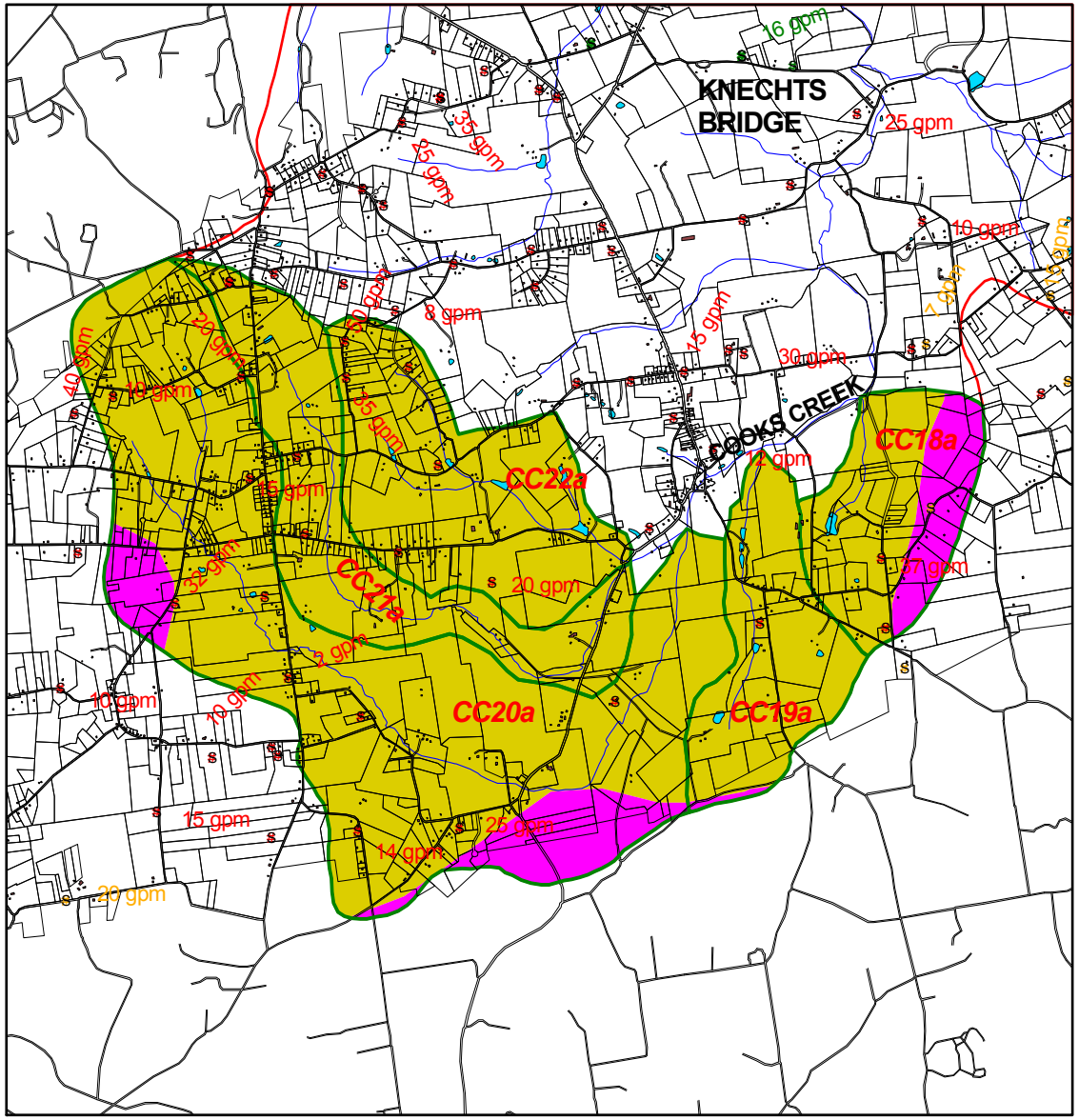

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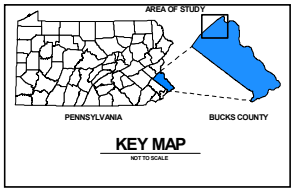

- Figure 22.6 - Sub-basin Hydrogeologic Units Map (Area 6)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basin
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS

- Brunswick
- Diabase

FIRST ORDER SUB-BASIN ID:

CC18a CC21a
CC19a CC22a
CC20a

TAPED HYDROGEOLOGIC UNIT FOR PaGWIS DATABASE WELLS:

- S Limestone
- S Brunswick
- S Crystalline
- S Diabase
- 35 gpm Maximum Recorded Yield

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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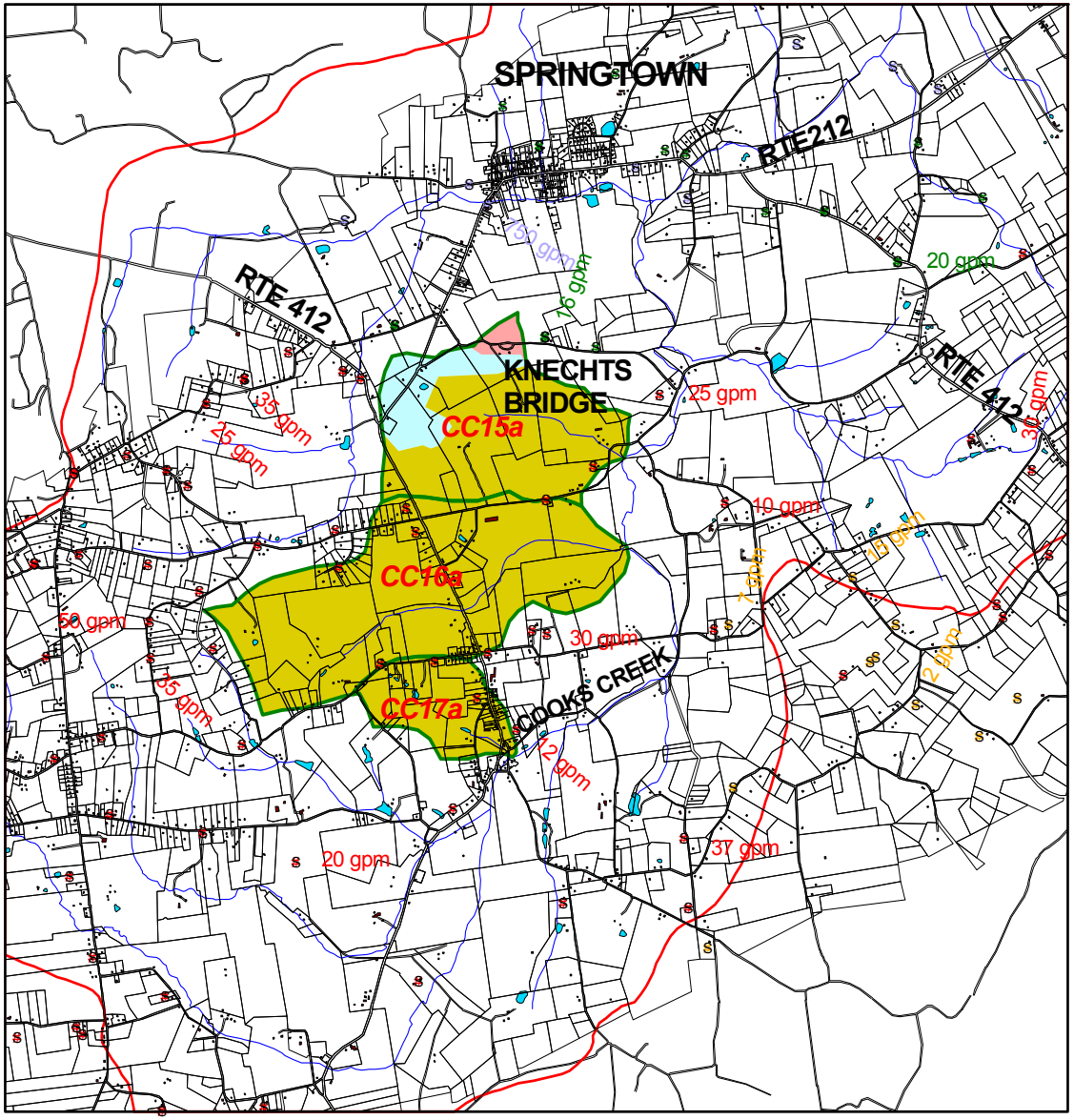

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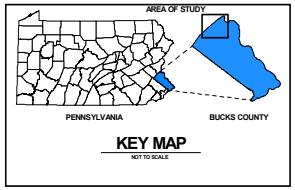

- Figure 22.7 - Sub-basin Hydrogeologic Units Map (Area 7)

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Sub-basin
- Buildings
- Tax Map Parcels
- Lakes and Ponds

HYDROGEOLOGIC UNITS
- Limestone
- Brunswick

FIRST ORDER SUB-BASIN ID:
- *CC15a*
- *CC16a*
- *CC17a*

TAPED HYDROGEOLOGIC UNIT FOR PaGWIS DATABASE WELLS:
- S Limestone
- S Brunswick
- S Crystalline
- S Diabase
- 35 gpm Maximum Recorded Yield

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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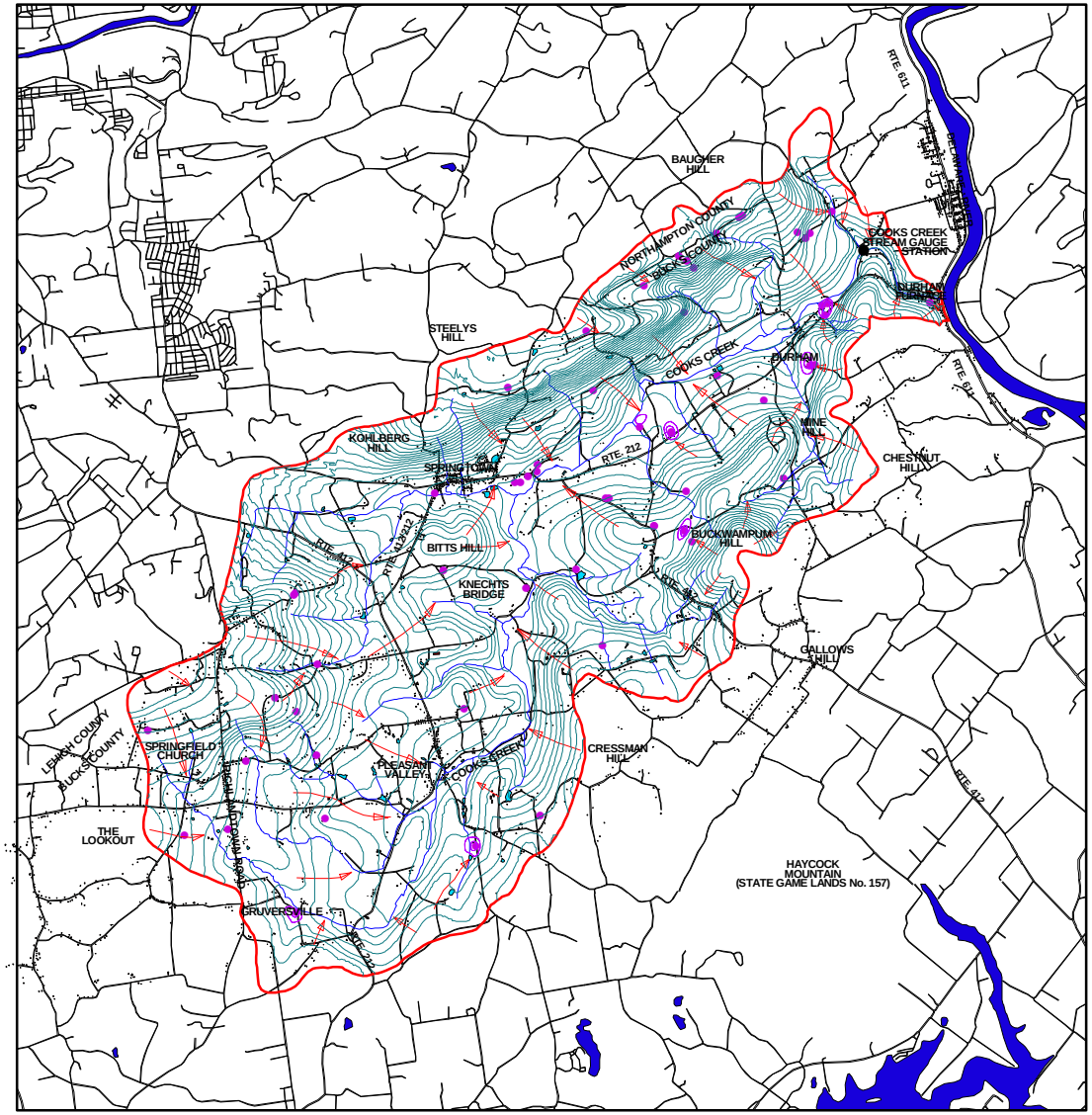

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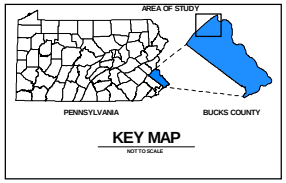

- Figure 23 - Groundwater Contour Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Buildings
- Groundwater Contour
- Groundwater Flow Direction
- Water Well

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
3) DCNR, Pennsylvania Ground Water Information System, Water Well Data, July 1998.
4) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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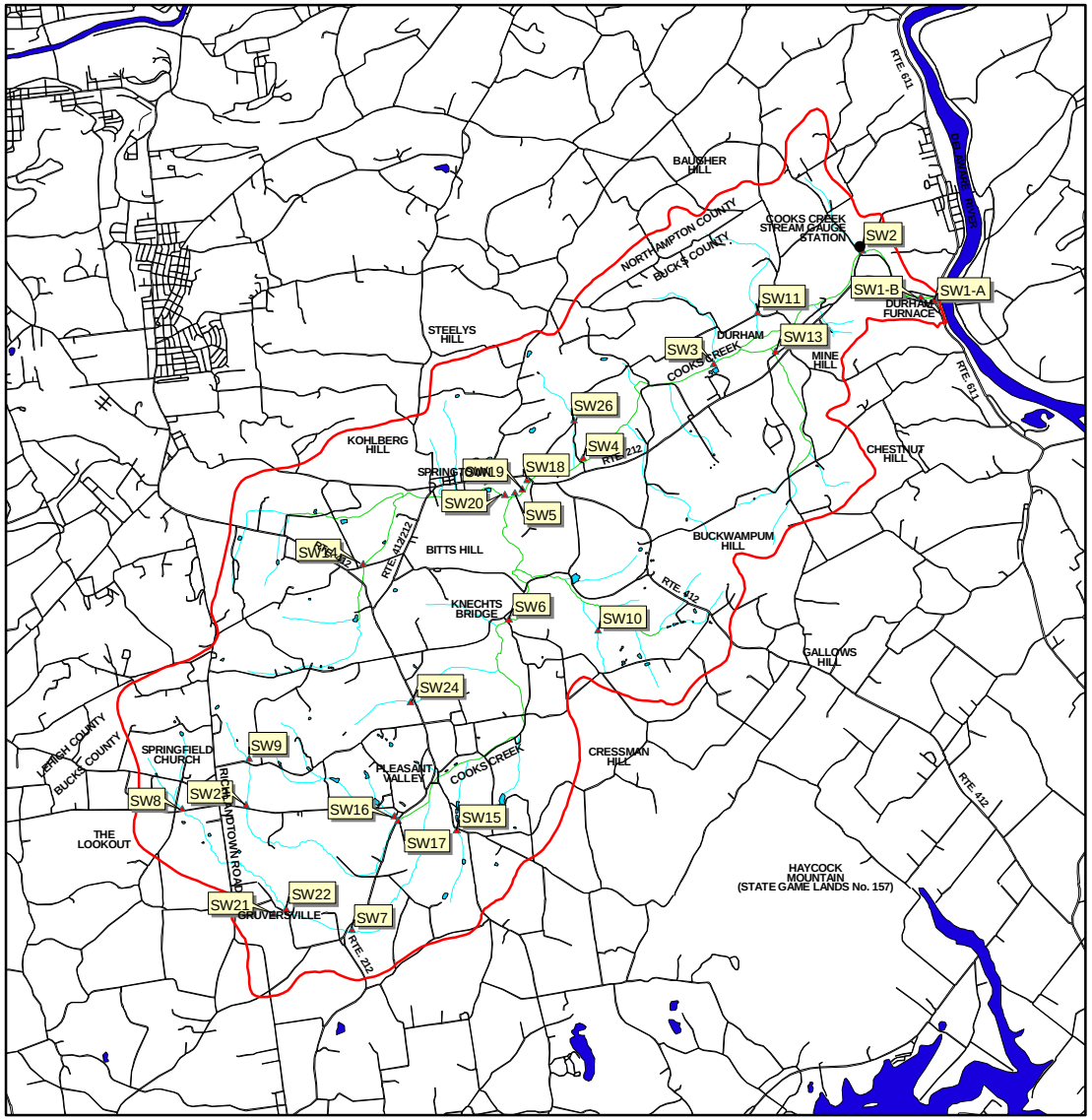

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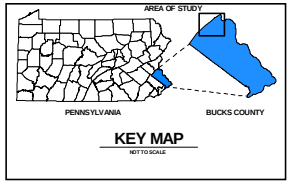

- Figure 24 - Stream Properties and Stream Conditions Sampling

LEGEND

- Stream Sampling Location
- Watershed Boundaries
- Lakes and Ponds
- Stream
- Waterways
- Minor Roads
- Major Roads
- First Order Stream
- Second Order Stream

SOURCES:1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.

2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) United States Geologic Survey Topographic Quadrangle Map, Riegelsville, PA - NJ, 1973; Hellertown, PA 1992; Quakertown, PA 1994; Bedminster, PA 1992, Translation, attribution and analysis by MJE, August 2000.

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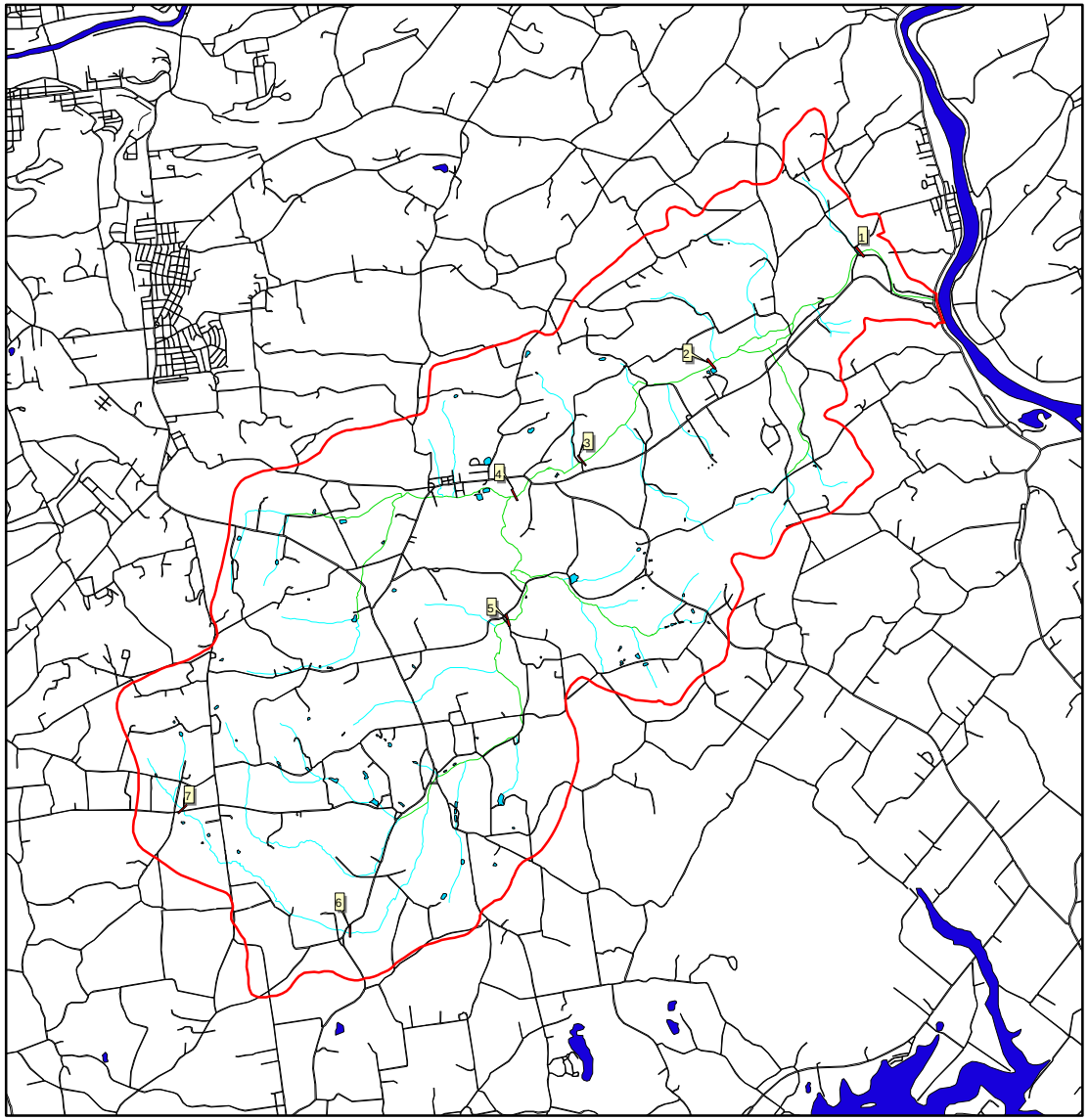

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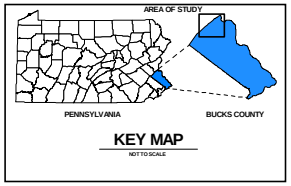

- Figure 25 - Rosgen Transects Map

LEGEND

- Survey Transect Location, Rosgen Method
- Watershed
- Lakes and Ponds
- Stream
- Waterways
- Minor Road
- Major Road
- First Order Stream
- Second Order Stream

SOURCES:
1) Pennsylvania Spatial Data Access system (PASDA) , Surface Geology, Translation, attribution and analysis by MJE and Golder, 1999.
2) DTEAC , MJE , Wetlands Management Plan, digital Tax Map, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.
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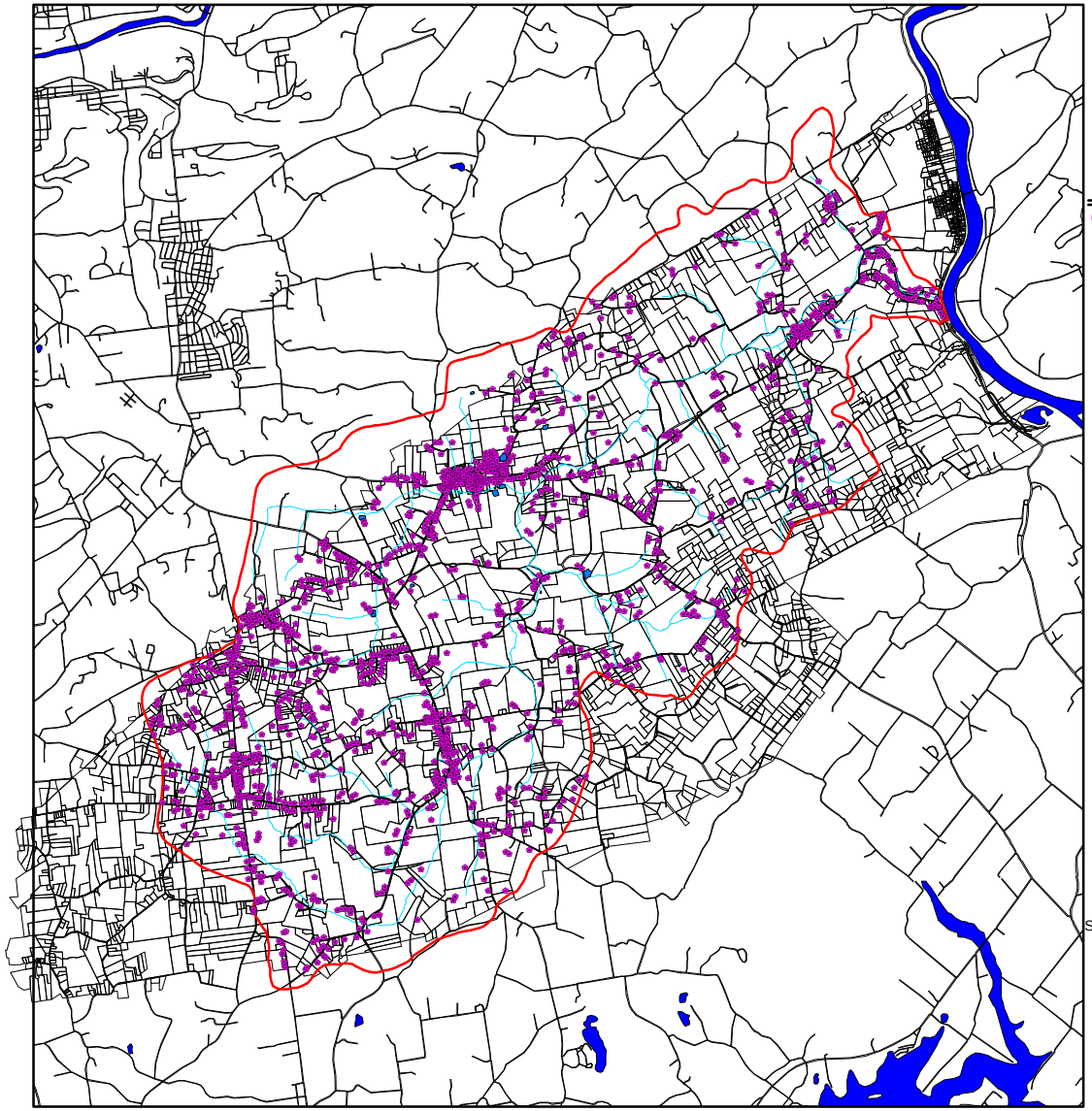

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BUCKS COUNTY, PENNSYLVANIA

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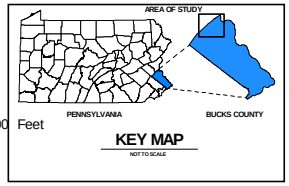

- Figure 26 -
Septic Systems Location Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds
- Tax Map Parcels
- Septic System Location

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

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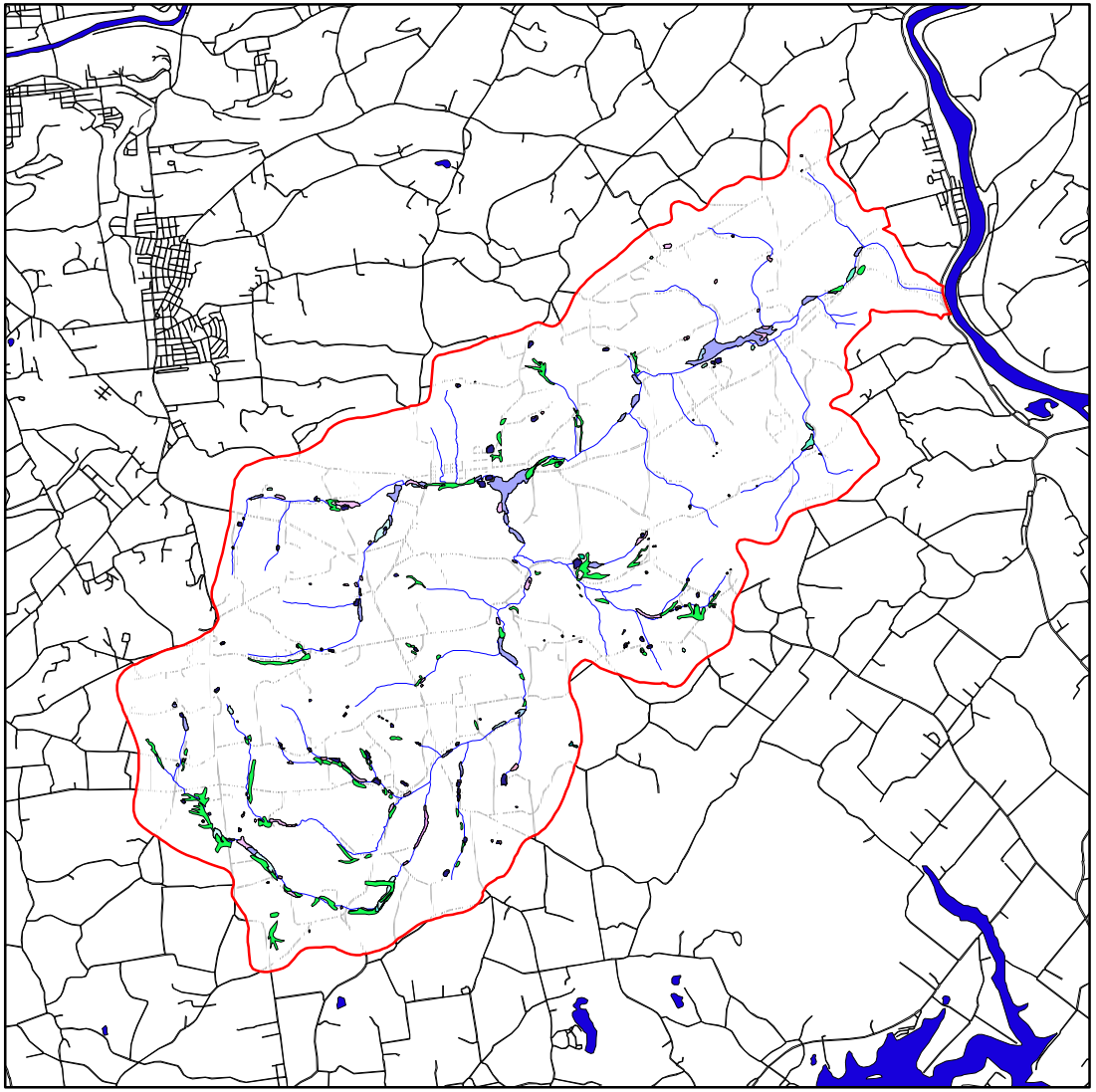

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BUCKS COUNTY, PENNSYLVANIA

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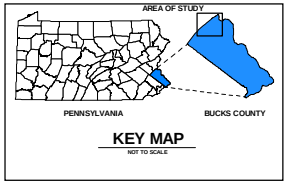

- Figure 27 - Wetlands Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Stream
- Waterways
- Lakes and Ponds

Wetlands Overlay District

Field Identified Wetlands, EEE, June, 1999:

National Wetlands Inventory:

PEM5A	PFO1E
PEM5C	POWZH
PEM5CH	POWZX
PFO/SS1A	PSS1/EM5
PFO1/EM5	PSS1A
PFO1A	PSS1C
PFO1C	

SOURCES:1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) EEE, wetlands field survey of the Cooks Creek Watershed, June 1999.

4) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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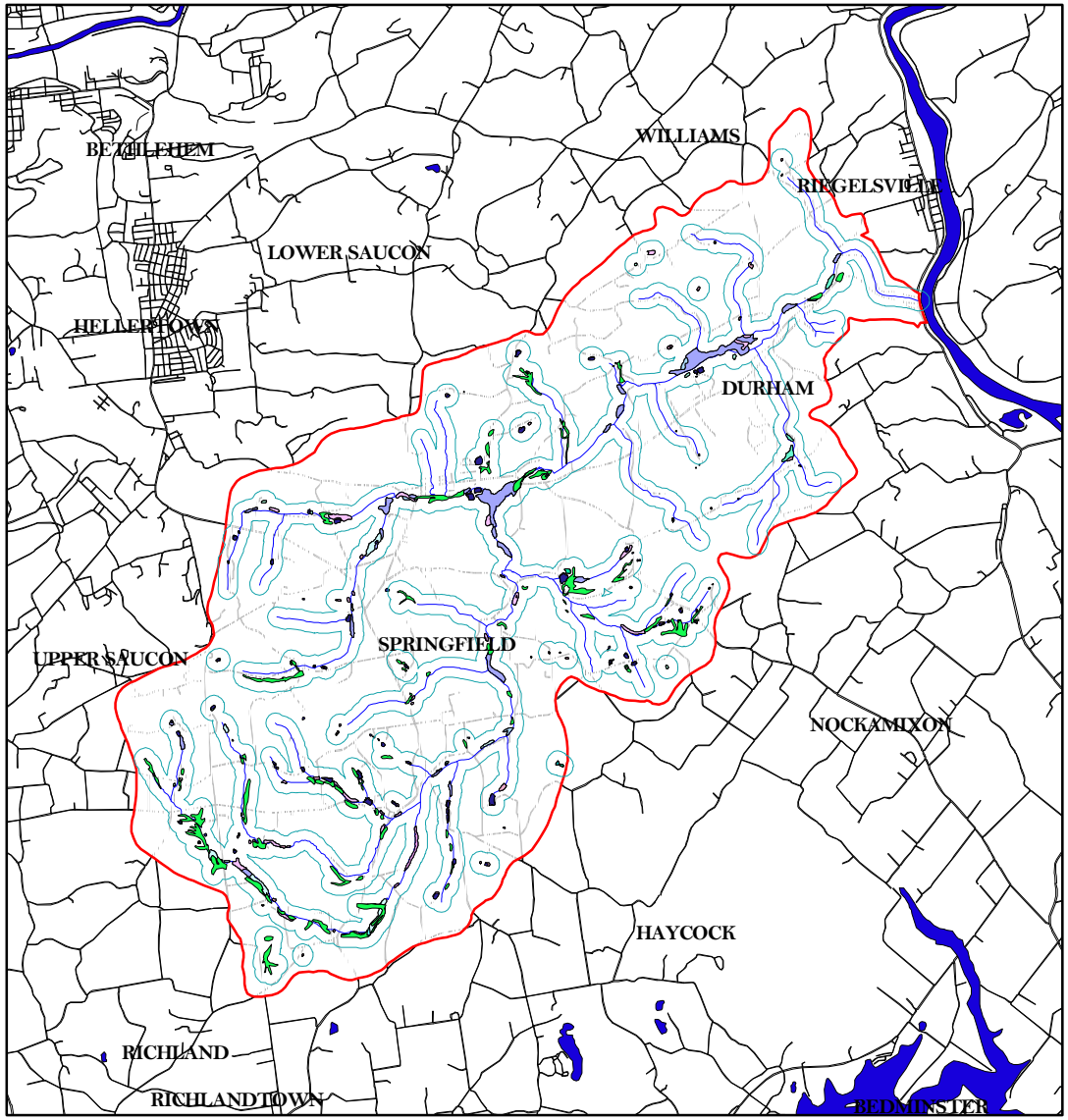

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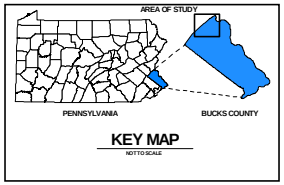

- Figure 28 - 500 feet All Waters Buffer

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Stream
- Waterways
- Lakes and Ponds
- 500 feet All Waters Buffer

Wetlands Overlay District

Field Identified Wetlands, EEE, June, 1999:

National Wetlands Inventory:

PEM5A	PFO1E
PEM5C	POWZH
PEM5CH	POWZX
PFO/SS1A	PSS1/EM5
PFO1/EM5	PSS1A
PFO1A	PSS1C
PFO1C	

SOURCES:1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

3) EEE, wetlands field survey of the Cooks Creek Watershed, June 1999.

4) MJE, digital Sub-basins Map of the Cooks Creek Watershed, October 2000.

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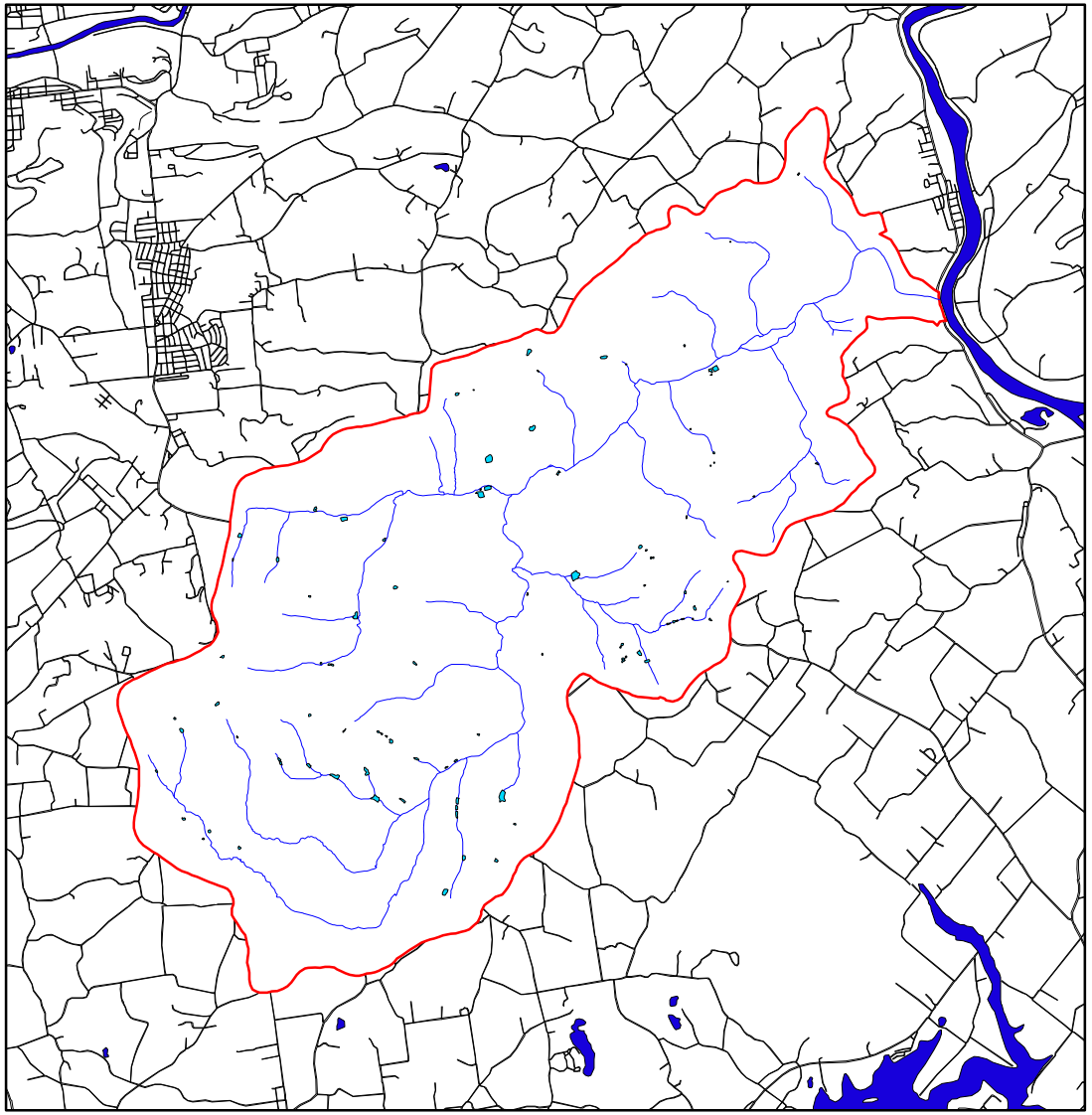

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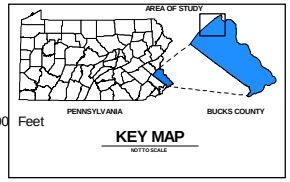

- Figure 29 - Lakes and Ponds Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways
- Lakes and Ponds

SOURCES: 1) GIS Data Depot (GIS Web Sites located on the Internet). Translation, attribution and analysis by MJE.

2) DTEAC, MJE, Wetlands Management Plan, digital Tax Map, digital buildings, digital Watershed Map, digital Cooks Creek Map, digital Lakes and Ponds Map, May 2000.

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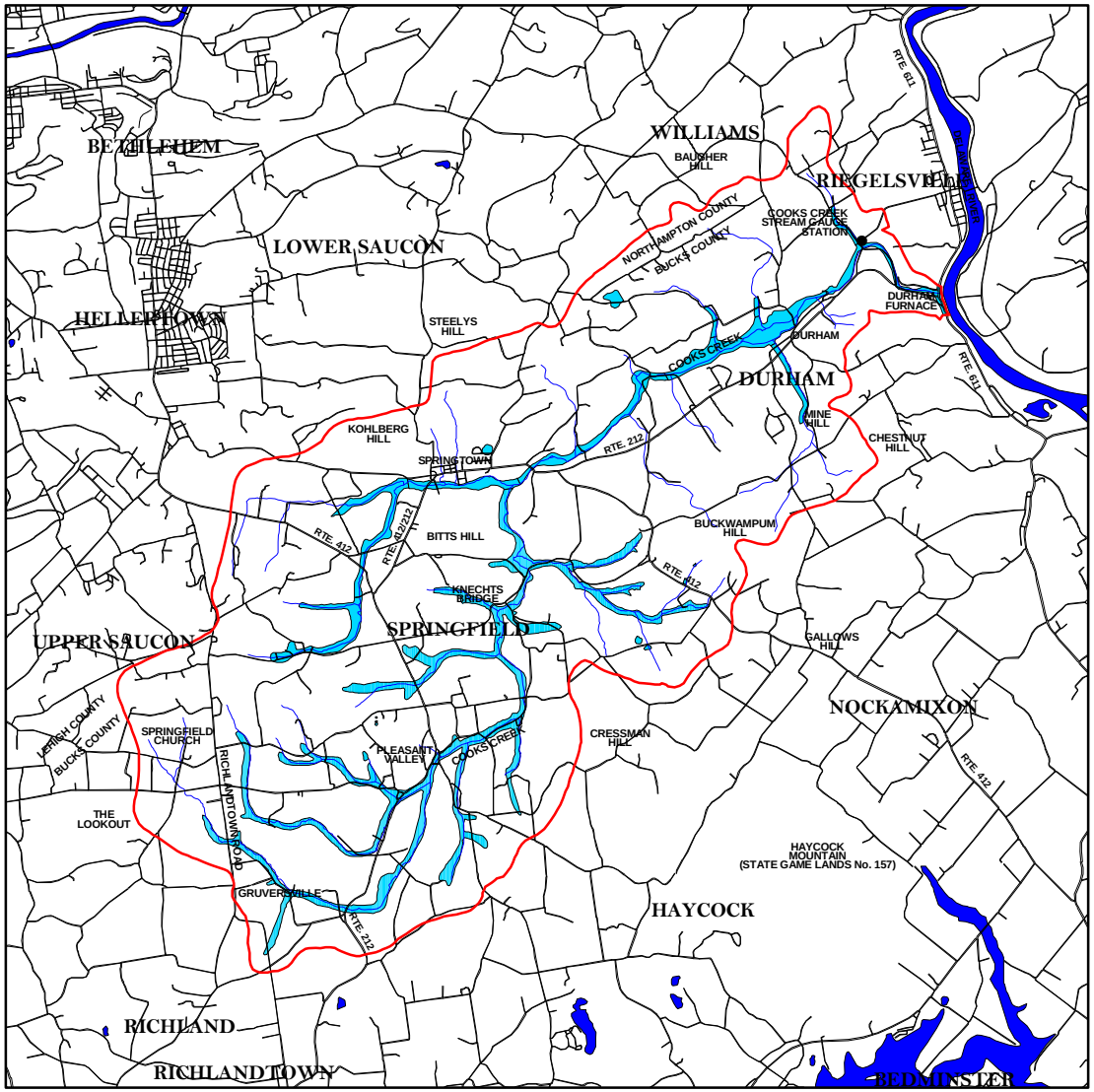

DTEAC- PaDCNR

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BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis

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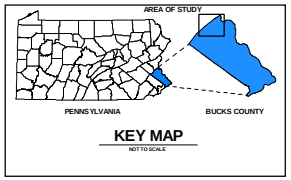

- Figure 30 - 100-year Floodplain Map

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Streams
- Waterways
- 100-year Floodplain Area

SOURCES: 1) PASDA , Digital data of the floodplains of Bucks, Lehigh and Northampton Counties, Translation, attribution and analysis by MJE, 2000.

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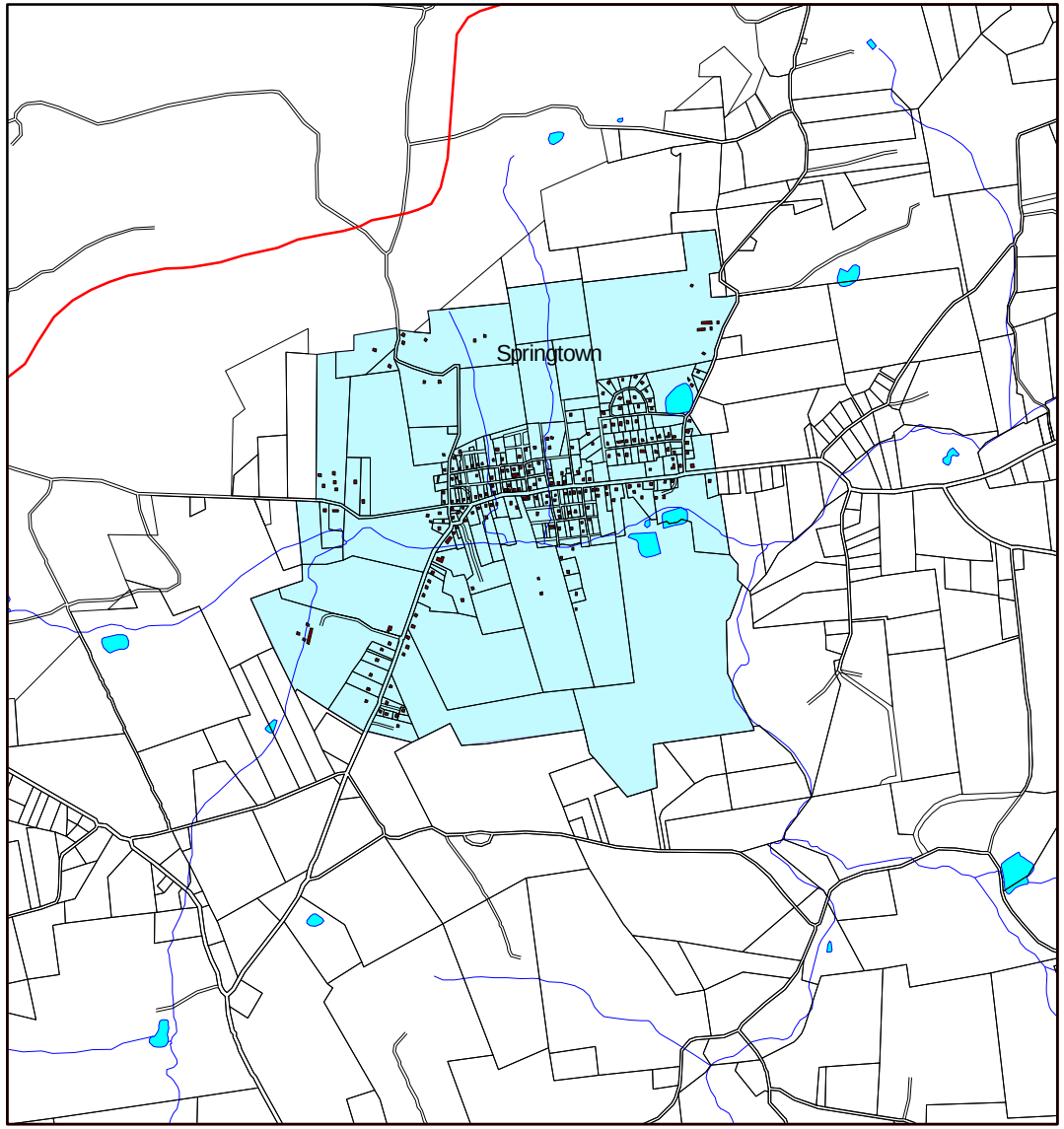

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COOKS CREEK WATERSHED RIVERS CONSERVATION PLAN

DURHAM AND SPRINGFIELD
BUCKS COUNTY, PENNSYLVANIA

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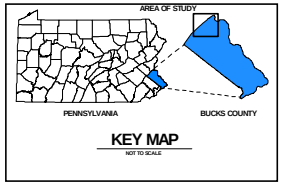

- Figure 31- Centralized Water Area

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Streams
- Buildings
- Lakes and Ponds
- Public Water Supply Area

SOURCES: 1) Bucks County Water Suply System, Bucks County Planning Commission, 1994

2) Water System Plan, Springfield Township Municipal Authority, Bucks County, August 17, 1987

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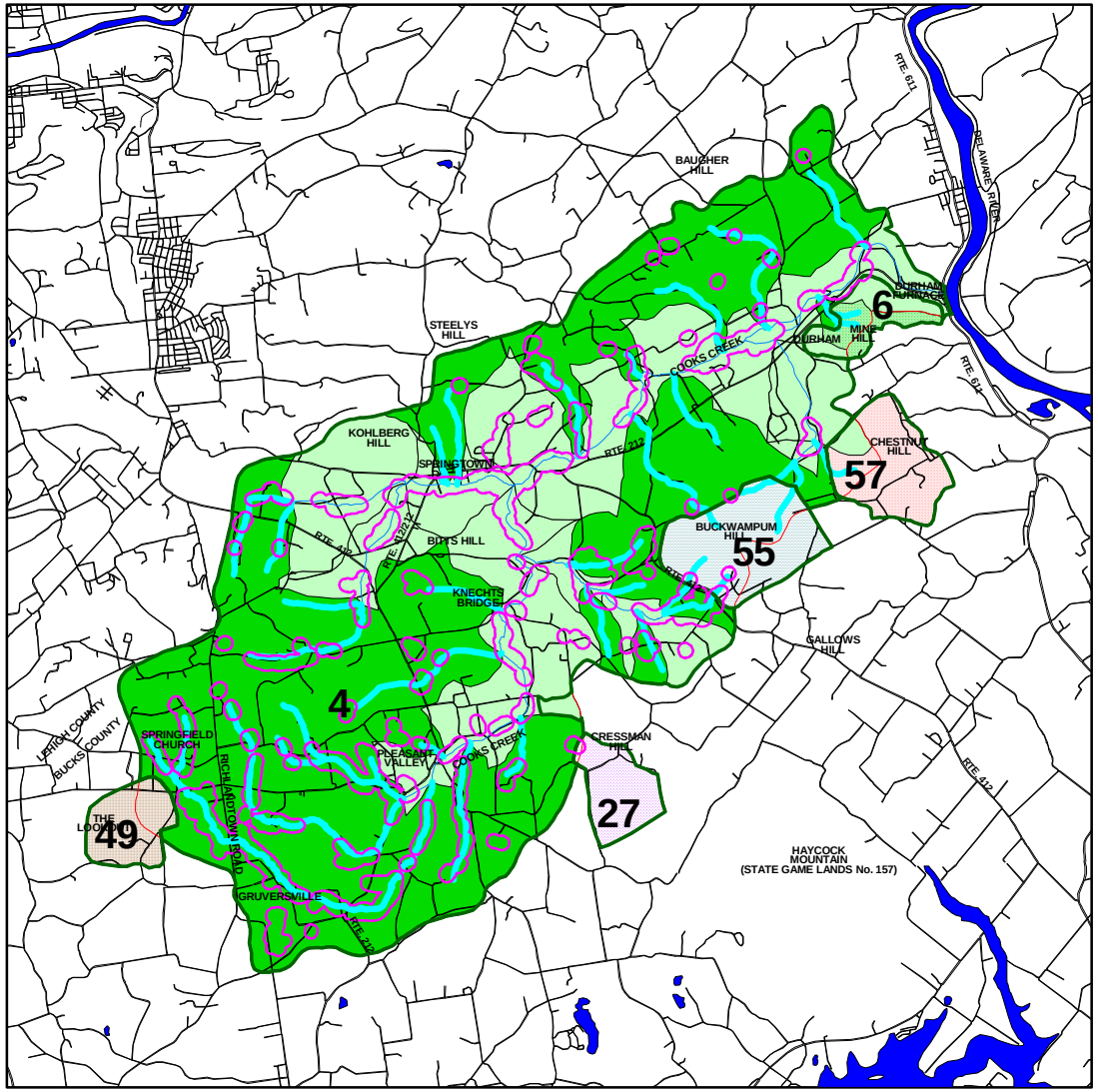

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DURHAM AND SPRINGFIELD
BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis

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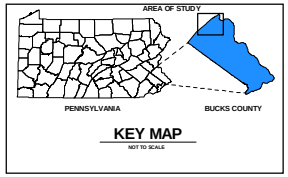

- Figure 32 - Priority Inventory Sites.

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Priority Areas

- First Order Stream
- First Order Sub-basin
- Wetland Buffer

Inventory Sites

- 4 - Cooks Creek (Priority 1 Site)
- 6 - Durham Mine, Mine Hill, and Rattlesnake Hill (Priority 1 Site)
- 27 - Cressman Hill and contiguous forested areas (Priority 2 Site)
- 49 - The Lookout (Priority 2 Site)
- 55 - Buckwampum Mountain (Priority 3 Site)
- 57 - Chestnut Hill (Priority 3 Sites)

SOURCES: 1) Natural Areas Inventory of Bucks County, Pennsylvania, Ann F. Rhoads & Timothy A. Block, Submitted to the Bucks County Commissioners. June, 1999.

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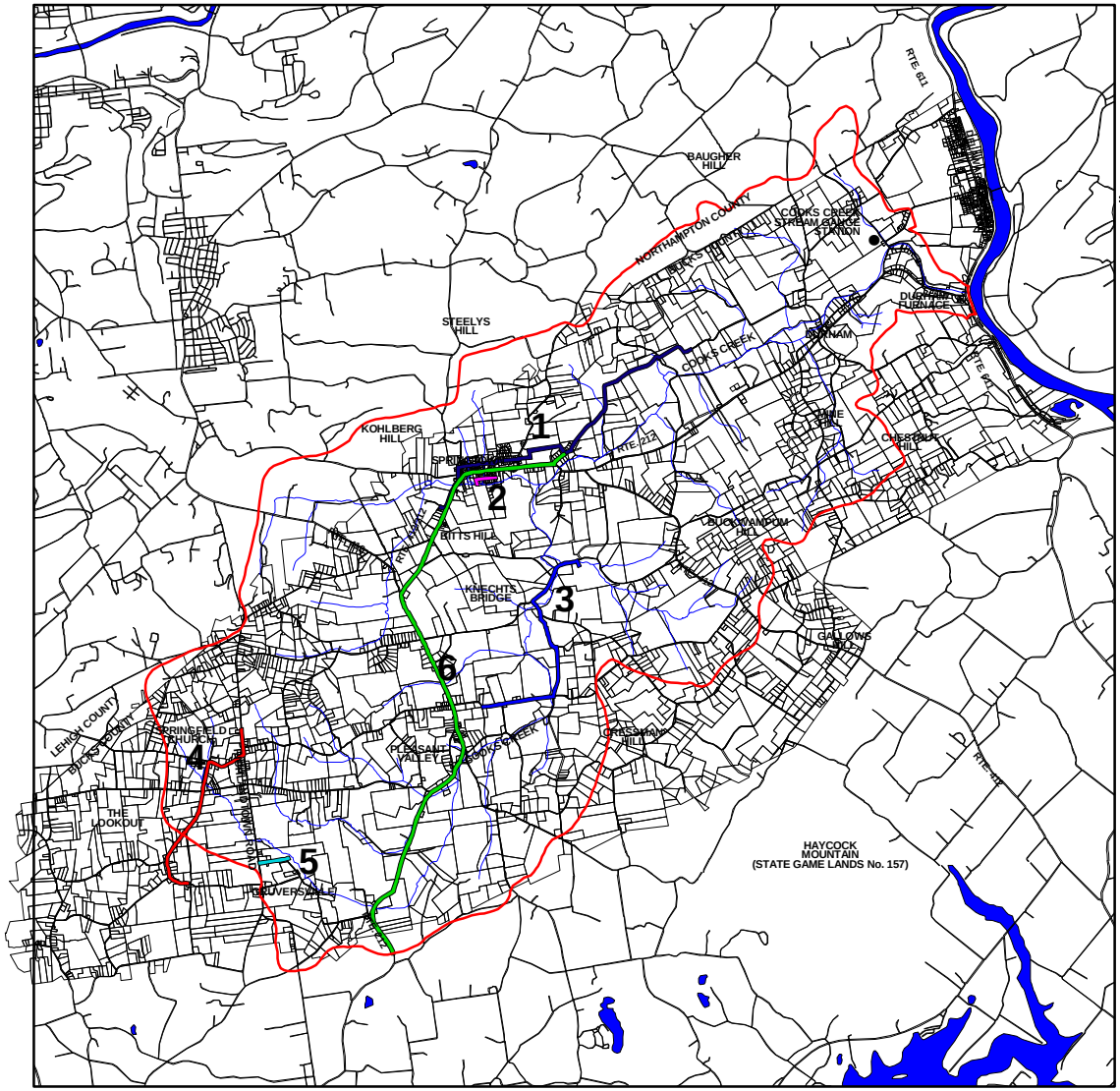

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DURHAM AND SPRINGFIELD
BUCKS COUNTY, PENNSYLVANIA

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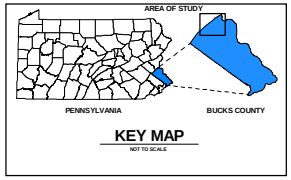

- Figure 33 -
Proposed Recreational Trails

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Linkage Map

1. Silver Creek Athletic Association to Durham Athletic Association
2. Walnut Street, Springtown to Springtown Rod and Gun Club
3. Springfield School to Silver Valley Conservation Area
4. Quarry Road to Ebert Road for Access to Passer Community Assoc.
5. Active/Passive Recreation Area on PP&L Property on Wrecsics Rd.
6. Rt. 212 Richlandtown Borough to Funks Mill Rd./Old Bethleem Road

SOURCES:1) Springfield Township Open Space and Farmland Preservation Plan, Bucks County Planning Commission, July 1999.

2) DTEAC, Durham Resource Inventory Plan, 1994

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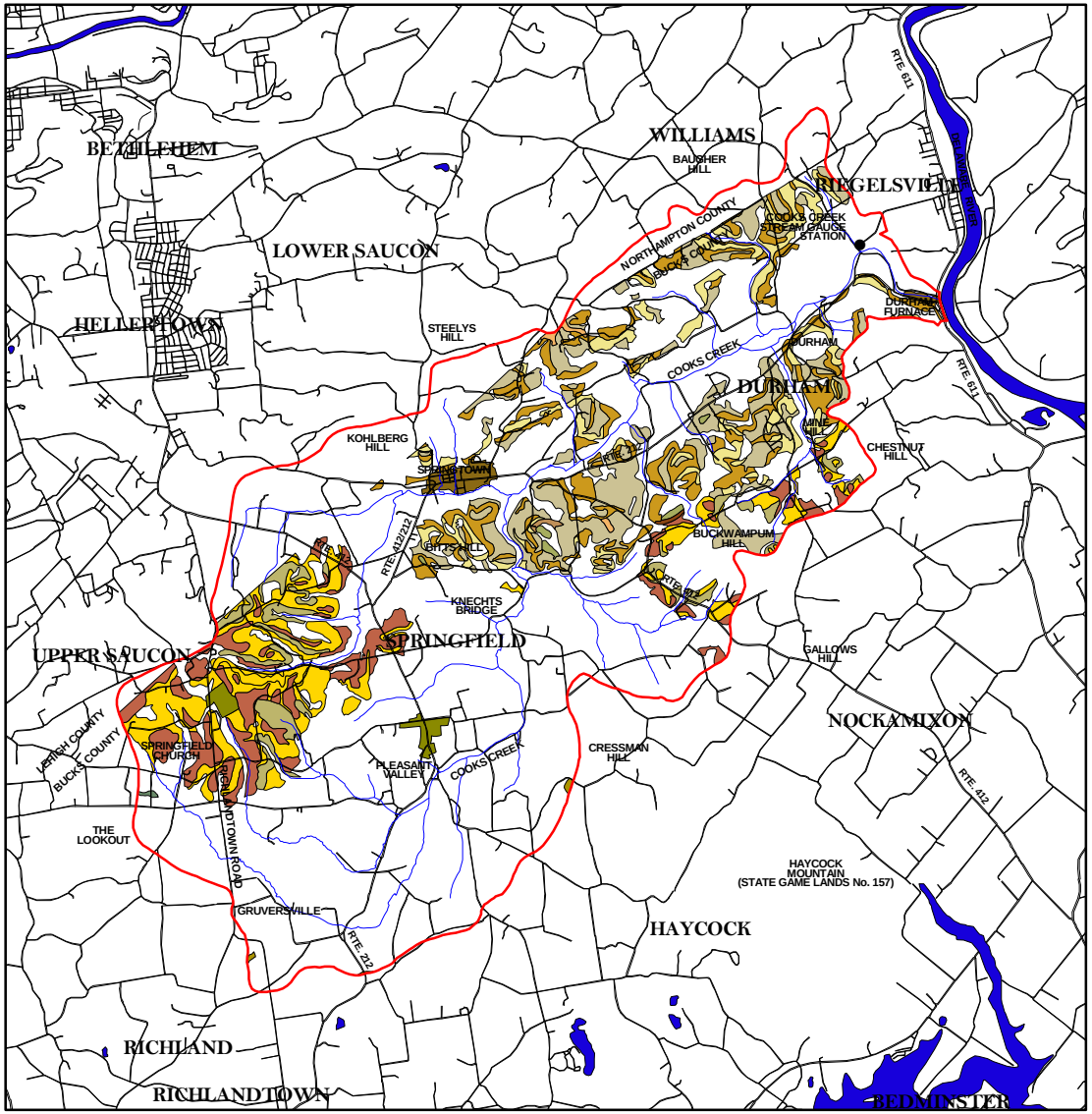

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COOKS CREEK WATERSHED RIVERS CONSERVATION PLAN

DURHAM AND SPRIENGFIELD
BUCKS COUNTY, PENNSYLVANIA

Geographic Information Systems Analysis

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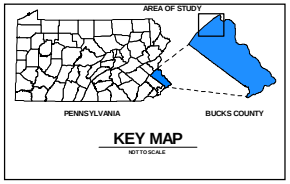

- Figure 34 -
Soil Series Feasible For Conventional Sewage Disposal Systems

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Feasible for Conventional
On-Site Sewage Disposal Systems

	AdB		MaB
	AdC		MaC
	AdD		MaD
	CeA		NeB
	CeB		NeC
	CeC		UdB
	CeD		UlC

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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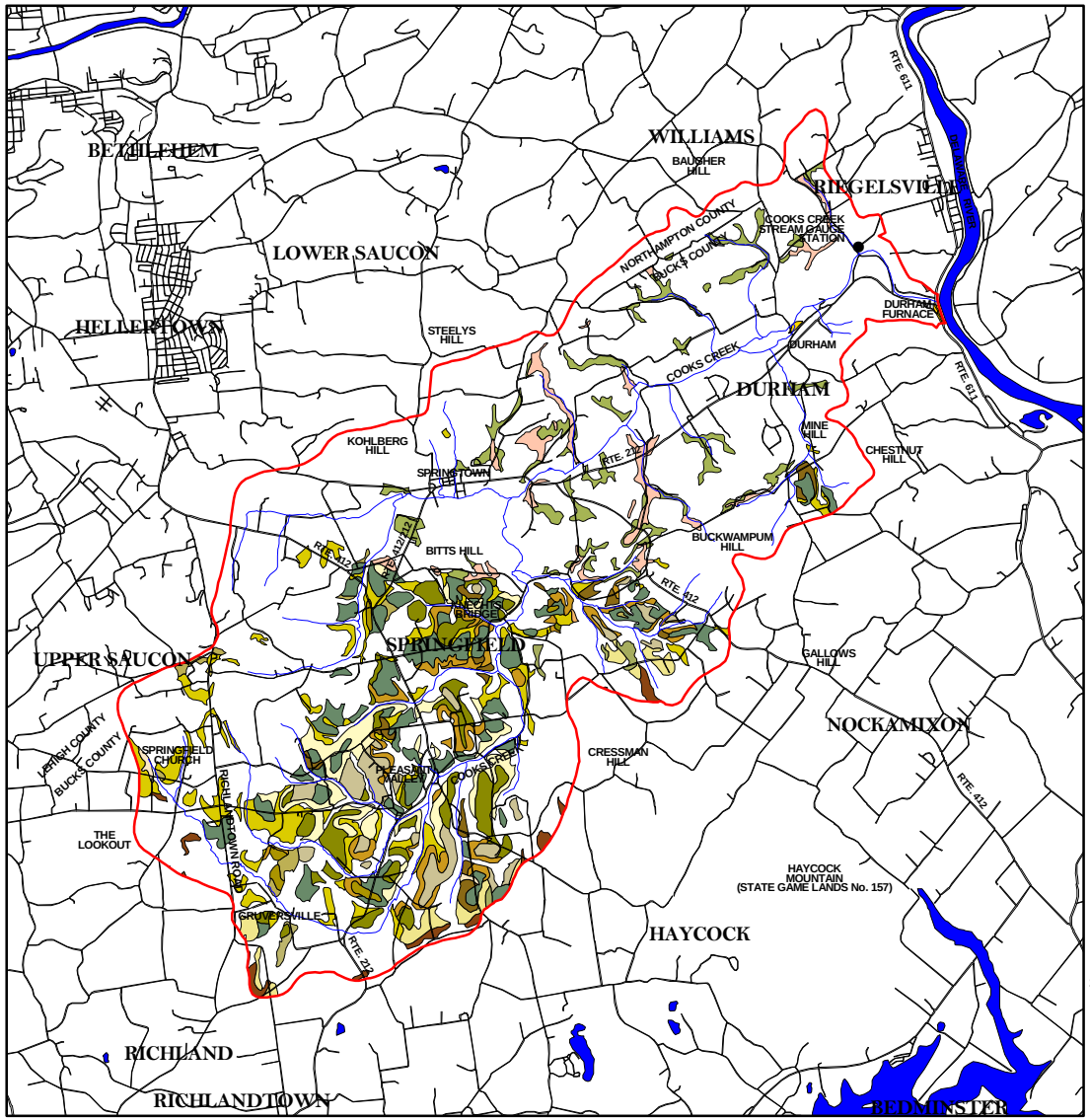

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COOKS CREEK WATERSHED RIVERS CONSERVATION PLAN

DURHAM AND SPRIENGFIELD
BUCKS COUNTY, PENNSYLVANIA

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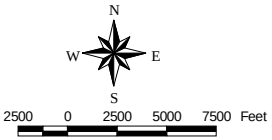

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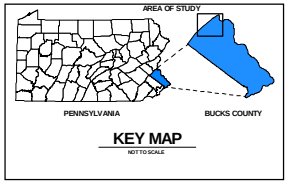

- Figure 35 -
Soil Series Feasible For Alternate Sewage Disposal Systems

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Feasible for Alternate On-Site Sewage Disposal Systems

	AgB		PeA
	AlA		PeB
	CwB		PeC
	CwC		PhB3
	KlB		PkC3
	KlC		RdA
	LhB		RdB
	LhC		RdC
	MlA		UrA
	MlB		UrB

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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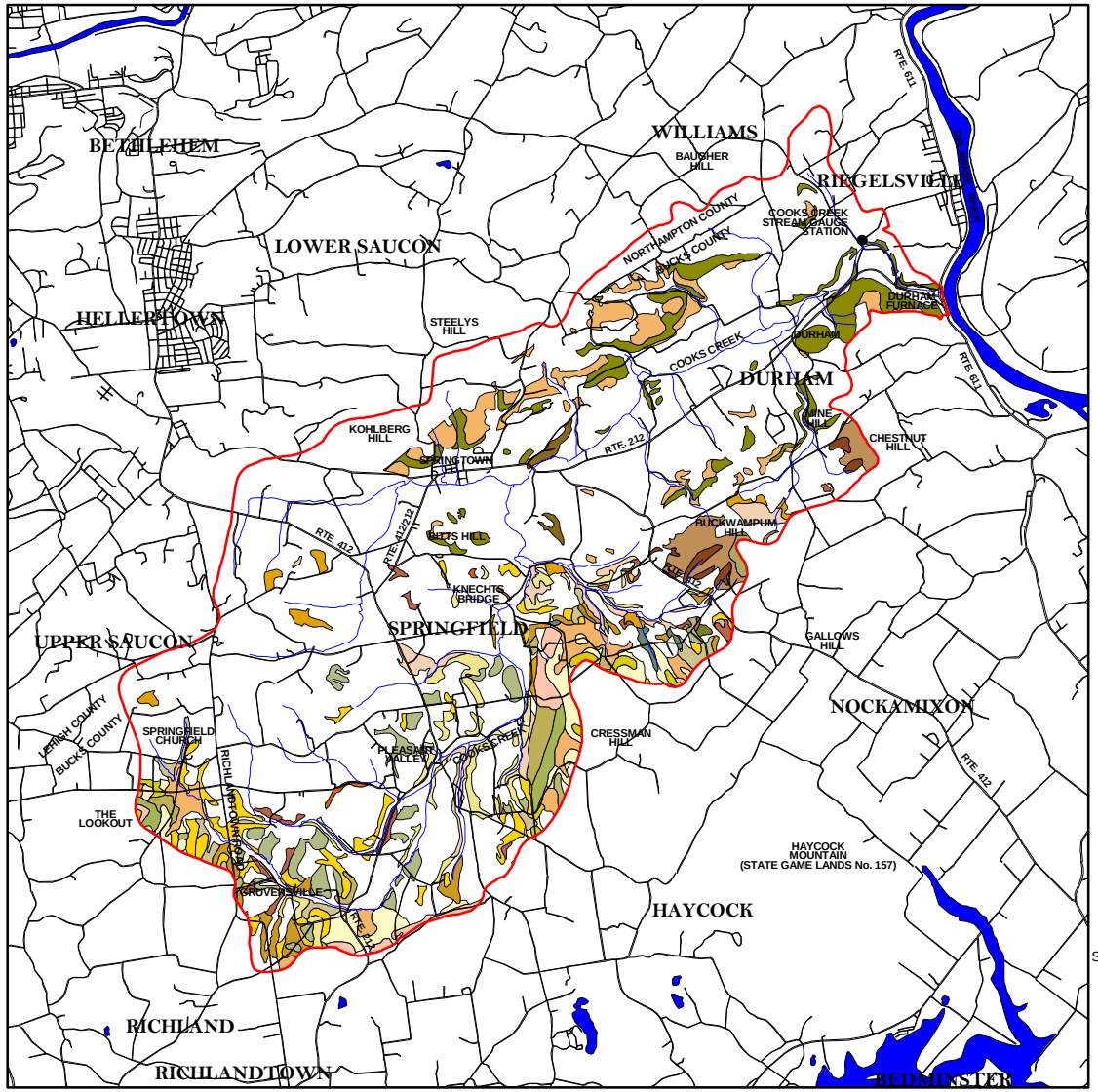

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BUCKS COUNTY, PENNSYLVANIA

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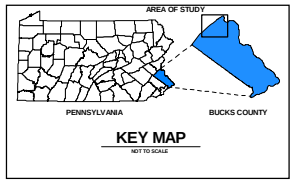

- Figure 36 -
Soil Series Not Feasible For Any Type of Sewage Disposal Systems

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Not Feasible for Any On-Site Sewage Disposal Systems

AbA	LhD	PeD
AbB	LlD	PlD
AbC	MbD	PlE
ChD	McE	ReA
DoA	MoB	ReB
DoB	MoD	ReC
KlD	NhB	ToA
LdB	NhC	ToB
LdD	NhD	TwB
LdE	NhE	WcD

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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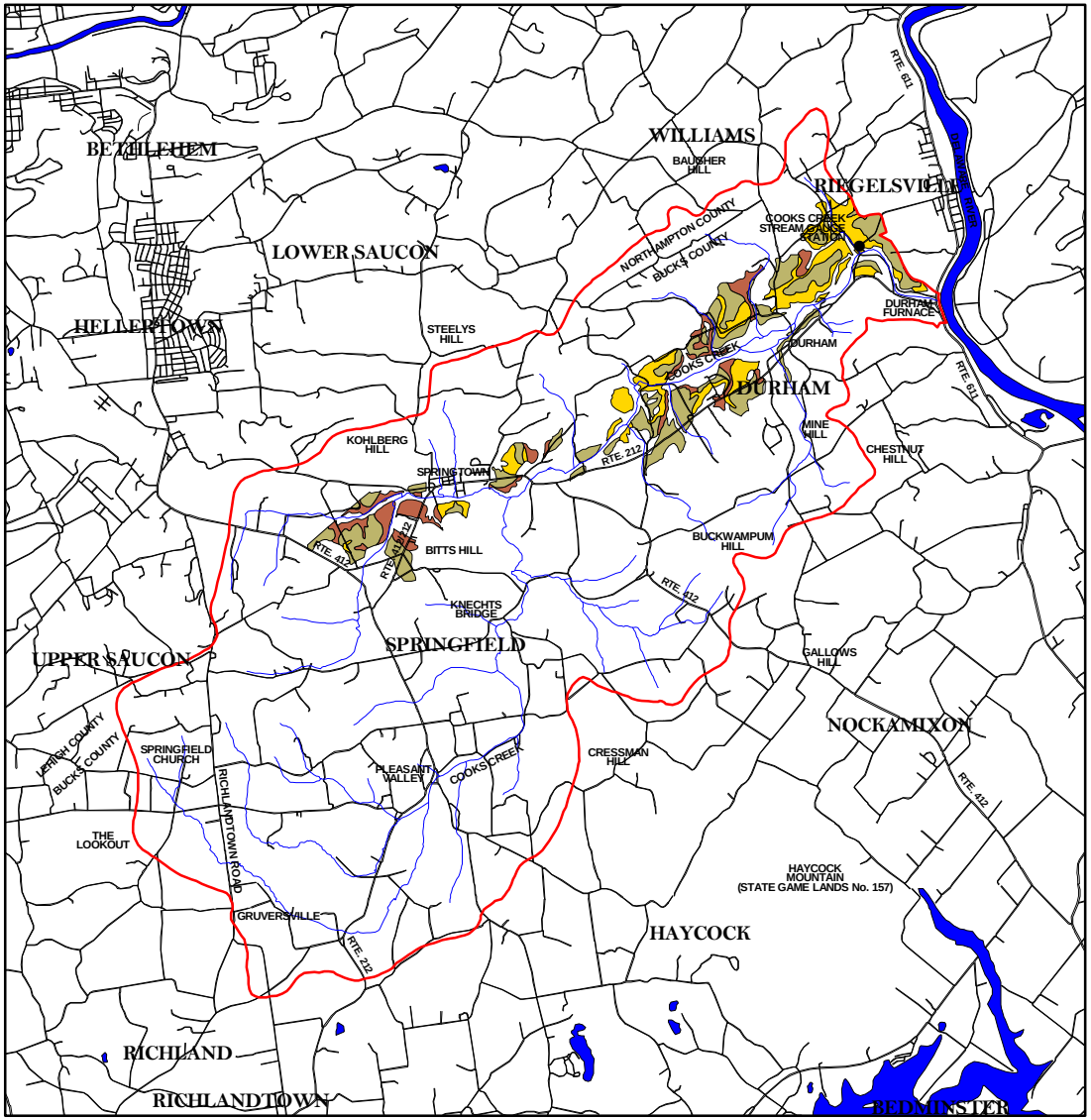

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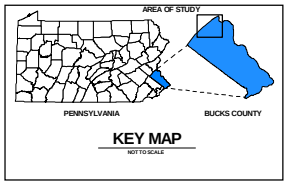

- Figure 37 -
Carbonate Derived Soils Not Feasible For Any Type of Sewage Disposal Systems

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Carbonate Derived Soils Not Feasible for Any On-Site Sewage Disposal Systems

- ClB
- DtC
- WaB

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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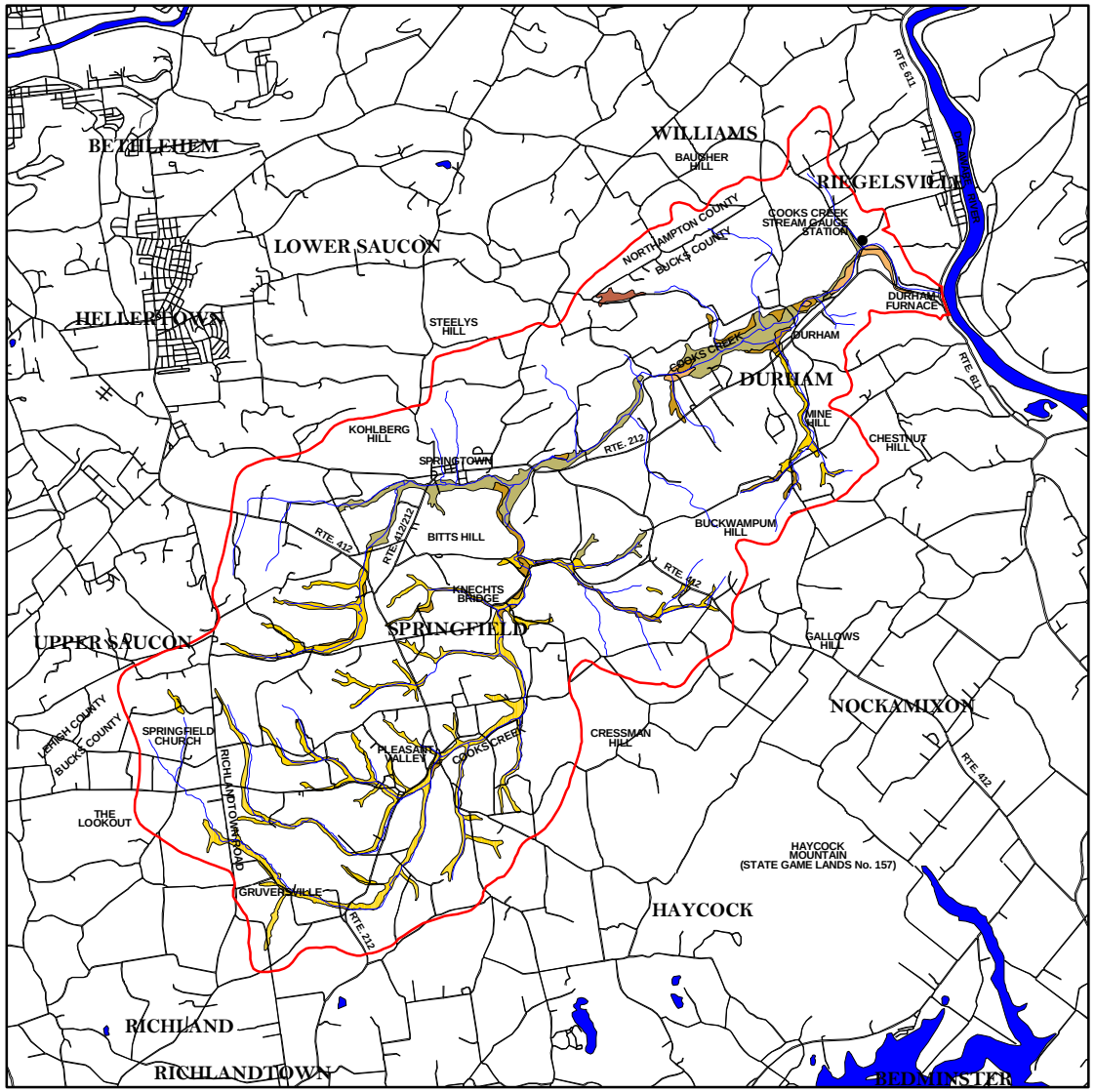

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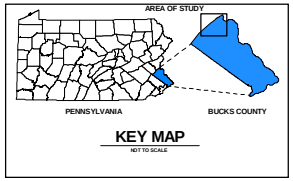

- Figure 38 -
Soils Subject to Flooding Not Feasible For Any Type of Sewage Disposal Systems

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Soils Subject to Flooding Not Feasible for Any On-Site Sewage Disposal Systems

- Ae
- Bo
- Ha
- PoA
- PpA
- Ro

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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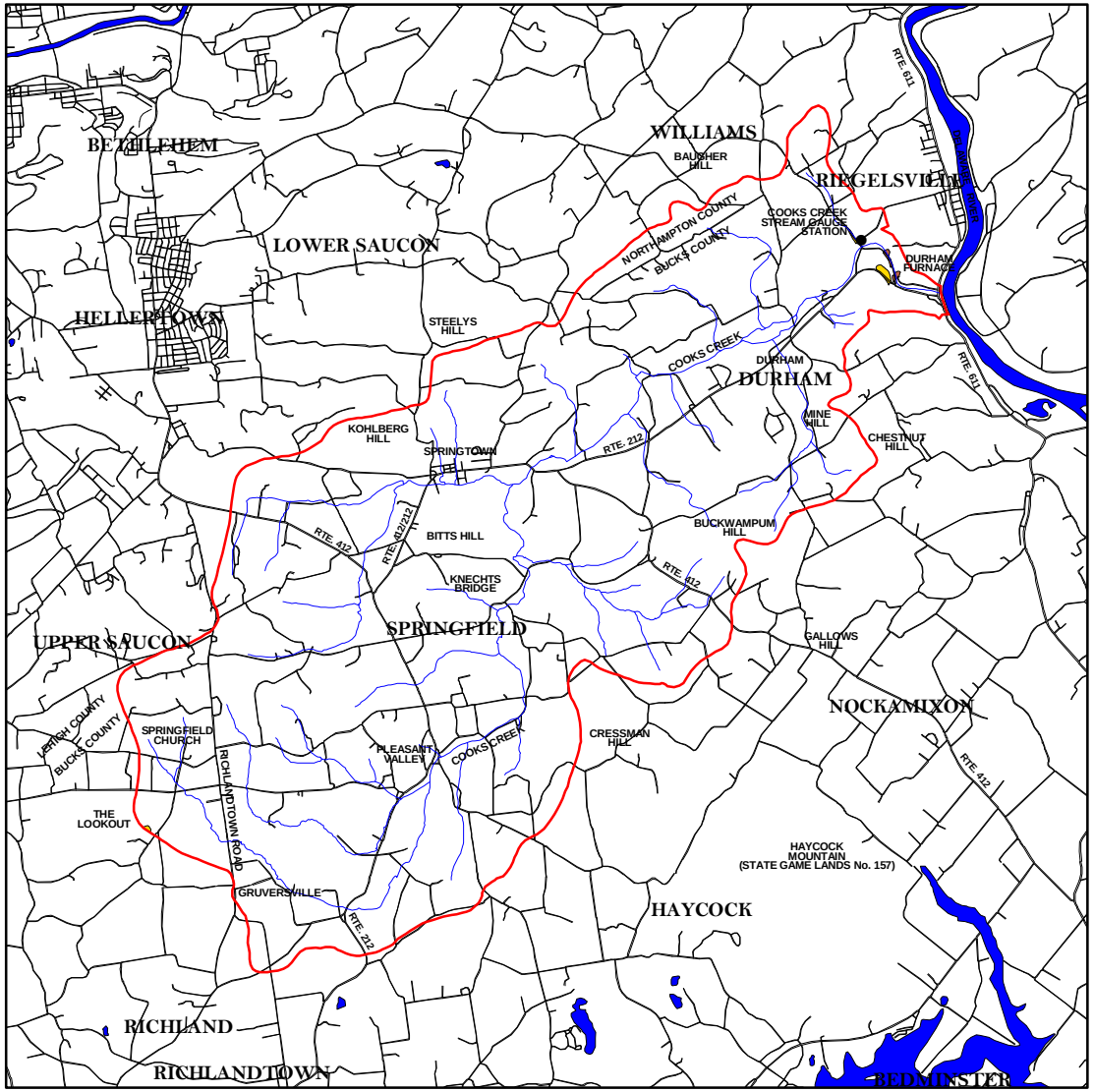

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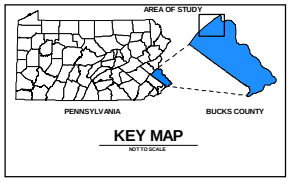

- Figure 39 -
Fill and/or Former Sand Pit or Quarry Not Feasible For Any Type of Sewage Disposal Systems

LEGEND

- Watershed Boundaries
- Roads & Railroads
- Waterways

Fill and/or Former Sand Pit or Quarry Not Feasible
For Any Type of Sewage Disposal Systems

- Gravel Pit
- Quarry

SOURCES: 1) Soil Survey of Bucks and Philadelphia Counties, Pennsylvania, United States Department of Agriculture Soil Conservation Service, Pennsylvania Department of Environmental Resources State Conservation Commission, July 1975.

2) Bucks County Natural Resources Plan, Bucks County Planning Commission, March 1999

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Summary of:
Cooks Creek, Bucks, Lehigh, and Northampton Counties,
Special Protection Evaluation Report, Water Quality Standards Review,
Quality Assessment Unit, Division of Water Quality,
Bureau of Water Quality Management, PADER, July 1990.

Surface Water

Water chemistry from surveys of the Cooks Creek basin by the Pennsylvania Fish Commission and the Bureau of Water Quality Management reveal excellent water quality, which is better than all applicable criteria. These surveys demonstrate that the main stem of Cooks Creek is a naturally fertile, slightly alkaline, well-buffered limestone-influenced stream. Most of the limestone influence can be attributed to springs and tributaries in the vicinity of Springtown. For all samples collected from the basin, pH values are between 7 and 9.5, with hardness and alkalinity values ranging from 40 to 160 mg/1 and 20 to 110 mg/1, respectively.

No permitted discharges are located within the basin, however, a number of potential agricultural related non-point sources of pollution do exist. Given the vast extent of agricultural lands (pasture and cropland) in the basin, Cooks Creek would appear to be highly susceptible to runoff of fertilizers and manure; however, water quality samples do not indicate any serious problems. Unfortunately, the same cannot be said for livestock access to stream channels. Within a number of tributary basins, most notably UNTs 7 and 15 (Figure 1), livestock have complete and unrestricted access to the stream. The results are increased erosion, loss of riparian vegetation, and reduced instream habitat diversity. Although livestock only have access to a very limited %age of the total miles of stream channel in the watershed, aquatic biota within the Cooks Creek basin would benefit from eliminating these sources of water quality and habitat degradation.

Aquatic Biota

Terrestrial Biota

Wetlands and Species of Special Concern

The value of the wetlands includes their function in stabilizing stream flow, maintaining water quality, and as habitat for numerous plant and wildlife species. At least one wetland in the basin is of exceptional ecological significance, supporting numerous rare and endangered wildlife and plant species. In response to both state and federal actions, the Department is placing a high priority on the protection of ecologically valuable wetlands. In light of this, it is appropriate that the Bureau of Water Quality Management provide the highest

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degree of protection available to the water resources supporting wetlands in the Cooks Creek basin.

Ten species of special concern in Pennsylvania have been recorded from the Cooks Creek Watershed (Table 8). Although six plant species have not been officially observed in over sixty years, it is possible that they are still present but have not been recently observed. The Nature Conservancy has documented the current existence of several endangered herpetofaunal species in the basin, including the bog turtle, the eastern mud salamander, and the red-bellied turtle. These three species have been located in a single palustrine (open water, forested, and emergent) wetland which also supports spotted and wood turtles and a number of significant wildflowers and shrub species. The landowners, in recognition of the site's significant natural resources, have entered the wetland into a conservation easement.

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Summary of:
PA Fish and Boat Commission,
Comments and Recommendations,
Cooks Creek, Bucks County, June 1992

Adult trout were first stocked in Cooks Creek. in 1939. The PFBC continued to stock adult trout in Cooks Creek until 1975, when trout stocking was discontinued due to landowner posting. The stream sections stocked with trout varied over the years, and ranged from near the source to one mile upstream from the mouth. Numbers and species of trout stocked also varied, with brown trout (Salmo trutta), brook trout (Salvelinus fontinalis), and rainbow trout (Oncorhynchus mykiss) all being stocked at one time or another.

Cooks Creek. was divided into three sections for fisheries management purposes. The sectioning strategy was based on water quality, physical habitat, wild trout density, and accessibility differences among the three sections. Physical and social data were collected for these sections, but parking counts were not made. The %age of private land open to public fishing was determined by contacting landowners in the sections.

Discussion

Cooks Creek. is a moderately alkaline, well-buffered limestone stream that supports excellent aquatic macroinvertebrate populations and a Class A wild brown trout population. Class A wild trout populations are also present in Silver Creek. and Coon Hollow Run, small tributary streams to Cooks Creek. The wild brown trout populations in the Cooks Creek. basin are unique in Bucks County, and the wild brook trout population in Coon Hollow Run is not only unique in Bucks County, but is also very rare in the entire Area 6 fisheries management region. Both surface and groundwater resources in the basin, on which the Class A wild trout populations depend, are very susceptible to contamination due to the limestone nature of the underlying geology. Because of its uniqueness, its proximity to heavily developed areas, the sensitivity of its environment, and its scenic and historical qualities, the DER should continue to protect the Cooks Ck. basin with EV-CWF designation.

No trout longer than 350-374 mm (14.5 in.) were seen or captured during the survey, indicating that trophy size fish reported by anglers are truly rare fish in Cooks Creek. Habitat for large trout is limited by relatively low flows for a limestone spring creek and a very scanty distribution of deep channels and pools. Physical habitat improvement, especially in Section 03 (between Red Bridge Road bridge and the mouth of Cooks Creek), would benefit wild trout populations in Cooks Creek. Physical habitat improvement should be directed toward narrowing and deepening the channel, which can best be accomplished through the use of various current deflector devices and rip-rap.

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Summary of:
Pa Fish and Boat Commission,
Comments and Recommendations,
Cooks Creek, Bucks County, April 1993

Discussion

Coon Hollow Run is a dolomitic limestone spring run that boasts excellent water quality. The presences of some pollution sensitive aquatic macroinvertebrate taxa and fish species reflect its excellent water quality. Excessive siltation is currently the only major source of pollution in the basin. The fish community is dominated by a Class A wild brook trout population and an abundant mottled sculpin population. Because of its excellent water quality and rare (for southeastern Pennsylvania) wild brook trout and mottled sculpin populations, Coon Hollow Run merits its EV-CWF designation.

Coon Hollow Run is not listed separately in the Pennsylvania Department of Environmental Resources (DER) chapter 93 Water Quality Standards. Coon Hollow Run is considered part of the Cooks Creek basin, which is designated as an exceptional value coldwater fishery (HV-CWF) Currently permitted discharges to Coon Hollow Run are not known and the Pennsylvania Fish and boat commission (PFBC) has no pollution reports on file for the stream.
The objective of the investigation was to gather baseline data on the physical, social, chemical, and biological characteristics of Coon Hollow Run, and to formulate a fisheries management plan based oh the survey results.

Results

Water quality in Coon Hollow Run was excellent, with excessive siltation the only major source of pollution noted during the survey. The limestone nature of the stream was a product of the underlying geology of the watershed, and provided excellent buffering capacity and good fertility. Aquatic macroinvertebrate community composition was reflective of the excellent water quality, as some pollution intolerant forms were present in the stream. While aquatic macroinvertebrate diversity was only rated as fair, this is typical of limestone spring runs.

Fish community composition also reflected Coon Hollow Run's excellent water quality, Coon Hollow Run supported the only documented Class A wild brook trout population in Bucks Counnty, and one of the few documented Class A wild brook trout populations in southeastern Pennsylvania. Because of its excellent water quality and rare limestone brook trout and mottled sculpin populations, Coon Hollow Run merits its EV-CWF designation.

Statewide angling regulations are adequate to protected this Class A wild brook trout population. The stream is narrow, making fishing difficult, and access is limited. Thus, angling pressure is presumably low.

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Summary of:
Final Report, Bioassessment of Cook's Creek, Rodges Run, Coon Hollow Run and the Unnamed Brook, Durham, PA
W. Scott Douglas Symbiosis Environmental, September 1998

Discussion

The objectives of the surveys were 1) to determine the overall health of the benthic communities relative to historical data, and; 2) to determine if Rodges Run And Unnamed Brook are worthy of detailed studies in support of petitions for upgrades in water quality status. The surveys were conducted during spring, summer and fall of 1997, with additional samples taken during the spring of 1998. A taxonomic expert processed samples and the communities assessed the utilizing standard USEPA (1989) procedures.

The purpose of the survey was to monitor the condition of the benthic communities in the Township's Exceptional Value streams and to evaluate the benthic communities in the remainder of the Township's surface waters. Taxonomic analysis was performed by Symbiosis Environmental and the results are detailed in four interim reports (Symbiosis Environmental 1997a,b,c and 1998). Benthic communities in the Townships exceptional value streams: Cooks Creek and Coon Hollow Run were compared to historical data.

Comparisons of the communties found at different locations within watershed were also made to assess potential impacts of localized land use within each watershed. It was planned that these data could be used by the DTEAC to gauge the surface water quality in the Township, as well as to assess the effectiveness of local land use policies in the protection of these valuable resources.

Results

Habitat Evaluation, Cooks Creek

Upstream: The samples were taken in the mainstem of Cooks Creek, approximately ½ mile after the creek enters Durham Township, just downstream from the confluence of Frye's Run (see Figure 1): Surrounding land use is forested and agriculture (tree farm). The canopy was mature with-oaks, maples and sycamores predominant. Light penetration was moderate. The banks were steep on the south side with signs of erosion. The banks on the north side were gently sloped with wetlands and natural understory vegetation. Both banks had adequate natural buffer. Samples were taken in the riffles, where substrate was large cobble, gravel and sand. Some amount of settled particulate matter was observed in the area, notably so in the nearby run habitat. Rocks were covered with moss and algae, but there were relatively little filamentous green algae present. The velocity ranged from 0.7 to 1.3 m/s with a wetted width varying from 20 to 25 meters. Benthic kick samples were taken in the middle, north and south sides and then composited.

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Downstream: samples were taken in the mainstem of Cooks Creek, approximately 1/2 mile downstream from where Stout's Valley Road crosses the creek and adjacent to Red Bridge Road (see Figure 1). Surrounding land use was forested and rural residential. The canopy was mature with oaks, maples and sycamores predominant. Light penetration was good, with the trees overhanging the streambanks. The banks on both sides were relatively steep, with signs of erosion, but less so than observed at the upstream station. The north bank was more natural, with a relatively stable bank, but naturally quite steep. The south bank was bordered closely by Red Bridge Road with little or no natural buffer remaining. The result was a somewhat channelized stream flow and little natural filter for stormwater runoff from the development on the south bank and no capacity for attenuation. Samples were taken in the riffle area, where the substrate was medium cobble, gravel and sand. Some amount of settled particulate matter was observed, notably more in the slower run habitats. The rocks held no moss, but some were covered with brownish-green algae and aufwuchs. The velocity ranged from 0.71 to 2.0 m/s with a wetted width varying from 25 to 30 meters. Benthic kick samples were taken in the middle, north and south banks and then composited. The middle sample was in shallow water, with the bank samples being in relatively deeper and faster moving water. Coarse particulate matter was collected from leaf packs and in the slower moving run upstream of the riffle area.

Habitat Evaluation, Coon Hollow Run

Headwater: The headwater sample was taken on the south side of Lehnenburg Road just upstream from the culvert, immediately west of the intersection of Lehnenburg Road and Coon Hollow Road (see Figure 1). The banks on both sides were steep, with a paved driveway bordering the east bank and a secondary tree stand of birch and oak bordering the west. The wetted width was only approximately 1.0 meter or less, with velocity of 0.22 m/s. The landowner had mown down to the water on the east bank, but natural vegetation predominated on the west. Light penetration varied from open to partly shaded. Signs of slight erosion was present with some amount of silt present in slower moving pools. Surrounding land use was residential and unused pasture. Substrate was small cobble, gavel and sand. Three benthic kick samples were taken in three riffle areas and composited.

A second headwater site was sampled during the spring of 1998, in order to further characterize the headwaters and to assure the township that the proximity of the first station to the driveway was not impacting the overall interpretation of the survey. This site was located at the intersection of Gallows Hill Road and Lehnenburg Road and is approximately in the location of previous PADER sampling. The station is on the northwest corner of the intersection and is characterized by overgrown pasture and alder. The stream banks are heavily vegetated and shaded. Light penetration ranged from partly open to shaded. No signs of erosion were visible. The stream was approximately 1-2 meters in width, with a velocity of 0.4 meters per second. Rifle areas varied from 2 to 5 inches in

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depth with cobble and gravel substrate. Runs were 9-13 inches in depth with some deep pools (greater than 24 inches). Substrate in pools was sandy silt with pockets of organic detritus.

Upstream: The upstream sample was taken approximately ½ mile down Coon Hollow Road from Lehnenburg Road just upstream from a landowner residing on the west bank across a small private bridge (see Figure 1). The stream enters mature woods at this point comprised of oaks, maples and sycamores. Light penetration was moderate, with adequate bank shading. The unpaved road followed the stream closely on the east bank, with only about 5 meters of buffer. The west bank was naturally steeply sloped, with the flat areas taken by rural residences. The landowner mowed almost up to the stream banks, but natural understory vegetation (gasses, shrubs, berry bushes) predominated outside of a small yard area. Erosion was not apparent, although some silt was present in pools. This silt was more organic in nature than that observed lower in the watershed. The wetted width was 2-3 meters, with a velocity of 0.33 to 0.5 m/s. Substrate was boulders and large cobble, gravel and sand. The rocks were covered with moss and algae, but very little filamentous green algae were observed. Kick net samples were taken in three rifle areas moving upstream during sampling.

Downstream: The downstream samples were taken approximately 100 yards upstream of route 212 in unused pasture surrounded by rural residential development (see Figure 1). The stream bank is well buffered, with very little sign of localized erosion. Some mature trees line the stream bank, and understory vegetation approaches and overhangs the banks. Substrate is medium cobble, gravel and sand. The light penetration is partly shaded. Silt was not present in riffle areas, but became deep in pool areas, indicating an upstream source (possibly the unpaved road). The wetted width was 2.0 to 7.0 meters with a velocity of 0.3 to 0.5 m/s. Rocks are covered with moss and algae, but very little filamentous green algae was observed. Kick net samples were taken in three riffles, with attempts to sample the middle, and both banks when sufficient width was available. Coarse particulate matter was taken from leaf packs and from pool litter.

Benthic Community Bioassessment

A summary was prepared of the community metrics calculated during each of the sampling periods, for each watershed (Appendix ___, 5-8). These data were used to answer several questions concerning the health of the benthic communities in each watershed. To determine if current land use practices have altered the water quality of Cooks Creek and Coon Hollow Run compared to the water quality present at the time that Exceptional Value status was granted, comparisons were made to historical data. To determine if localized land use in a watershed was impacting water quality, comparisons of downstream stations to upstream stations within a watershed were made. In order to determine the potential impacts of drought conditions observed in the summer and fall of 1997, comparisons of benthic community structure were made using the Spring

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sampling as a reference. Additional sampling in the spring of 1998 allowed for determination of recovery of the Unnamed Brook community by using the spring 1997 sampling as a reference.

In Cooks Creek, low flow conditions in the fall resulted in slight to moderate impacts (Appendix ____, Table 9). The changes observed include a significant loss of sensitive mayfly, caddisfly and stonefly taxa and a shift in the scraper/filterer ratio to more filterers. Also observed was an increase in the %age of the most dominant taxa. There were no observed impacts to benthic community structure when comparing upstream and downstream stations, indicating that Township land use practices do not impact the benthic community in Cooks Creek. Comparisons to historical data indicate that there has been no change (or slight improvement) in the quality of the benthic community over time.

In Coon Hollow Run, low flow conditions resulted in lower impacts to the benthic community than in Cooks Creek, but slight impacts were observed in the downstream station (Appendix ___ , Table 10). Localized land use practices appear to impact the creek slightly as it flows through the township, however comparison to historical data indicate no changes over time.

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Summary of:
Natural Areas Inventory of Bucks County, Pennsylvania
Ann F. Rhoads & Timothy A. Block,
Morris Arboretum of the University of Pennsylvania, June 30, 1999

Discussion

An inventory of natural features of Bucks County has been carried out. Starting with records from Pennsylvania Natural Diversity Inventory (PNDI) and other historical data, 240 individual sites were surveyed for unusual plants, animals, natural communities, and geological and hydrological features. Criteria were developed to evaluate and prioritize the sites. Of the total sites surveyed, some were grouped into larger "megasites" and 29 were eliminated from consideration.The result of 115 sites prioritized at four levels of importance. All sites listed have important resources. In the highest priority levels, Bucks County contains natural resources of statewide importance.

In Upper Bucks the diabase zone that stretches across the county remains mostly forested. This region is also very important because of its continuous forest cover and unusual geology. It provides habitat for birds and other species that depend on extensive tree-covered areas, and is likely the source of some of the bird diversity seen elsewhere in the county. Several complete stream valleys (i.e. Cooks Creek) were also included in the high-priority site lists due to their high quality aquatic resources, ecological integrity, and the diversity of species they contain.

The evaluation of sites was based on biological, ecological, geological, and hydrological criteria. We did not distinguish between sites that are already protected entirely or in part, and those that are not. Some partially protected sites require additional measures to secure important adjacent areas. In other cases the information gathered in our survey will assist in determining management needs or strategies.

Flora

Human Impact

Few early descriptions of the flora exist, and those that are available are fragmentary. However, it is clear that Bucks County originally was completely forested. Native American tribes created small clearings to grow corn and beans and may have used fire to manage game on a larger scale, but when the earliest European settlers arrived, the county was still primarily forest covered. Bucks County was one of the earliest parts of the state to be settled by Europeans beginning in the 1670s. The land was cleared for agriculture and settlements until the only forested lands remaining were those unsuited for agriculture due to steepness, excessive rockiness, or the presence of a high water table. There are no intact old growth forests remaining in the county, however individual old trees persist. The Bucks County Audubon Society maintains a big tree register, which contains records of the largest examples of each species.

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Towns sprang up along early roads and later the Delaware Canal which was in use for approximately 100 years beginning in 1832. The industrial revolution and improved rail transportation followed by the automobile brought changes leading to the development of the county as a vacation destination or location for a country home. As of 1990, the latest year for which data are available, the % of land classified as agricultural or vacant by region was 62% in Upper Bucks (BCPC 1994). In recent years the most intensive development pressure has shifted from the lower part of the county to central areas and is spreading northward.

Role of natural resources

The natural features of Bucks County provided the needs of the early residents and attracted the attention of waves of settlers who established productive farms. Local mineral and forest resources supported the development of early industry such as the Durham Iron Works, which used nearby deposits of iron ore and limestone plus charcoal made from forest trees. Later, as a modern transportation-based economy developed, the natural setting of the county remained an attraction leading to the development of a strong tourism segment in the local economy dependent on natural beauty, clean air, and clean water.

From the earliest human use to the present, natural systems in the form of fields, forests, streams, and wetlands have provided essential ecosystem services without which human communities could not continue to exist. Its easy to forget that when we send partially treated wastewater into streams we are counting on natural systems to finish the job of cleaning up; or when we emit carbon dioxide and other pollutants into the atmosphere from our cars and smokestacks we expect those pollutants to be absorbed and transformed. Supplies of air and water are finite and must be recycled again and again. Only when we overwhelm the ability of natural systems to absorb and transform our wastes do we begin to appreciate the role of these essential ecological services. The functioning of natural systems depends on their remaining intact with all their interacting parts. The loss of species threatens the functioning of the whole. Rare species serve as the proverbial "canary in the mine", warning us that ecosystems are stressed and may be reaching a point where they can no longer function.

A goal of an open space protection program must be to preserve ecosystem functions such as air, water, and mineral recycling, photosynthesis, pollination, climate moderation, and soil formation (Daily 1997) and thus earth's ability to support future generations of humans.

Results

Analysis and evaluation of the data available for the 240 sites considered in this survey for the entire Bucks County resulted in classification at four levels of

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importance (see prioritized lists below) based on the criteria described above. Twenty-nine sites were eliminated from further consideration. All sites listed have significant biological, ecological, geological, or hydrological features. Differences between sites within each category are not significant. In arriving at decisions regarding site categorization, the authors emphasized ecologically sustainable sites to the extent that we could make that judgment; hence the number of large forested areas, wooded ridge tops, and entire stream valleys. For the most part it was not included small isolated sites that, although they contain remnant populations of rare species, are not part of a sustainable natural community or system.

Out of 115 sites, six sites are located entirely or partially within Cooks Creek Watershed.

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Summary of:
Cooks Creek Watershed Monitoring and Planning Program,
Wetlands Management Plan,
DTEAC / MJE, May 22, 2000

Discussion

The goal of the project was to provide information to the DTEAC for a wetlands conservation plan that would be supported by the municipalities and will be integrated with a total water resources management plan of the hydrologic system within the project area.

The principal objectives of the project included:

- Wetland delineation and determining the soils characteristics of the study area;
- Delineating Karst features, and other hydrogeologic properties of the geologic formations in the study area;
- Determining the important hydrologic characteristics and preparing a water budget of the study area;
- Cooks Creek continuous stage recording and computation of discharge; and,
- Initial GIS development, structured to allow for the inclusion of additional information collected in the future.

The central element of the fieldwork for this project was collecting data to develop a Wetland Management Plan for the study area. This was accomplished through review of available literature for the study area, site reconnaissance, and field measurements. This phase of the project does not include any sampling and analysis of surface water, groundwater, or soil to determine “water quality”.

Surface water bodies and wetlands in the Cooks Creek Watershed, within Durham Township and Springfield Township, were identified using the existing National Wetlands Inventory Maps (NWI), the existing County Soil Survey, and using field techniques consistent with the U.S. Army Corps of Engineers Wetlands Delineation Manual (1987). The fieldwork targeted potential wetland areas that do not appear on the NWI maps, such as areas with hydric soils that are not delineated. Wetland functions and values were also identified by using the Wetland Evaluation Technique (WET II) developed by the US Army Corps of Engineers (1987). Finally, a database search and field reconnaissance was conducted of threatened and endangered species within the Cooks Creek Watershed.

The geological survey task included a desktop study and follow-up field reconnaissance. The existing database of groundwater wells in this area from The Pennsylvania Department of Conservation and Natural Resources (PaDCNR) was reviewed. Selection of wells to be surveyed included those that

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provided a spatial distribution in relation to main topographic features. These features include: divides, Cooks Creek tributaries, wetlands, flat areas, side hills, etc.

Water level measurements were collected at selected wells. The measurements were based on depth to water from the ground surface (USGS Quadrangle Maps, scale1:24,000 determined the ground surface elevation of selected wells.). One round of water level was collected over a three-day period. A drawing of the groundwater table map was generated for a 20-foot contour interval and was included in the GIS graphics and 3-D block diagram representation.

The preliminary water budget was estimated as the amount of water entering and leaving the basin, plus or minus changes in storage, for a given period of time. Water enters as precipitation and leaves in several ways: as stream flow, ground-water underflow, diversion of groundwater from the basin where it was pumped, and evapotranspiration, plus or minus interbasin flow and changes in groundwater and soil-moisture storage. During dry periods, streamflow is sustained by base flow, which is groundwater discharge to streams. The water budget evaluation has been designed and developed as a computer application under the name of Water Monitoring System (WAMOS).

WAMOS software package is a computer friendly-user interface designed for downloading stage data, calibrating and develop rating curves for the stream gauge, maintaining database and calculating flows, statistics analysis, water budget, and finally integration of the monitoring stream gauge data in the Township Management Plan.

Water quality impacts

Water quality impacts from wastewater effluent discharges downstream can be extremely harmful. In addition to these direct water quality impacts, development typically translates into removal or partial removal of riparian vegetation, which serves multiple critical functions for overall stream quality. Stream temperature regimes are adversely affected as the result of reduction in stream shading. All of these pollution impacts combine to adversely affect the stream system

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VISUAL ASSESSMENT of SMALL (WADEABLE) STREAMS

Creek and surrounding area for 50 yds. upstream and 50 yds. downstream of the sampling site.

ASSESSMENT FACTOR	RESPONSE			
	EXCELLENT GOOD MARGINAL POOR	**EXCELLENT GOOD MARGINAL POOR**	**EXCELLENT GOOD MARGINAL POOR**	**EXCELLENT GOOD MARGINAL POOR**
1. Instream cover (habitat for fish & aquatic organisms)	The stream contains lots of boulders (over 10”), cobble (2-10”), submerged logs, undercut banks or other stable habitat	There is adequate habitat of both rock & wood for maintenance of diverse populations of fish & bugs	Some rock and wood or other stable habitat, but much less than desirable	Not much stable habitat; lack of habitat is obvious
2. Fine particle sediments (sand, silt, mud)	The rocks in the stream are not surrounded by fine sediments; I see very little sand, silt, or mud on the bottom	Rocks are partly surrounded by fine sediments; I could easily flip over the rocks on the bottom	Rocks are more than half surrounded by fine sediments; rocks are firmly stuck into sediments	Rocks are deeply stuck into fine sediments; bottom is mostly sand, silt, or mud
3. “Flow patterns”: How many does the stream have?	All 4 of these velocity/depth patterns are present within 50 yards upstream or downstream of this site: **slow/deep, slow/shallow, fast/deep, fast/shallow**	Only 3 of 4 regimes (flow patterns) are present	Only 2 of the 4 regimes present	Dominated by 1 velocity/depth regime
4. Condition of banks & coverage? (If the two banks are very different, assess the worse side, if possible)	The banks are stable; no evidence of erosion or bank failure; the whole bank is covered with vegetation or rock	Moderately stable; some small areas of erosion mostly healed over; most of the bank is covered by vegetation or rock	Largely unstable; almost half of the bank has areas of erosion or is NOT covered by vegetation or rock	Unstable; eroded areas; "raw" areas occur frequently; less than half of the bank is covered by vegetation or rock

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5. Disruptive pressures to the "riparian" area? (If the two banks are very different, assess the worse side, if possible)	Trees, shrubs, or grasses have not been disturbed through forestry, grazing or mowing; almost all plants are growing naturally; mature trees, understory, and vegetation are present	Some disruption, but not affecting full plant growth potential to any great extent; trees, woody plants, and soft green plants are dominant	Disruption is obvious; some patches of bare soil, cultivated fields or closely cropped vegetation are the norm	There is not much natural vegetation left or it has been removed to 3 inches or less in average stubble height
6. Riparian vegetative zone width (If the two banks are very different, assess the worse side, if possible)	Riparian zone is more than 35 yards wide; human activities (parking lots, roads, learcuts, lawns, or crops) have not impacted zone	Riparian zone 12-35 yards wide; human activities have impacted zone only minimally	Width of riparian zone 6-12 yards; human activities impacting zone are commonly evident	Width of riparian zone is less than 6 yards; lots of nearby human activities
7. Litter	There is no litter in the area	There is very little litter in the area; probably some degradable paper accidentally dropped by fishermen or hikers	Litter is fairly common and includes metal or plastic, obviously purposely dropped.	Area is a candidate for a clean-up project; lots of litter, dumping, tires, or barrels present
8. Overall I rate the VISUAL ASSESSMENT of this site …	EXCELLENT	GOOD	MARGINAL	POOR

DEFINITIONS:

Riparian zone - The land connected with or immediately adjacent to the banks of a stream or other body of water.

Disruptive pressure - Any activities which interfere with the natural unity of a system. In the case of riparian assessment, this usually refers to land use practices such as mowing, grazing, logging, paving, building construction, heavily worn paths, etc.

Habitat - The "places" where a plant or animal normally lives and grows throughout all the phases of its life cycle.

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Stable Habitat - The condition in which places used for hiding, resting, reproducing, living, and growing are not undergoing rapid or constant change. In the case of stream assessment, this is usually referring to large rocks, logs, and undercut banks which are more or less permanently in place.

The DRBC and several organizations originally conceived the WATER SNAPSHOT project in 1996. DRBC leads the annual effort, with the valuable assistance of a committee consisting of representatives from the following organizations in 2000: Del. Dept. of Natural Resources and Environmental Control, Delaware Riverkeeper Network, Delaware Estuary Program, National Park Service, N.J. Dept. of Environmental Protection, N.Y. State Dept. of Environmental Conservation, Pa. Dept. of Conservation and Natural Resources, Pa. Dept. of Environmental Protection, Pennsylvania Environmental Council, Pocono Environmental Education Center, Upper Delaware Council, U.S. Environmental Protection Agency, and U.S. Geological Survey.

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7. BMPs

In the Cooks Creek Watershed area non-residential land use developed acreage increased by nearly 3 percent in Durham and 2 percent in Springfield during the 80-90s decades, even though total population remained virtually constant. All other land uses, residential, agricultural/vacant, and park/recreation remained constant or decreased. From water resources perspective both water quality and water quantity, may have or may haven't consequences. Water resources are affected as water supply systems, wastewater treatment systems and stormwater management systems are constructed.

New impervious surfaces translate into significantly reduced ground water infiltration and aquifer recharge if water or wastewater is exported from the watershed system or if consumptive loss increases more than subsurface water contributions. Reduced recharge, by definition, results in lowering the water table with a corresponding reduction in stream base flow the life of the stream for most of the year. As base flow decreases during dry periods, crucial first-order tributaries may literally dry up, and existing wells, especially older shallow wells and springs, may be jeopardized with drastic ecological consequences.

At the other flow extreme, the impervious surfaces which reduce infiltration mean increased stormwater discharges. Even with careful design, the use of detention basins for stormwater management, which only controls the peak rates of stormwater discharge site-by-site, increases the total volume of stormwater discharged. As detention basins multiply throughout a watershed, these delayed releases may also accumulate, with destructive downstream impacts. Flooding may actually worsen. With these increased runoff volumes, stream bank and channel erosion is aggravated, and basic stream morphology is adversely altered. A mix of water pollutants, scoured from the urbanizing landscape with stormwater, is also an important concern. This is especially true in high quality watersheds. This water quality impact includes wet weather discharges or "mass loads" of nonpoint source pollution from these new impervious areas, containing hydrocarbons, metals, other toxics, BOD/COD, and a host of other pollutants. Stormwater pollution also is generated from large areas of created and chemically maintained landscapes, such as lawns and gardens, generating nutrients, sediment, COD, pesticides and herbicides. During dry weather, nonpoint source water quality impacts include malfunctioning on-site septic systems and other small but significant wastewater flows.

Water supply typically is ground water-based, pumped from the aquifers with corresponding reductions in stream base flow. Water use can be considerable for different land uses and activities and often increases during the warmer weather months when stream flow is already at its lowest point. Land-based wastewater treatment systems lessen these water loss impacts on aquifers and stream flow, although a significant portion of water used is lost by evapotranspiration with some systems. If conventional wastewater treatment plants with centralized collection and conveyance systems are constructed, water is completely "lost" to the immediate watershed area.

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Furthermore, water quality impacts of wastewater effluent discharges downstream can be extremely harmful. In addition to these direct water quality impacts, development typically translates into removal or partial removal of riparian vegetation, which serves multiple critical functions for overall stream quality. Stream temperature regimes are adversely affected as the result of reduction in stream shading. All of these pollution impacts combine to adversely affect the stream system and its biota in a variety of ways.

The concept of Sustainable Watershed Management (Sustainable Watershed Management at the Rapidly Growing Urban Fringe, T. H. Cahill, et al., Watershed 96 Proceedings) proposes as fundamental resource management objective to measure the tolerance limits of the natural system and balance the human use of these land and water resources so that we live within the carrying capacity of these natural systems. The following management objectives have been established based on this concept, with modeling methodologies developed to achieve these objectives:

- Maintain stream base flow, and in particular during drought periods (Q7-10).
- Maintain ground water levels in order to protect existing/future wells.
- Assure that stream flooding is not increased.
- Prevent ground water contamination, particularly from nitrate.
- Minimize additional point and non-point source pollutant inputs into surface waters.

7.1 Drinking Water Well Management

Keeping your well water free of harmful contaminants is a top priority - for your health a I Id for the environment. This chapter helps

amin e how you manage your well, and how activities on or near your property may affect well water quality The Mowing topics are covered:

- Well Location -- How dose is your well to potential pollution sources? How might your soil type af- water quality?
- Well Construction and Maintenance -- Do you know how old your well is and what type of well it is? Is your well casing properly sealed?
- Water Testing and Unused Wells -- Have tests of your well water revealed any problems? Are abandoned wells protected against contamination?

Why Should You Be Concerned?

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About 95% of rural residents use private wells to supply drinking water. These wells, which tap into local groundwater, are designed to provide clean, safe drinking water. However, improperly constructed or poorly maintained wells can create a pathway for fertilizer bacteria, pesticides, or other materials to enter the water supply Once in groundwater, contaminants can flow from your property to a neighbor's well, or from a neighbor's property to your well.

Contaminants often have no odor or color and therefore are hard to detect. They can put your health at risk and it is difficult and expensive to remove them. Once your water becomes contaminated, the only options may be to treat your water after pumping, drill a new well, or get your water from another source.

A. Well Location

The location in relation to other features on or near your property will determine some pollution risks. The nearness of your well to sources of pollution and the direction of groundwater flow between the pollution sources and your well are the primary concerns.

What pollution sources might reach your well?

Whether groundwater in your area is just below the surface or hundreds of feet down, the location of your well on the land surface is very important. Installing a well in a safe place takes careful planning and consideration. Where the well is located in relation to potential pollution sources is a critical factor.

When possible, locate a well where surface water (stormwater runoff, for example) drains away from it. If a well is downhill from a leaking fuel storage tank, septic system, or overfertilized farm field, it runs a greater risk of becoming contaminated than a well on the uphill side of these pollution sources. In areas where the water table is near the surface, groundwater often flows in the same direction as surface water Surface slope, however, is not always an indicator of groundwater flow.

Changing the location or depth of the well may protect your water supply, but not the groundwater itself. Any condition likely to cause groundwater contamination should be eliminated, even if your well is far removed from the potential source.

Provide as much separation as possible between your well and any potential pollution source - at least 100 feet. Separating your well from a pollution source may reduce the chance of contamination, but it does not guarantee that the well will be safe.

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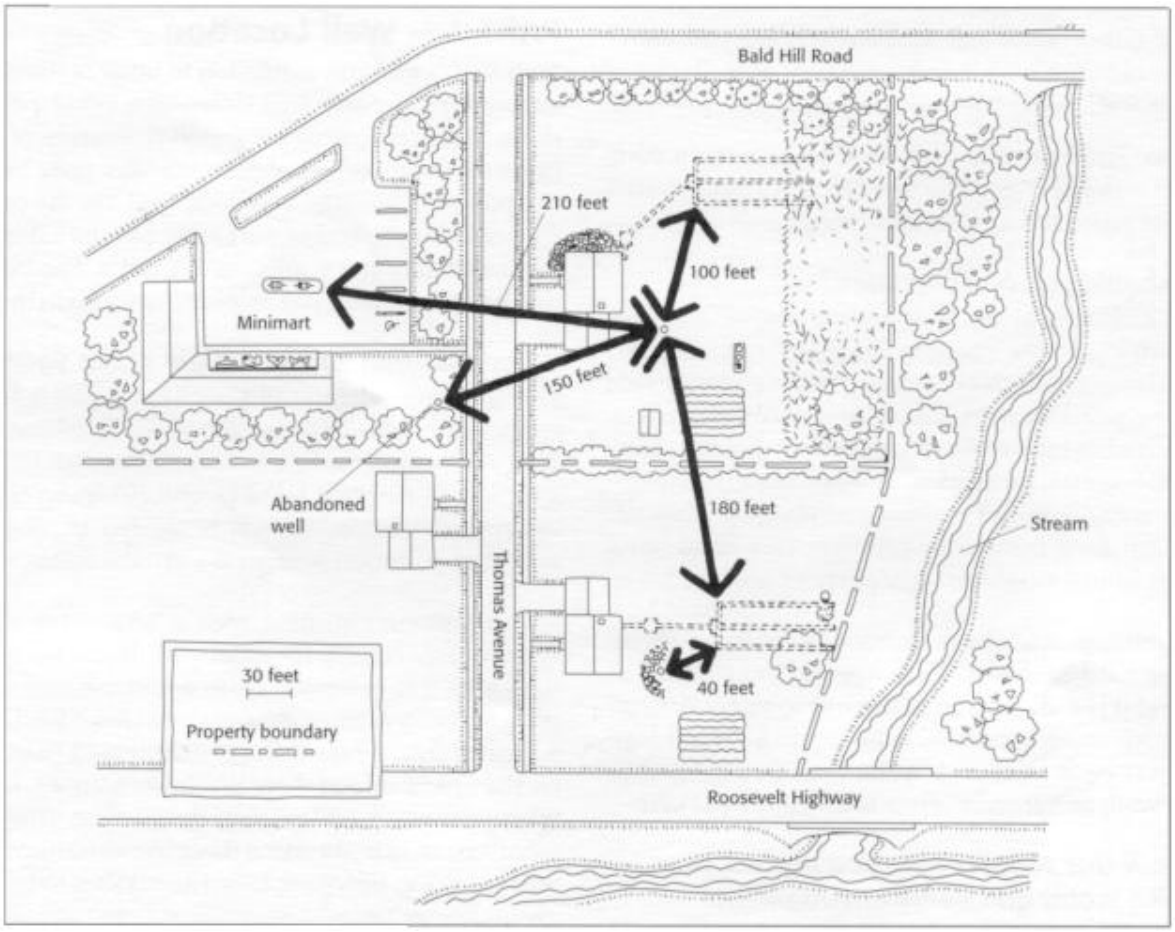

Figure 7-9 Map of Homesite showing distances of pollution sources from well.

Pollution risks are greater when the water table is near the surface, because contaminants do not have far to travel. Groundwater contamination is more likely if soils are shallow (a few feet above bedrock) or if they are highly porous (sandy or gravelly). If bedrock below the soil is fractured - that is, if it has many cracks that allow water to seep down rapidly - then groundwater contamination is more likely. See Figure ___ for the type of soils are on that property and if is feasible for on-site wastewater treatment.

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Assessment - Well Location

	LOW RISK	MEDIUM RISK	HIGH RISK
Position of well in relation to pollution sources	Well is uphill from all pollution sources. Surface water doesn't reach well or is diverted.	Well is level with or uphill from most pollution sources. Some surface water runoff may reach well.	Well is downhill from pollution sources or in a pit or depression. Surface water runoff reaches well.
Separation distances between well and pollution sources*	Distances from Potential pollution sources meet or exceed all state minimum requirements.	Some but not all distances from potential pollution sources meet state minimum requirements.	Distances from most or all potential pollution sources do not meet state minimum requirements.
Soil type	Soil is fine-textured like clay loams or silty clay.	Soil is medium-textured like silt or loam.	Soil is coarse-textured like sand, sandy loam, or gravel.
Subsurface conditions	The water table or fractured bedrock are deeper than 20 feet.	The water table or fractured bedrock are deeper than 20 feet.	The water table or fractured bedrock are shallower than 20 feet.

B. Well Construction and Maintenance

Old or poorly designed wells increase the risk of groundwater contamination by allowing rain or snowmelt to reach the water table without being filtered through soil. If a well is located in a depression or pit or is not properly sealed and capped, surface water carrying nitrates, bacteria, pesticides, and other pollutants may easily contaminate drinking water.

You wouldn't let a car go too long without a tune-up or oil change. Your well deserves the same attention. Good maintenance means keeping the well area clean and accessible, keeping pollutants as far away as possible, and having a qualified well driller or pump installer check the well periodically or when problems are suspected.

How old is your well

Well age is an important factor in predicting the likelihood of contamination. Wells constructed more than fifty years ago axe likely to be shallow and poorly constructed. Older well pumps are more likely to leak lubricating offs, which can get into the water. Older wells are also more likely

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to have thinner casings that may be cracked or corroded. Even wells with modem casings that am thirty to forty years old are subject to corrosion and perforation. If you have an older well, you may want to have it inspected by a qualified well driller. If you don't know how old your well is, assume it needs an- inspection. For some of these wells we provided the drilling date in Table ____, Attachment X

Are your well casing and well cap protecting your water?

Well drillers install a steel or plastic pipe "casing" to prevent collapse of the well hole during drilling The space between the casing and sides of the hole is a direct channel for surface water- and pollutants-to reach the water table (figure 3.3 on the following page). To seal off that channel, drillers fill the space with grout (cement or a type of clay called bentonite).

You should visually inspect the condition of your well casing for holes or cracks. Examine the part that extends up out of the ground. Remove the cap and inspect inside the casing using a flashlight. If you can move the casing around by pushing it, you may have a problem with your well casing's ability to keep out contaminants. Sometimes damaged casings can be detected by listening for water running down into the well when the pump is not running. If you hear water, there might be a crack in the casing, or the casing may not reach the water table. Either situation is risky.

The depth of casing required for your well depends on the depth to groundwater and the nature of the soils and bedrock below. In sand and gravel soils, well casings should extend to a depth of at least 20 fee and should reach the water table. For wells in bedrock, the casing should extend through the weathered zone and into at least 10 feet of bedrock. A minimum of 20 feet of casing should be used for all wells.

The casing should extend at least 12 inches above the ground surface. If there are occasional floods in your area, the casing should extend 1 to 2 feet above the highest flood level recorded for the site. The ground around the casing should slope away from the wellhead in all directions to prevent water from pooling around the casing.

The well cap should be firmly attached to the casing, with a vent that allows only air to enter. If your well has a vent, be sure that it faces the ground, is tightly connected to the well cap or seal, and is properly screened to keep insects out. Wiring for the pump should be secured in an electric conduit pipe.

Is the well shallow or deep?

As rain and surface water soak into the soil, they may carry pollutants down to the water table. Local geologic conditions determine how long this takes. In some places, the process happens quickly - in weeks, days, or even hours. Shallow wells, which draw from groundwater nearest the land surface, are most likely to be affected by local sources of contamination.

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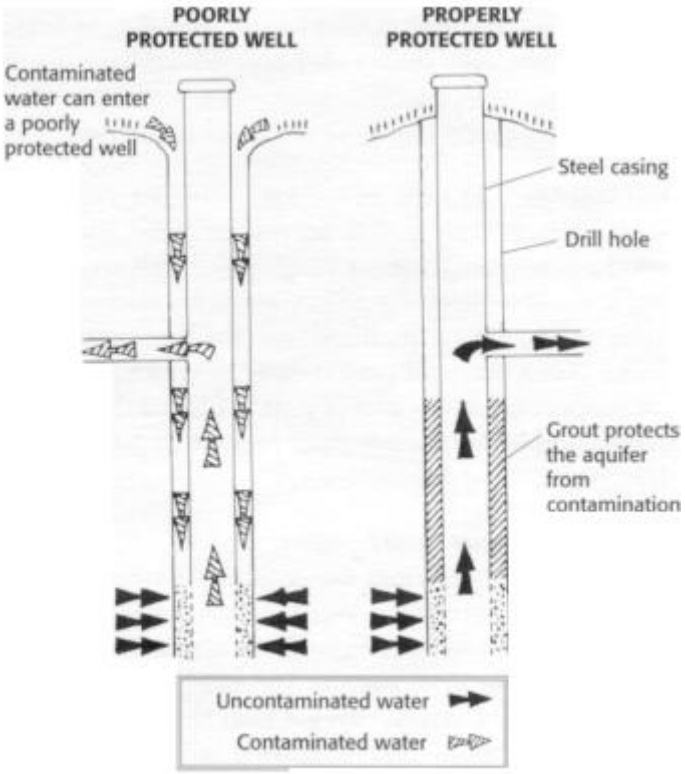

Figure 3.3 A poorly protected well versus a properly protected well.

Do you take measures to prevent backflow?

Backflow of contaminated water into your water supply can occur if your system undergoes sudden pressure loss. Pressure loss can occur if the well fails or, if you are on a public water system, if there is a line break in the system. The simplest way to guard against backflow is to leave an air gap between the water supply line and any reservoir of "dirty" water. For example, if you are filling a swimming pool with a hose, make sure that you leave an air gap between the hose and the water in the pool. Toilets and washing machines have built-in air gaps.

Where an air gap cannot be maintained, a backflow prevention device such a check valve or vacuum breaker should be installed on the water supply line. For example, if you are using a pesticide sprayer that attaches directly to a hose, a check valve should be installed on the faucet to which the hose is connected.

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C. Water Testing and Unused Wells

Water testing helps monitor water quality and identify potential risks to the health. Contaminants enter drinking water from many sources. Many contaminants can only be detected through a water test.

Abandoned wells, if improperly sealed, can provide a direct route for contaminants to enter groundwater. It is important to identify old or abandoned wells and determine appropriate action.

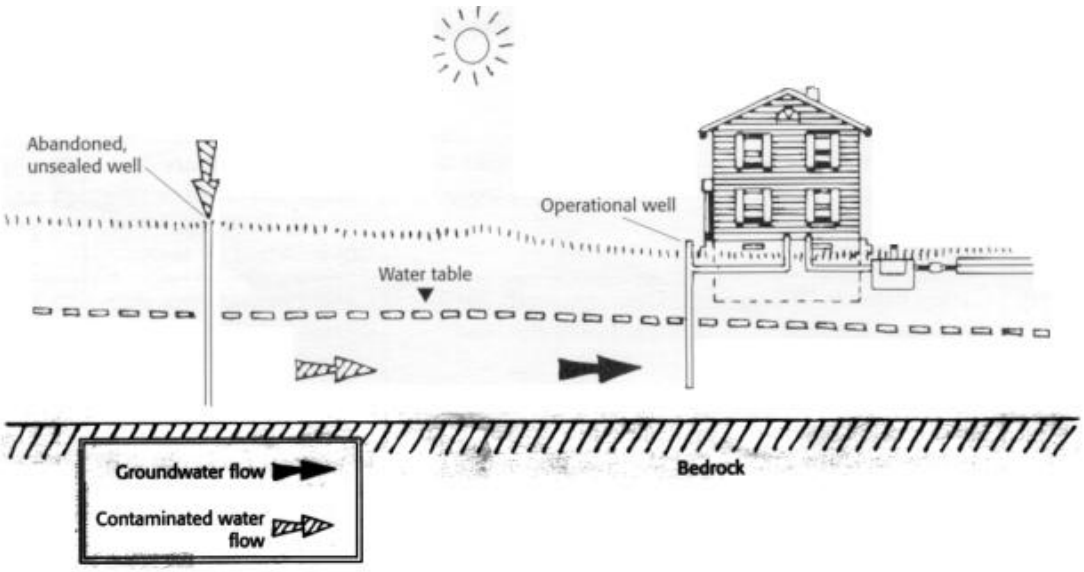

Figure 3.4 Abandoned wells that are not properly sealed provide a pathway for contaminants to reach groundwater.

Many properties have wells that are no longer used. Sites with older homes often have an abandoned shallow well that was installed when the house was first built. If not properly filled and sealed, these wells can provide a direct channel for waterborne pollutants to reach groundwater (figure 3-4). A licensed, registered well driller or pump installer should be hired to dose these wells. Effective well plugging calls for experience with well construction materials and methods, as well as knowledge of the geology of the site. The cost to close a well will vary with well depth, well diameter, and soil/rock type. The money spent sealing a well will be a bargain compared to the potential costs of cleanup or the loss of property value if contamination occurs.

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When was the water last tested?

At a minimum, the water should be tested every year for the four most common indicators of trouble: bacteria, nitrates, pH, and total dissolved solids (TDS). If you haven't had a full-spectrum, comprehensive water test, then you don't know the characteristics of your water. For the general procedure for taking water sample always follow lab instructions.

A more complete water analysis for a private well will tell you about its hardness; corrosivity; and iron, sodium, and chloride content. In addition, you may choose to obtain a broad-scan test of your water for other contaminants such as pesticides. A good source of information on well water quality may be your neighbors. Ask them what their tests have revealed.

What contaminants should you look for?

Test for the contaminants that might be found at your location. For example, if you have lead pipes, soldered copper joints, or brass parts in the pump, test for the presence of lead. Test for volatile organic chemicals (VOCs) if there has been a nearby use or spill of oil, liquid fuels, or solvents.

Pesticide tests, though expensive, may be justified if your well has high nitrate levels - more than 10 milligrams per liter (mg/l) of nitrate-nitrogen (NO3-N) or 45 mg/l of nitrate (NO3). Tests are also warranted if a pesticide spill has occurred near the well. Pesticides are more likely to be a problem if your well is shallow, has less than 15 feet of casing below the water table, or is located in sandy soil and is downslope from irrigated lands such as farms or golf courses where pesticides are used.

You can seek further advice on testing from your local Cooperative Extension office or health department. You should test your water more than once a year if (1) someone in your household is pregnant or nursing; (2) there are unexplained illnesses in the family, (3) your neighbors find a dangerous contaminant in their water; (4) you note a change in water taste, odor, color, or clarity; or (5) you have a spill or backsiphonage of chemicals or fuels into or near your well. Water can be tested by both public and private laboratories. Once tested, keep a record of your results with your records on well construction and maintenance. This will allow you to monitor water quality over time.

7.2 Septic Systems

Why should you be concerne?

Wastewater treatment systems help protect your health and the environment. Household wastewater from sinks, toilets, washing machines, and showers carries dirt, soap, food, grease, and bodily wastes "down the drain" and out of your house. Wastewater also carries disease-causing bacteria, viruses, and other pathogens as well as nutrients like nitrogen, phosphorus, and organic

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wastes. Such nutrients promote weed growth and lower oxygen levels in surface water and thus affect fishing and recreational use of rivers and lakes.

Wastewater treatment systems are designed to remove or break down these contaminants before they enter groundwater - the source of drinking water via wells or nearby lakes, streams, or wetlands.

Wastewater treatment is often out-of-sight and out of-mind until problems occur. Knowing the basics about your household system and taking simple precautions can prevent problems. It's a wise investment to keep your system working well. Replacing a failed system can cost thousands of dollars.

General suitability of soils for on-site sewage is regulated in Pennsylvania by DER Title 25, Rules and Regulations, chapter 73, Standards For Sewage Disposal Facility, USA Department of Agriculture, Soil Survey of Bucks and Philadelphia Counties, July 1975. Bucks County Planning Commission refers to the following soil classification for on-site sewage disposal system suitability:

1. Soils feasible for conventional systems;

2. Soils feasible for alternate systems;

3. Soils not feasible for any type of on site system;

4. Carbonate derived soils, not feasible in Bucks County for any on-site system; and,

5. Soils subject to flooding; not feasible for any on-site sytems.

Maps with location of soils types grouped by their suitability for on-site sewage were prepared for the entire Cooks Creek watershed area by use of the GIS database. These maps are presented in Figures 20c through 20h.

The soil must be of a suitable type and deep enough to treat wastewater before it reaches groundwater. The soil filters out larger particles and pathogens, which eventually die off in the inhospitable soil environment. Under suitable conditions, beneficial soil microbes and natural chemical processes break down or remove most of the contaminants in the effluent. Hazardous synthetic chemicals such as solvents and fuels are not easily degraded in wastewater treatment systems. These chemicals can contaminate sludge in the septic tank, kill the beneficial bacteria that digest wastes, and travel into groundwater.

The existing soil type on a property determines which type of on-site sewage disposal system should be used on that property. A typical septic system consists of a septic tank and drainfield, which is also known as a soil absorption field, leach field, or tile field. It is important to maintain your wastewater treatment system and use it wisely whether you have a holding tank or septic tank followed by a mound, sand filter, or other alternative on-site treatment system.

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Conventional Septic Systems

Soils vary in their ability to absorb and treat wastewater. Well-drained, medium-textured soils such as loam are best. Coarse gravel or sandy soils allow wastewater to flow too quickly for treatment. In fine clay or compacted soils, water moves too slowly. Soil microbes need oxygen to digest wastes quickly. If the air spaces between soil particles remain filled with water, the lack of oxygen prevents the rapid breakdown of wastes by aerobic (oxygen-requiring) soil microbes.

Anaerobic soil microbes (those that live in the absence of oxygen) digest wastes slowly and give off putrid, smelly gases characteristic of a failing septic system. Anaerobic conditions occur when soils are poorly drained, groundwater levels are high, surface runoff saturates the drainfield, or excessive amounts of water are used in your household.

Good wastewater treatment depends on good dispersal of wastewater over the drainfield. In a conventional, gravity-fed distribution system, the distribution pipes are often laid out in a fork-shaped pattern joined by a distribution box (Figure 7-9). Leveling devices on the distribution box help ensure an even flow of wastewater to every trench. Often, however, certain trenches or low points in the distribution system receive more effluent than others.

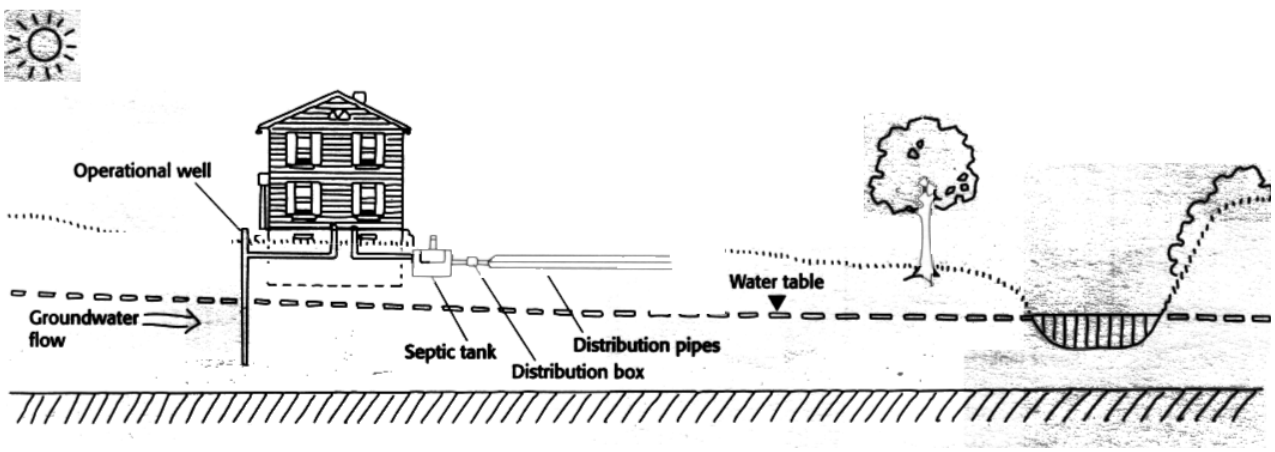

Figure 7- 9 Cross section of a septic system showing the septic tank an distribution System.

A dosing or enhanced-flow system has a pump or siphon to improve the distribution of effluent. Periodically pumping a certain volume of effluent to wet the entire drainfield area and then allowing the soil to drain between doses provides a period of aeration, which helps microorganisms in the soil digest the wastes.

In a pressure distribution system, effluent is pumped directly through small-diameter pipes, not sent through a distribution box. Wastewater is evenly distributed throughout the entire drainfield, promoting better treatment of wastewater and system longevity.

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Alternative Septic Systems

If soil or site conditions are not suitable for a conventional drainfield, an alternative system might be used. In a mound system, the drainfield is elevated to provide additional soil depth for treatment before the effluent reaches groundwater. A sand filter consists of layers of sand and gravel in which the wastewater is treated before it is distributed into the soil. Other types of filters use small foam pieces or peat as a filter medium.

With suitable climate and soil conditions, other alternative systems such as evapotranspiration systems, constructed wetlands, spray irrigation, lagoons, or mechanically aerated systems for household wastewater treatment are approved in some localities. Descriptions of these systems are beyond the scope of this report.

Aerobic treatment units operate much like a municipal sewage treatment plant, where wastewater is mixed with air, promoting bacterial digestion of organic wastes and pathogens. The biological breakdown of wastes in a septic tank's anaerobic (oxygen-deprived) conditions is relatively slow. Aerobic units are more expensive and require significantly more maintenance than conventional septic tanks. However, they provide good wastewater treatment on homesites that are otherwise unsuitable for development because the soil type, depth, or area is inadequate for an on-site treatment system. The effluent from an aerobic unit can be discharged into a soil absorption system or may be treated with chlorine, ozone, or other disinfectant before surface discharge if state and local regulations permit.

Disposal of toilet wastes does not have to mean flushing away great volumes of water. Composting toilets use microbes to aerobically digest toilet wastes; they work well only if the right temperature, moisture level, oxygen level, and nutrient mixture is maintained. Other types of waterless toilets include incinerating toilets, recirculating oil flush toi
disinfecting toilets. Without the blackwater (water carrying human body waste) from toilets, greywater (wastewater other than sewage) from sinks, tubs, and washing machines can be treated in a household wastewater system sized to handle about half the volume of a standard wastewater system.
There is controversy over the safe use and disposal of greywater (wastewater other than sewage, from sinks, tubs, and washing machines): state health regulations covering if and how greywater can be used vary. Many states strictly prohibit any surface disposal of greywater but permit its use in subsurface irrigation systems for watering plants. However, caution is advised because greywater may contain infectious bacteria and viruses (for example, from soiled diapers or clothing worn by someone with an infectious disease). Direct contact with greywater must be prevented. Beware that certain detergents, bleach, and salts may damage the health of plants and soils.

In areas with limited water resources, particularly during drought periods, water use must be reduced. Water conservation methods are encouraged, along with unrestricted uses of clear water (for example, flushing toilets with shower warm-up water).

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Septic System Location, How close is too close?

To prevent contamination of water supplies, the drainfield must be at least 100 feet from any wetland, shoreline, stream bed, or drinking water well (see figure 4.6; state and local regulations regarding separation distances may vary). The greater the distance, the lower the chance of contaminating the water supply. If your system is downhill from a well, the well will be better protected. You should test your well water more often for nitrates and bacteria if your system is closer to your well than recommended.

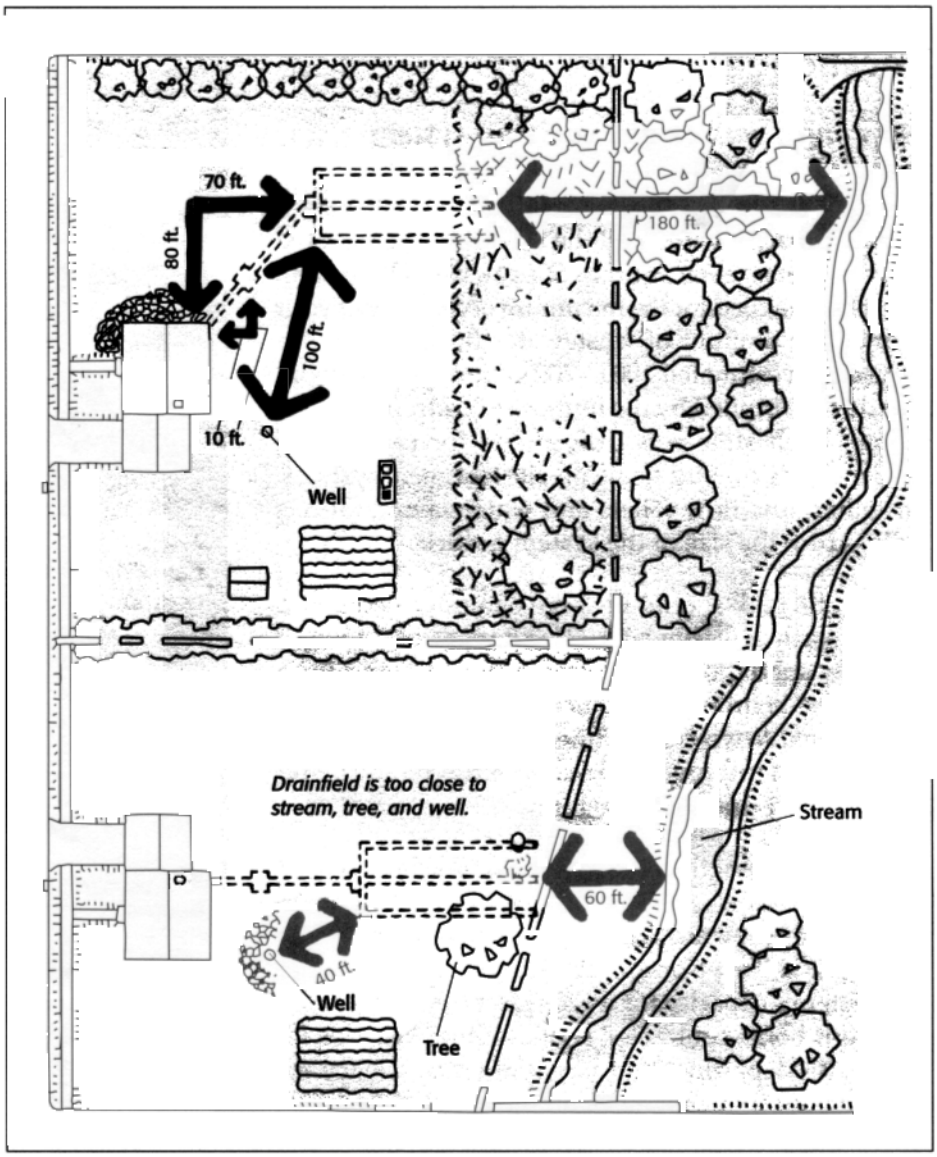

Figure 7-10 Homesite Map showing location of septic system.

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7.3 Stream Visual assessment

Visual assessment (cover instream, fine sediments, flow pattern, bank conditions, pressures (riparian), width of riparian zone, litter, overall assessment) performed at 27 locations pointed out a few stream segments that have qualifiers "marginal" and "poor" for overall assessment conditions (see Figure 33). The following table shows the DRBC concept of the visual assessment of small streams.

Table 7-3. Visual assessment of small (wadeable) streams, the creek and surrounding area for 50 yds. upstream and 50 yds. downstream of the sampling site.

ASSESSMENT FACTOR	RESPONSE			
	EXCELLENT	GOOD	MARGINAL	POOR
1. Instream cover (habitat for fish & aquatic organisms)	The stream contains lots of boulders (over 10"), cobble (2-10"), submerged logs, undercut banks or other stable habitat	There is adequate habitat of both rock & wood for maintenance of diverse populations of fish & bugs	Some rock and wood or other stable habitat, but much less than desirable	Not much stable habitat; lack of habitat is obvious
2. Fine particle sediments (sand, silt, mud)	The rocks in the stream are not surrounded by fine sediments; I see very little sand, silt, or mud on the bottom	Rocks are partly surrounded by fine sediments; I could easily flip over the rocks on the bottom	Rocks are more than half surrounded by fine sediments; rocks are firmly stuck into sediments	Rocks are deeply stuck into fine sediments; bottom is mostly sand, silt, or mud
3. "Flow patterns": How many does the stream have?	All 4 of these velocity/depth patterns are present within 50 yards upstream or downstream of this site: **slow/deep, slow/shallow, fast/deep, fast/shallow**	Only 3 of 4 regimes (flow patterns) are present	Only 2 of the 4 regimes present	Dominated by 1 velocity/depth regime
4. Condition of banks & coverage? (If the	The banks are stable; no evidence of erosion or bank	Moderately stable; some small areas of	Largely unstable; almost half of the bank	Unstable; eroded areas; "raw" areas occur frequently; less

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two banks are very different, assess the worse side, if possible)	failure; the whole bank is covered with vegetation or rock	erosion mostly healed over; most of the bank is covered by vegetation or rock	has areas of erosion or is NOT covered by vegetation or rock	than half of the bank is covered by vegetation or rock
5. Disruptive pressures to the "riparian" area? (If the two banks are very different, assess the worse side, if possible)	Trees, shrubs, or grasses have not been disturbed through forestry, grazing or mowing; almost all plants are growing naturally; mature trees, understory, and vegetation are present	Some disruption, but not affecting full plant growth potential to any great extent; trees, woody plants, and soft green plants are dominant	Disruption is obvious; some patches of bare soil, cultivated fields or closely cropped vegetation are the norm	There is not much natural vegetation left or it has been removed to 3 inches or less in average stubble height
6. Riparian vegetative zone width (If the two banks are very different, assess the worse side, if possible)	Riparian zone is more than 35 yards wide; human activities (parking lots, roads, learcuts, lawns, or crops) have not impacted zone	Riparian zone 12-35 yards wide; human activities have impacted zone only minimally	Width of riparian zone 6-12 yards; human activities impacting zone are commonly evident	Width of riparian zone is less than 6 yards; lots of nearby human activities
7. Litter	There is no litter in the area	There is very little litter in the area; probably some degradable paper accidentally dropped by fishermen or hikers	Litter is fairly common and includes metal or plastic, obviously purposely dropped.	Area is a candidate for a clean-up project; lots of litter, dumping, tires, or barrels present
8. Overall I rate the VISUAL ASSESSMENT of this site …	EXCELLENT	GOOD	MARGINAL	POOR

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DEFINITIONS:
Riparian zone - The land connected with or immediately adjacent to the banks of a stream or other body of water.
Disruptive pressure - Any activities, which interfere with the natural unity of a system. In the case of riparian assessment, this usually refers to land use practices such as mowing, grazing, logging, paving, building construction, heavily worn paths, etc.
Habitat - The "places" where a plant or animal normally lives and grows throughout all the phases of its life cycle.
Stable Habitat - The condition in which places used for hiding, resting, reproducing, living, and growing are not undergoing rapid or constant change. In the case of stream assessment, this is usually referring to large rocks, logs, and undercut banks which are more or less permanently in place.

The DRBC and several organizations originally conceived the WATER SNAPSHOT project in 1996. DRBC leads the annual effort, with the valuable assistance of a committee consisting of representatives from the following organizations in 2000: Del. Dept. of Natural Resources and Environmental Control, Delaware Riverkeeper Network, Delaware Estuary Program, National Park Service, N.J. Dept. of Environmental Protection, N.Y. State Dept. of Environmental Conservation, Pa. Dept. of Conservation and Natural Resources, Pa. Dept. of Environmental Protection, Pennsylvania Environmental Council, Pocono Environmental Education Center, Upper Delaware Council, U.S. Environmental Protection Agency, and U.S. Geological Survey.

7.4 Stream Morphology Stability

The most widely accepted method of describing channel morphology has been proposed by David L. Rosgen. Basically, the Rosgen system of channel classification is modeled after parameters of form and pattern. Of importance is its ability to elucidate channel behavior, which can be important to restoration efforts and provide clues of deviation from normal river conditions.

Under the Rosgen system of classification, river types are the result of a combination of channel slope, substrate (bed) material, width to depth ratio, sinuosity (meandering), and the degree of lateral constraint and confinement. The Rosgen Classification System has seven types ranging from A to G and various subclasses that describe the size and coarseness of parent material. Generally, most channel types are in the A to D range with subclasses between 2 and 6.

The morphology survey completed for Cooks Creek shows significant longitudinal (upstream or downstream) change in character and class under natural conditions as a result of varying substrate material, entrance of tributaries, or change in landscape. Summaries of field morphology survey are presented in Table 6 and Table 7.

In Natural Stability Concept natural stream channel stability is achieved by allowing the stream to develop a stable dimension, pattern, and profile such that, over time, channel features are maintained

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and the stream system neither aggrades nor degrades Finally, stream observation data is to be used to understand past treatments and responses to the following questions:

- What caused the problem?
- How did the stream respond?
- What was the consequence of the stream response?
- How can we remedy the problem?
- How can we prevent the problem?

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The table below lists the BMPs that are described in Section 8.

Table 8-1. Summary of BMP Descriptions

BMP	Type (structural/ vegetative)	Permanence (permanent/ temporary)
Bioretention	vegetative	permanent
	Constructed Treatment Wetland	structural	permanent
	Critical-Area Planting	vegetative	permanent
	Diversion	structural	permanent/temporary
	Energy Dissipator	structural	permanent
	Filter Bag	structural	temporary
	Filter Strip	vegetative	permanent
	Grass Swale	vegetative	permanent
	Infiltration Trench and Dry Well	structural	permanent
	Inlet Protection, Block and Gravel	structural	temporary
	Inlet Protection, Excavated Drain	structural	temporary
	Inlet Protection, Fabric Insert	structural	temporary
	Interim Stabilization	vegetative	temporary
	Lined Channel	structural	permanent
	Outlet Stabilization Structure	structural	permanent/temporary
	Permanent Vegetative Stabilizatio	vegetative	permanent
	Permeable Paving System	structural	permanent
	Pond, Dry	structural	permanent
	Pond, Wet	structural	permanent
	Portable Sediment Tank	structural	temporary
	Riparian Corridor Management	vegetative	permanent
	Riparian Forested Buffer	vegetative	permanent
	Rooftop Runoff Management	structural	permanent
	Sand Filter, Closed	structural	permanent
	Sand Filter, Open	structural	permanent
	Sediment Basin	structural	temporary
	Sediment Trap	structural	temporary
	Silt Curtain	structural	temporary
	Silt Fence	structural	temporary
	Slope Drain	structural	permanent
	Stabilized Construction Entrance	structural	temporary
	Straw Bale Barrier	structural	temporary
	Stream Bank Stabilization	structural/vegetative	permanent
	Temporary Stream Crossing	structural	temporary
	Tree Preservation and Protection	structural	temporary
	Trench Plug	structural	permanent
	Water Quality Inlet	structural	temporary

The table below lists the BMP names with alternative BMP references.

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Table 8-2. Summary of Alternative BMP References

BMP	Alternative References
Below-Grade Detention Basi	See DRY POND and INFILTRATION AND DRY WELL
Dry Well	See DRY POND and INFILTRATION AND DRY WELL
Level Spreader	See FILTER STRIP
Detention Basin	See DRY POND and WET POND
Recharge Bed	See INFILTRATION TRENCH AND DRY WELL and PERMEABLE PAVING SYSTEM
Seepage Bed	See INFILTRATION TRENCH AND DRY WELL and PERMEABLE PAVING SYSTEM
Tire Cleaning Strip	See STABILIZED CONSTRUCTION ENTRANCE
Chute	SLOPE DRAIN

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WELL WATER LEVEL MONITORING

The water-level data from four observation wells owned by Douglas, Fry, Hunt and Hutchinson is collected starting with November 1999. The data from observation wells is continuously collected as part of Cooks Creek Monitoring and Planning Program and is used to calculate the change in groundwater storage. The annual water level change is multiplied by 0.02, the estimated specific yield of the zone of water level fluctuation (Wood, 1980, p. 18-19; Nutter, 1975, p. 10), to calculate the annual change in groundwater storage(dGWS). The dGWS component is finally input in the computer interface WAMOS to estimate the Water Budget.

Table 2. Summary of Water-Level Fluctuation, November 2000 – July 2001.

	Date	Douglas			Frye		
		Depth To Water (feet)	Change in Level (feet)	Change in Level (inches)	Depth To Water (feet)	Change in Level (feet)	Change in Level (inches)
November	11/13/99	7.50			127.83		
December			-0.03	-0.36		1.23	14.76
January			-0.03	-0.36		1.23	14.76
February	3/5/00	7.58	-0.03	-0.32	123.83	1.33	16.00
March	4/1/00	8.67	-1.09	-13.08	122.75	1.08	12.96
April	4/29/00	7.75	0.92	11.04	121.50	1.25	15.00
May	6/4/00	9.50	-1.75	-21.00	123.58	-2.08	-24.96
June	7/4/00	9.17	0.33	3.96	124.33	-0.75	-9.00
July	7/30/00	9.08	0.09	1.08	125.67	-1.34	-16.08
August	9/4/00	9.00	0.08	0.96	125.83	-0.16	-1.92
September	10/9/00	9.17	-0.17	-2.04	126.67	-0.84	-10.08
October	12/1/00	9.83	-0.33	-3.96	128.25	-0.79	-9.48
November	12/1/00	9.83	-0.33	-3.96	128.25	-0.79	-9.48
December	1/1/01	9.33	0.50	6.00	127.25	1.00	12.00
January	2/3/01	8.50	0.83	9.96	126.00	1.25	15.00
February	3/5/01	8.75	-0.25	-3.00	123.16	2.84	34.08
March	4/1/01	7.75	1.00	12.00	120.67	2.49	29.88
April	5/5/01	8.58	-0.83	-9.96	121.75	-1.08	-12.96
May	6/9/01	8.42	0.16	1.92	122.16	-0.41	-4.92
June	7/1/01	9.00	-0.58	-6.96	122.58	-0.42	-5.04
July	7/29/01	9.33	-0.33	-3.96	124.67	-2.09	-25.08
August	9/2/01	9.50	-0.17	-2.04	125.83	-1.16	-13.92
September	9/30/01	9.83	-0.33	-3.96	127.33	-1.50	-18.00

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	Date	Hunt			Hutchinson		
		Depth To Water (feet)	Change in Level (feet)	Change in Level (inches)	Depth To Water (feet)	Change in Level (feet)	Change in Level (inches)
November	11/13/99	17.00			71.17		
December			1.17	14.04		0.92	11.04
January			1.17	14.04		0.92	11.04
February	3/5/00	13.50	1.17	14.00	68.42	0.92	11.00
March	4/1/00	12.58	0.92	11.04	64.42	4.00	48.00
April	4/29/00	12.58	0.00	0.00	62.25	2.17	26.04
May	6/4/00	15.00	-2.42	-29.04	63.33	-1.08	-12.96
June	7/4/00	15.50	-0.50	-6.00	65.50	-2.17	-26.04
July	7/30/00	16.08	-0.58	-6.96	67.75	-2.25	-27.00
August	9/4/00	16.08	0.00	0.00	69.42	-1.67	-20.04
September	10/9/00	16.67	-0.59	-7.08	72.08	-2.66	-31.92
October	12/1/00	17.42	-0.67	-8.04	73.25	-1.92	-22.98
November	12/1/00	17.42	-0.38	-4.50	73.25	-0.59	-7.02
December	1/1/01	16.50	0.92	11.04	72.75	0.50	6.00
January	2/3/01	14.75	1.75	21.00	71.08	1.67	20.04
February	3/5/01	14.50	0.25	3.00	66.75	4.33	51.96
March	4/1/01	12.67	1.83	21.96	63.42	3.33	39.96
April	5/5/01	15.42	-2.75	-33.00	63.50	-0.08	-0.96
May	6/9/01	15.00	0.42	5.04	64.25	-0.75	-9.00
June	7/1/01	16.17	-1.17	-14.04	65.50	-1.25	-15.00
July	7/29/01	16.50	-0.33	-3.96	67.17	-1.67	-20.04
August	9/2/01	17.25	-0.75	-9.00	70.00	-2.83	-33.96
September	9/30/01	17.25	0.00	0.00	70.42	-0.42	-5.04

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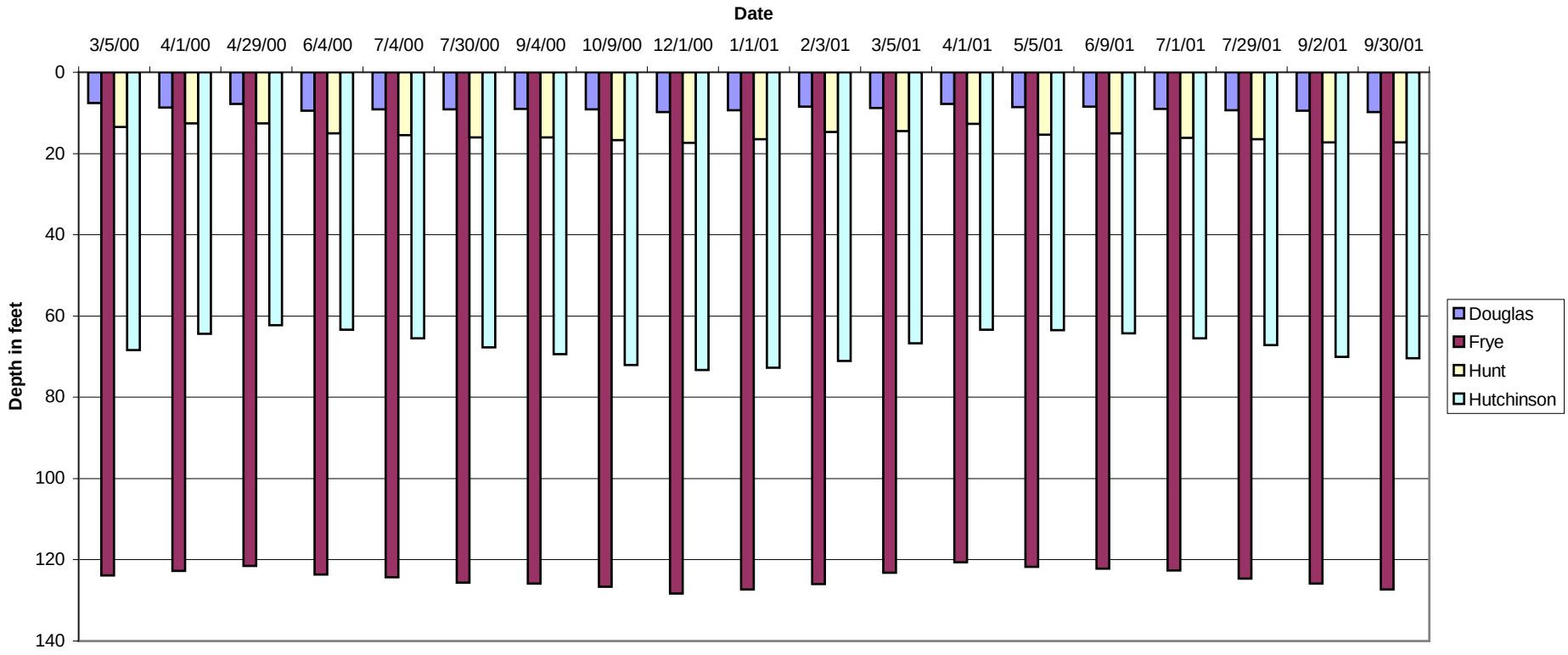
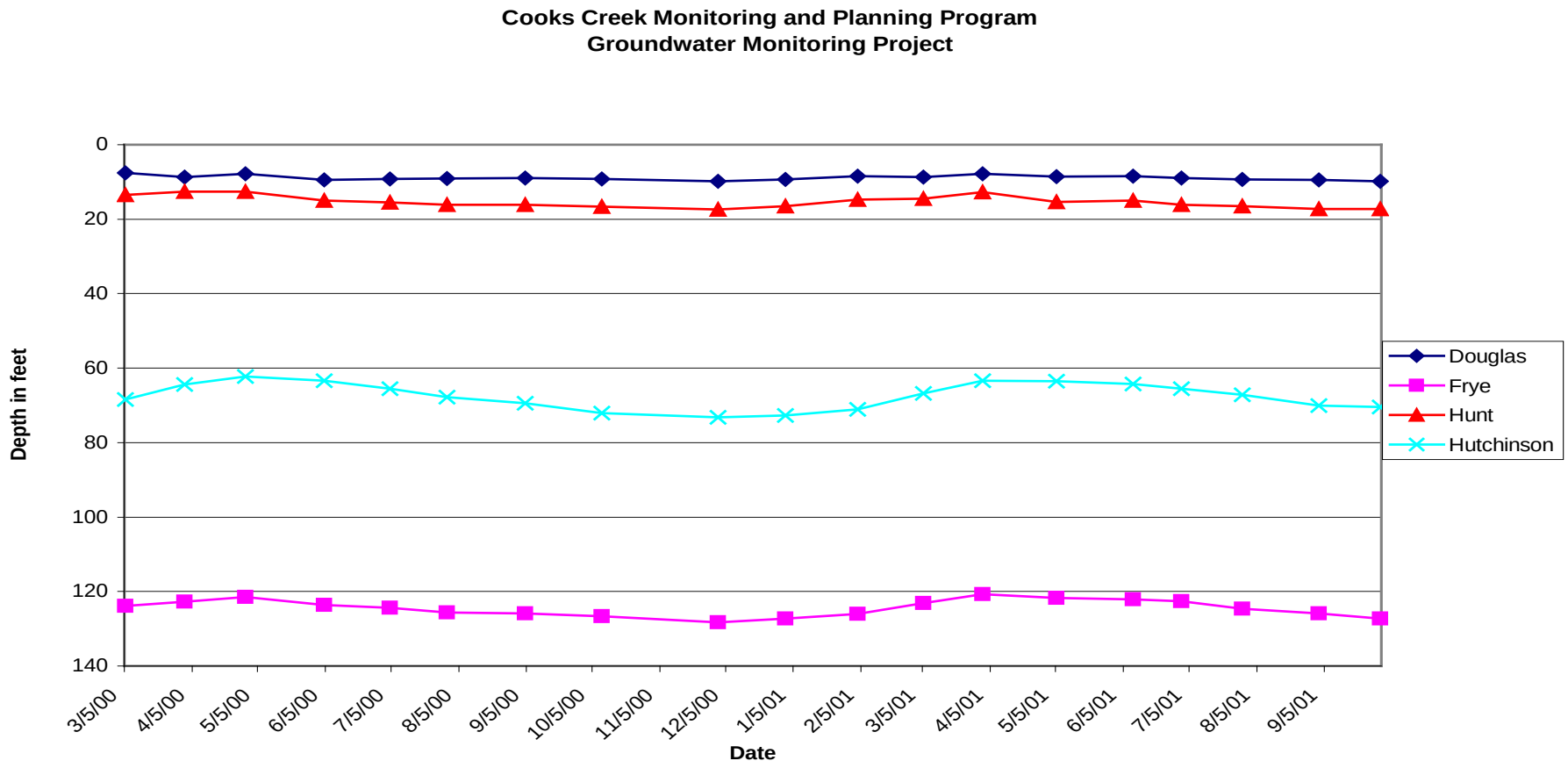
Cooks Creek Monitoring and Planning Program
Groundwater Monitoring Project




Cooks Creek Monitoring and Planning Program
Groundwater Monitoring Project
Depth in feet
0
20
40
60
80
100
120
140
3/5/00
4/5/00
5/5/00
6/5/00
7/5/00
8/5/00
9/5/00
10/5/00
11/5/00
12/5/00
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WATER TABLE CONTOURS

On Figure 23 the potentiometric contours shows altitude of potentiometric surface as defined by measured water levels, altitudes of streams and springs, and topography. The contours are approximately located for most of the mapped areas where the distance between wells are significant large. Measured and reported depths to water are summarized in Table 1.

Intermittent streams are discharge areas during periods of high ground-water levels. Contoured potentiometric surface (Figure 23) represents the water table except at wells that are completed in semiconfined zones in the aquifer. Contour interval is 20 feet except north of Springtown, where the contour interval is 20 feet up to an altitude 400 feet and then 50 feet to an altitude 800 feet.

On areas of Buckwampum Hill, north of Springtown, the Lookout, Bitts Hill and two hills west of Buckwampum the contours were inferred based of 1992 USGS data. The altitude is in feet above National Geodetic Vertical Datum of 1929.

The dot symbol gives location of a well site. Number is elevation of water level in feet above National Geodetic Vertical Datum of 1929. Wells outside the study area are shown where they were used to contour the potentiometric surface.

Depression on water table contours shows the altitude of water level that represents a potentiometric surface other than the water table. Measuring points include wells that may penetrate a deeper semiconfined zone, and data may reflect a composite bead. These data were not used to contour the potentiometric surface and are included for information only.

The mapped area is underlain by layered sedimentary rocks chiefly consisting of shale, mudstone, and siltstone and by a diabase sheet that has intruded the sedimentary rocks (see Figure 3.1). Also, a part of the mapped area is underlain by dolomite and crystalline rocks .

Triassic Sedimentary Rocks Aquifer

The Triassic Sedimentary Rocks Aquifer includes Brunswick Group and Lockatong Formation. The groundwater system can be visualized as a series of sedimentary beds with a relatively high transmissivity separated by beds with a relatively low transmissivity. The beds, a few inches to a few feet thick, act as a series of alternating aquifers and confining or semi-confining units that form a leaky, multiaquifer system. Each bed generally has different hydraulic properties, and permeability commonly differs from one bed to another. Soft shale beds deform without breaking under stress and, as a result, have lower permeability than the harder sandstone beds, which tend to develop fractures and joints and are more permeable. Thick, hard, competent sandstone beds develop fewer joints than thin sandstone beds (Wood, 1980, p. 16) and bedding planes are widely spaced; therefore, they are less permeable.

Groundwater is unconfined in the shallower part of the aquifer and confined or semiconfined in the deeper part of the aquifer. Under confined conditions, ground water is confined under pressure greater than atmospheric by less permeable beds or hydrogeologic units and is not free to rise and fall. Differences In vertical hydraulic conductivity within and among hydrogeologic units create confining conditions.

The water level in a well constructed in a confined aquifer rises above the top of the aquifer. The imaginary surface to which water will rise in wells tightly cased in a confined aquifer is the potentiometric surface. If the potentiometric surface is above the land surface, the well will flow.

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Most deep wells are open to several water-bearing zones and are multiaquifer wells. Some wells may be open to more than one hydrogeologic unit. Each water-bearing zone usually has a different hydraulic head. The hydraulic head in a deep well is the composite of the heads in the several water bearing zones penetrated. This can cause water levels in some wells to be different than water levels in adjacent wells of different depths. If the composite head is below the uppermost water-bearing zone or zones, water from these zones will drain into the well and cascade down the borehole to the water surface. In the area of the former mining activity is possible that deep wells to intercept fractures which are connected with the tunneling system. The altitude of these old mines are believed to be near 150 feet-msl.

Where differences in hydraulic head exist between water-bearing zones, water in the well bore flows under non-pumping conditions in the direction of decreasing head. Flow from an upper zone of higher head to a lower zone of lower head can result in a cone of depression forming around the well under non-pumping conditions and can locally lower water levels, in special for those wells located in former mines area. Under seasonal fluctuation conditions the flow direction may even reverse. Could this explain why some times the water pumped from wells located in the Mine Hill area taste very bad, likewise bats excrements? Bat colonies are known to exist in the closed mines tunnels and shafts.

The ground-water-flow system in Triassic sedimentary rocks is highly anisotropic with the predominant flow direction in the direction of strike (Vecchioli and others, 1969, p. 154). The network of interconnected water-bearing openings is more or less continuous along strike, but the continuity of individual beds downdip is limited because fractures are closed by compression or absent with depth.

Because of anisotropy, wells aligned parallel to strike generally show more interference than wells aligned perpendicular to strike. Drawdown in wells aligned along strike may be many times greater than in wells aligned in other directions (Vecchioh and others, 1969, p. 157). Wells drilled to the same depth along strike generally penetrate the same water-bearing beds, whereas wells drilled to the same depth several hundred feet downdip of each other rarely intersect the same water-bearing beds. Therefore, the potential for well interference caused by pumping is greater in wells along strike than in wells in the direction of dip. In the anisotropic Triassic formations, cones of depression are usually elliptical, with the long axis aligned parallel to strike.

In the anisotropic systems of the Newark Basin, groundwater flow is not necessarily perpendicular to lines of equal hydraulic head, but may be skewed in the direction of strike (Lewis, 1992, p. 96). Because the beds dip and because fractures are absent or dosed at depths greater than a few hundred feet, ground water flows preferentially along strike, even in places where the cross-strike hydraulic gradient is substantial.

Ground-water flow in the Triassic sedimentary rocks has local and regional components. Shallow ground water discharges locally to nearby streams. Deeper, regional ground-water flow is toward points of regional ground-water discharge, such as the Delaware River.

Groundwater divides may be different for each zone of groundwater flow, and may not coincide with surface-water divides. Groundwater flow directions may be different for each zone. More water level data have to be collected to assess groundwater divides for each area.

Brunswick Group

Rocks of the Brunswick Group underlie 32% percent of the study area. The Brunswick is highly fractured and has many closely spaced joints, which accounts for the relatively high well yields from a shale and siltstone formation. Bedding plane openings may extend to 300 ft below land surface Wasabach, 1966, p. 33). However, the upper part of the weathered zone, although more fractured than

the lower part, may be less permeable than the lower part because the fractures may be clogged with day derived from weathered shale and siltstone.

Lockatong Formation

Depth to water depends on many factors, including geology, topography, and proximity to pumped wells and quarries. Geologic controls often influence depth to water. For example, a well drilled in the Lockatong Formation near the contact with the Brunswick Group may penetrate the underlying Brunswick Group. The Stockton Formation may have a lower hydraulic head than the Brunswick Group, and the water level in the well would be a composite of heads in the Lockatong and the Brunswick Group. The composite head would be higher than the head in the Brunswick Group and lower than the head in the Lockatong Formation.

Table 1. Summary of Water Table Level Measurements, November 5, 2000.

WELL	NAME	ADDRESS	DEPTH TO WATER	ELEVATION
1	Takahashi, Mark	273 County Line Rd	178.25	729.60
2	Wagenvoord, Anita	291 County Line Rd	48.67	718.99
3	Ponzol, Kim & Danton	275 County Line Rd	67.92	742.84
4	Klein, Jill & Ken	185 County Line Rd	18.00	560.10
5	Ulrey, Bill And Kim	95 County Line Road	47.50	578.00
6	Tade, Stephanie & Philip	105 County Line Rd	50.75	577.57
7	Juall David And Bonnie	Dogwood Lane, Durham	46.92	650.74
8	Peacock	969 Spring Hill Rd	56.75	394.12
9	Beerer, Jim & Karen	Spring Hill Rd	5.33	362.40
10	Anderson, Ken	940 Spring Hill Rs	73.67	361.84
11	Marschewski, Fred	803 Stouts Valley Rd	7.92	227.04
12	Millett, Bart	4395 Rte 212	5.08	209.12
13	Jones, Cheryl	275 Valley View Rd	166.17	359.32
14	Miller, Bob	4227 Lehnenburg Rd	17.33	411.43
15	Oleksa, David	902 Durham Rd	11.42	235.21
16	Apgar, Wayne & Marti	299 Old Furnace Rd	42.67	188.94
17	Reed, Lynette & John	180 Mine Hill Rd	149.00	326.96
18	Willey, Stephen And Sharon	4912 Rte 212	75.00	224.93
19	Davis, Janet	443 Mine Hill Rd	28.92	326.70
20	Martz, Valerie	215 Mine Hill Rd,	72.00	349.65
21	Killcoyne, Andy & Liz	281 Old Furnace Rd	32.54	208.53
WELL ID	Name	Address	DEPTH TO WATER	ELEVATION
22	Hughes, Tom And Linda	120 River View Lane,	86.75	201.48
23	Uttard Robert & Christine	930 Ebert Rd	80.00	868.49
24	Morgan, Douglas & Priscilla	1654 High Point Rd	62.42	714.49
25	Walter Rudi	1720 Hightop Rd,	56.67	695.52
26	Mitchell, David & Erinfly-M	2159 Quarry Rd	68.42	728.86
27	Seifert, David	2212 Richlandtown Pike	25.50	636.07
28	Pross, Earl & Mary Ann	2279 Deer Trail Rd	75.33	819.71
29	Lawrence, Bruce & Anne	2050 Chestnut Rd	16.42	573.26
30	Cooper, James	2233 Chestnut Rd	41.00	714.34
31	Frye, Timothy & Sharon	1382 Pleasant View Rd	127.83	731.15
32	Bilger, Raymond & Greta	1706 State Rd	95.92	561.80

33	Bauman, Gary & Deborah	1544 Gruversville Rd	65.33	589.49
34	Kurtesan, Milton & Elizabet	1801 Peppermint Valley	31.17	581.10
35	Hunt, John & Marjorie	2916 Lower Saucon Rd	17.00	370.46
36	Singer, Webster & Nancy	2371 Township Rd	50.25	490.07
37	Bodian Alex	2412 Hickory Lane	14.08	523.73
38	Lovekin, Virginia	2789 Slifer Valley Rd	22.00	339.63
39	Dunlap, Anne & Bill	3005 Slifer Valley Rd		554.09
40	Jones, Mel & Kathy	Rte 212, Springtown	17.75	326.60
41	Young, Nancy	Rte 212	-0.50	393.56
42	Douglas, Scott & Aimee	3450 Rte 212	7.50	322.46
43	Mcmath Margaret & Barrie	3030 Cooks Creek Rd	17.83	518.66
44	Seifert, Harry & Theresa	3220 Drifting Drive	52.83	823.47
45	Lodwig David	3055 Funks Mill Road	21.17	349.44
46	Baier, Arthur	3024 Funks Mill Rd	38.92	320.43
47	Orben, Jim	3465 Owl Hollow Rd	45.21	492.20
48	Millett, Virgil & Adele	3020 Haupts Bridge Rd	56.42	318.97
49	Moran, Thomas & Nancy	2710 Bodder Rd	96.42	459.04
50	Jensen, Eric & Janet	6395 Rte 412	165.54	453.56
51	Feher, Joseph & Judith	3775 Haupts Bridge	37.30	398.43
52	Chipman Doug	4470 Rt 212	124.25	280.37
53	Kucher, Donald & Violet	1520 Oak Lane	106.00	523.49
54	Durrwachter, Doris	2917 Grouse Lane	10.50	321.31
55	Hutchinson, Stuart & Louise	1661 Oak Lane	71.17	604.78
56	Hoffman Diana	1529 Maple Rd	28.83	328.59
57	Campeau, David & Betsey	1559 Maple Rd	24.08	548.48
58	Lang, Lisa And Chris Olsen	6145 Rt 412		458.35
59	Hermo, Raymond	3590 Lenape Way	115.58	459.30
60	Becker, David & Lee	3750 Lehnenburg Rd	107.70	308.89
61	Halderman, Charles	3760 Lehnenburg Road	147.75	644.56
62	Bell, Robert & Helene	3465 School Rd	23.42	594.83
63	Rosenthal Richard	3341 School Rd	17.17	549.33
64	Kocsis Martha	1810 Gallows Hill Rd	69.50	594.21

Some anthropogenic activities, such as pumping of nondomestic wells may lower water levels and create a cone of depression around the pumping well. For example, the potentiometric-surface map of

Carbonate Rocks Aquifer

17.29 percent of the study area is underlain by carbonate rocks, which crop out in parts of Durham Valley. The principal formations are the Limestone Formation, Allentown Dolomite, and Leithsville Formation. Most ground water in carbonate rock flows through a network of secondary openings-fractures, joints, and bedding planes enlarged by solution. Some openings enlarged by solution are several feet wide; however, most are only a fraction of an inch wide, but they are capable of transmitting large quantities of water. The vertical distribution of solution openings is irregular and unpredictable. Adjacent wells may tap different systems of openings in the bedrock.

Permeability of carbonate rock is predominately the result of solution-enlarged fractures. Where solution has been active, permeability may be high; elsewhere, the same unit may be nearly impermeable. Solution is the principle weathering agent of carbonate rocks, which are soluble in acidic water. Solution generally is most active above and within the zone of water table fluctuation where water movement is relatively rapid and recharge water is acidic. Below the zone of water table fluctuation, water movement is slower, and acidic recharge water is neutralized.

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Clay and unconsolidated material sometimes move downward from the surface, plugging openings. This plugging results in decreased well yields and turbid ground-water discharge from some wells.

Crystalline Rocks Aquifer

Nine percent of the study area is underlain by crystalline rocks. Crystalline rocks are found in Durham Valleys and in the Reading Prong to the north of Durham Valley. The crystalline rocks in the northern part of the study area are Hardyston Quartzite in Durham Valley and granitic and hornblende gneisses in the Readiftg Prong.

In crystalline rocks, ground water moves through intergranular openings in the weathered zone (saprolite) and through a network of interconnecting secondary openings - fractures and joints - in the underlying unweathered rock. The permeability of fractured crystalline rock depends on the number of fractures, the size of the fracture openings, and the degree of interconnection of the fractures. A considerable quantity of water may be stored in the weathered zone where ft is thick.

The ground-water-flow system in crystalline rock is local with streams acting as drains. Flow paths are short, and ground water flows from areas of higher elevation to adjacent streams. Groundwater and surface water divides usually coincide. The hydrologic system generally is under unconfined (water-table) conditions; the water-table surface is a subdued replica of the land surface. In areas where the fractures are far apart and poorly interconnected, a true water table may be absent and each system of fractures may have its own water level. Semiconfined ground water may occur locally.

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7.1Preparing the Water Budget

Quantification of the flow system concept with respect to the occurrence and distribution of groundwater requires the introduction of a hydrologic budget equation, or water balance, that describes the hydrologic regime in a drainage basin (Freeze and Cherry, 1979). However, the application of steady-state hydrologic budget equations provides only a crude approximation of the hydrologic regime in a drainage basin.

If we limit ourselves to drainage basins in which the surface water divides and groundwater divides coincide, and for which there are no external inflows or outflows of groundwater, the water-balance equation for an annual period would take the form

$$P = SF + dGWS + dSWS + ET \qquad (1)$$

where P = precipitation

SF = streamflow

ET = evapotranspiration

dSWS = change in surface-water storage

dGWS = change in groundwater storage

Averaged over many years of record, dSWS = dGWS = 0, and Eq. (1) becomes

$$P = SF + ET \qquad (2)$$

Considering an ideal drainage basin, wherein the discharge area constitutes a very small percentage of the total basin area, then

$$Q = QS + QG \qquad (3)$$

where QS is the surface water component of average annual runoff and QG is the groundwater component, or average annual baseflow, of average annual runoff. Equation (3) suggests that it might be possible to separate streamflow hygrographs into their surface-water and groundwater components.

Baseflow separation and water budget analysis performed for Cooks Creek stream gage data (1991, 1992 and 2000) indicate that the watershed basin has a large storage capacity (low discharge ratio discharge ratio = (O25/Q75)^0.5= 1.56), sustaining up to 92.29 percent of Cooks Creek streamflow (still 7 cfs) during dry seasons (July 2000).

Ground-water contribution to streamflow through 2000 year, from January to September is presented in Figure A-13. The analysis indicated that, for Cooks Creek over the 10 months period, an average of 65.95 percent of the streamflow was contributed by ground water. Ground-water contributions ranged from 58.13 percent to 92.29 percent, and the median was

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68.24 percent. For a complete analyze for the existing data between 1990 and 1999 see Appendix A.

The capacity of a basin to store ground water can be illustrated by flow duration curves. Flow duration curve for Cooks Creek, 1991-92 period is shown in figure F-1. A flow duration curve is a cumulative frequency curve that shows the percentage of time specified discharges were equaled or exceeded during a given period.

The curve describe the flow characteristics of a stream without regard to the sequence of occurrence. Flow duration curves in figure F-1 are mean daily discharge in cubic feet per second per square mile so that drainage basins of different sizes can easily be compared. Although the flow duration curves for 1991-92 represent flow for a period of slightly below normal precipitation and are not representative of the long term probability distribution, they give an indication of the variability of streamflow among the basins. Flatter slopes, particularly at the lower end of the flow duration curve, indicate streamflow contributions from the ground water system. The flow duration curves in figure F-1 shows that the flow of Cooks Creek is better sustained by ground water discharge at the low end of the discharge range than the flow in other basins. The flow of Tinicum Creek is poorly sustained by ground water discharge at the low end of the discharge range, largely because 54 percent of the basin is underlain by diabase.

Discharge ratios taken from the flow duration curves can be used to quantitatively evaluate the capacity of the basin to store ground water (Walton, 1970). The discharge ratio is calculated by the following equation:

discharge ratio = (O25/Q75)0.5 (3)

where Q25 is discharge that is equaled or exceeded 25 percent of the time, and

Q75 is discharge that is equaled or exceeded 75 percent of the time.

Small ratios represent relatively permeable basins with a large storage capacity; larger ratios represent less permeable basins with a smaller storage capacity. Discharge ratios are given in table F-T1. The smallest discharge ratio was calculated for the Cooks Creek Basin, indicating that it has the largest storage capacity. The largest discharge ratio was calculated for the Tinicum Creek Basin, indicating that it has the smallest storage capacity.

The calculation of a hydrologic budget is relatively simple, involving only the subtraction of total outflow from total inflow, plus or minus the change in storage within the study region. However, the application of the steady-state hydrologic-budget equation provides only a crude approximation of the hydrologic regime in a drainage basin and estimation of values for the individual variables within the equation may be difficult.

Of all these variables, it is the evapotranspiration estimates that pose the greatest problem since it includes water evaporated from water surfaces, soils, and other surfaces, as well as that transpired by vegetation. The most widely used methods of calculation utilize the concept of potential evapotranspiration (PET), which is defined as the amount of water

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that would be removed from the land surface by evaporation and transpiration processes if sufficient water were available in the soil to meet the demand.

In a discharge area where upward rising groundwater provides a continuous moisture supply, actual evapotranspiration (AET) may closely approach potential evapotranspiration. In a recharge area, actual evapotranspiration is always considerably less than potential evapotranspiration.

Numerous empirical methods of calculating evapotranspiration have been developed. The most common is that of Thornthwaite and Mather (1957) where potential evapotranspiration (PET) is estimated solely from climatological measurements. The potential evapotranspiration (PET) per month is given by

PET = E x C (4)

Where: E = unadjusted potential evapotranspiration equal to 16(10t/TE)a

a = 0.000000675(TE)3 - 0.0000771(TE)2 + 0.01792(TE) + 0.49239

TE =temperature-efficiency index, being equal to the sum of twelve monthly values of heat index i = (t/5)1.514, where t is the mean monthly temperature in oC

C = correction coefficient, function of the latitude and month as given in the table of PET calculations.

Equation (4) provides an estimate of monthly "potential" evapotranspiration (PET) that represents the evaporating power of the atmosphere observed on the ground in a plant-covered area where there is at all times sufficient water in the soil for the needs of the vegetation. If there were a shortage of water, the actual evapotranspiration (AET) would be a function of the PET and the quantity of available water.

As a first approximation, one imagines that the upper layer of the soil constitutes a reservoir, the maximum capacity of which is estimated (St). In this reservoir, evapotranspiration may occur freely at the potential evapotranspiration (PET) rate. When it is empty, the evapotranspiration can only feed on the precipitation of the given month. When it is full, the excess moisture generates infiltration towards the aquifer. During a given month, one calculates the balance of the rainfall, the PET and the soil moisture storage (St), which makes it possible to compute the AE and the moisture surplus (N), that water available for runoff and/or groundwater recharge.

The attached table gives the results for the climatological station located at the Doylestown using the Thornthwaite formula to calculate PET. Thus we can estimate, as a first approximation, that the moisture surplus in 1999 ranged between –2.67 inches (deficit), August 1999, and 5.45 inches, September 1999. In 2000 the moisture surplus ranged between –1.18 inches (deficit), June 2000, and 3.56 inches, March 1999.

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7.2 Water Balance

The concept of a groundwater regime is based on the fact that the occurrence and distribution of groundwater is not merely a product of chance, but the consequence of a finite combination of climatic, hydrologic, geologic, topographic, ecologic and soil-forming factors that together form an integrated dynamic system. These factors are interrelated in such a way that each provides some insight into the functioning of the total system and thus serves as an indicator of local conditions of groundwater occurrence. It is possible, therefore, to evaluate the general potential of an area for groundwater development by appraising as many of the factors listed above as practical and then by interpreting the local regime on the basis of known relationships among the factors and their effect on the groundwater regime.

Most important among the preceding relationships are the physical characteristics of the framework in which the groundwater system occurs, the balance between groundwater recharge and discharge and the consequent hydrologic and lithologic implications that may be drawn, and the relationship among the factors affecting the movement of groundwater from the point of recharge to the point of discharge.

Obviously the groundwater regime must be viewed as a dynamic system in which water is absorbed at the land surface and eventually recycled back to that surface. Groundwater may be visualized as occurring in a subsurface reservoir, the boundaries of which are formed by adjacent less permeable or impermeable geological materials. The reservoir may be open everywhere to the land surface (unconfined), or it may be capped in large part by impermeable or relatively impermeable geological materials (confined).

The hydrologic equation, which is basically a statement of the law of conservation of matter as applied to the hydrologic cycle, defines the water balance. It states that in a specified period of time all water entering a specified area must either go into storage within its boundaries, be consumed therein, be exported from, or flow out either on the surface or underground.

In developing an estimate of balance between recharge to, and discharge from, a groundwater regime the general manner in which that regime functions must be identified. The potential for recharge to the groundwater regime in an area depends on the amount and pattern of annual precipitation in relation to the potential for evaporation and to the occurrence of any surface or subsurface inflow from adjacent areas. Most of this potential recharge is commonly intercepted by the soil veneer and eventually returned to the atmosphere through processes of evapotranspiration or dissipated as surface runoff.

The GIS tools were used to create areal coverages of drainage basin divides, bedrock geology, and boundaries for the Cooks Creek Basin. Drainage basin divides were digitized from USGS 1:24,000 scale 7 ½ minute topographic quadrangle maps. The Cooks Creek Basin, including the mainstem lower section, was divided into 40 basins or

subbasins so that the basin or subbasin areas were determined their local geology. The mainstem Cooks Creek, lower section subbasin (area CC1), has a drainage area of 3.79 mi^2 (Figure 24-2 and Figure 25-2). The drainage basin coverages will be used in determining ground water contributions to base flow for the basins or subbasins on the basis of geology. Assigned basin and subbasin names, and drainage areas are listed in Tables C-T1 and C-T2.

Bedrock geologic contact lines were transferred on the subbasins maps and the refined geologic coverages on the basis of basin/subbasins areas will be used to calculate the percentage of each geologic unit in each subbasin. The geologic units of the entire watershed were grouped into four geologic categories, (1) Brunswick Group and Lockatong Formation, (2) the diabase, (3) carbonate rocks, and (4) crystaline rocks, that will be used in determining ground water contributions to base flow for the basins or subbasins. Figures 25-1 through 25-7 present the geology for the entire local area, areas 1 through 7, while Figures 24-1a through 24-7a present the geologc composition of subbasins areas grouped by the designation of subbasins, such as first-order and second order.

For a small scale analysis the subbasins were grouped into seven areas determined of the dominant local geology and of the subbasin type .

One statistic available to define the critical base flow condition is the Q7-10, the lowest 7-consecutive-day average flow with a probability of occurring no more than once in 10 years. The recorded data for Cooks Creek streamflow-measurements station (12/12/1990 – 02/20/93, 05/11/199 – 08/29/1999, and 12/18/1999 – to present date) provided a Q7 = 222 GPD/acre (between 09/11/1991 and 09/18/1991 the average stream flow was 7.14 cfs). The average stream flow for 1991 was 40.20 cfs which yields a Q365 = 1255 GPD/acre.

Having the limited stream gage data collected for Cooks Creek, yield ratios for the various rocks aquifers were estimated from annual base flow for the 2-,5-, 10-, 25-, and 50-year recurrence intervals at streamflow-measurements station of Brandywine Creek and Neshaminy Creek Basins (USGS Water-Resources Investigations Report 96-4127).

The technical analysis of land and water resources within the study area begins with a careful measurement of both, making use of the Geographic Information System (GIS) files created for this purpose and which cover the full study area. The delineation of first order streams and larger catchments within Cooks Creek basin was required for analysis, as discussed previously. As was shown in Figure ____ and repeated here as Figure ___ through Figure ____, the watershed has been divided into 40 sub-basins. These areas vary significantly in size, but average about 609 acres for the 40 sub-basins.

Analyzing the existing and potential future hydrologic balance in each of these sub-basins required the application of what is referred to here as the Water Balance Model (WBM). On a conceptual basis, the model considers the dynamics of water movement from incident rainfall through the soil into the groundwater reservoir, with gradual discharge as stream base flow. It is the stream base flow which is taken as the net result of all

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intervening processes, including evaporation, transpiration and human intervention, so that existing uses and conditions are all reflected in this statistic. The model can consider base flow variability by each geological structural element, surface yield and subsurface withdrawals, with hydrologic analysis for wet, dry and average years. The WBM can be thought of as a bookkeeping process which accounts for the dynamics of the water cycle by considering each catchment under stress conditions which test the specific resource impact; drought periods of base flow for water supply (Q7-10 = 222 GPD/acre), dry years cycles (Q365-10 = 1255 GPD/acre) for groundwater contaminants such as Nitrate (1 Nb3), and storm periods (based on annual runoff) for estimates of potential pollutant runoff from future urbanized lands.

Of course any such fixed analysis of the hydrologic cycle ignores the dynamic nature of the process, with the water in constant movement. All elements of the cycle vary with time and seasonal change. Patterns of incident rainfall, as documented by the climatological record in terms of seasonal variability and event probability, changes in the evaporative and transpirational losses as a function of temperature and vegetative land cover, changes in the net withdrawals from the aquifers by wells and additions by wastewater effluent of on-site systems, and the resultant impact on storm and dry weather stream flows which are produced by land surface alteration, all contribute to the dynamic nature of this process. The VBM has been applied and aggregated to reflect the total watershed, balance and variability within each basin for planning purposes, and to allow us to identify potential stress conditions in the system so that we may prevent or intervene to protect the resource.

Water Use Based on Existing Conditions

Each of the 40 sub-basins experience some amount of water use at present, primarily based on residential use or the equivalent use of other land activities expressed in "equivalent dwelling units" (EDUs) The demands of agriculture are not included in this estimate, since the future land use scenarios all assume that the lands zoned agricultural and used as such at present will provide the developable lands (excluding those parcels under permanent easements or protective covenants). For a more accurate estimate, the individual agricultural parcels could be evaluated and a current demand estimated, but this level of data gathering was not considered necessary for this study of future impacts.

Based on a set of assumptions with respect to the number of dwelling units in each sub-basin (as estimated from the existing GIS database of population and households for 1990 census) and the water use per dwelling unit (300 GPD/DU), the existing water use is summarized in Table 8 by sub-basins. The estimated water demand is based on assumptions as to an approximate number of dwelling units, which exist in a given sub-basin. Of course, where a current count of actual dwelling units can be made, it is a more accurate statistic, and as the individual sub-basins are studied in greater detail, that value will replace this estimate. Also the average value of Q7-10 = 222 GPD/acre (7.14 cfs/29.7 square miles) is based on only 3.5 years stream flow recording and could overestimate the aquifer contribution during a drought period. However other streamflow measurements for similar settings (streamflow-measurements station of Brandywine

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Creek and Neshaminy Creek Basins for 10 consecutive years) yielded close statistic value of Q7-10 (i.e. 192 GPD/acre).

For example, in sub-basin CC1, the 2,643 acres should yield 222 GPD/acre in a drought, and setting a consumptive loss limit at 50% of this base flow means that 305,852 GPD can be evaporated. The 409 existing dwelling units in the sub-basin at present, all of which are assumed to use on-site wastewater systems, will lose about 24,540 GPD, or only 4 % of the Q 7-10 flow, and so the answer to the limit question is no (2).

For those sub-basins where public water is provided throughout most of the drainage, such as SC1, SC2a, SC3a, and a very small area from CC, the water supply is not imported from other sub-basins and the resultant effluent is returned to the same system. Development still has an impact of water resources, but in the form of potential lost groundwater recharge and increased runoff with NPS pollution, from new (and existing) impervious surfaces.

For the most sub-basins both individual wells and on-site systems are utilized, the impact of consumptive loss on base flow is not the only issue. The Nitrate loading to the groundwater with land application of effluent raises the issue of increased Nitrate in the aquifer above the standard of 10 mg/1. The Nitrate loading estimated in the last column of Table 8 is evaluated in terms of the annual dry year groundwater volume available to dilute this addition, assuming an existing background concentration of 2 mg/1 in the groundwater. If this Nitrate limit (based on an annual groundwater volume of 1,255 GPD/Acre for 1991 as dry year) would be less than the present loading in sub-basins, which are supplied from individual wells, could be concern as to potential water quality constraints. Our calculation shows any concern since for all drainages the Nitrate limit is much higher than Nitrate Load.

"Futures" Analysis

For the potential impact of future growth on the regional water resources, it is useful to consider exactly how the resource capacity is estimated. As stated previously, the groundwater yield as stream base flow is used as the surrogate for system capacity, rather than the entire volume of water that may be contained in an aquifer at any given moment. This interrelationship between groundwater storage and surface water flow is frequently neglected in water resource studies, where the total discharge or stream flow (including both wet and dry periods) from a drainage area is the primary focus of analysis. The terms "safe yield" and "water budget" have been frequently mis-applied to suggest that a given amount of water can be withdrawn from an aquifer per unit area without impact. While such concepts have been used as the basis for regulation, the reality is that any withdrawal of a water resource, without recycling or compensation, has some given quantitative (and qualitative) effect elsewhere in the water system. This interconnection between ground and surface flows is an assumption that drives much of the analysis

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developed in the WBM. The projected impacts of both existing and future development, are driven by this' estimated limit of system capability.

Simulating different "future" outcomes or scenarios should be based initially on two basic sets of conditions. In the initial analysis, the question is what will be the water resources impacts of continuation of "baseline" or "business as usual" policies and programs (i.e., the existing management system), basically a build out of existing zoning. The second alternative future considers following the Landscapes Plan as the pattern of future land development. In both instances, the process begins with an estimate of potentially developable lands, derived as the vacant parcels and unrestricted agricultural parcels in the study area, as shown in Figure 22.

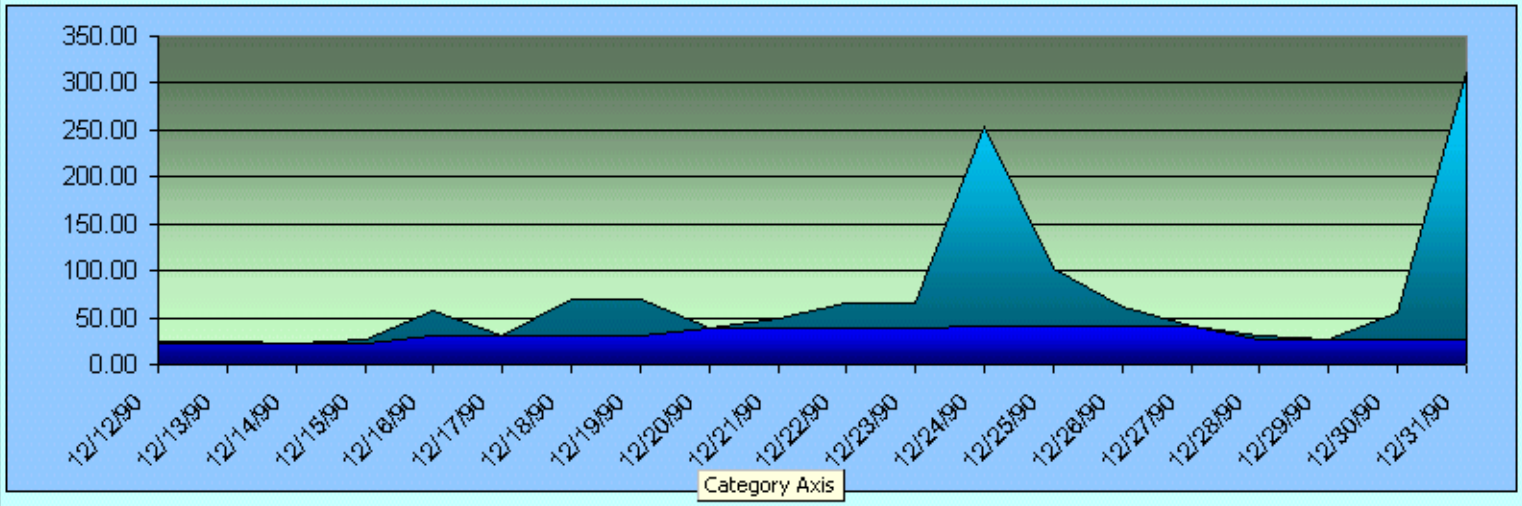
On the other hand multiple, alternative methods of estimating ground water discharge and recharge should be used (e.g. ground water flow modeling) because of the uncertainty associated with any one technique. Estimates of recession index from stream-discharge hydrographs, ground water hydrographs, and hydraulic diffusivity were performed by testing aquifers in basins throughout the eastern United States. Reliable identification of the recession index and so Q7-10 may require recession periods in excess of 200 days that were not influenced by hydrologic phenomena other than ground awter discharge to surface water features(Ground Water Journal, vol 38, No. 3, pp. 331-342, May-June 2000).

Year	Total streamflow (inches)	Base flow (inches)	Percentage of streamflow as base flow	Surface runoff (inches)	Percentage of streamflow as surface runoff
1990	32.33	14.48	45%	17.85	55%
1991	18.19	11.17	61%	7.02	39%
1992	19.01	8.29	44%	10.73	56%
1993	4.55	3.96	87%	0.59	13%
1999	7.19	5.96	83%	1.23	17%
2000	40.89	27.92	68%	12.97	32%

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

12/12/90 - 12/31/90



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	01/01/00	03/31/00
Last downlo		

Results

MIN	23.00
AVERAGE	71.45
MAX	312.00
BASEFLOW	44.79%
DIS. RATIO Q25/Q75	1.49

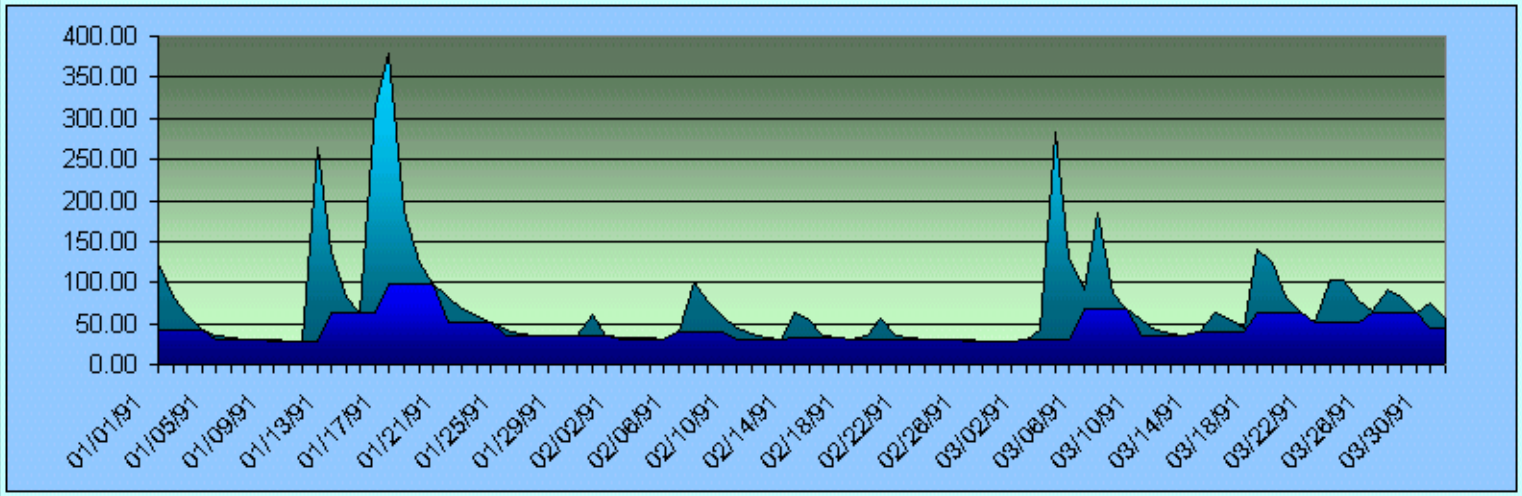
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

1/1/91 - 3/31/91



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	01/01/91	03/31/91
Last downlo		

Results

MIN	28.00
AVERAGE	70.61
MAX	380.00
BASEFLOW	61.68%
DIS. RATIO Q25/Q75	1.58

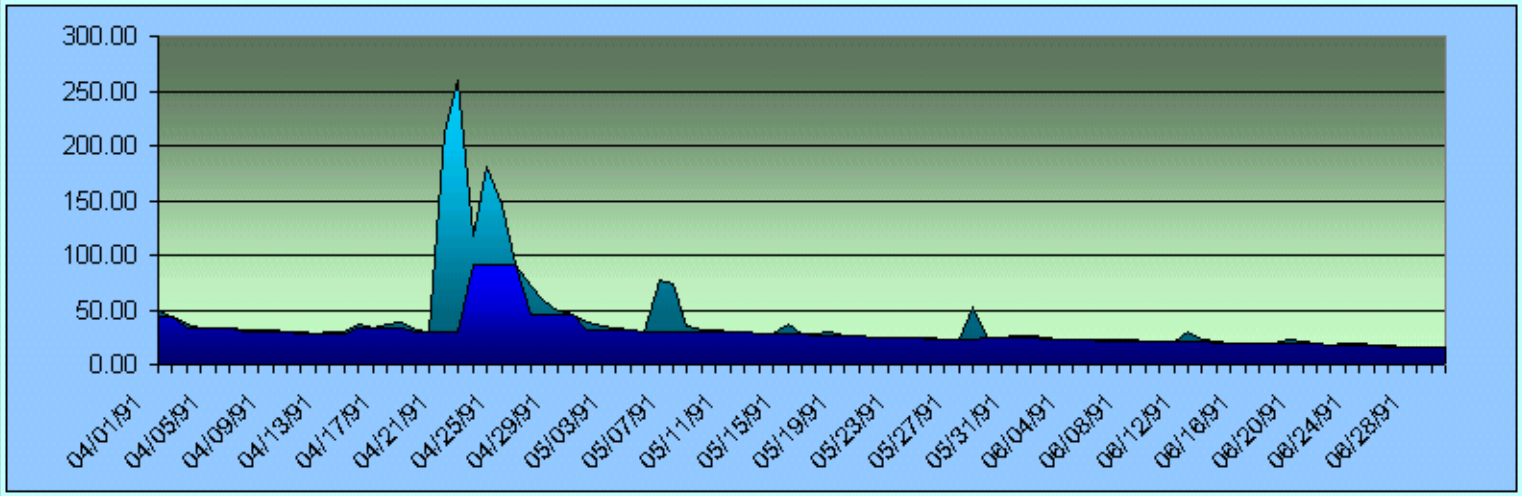
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

4/1/91 - 6/30/91



NEW DATA

PRINT

Time Base

○ All data		
○ Annual	1990	
○ Monthly	1	
◉ Between	04/01/91	06/30/91
○ Last downlo		

Results

MIN	15.00
AVERAGE	38.80
MAX	260.00
BASEFLOW	75.76%
DIS. RATIO Q25/Q75	1.23

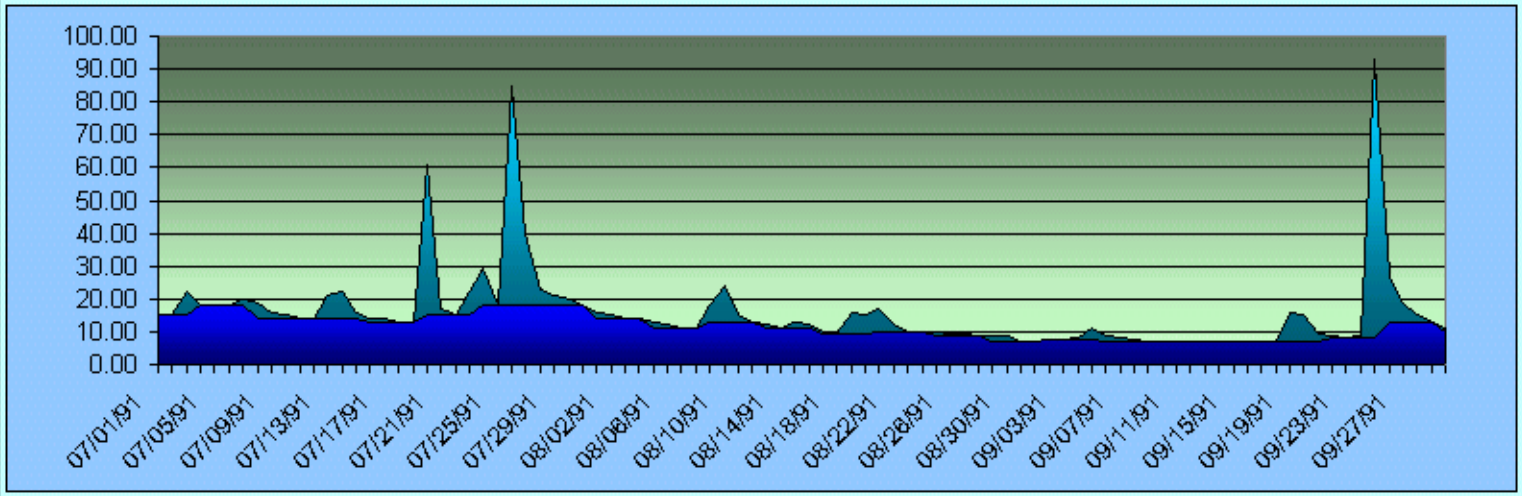
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

7/1/91 - 9/30/91



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	07/01/91	09/30/91
Last downlo		

Results

MIN	7.00
AVERAGE	15.80
MAX	93.00
BASEFLOW	73.08%
DIS. RATIO Q25/Q75	1.41

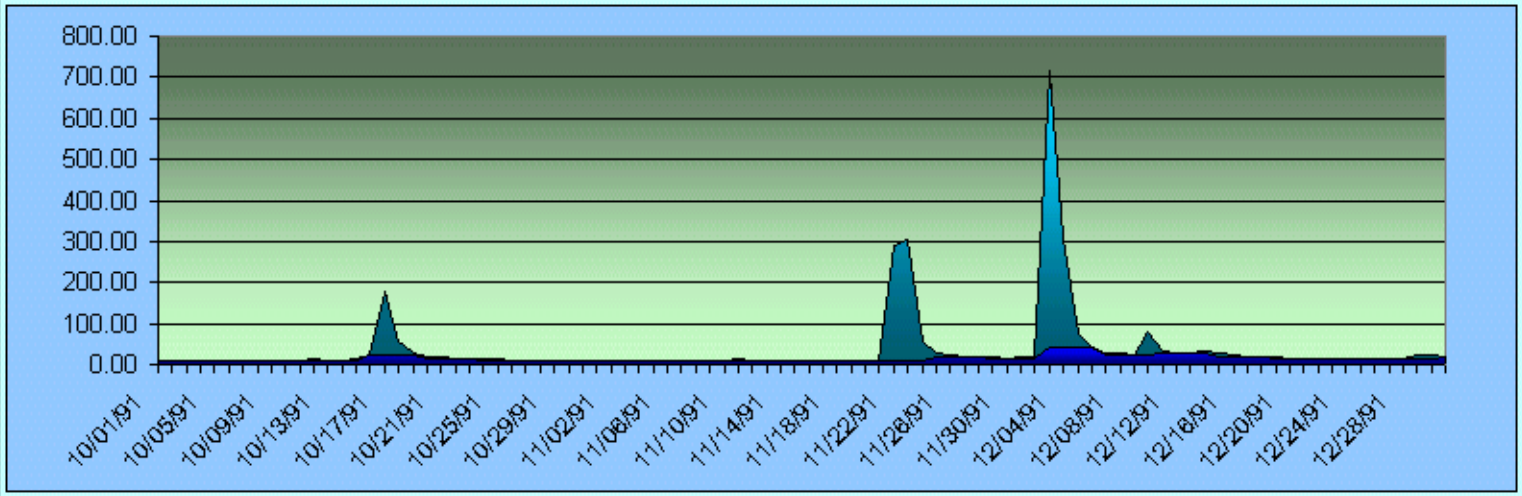
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

10/1/91 - 12/31/91



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	10/01/91	12/31/91
Last downlo		

Results

MIN	8.10
AVERAGE	36.25
MAX	718.00
BASEFLOW	40.59%
DIS. RATIO Q25/Q75	1.58

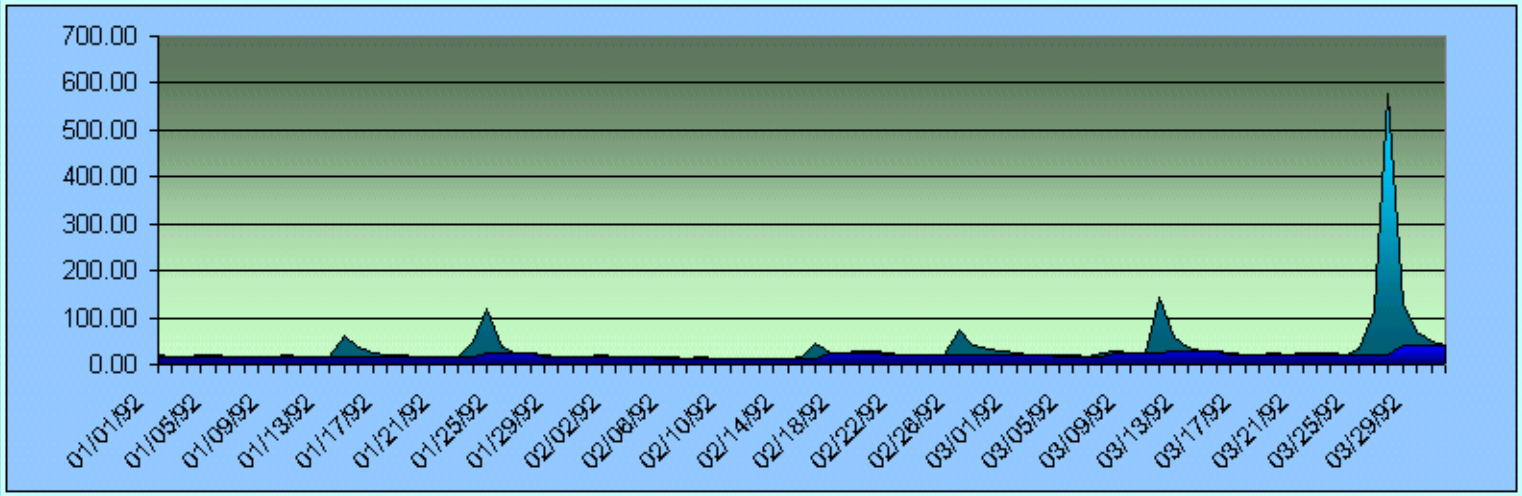
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

1/1/92 - 3/31/92



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	01/01/92	03/31/92
Last downlo		

Results

MIN	13.00
AVERAGE	35.03
MAX	578.00
BASEFLOW	56.68%
DIS. RATIO Q25/Q75	1.26

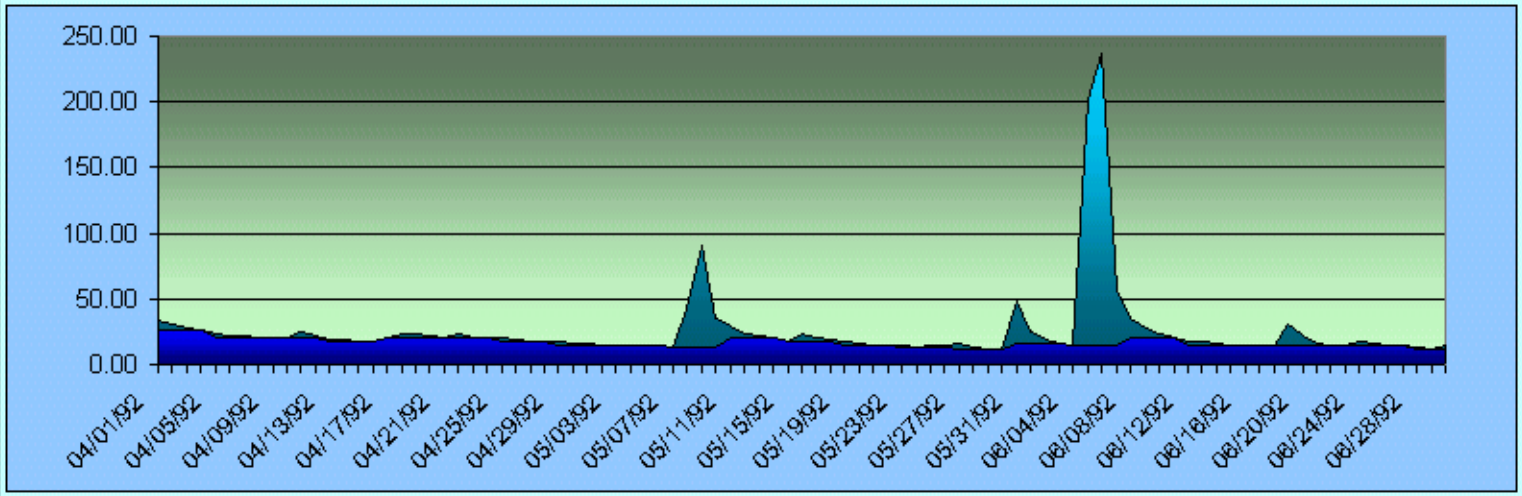
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

4/1/92 - 6/30/92



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	04/01/92	06/30/92
Last downloa		

Results

MIN	12.00
AVERAGE	25.22
MAX	237.00
BASEFLOW	65.88%
DIS. RATIO Q25/Q75	1.24

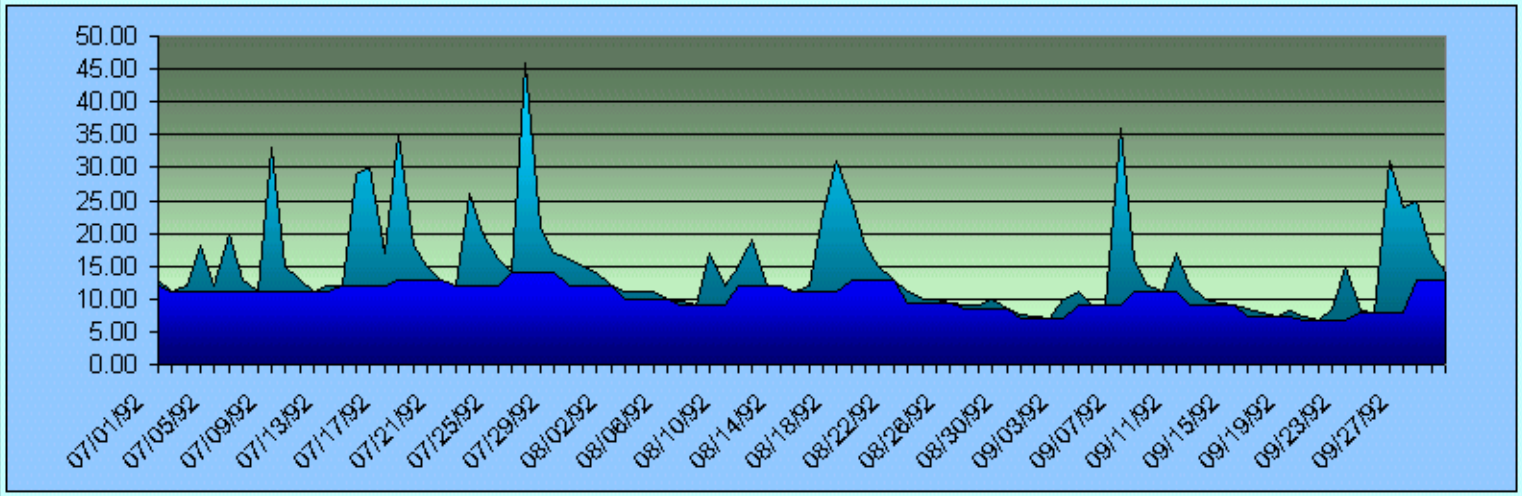
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

7/1/92 - 9/30/92



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	07/01/92	09/30/92
Last downloa		

Results

MIN	6.80
AVERAGE	14.74
MAX	46.00
BASEFLOW	70.80%
DIS. RATIO Q25/Q75	1.30

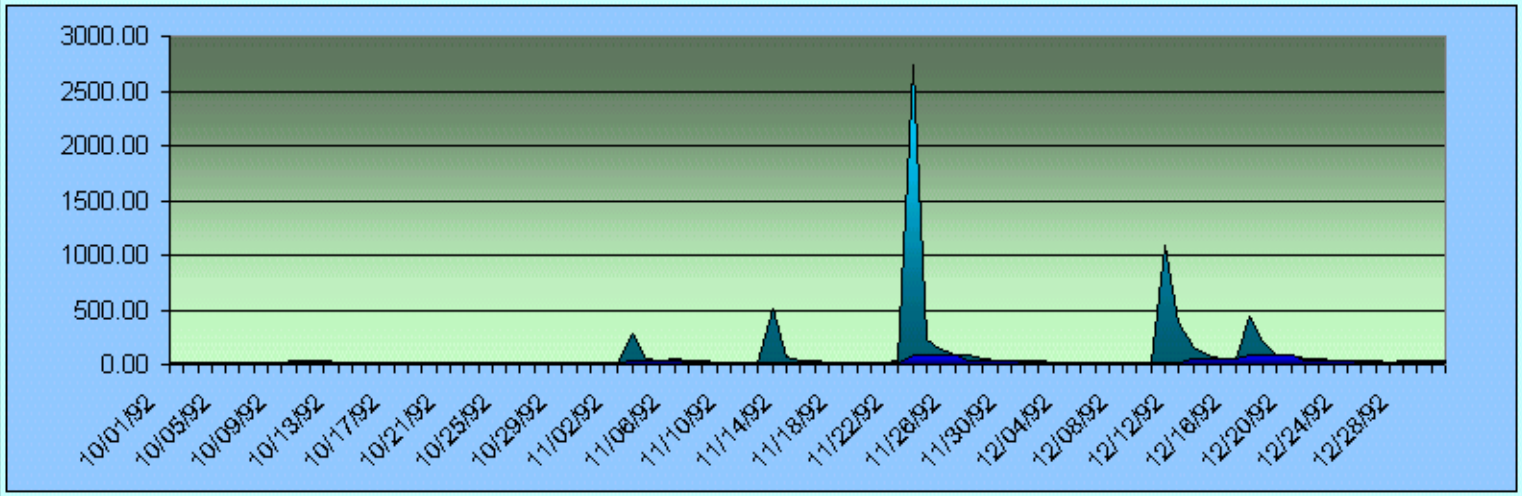
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

10/1/92 - 12/31/92



NEW DATA

PRINT

Time Base

All data		
Annual	1990	
Monthly	1	
Between	10/01/92	12/31/92
Last downlo		

Results

MIN	9.10
AVERAGE	92.83
MAX	2740.00
BASEFLOW	28.39%
DIS. RATIO Q25/Q75	1.77

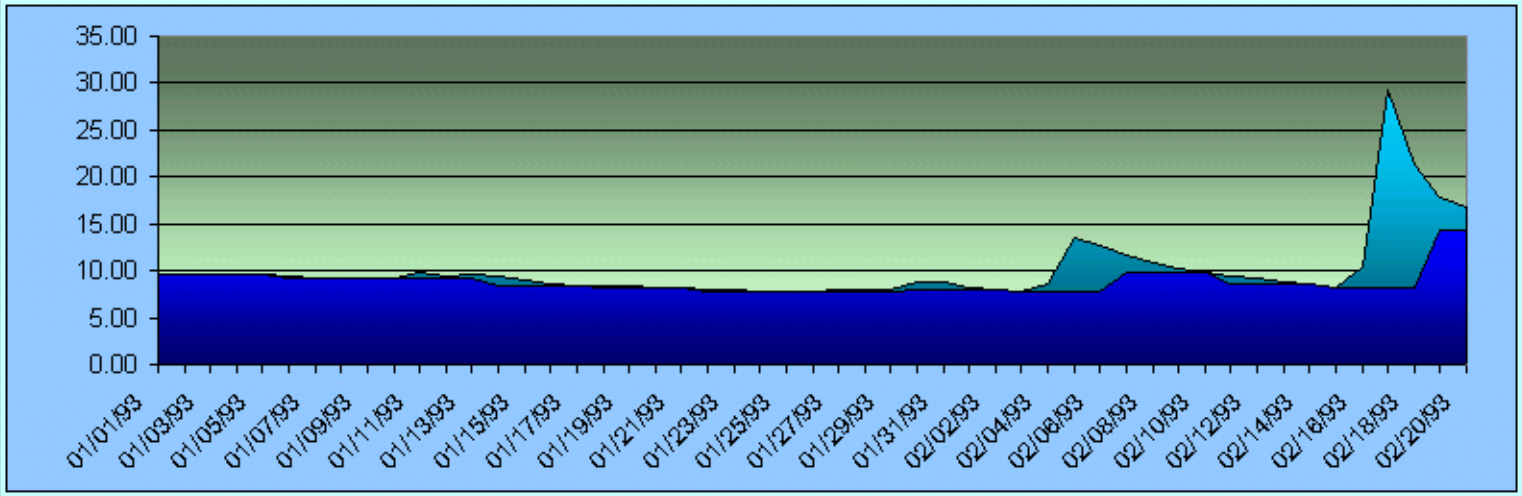
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

1/1/93 - 2/20/93



NEW DATA

PRINT

Time Base

All data		
Annual		1993
Monthly		1
Between	10/01/92	12/31/92
Last downloa		

Results

MIN	7.71
AVERAGE	10.06
MAX	29.23
BASEFLOW	87.09%
DIS. RATIO Q25/Q75	1.08

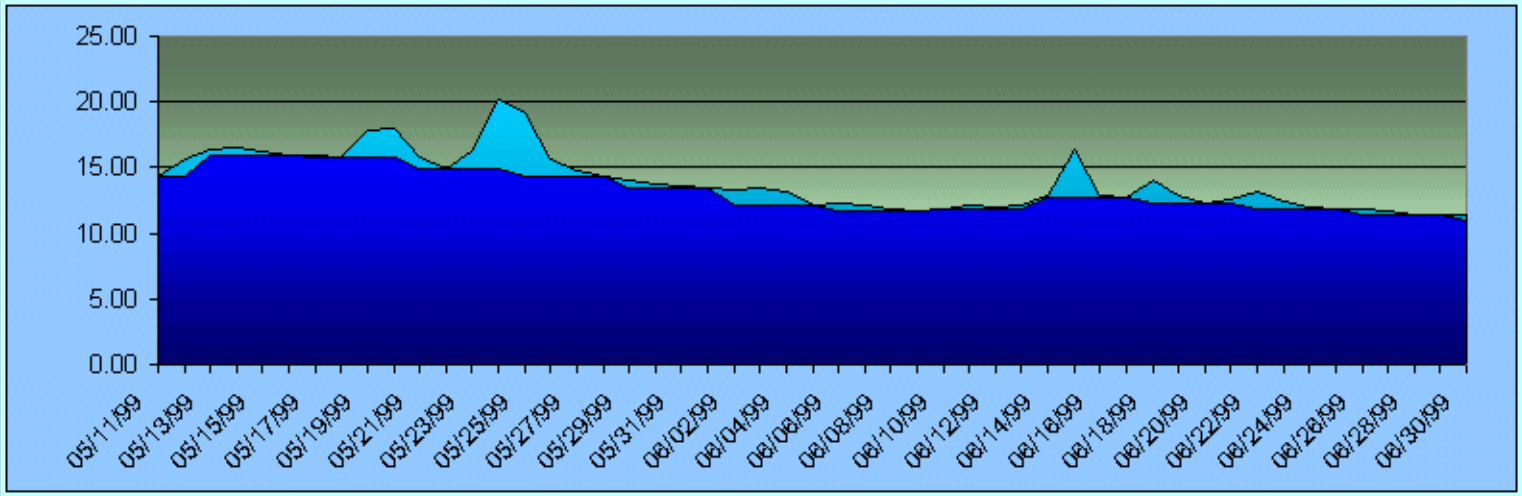
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

5/11/99 - 6/30/99



NEW DATA

PRINT

Time Base

All data		
Annual	1993	
Monthly	1	
Between	04/01/99	06/30/99
Last downlo		

Results

MIN	11.39
AVERAGE	13.91
MAX	20.11
BASEFLOW	94.82%
DIS. RATIO Q25/Q75	1.14

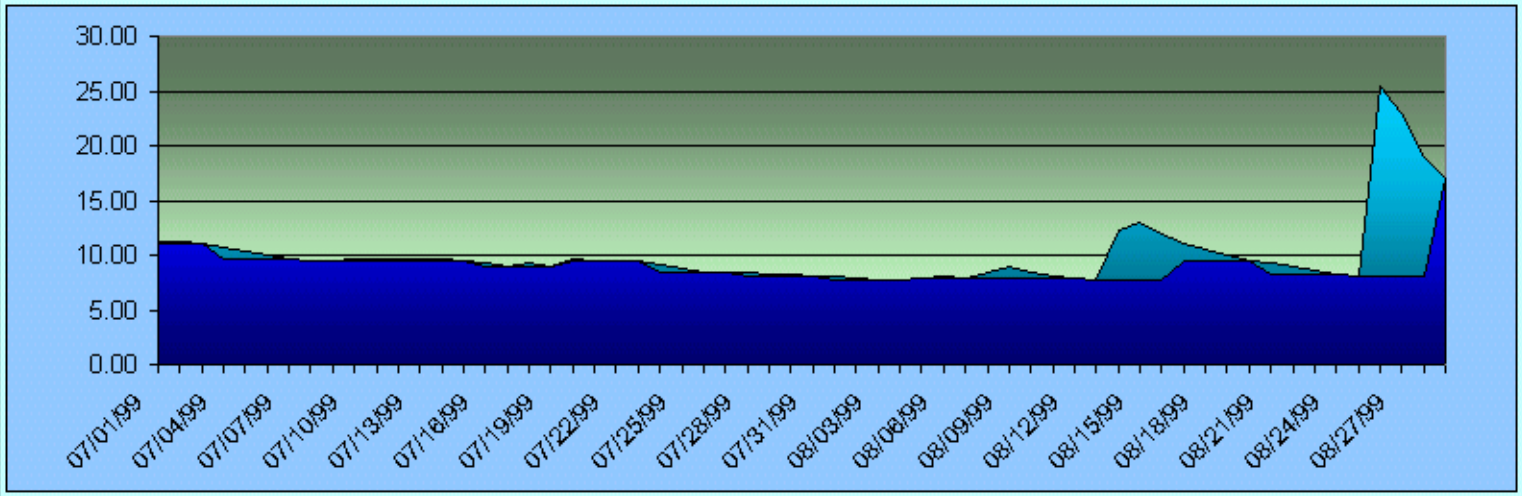
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

7/1/99 - 8/29/99



NEW DATA

PRINT

Time Base

All data		
Annual	1993	
Monthly	1	
Between	07/01/99	09/30/99
Last downlo		

Results

MIN	7.69
AVERAGE	10.06
MAX	25.37
BASEFLOW	88.18%
DIS. RATIO Q25/Q75	1.09

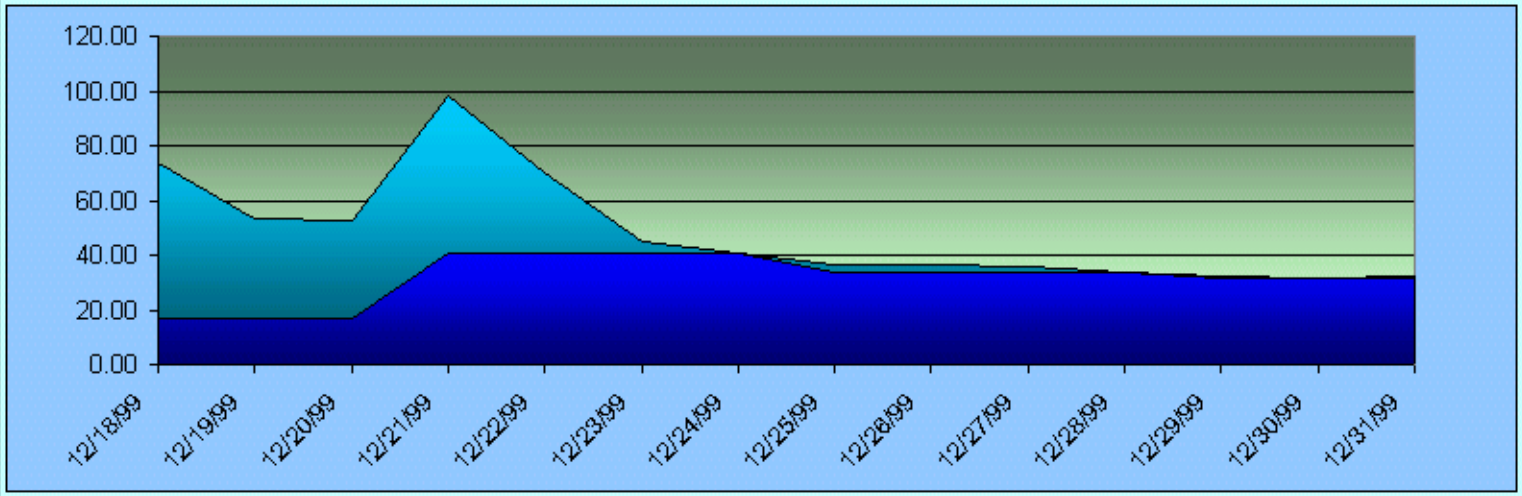
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

12/18/99 - 12/31/99



NEW DATA

PRINT

Time Base

All data		
Annual	1993	
Monthly	1	
Between	10/01/99	12/31/99
Last downlo		

Results

MIN	31.50
AVERAGE	48.05
MAX	98.34
BASEFLOW	65.65%
DIS. RATIO Q25/Q75	1.22

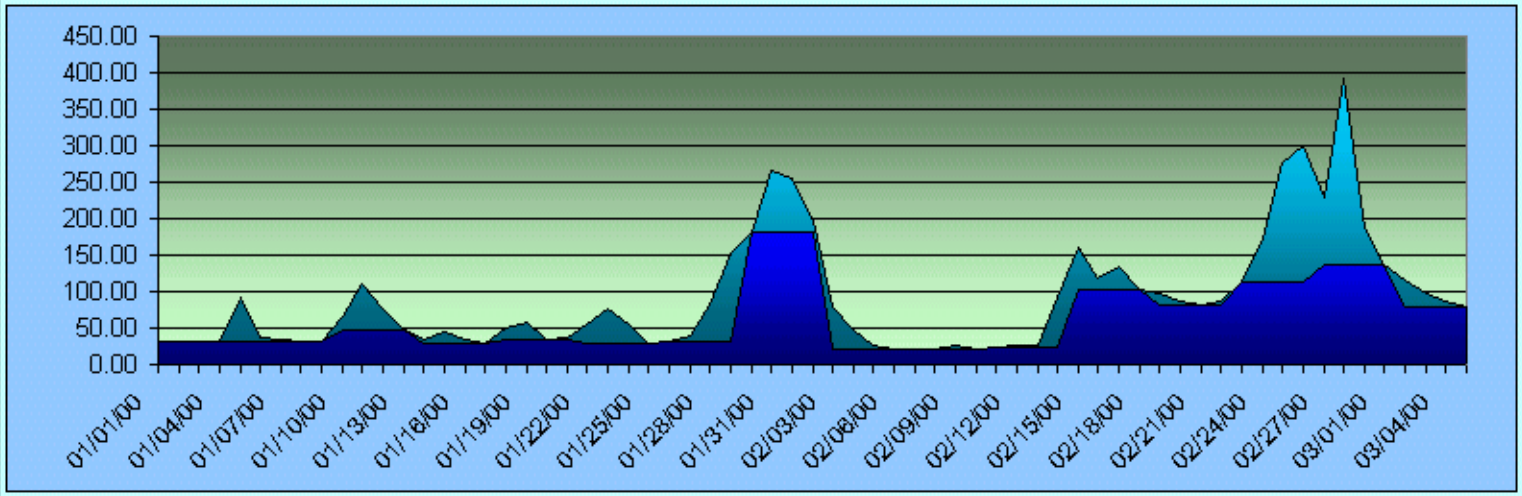
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help

COOKS CREEK STREAM ANALYSIS

1/1/00 - 3/5/00



NEW DATA

PRINT

Time Base

All data		
Annual	1993	
Monthly	1	
Between	01/01/00	03/31/00
Last downlo		

Results

MIN	20.32
AVERAGE	90.36
MAX	392.97
BASEFLOW	68.28%
DIS. RATIO Q25/Q75	1.88

CALIBRATE

CALCULATE

Date	Flow
12/12/90	25
12/13/90	25
12/14/90	23
12/15/90	27
12/16/90	58
12/17/90	31
12/18/90	69
12/19/90	69
12/20/90	38
12/21/90	49
12/22/90	66
12/23/90	65
12/24/90	254
12/25/90	103
12/26/90	61
12/27/90	41
12/28/90	31
12/29/90	27
12/30/90	55
12/31/90	312
01/01/91	125
01/02/91	83
01/03/91	60
01/04/91	43
01/05/91	35
01/06/91	33
01/07/91	31
01/08/91	30
01/09/91	30
01/10/91	29
01/11/91	29
01/12/91	265
01/13/91	139
01/14/91	82
01/15/91	63
01/16/91	315
01/17/91	380
01/18/91	186
01/19/91	123
01/20/91	99
01/21/91	82
01/22/91	69
01/23/91	59
01/24/91	51
01/25/91	42
01/26/91	38
01/27/91	35

Date	Flow
01/28/91	36
01/29/91	34
01/30/91	36
01/31/91	60
02/01/91	35
02/02/91	33
02/03/91	32
02/04/91	32
02/05/91	31
02/06/91	40
02/07/91	101
02/08/91	78
02/09/91	58
02/10/91	45
02/11/91	37
02/12/91	33
02/13/91	31
02/14/91	63
02/15/91	53
02/16/91	35
02/17/91	32
02/18/91	31
02/19/91	35
02/20/91	56
02/21/91	36
02/22/91	33
02/23/91	31
02/24/91	30
02/25/91	30
02/26/91	30
02/27/91	29
02/28/91	28
03/01/91	28
03/02/91	31
03/03/91	41
03/04/91	284
03/05/91	132
03/06/91	92
03/07/91	184
03/08/91	87
03/09/91	67
03/10/91	54
03/11/91	42
03/12/91	37
03/13/91	35
03/14/91	40
03/15/91	62

Date	Flow
03/16/91	57
03/17/91	44
03/18/91	141
03/19/91	125
03/20/91	81
03/21/91	62
03/22/91	52
03/23/91	102
03/24/91	104
03/25/91	78
03/26/91	66
03/27/91	91
03/28/91	82
03/29/91	64
03/30/91	74
03/31/91	56
04/01/91	49
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04/26/91	92
04/27/91	72
04/28/91	58
04/29/91	49
04/30/91	45
05/01/91	38

05/02/91	35
05/03/91	33
05/04/91	31
05/05/91	30
05/06/91	77
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06/14/91	21
06/15/91	20
06/16/91	20
06/17/91	20
06/18/91	20

06/19/91	23
06/20/91	21
06/21/91	19
06/22/91	18
06/23/91	20
06/24/91	20
06/25/91	18
06/26/91	17
06/27/91	16
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07/13/91	21
07/14/91	22
07/15/91	16
07/16/91	14
07/17/91	14
07/18/91	13
07/19/91	13
07/20/91	61
07/21/91	17
07/22/91	15
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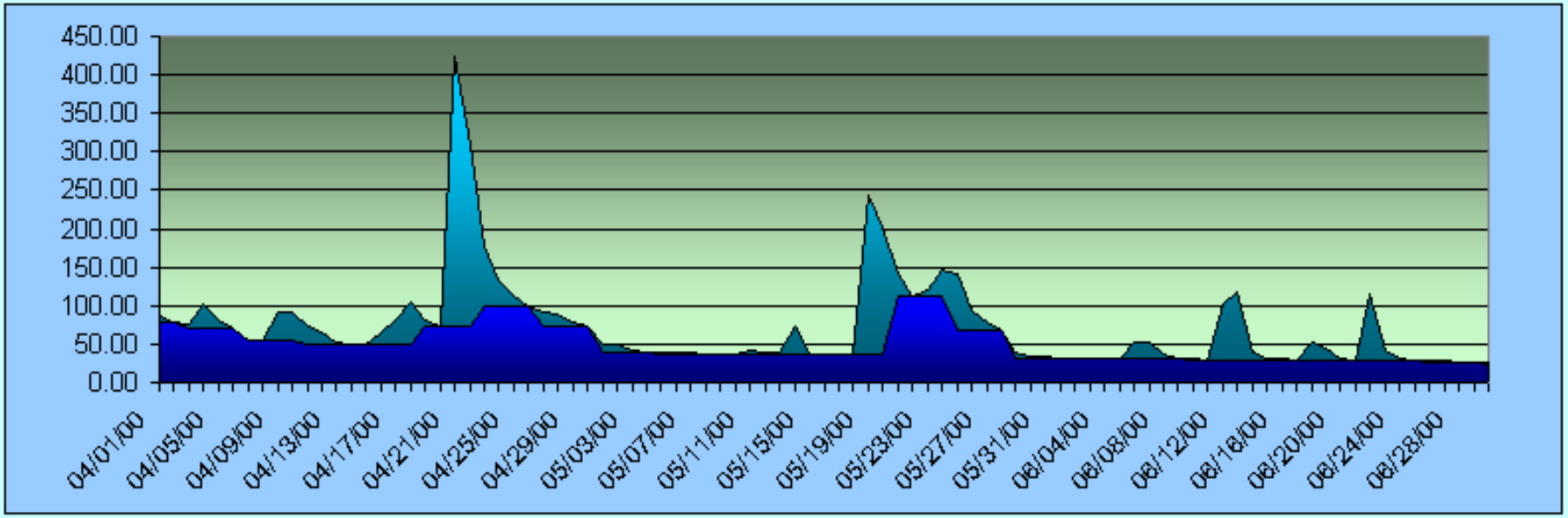
COOKS CREEK STREAM ANALYSIS

4/1/00 - 6/30/00



NEW DATA

PRINT

Time Base

All data		
Annual	2000	
Monthly	9	
Between	04/01/00	06/30/00
Last downloa		

Results

MIN	25.22
AVERAGE	71.64
MAX	423.74
BASEFLOW	68.92%
DIS. RATIO Q25/Q75	1.55

CALIBRATE

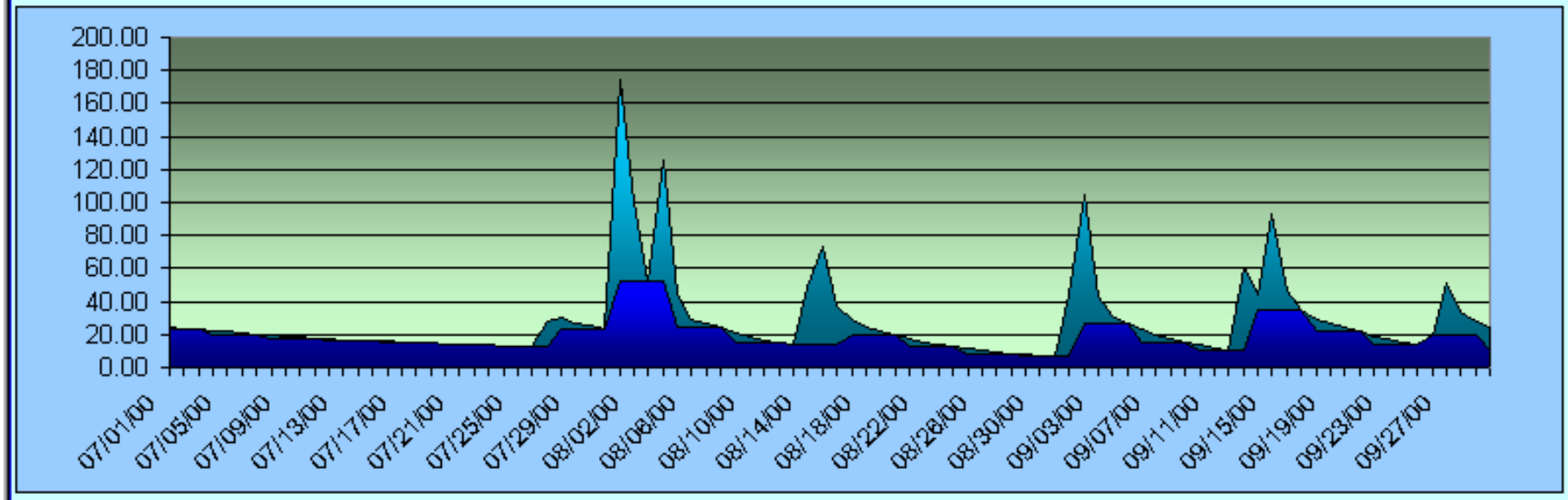
CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-06300

COOKS CREEK STREAM ANALYSIS

7/1/00 - 9/30/00



NEW DATA

PRINT

Time Base

All data		
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Monthly	9	
Between	07/01/00	09/30/00
Last downloa		

Results

MIN	6.75
AVERAGE	28.13
MAX	174.94
BASEFLOW	67.01%
DIS. RATIO Q25/Q75	1.39

CALIBRATE

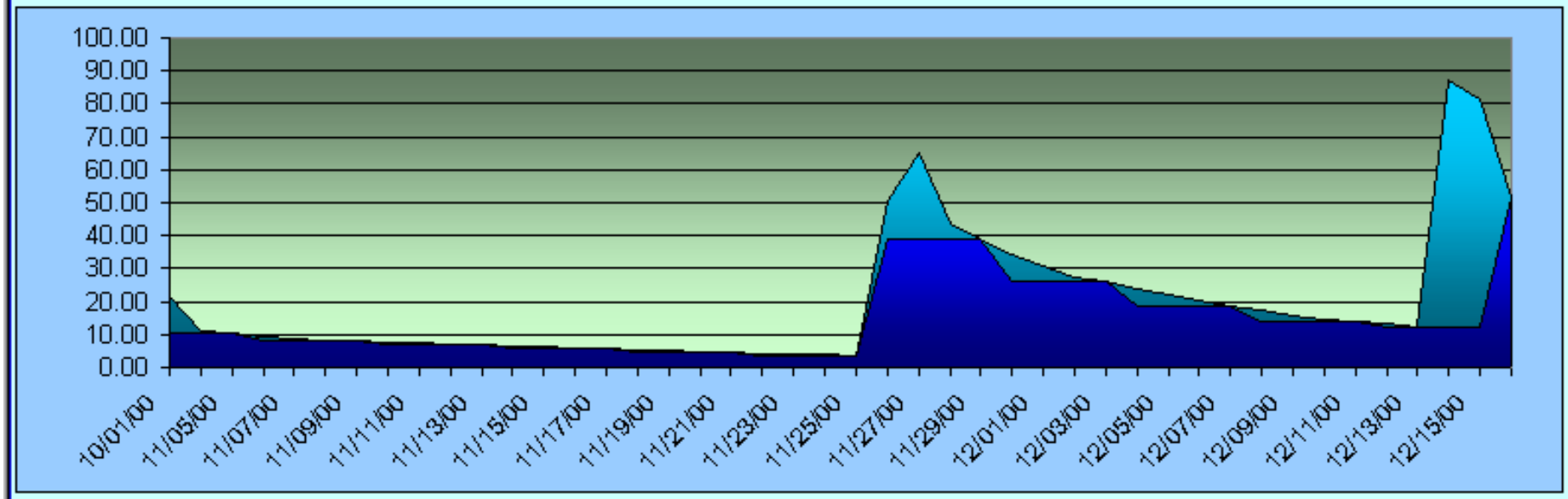
CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-06300

COOKS CREEK STREAM ANALYSIS

10/1/00 - 12/16/00



NEW DATA

PRINT

Time Base

All data		
Annual		2000
Monthly		9
Between	10/01/00	12/16/00
Last downlo		

Results

MIN	3.74
AVERAGE	19.93
MAX	87.47
BASEFLOW	72.60%
DIS. RATIO Q25/Q75	2.01

Category Axis

CALIBRATE

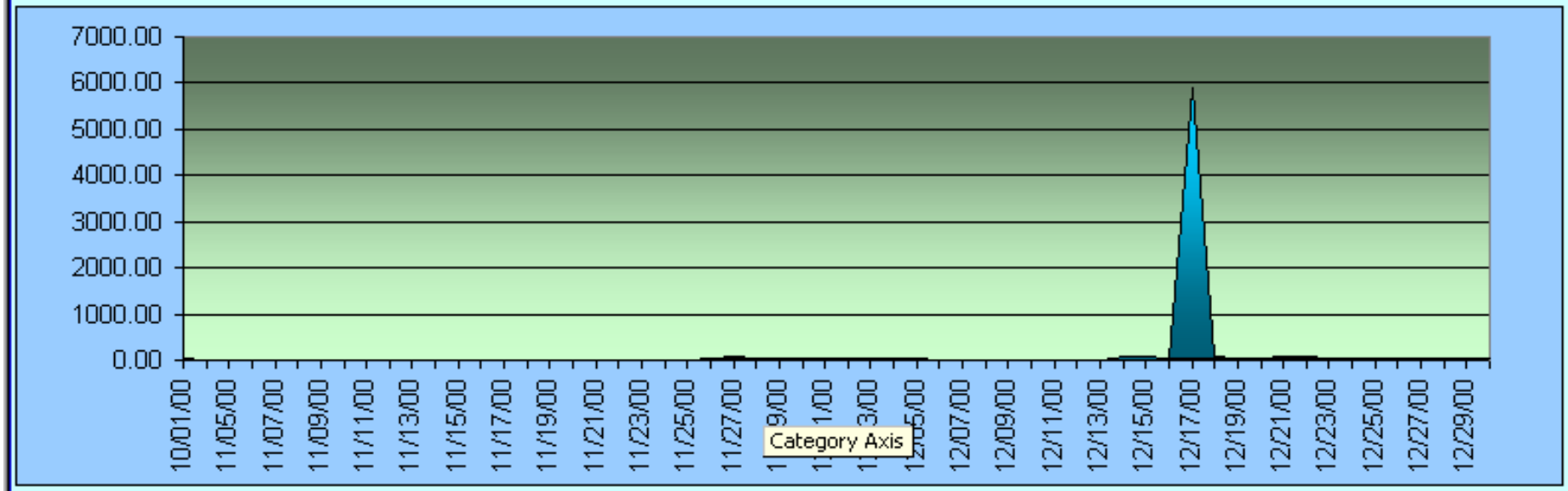
CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-06300

COOKS CREEK STREAM ANALYSIS

10/1/00 - 12/30/00



NEW DATA

PRINT

Time Base

All data		
Annual		2000
Monthly		9
Between	10/01/00	12/30/00
Last downloa		

Results

MIN	3.74
AVERAGE	127.89
MAX	5900.25
BASEFLOW	16.31%
DIS. RATIO Q25/Q75	2.29

CALIBRATE

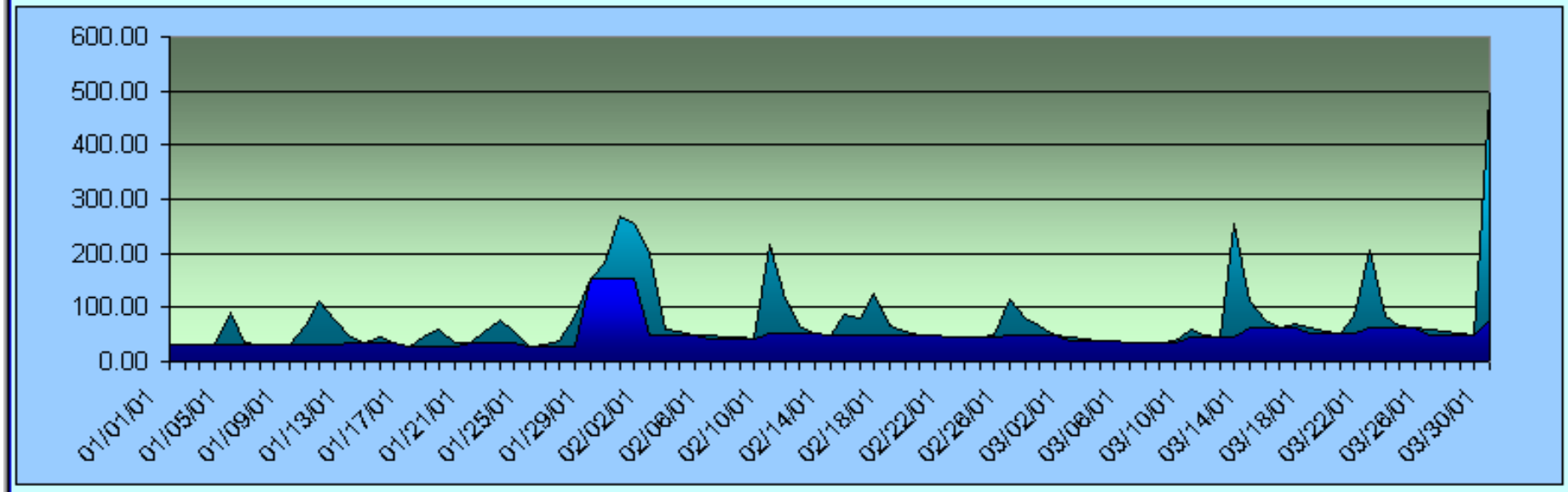
CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-06300

COOKS CREEK STREAM ANALYSIS

1/1/01 - 3/30/01



NEW DATA

PRINT

Time Base

All data		
Annual		2000
Monthly		9
Between	01/01/01	03/30/01
Last downloa		

Results

MIN	28.94
AVERAGE	74.94
MAX	495.41
BASEFLOW	64.55%
DIS. RATIO Q25/Q75	1.36

CALIBRATE

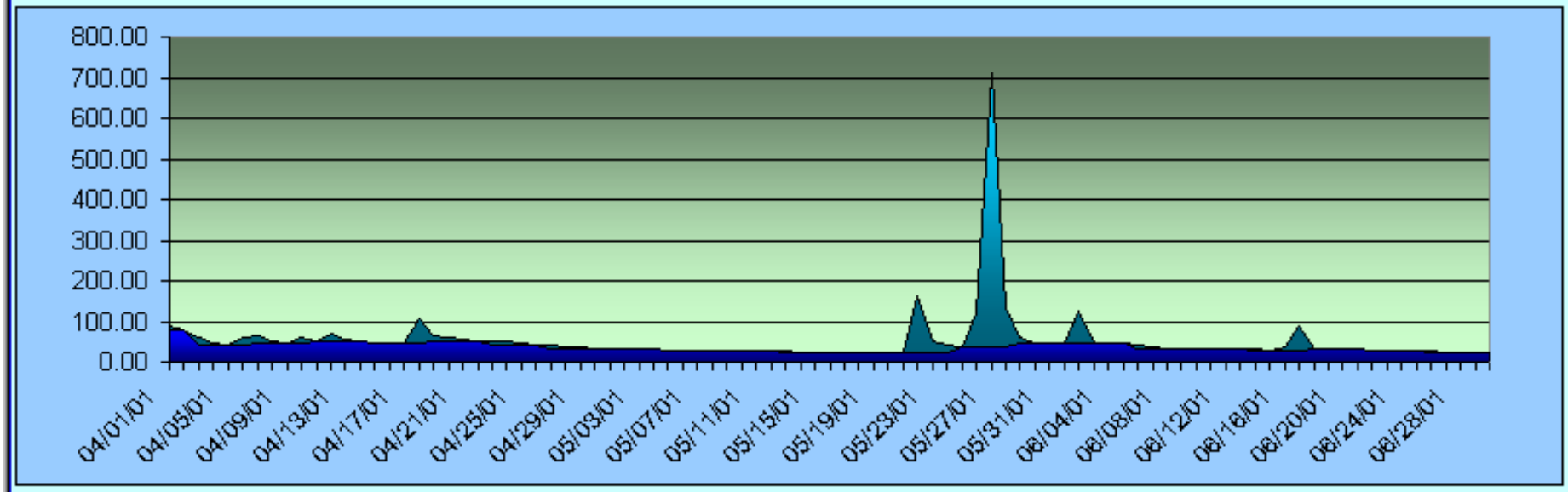
CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-06300

COOKS CREEK STREAM ANALYSIS

4/1/01 - 6/30/01



NEW DATA

PRINT

Time Base

All data		
Annual	2000	
Monthly	9	
Between	04/01/01	06/30/01
Last downloa		

Results

MIN	22.29
AVERAGE	52.41
MAX	713.61
BASEFLOW	68.59%
DIS. RATIO Q25/Q75	1.33

CALIBRATE

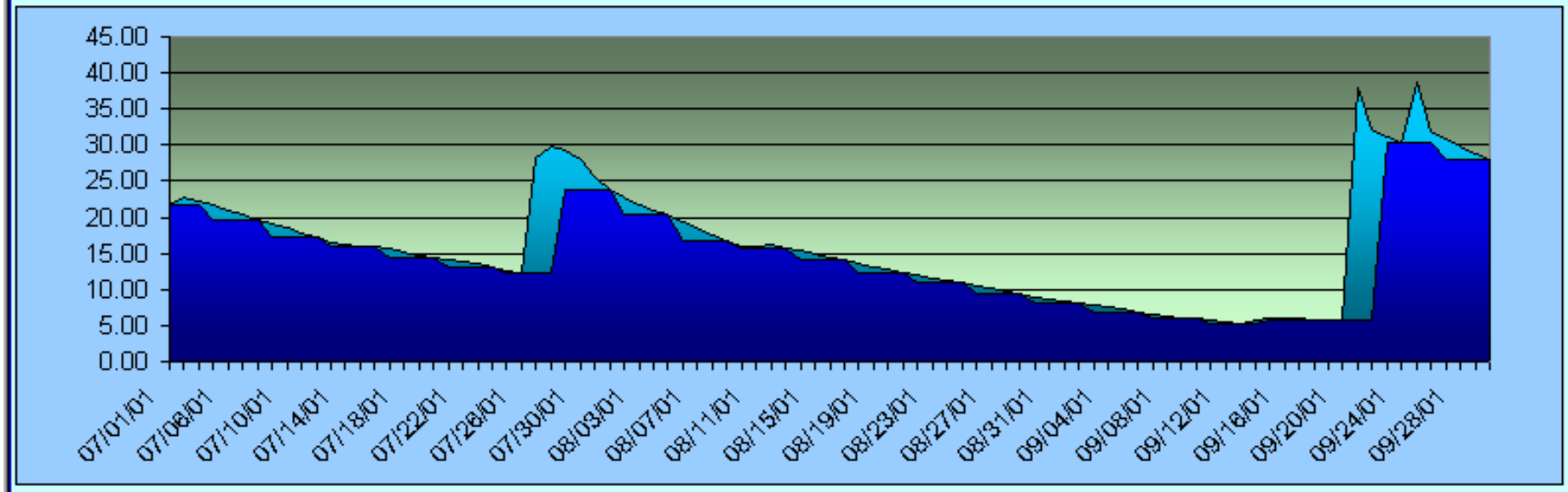
CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-06300

COOKS CREEK STREAM ANALYSIS

7/1/01 - 9/30/01



NEW DATA

PRINT

Time Base

All data		
Annual	2000	
Monthly	9	
Between	07/01/01	09/30/01
Last downloa		

Results

MIN	5.26
AVERAGE	16.20
MAX	38.63
BASEFLOW	88.95%
DIS. RATIO Q25/Q75	1.47

CALIBRATE

CALCULATE

05/06/00	39.35
05/07/00	38.24
05/08/00	37.90
05/09/00	37.47
05/10/00	37.52
05/11/00	41.70
05/12/00	38.75
05/13/00	38.48
05/14/00	74.12
05/15/00	36.58
05/16/00	36.46
05/17/00	36.37
05/18/00	36.34
05/19/00	244.58
05/20/00	200.52
05/21/00	139.98
05/22/00	111.92
05/23/00	120.07
05/24/00	145.66
05/25/00	141.76
05/26/00	94.47
05/27/00	79.32
05/28/00	67.30
05/29/00	38.89
05/30/00	34.70
05/31/00	33.38
06/01/00	32.55
06/02/00	32.66
06/03/00	31.83
06/04/00	31.33
06/05/00	31.18
06/06/00	51.41
06/07/00	51.49
06/08/00	36.70
06/09/00	31.47
06/10/00	30.59
06/11/00	29.75
06/12/00	101.19
06/13/00	117.77
06/14/00	40.33
06/15/00	31.22
06/16/00	30.52
06/17/00	29.80
06/18/00	52.18
06/19/00	43.29
06/20/00	31.24
06/21/00	29.95
06/22/00	113.92

06/23/00	42.93
06/24/00	31.30
06/25/00	29.94
06/26/00	28.70
06/27/00	27.55
06/28/00	26.62
06/29/00	25.70
06/30/00	25.22
07/01/00	24.40
07/02/00	23.57
07/03/00	22.82
07/04/00	22.29
07/05/00	21.72
07/06/00	20.99
07/07/00	20.31
07/08/00	19.62
07/09/00	18.98
07/10/00	18.47
07/11/00	17.87
07/12/00	17.15
07/13/00	16.54
07/14/00	16.20
07/15/00	16.05
07/16/00	15.92
07/17/00	15.69
07/18/00	15.24
07/19/00	14.68
07/20/00	14.44
07/21/00	14.01
07/22/00	13.89
07/23/00	13.56
07/24/00	13.04
07/25/00	12.61
07/26/00	12.23
07/27/00	28.36
07/28/00	29.76
07/29/00	27.29
07/30/00	25.30
07/31/00	23.53
08/01/00	174.94
08/02/00	100.30
08/03/00	52.83
08/04/00	125.62
08/05/00	44.10
08/06/00	29.45
08/07/00	26.67
08/08/00	23.99
08/09/00	20.78

08/10/00	18.40
08/11/00	16.22
08/12/00	14.71
08/13/00	13.66
08/14/00	49.15
08/15/00	73.61
08/16/00	37.44
08/17/00	28.97
08/18/00	24.95
08/19/00	21.84
08/20/00	19.22
08/21/00	17.01
08/22/00	15.19
08/23/00	13.74
08/24/00	12.73
08/25/00	11.64
08/26/00	10.59
08/27/00	9.55
08/28/00	8.66
08/29/00	8.03
08/30/00	7.30
08/31/00	6.75
09/01/00	44.39
09/02/00	104.48
09/03/00	42.61
09/04/00	31.37
09/05/00	27.00
09/06/00	23.29
09/07/00	20.10
09/08/00	17.55
09/09/00	14.99
09/10/00	13.72
09/11/00	12.15
09/12/00	10.79
09/13/00	60.54
09/14/00	43.76
09/15/00	92.95
09/16/00	46.84
09/17/00	34.58
09/18/00	29.33
09/19/00	26.26
09/20/00	23.93
09/21/00	21.59
09/22/00	19.13
09/23/00	17.01
09/24/00	15.51
09/25/00	14.11
09/26/00	20.13

09/27/00	50.69
09/28/00	33.40
09/29/00	27.60
09/30/00	23.94
10/01/00	21.64
11/04/00	10.81
11/05/00	10.22
11/06/00	9.50
11/07/00	8.89
11/08/00	8.36
11/09/00	7.97
11/10/00	7.80
11/11/00	7.70
11/12/00	7.23
11/13/00	6.82
11/14/00	6.48
11/15/00	6.22
11/16/00	5.92
11/17/00	5.63
11/18/00	5.30
11/19/00	5.03
11/20/00	4.79
11/21/00	4.55
11/22/00	4.33
11/23/00	4.10
11/24/00	3.90
11/25/00	3.74
11/26/00	50.46
11/27/00	64.95
11/28/00	43.77
11/29/00	38.85
11/30/00	34.23
12/01/00	30.63
12/02/00	27.51
12/03/00	26.11
12/04/00	23.92
12/05/00	22.07
12/06/00	20.38
12/07/00	18.77
12/08/00	17.37
12/09/00	15.98
12/10/00	14.79
12/11/00	13.97
12/12/00	13.19
12/13/00	12.12
12/14/00	87.47
12/15/00	81.64
12/16/00	51.98

12/17/00	5900.25
12/18/00	73.73
12/19/00	53.58
12/20/00	52.50
12/21/00	98.34
12/22/00	70.50
12/23/00	44.90
12/24/00	40.49
12/25/00	36.59
12/26/00	36.37
12/27/00	35.81
12/28/00	33.54
12/29/00	32.41
12/30/00	31.50
12/31/00	32.38
01/01/01	31.50
01/02/01	31.25
01/03/01	32.25
01/04/01	32.16
01/05/01	90.91
01/06/01	36.27
01/07/01	33.12
01/08/01	32.36
01/09/01	31.86
01/10/01	65.90
01/11/01	110.58
01/12/01	75.62
01/13/01	46.55
01/14/01	33.67
01/15/01	43.74
01/16/01	33.63
01/17/01	28.94
01/18/01	49.17
01/19/01	57.64
01/20/01	34.56
01/21/01	35.62
01/22/01	54.38
01/23/01	77.08
01/24/01	56.15
01/25/01	29.27
01/26/01	32.58
01/27/01	38.82
01/28/01	82.25
01/29/01	153.73
01/30/01	181.11
01/31/01	267.00
02/01/01	254.88
02/02/01	197.25

02/03/01	61.03
02/04/01	54.13
02/05/01	49.03
02/06/01	47.29
02/07/01	45.85
02/08/01	44.06
02/09/01	42.83
02/10/01	217.90
02/11/01	116.13
02/12/01	64.81
02/13/01	53.58
02/14/01	49.10
02/15/01	86.26
02/16/01	81.82
02/17/01	125.72
02/18/01	67.66
02/19/01	55.22
02/20/01	50.34
02/21/01	47.79
02/22/01	46.24
02/23/01	45.35
02/24/01	44.11
02/25/01	47.63
02/26/01	116.69
02/27/01	81.00
02/28/01	65.41
03/01/01	49.58
03/02/01	44.53
03/03/01	41.96
03/04/01	39.95
03/05/01	38.20
03/06/01	36.33
03/07/01	34.70
03/08/01	34.51
03/09/01	37.96
03/10/01	60.25
03/11/01	47.67
03/12/01	44.30
03/13/01	255.33
03/14/01	113.29
03/15/01	75.99
03/16/01	64.18
03/17/01	68.81
03/18/01	62.72
03/19/01	56.20
03/20/01	52.44
03/21/01	84.89
03/22/01	206.00

03/23/01	84.78
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04/01/01	90.41
04/02/01	77.07
04/03/01	60.62
04/04/01	47.67
04/05/01	43.82
04/06/01	59.22
04/07/01	62.96
04/08/01	50.68
04/09/01	46.98
04/10/01	62.04
04/11/01	52.19
04/12/01	70.97
04/13/01	57.55
04/14/01	50.24
04/15/01	47.13
04/16/01	47.74
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04/20/01	59.72
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05/11/01	26.62
05/12/01	26.23
05/13/01	25.78
05/14/01	25.29
05/15/01	24.94
05/16/01	24.51
05/17/01	24.10
05/18/01	23.76
05/19/01	23.55
05/20/01	23.09
05/21/01	22.87
05/22/01	164.96
05/23/01	51.55
05/24/01	41.05
05/25/01	37.43
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05/28/01	133.86
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06/14/01	30.49
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06/16/01	37.72
06/17/01	89.36
06/18/01	34.36
06/19/01	31.79
06/20/01	31.10
06/21/01	30.36
06/22/01	29.72
06/23/01	29.01
06/24/01	28.28
06/25/01	27.30
06/26/01	26.10

06/27/01	25.06
06/28/01	24.10
06/29/01	23.14
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07/06/01	20.99
07/07/01	20.31
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07/09/01	18.98
07/10/01	18.47
07/11/01	17.87
07/12/01	17.15
07/13/01	16.54
07/14/01	16.20
07/15/01	16.05
07/16/01	15.92
07/17/01	15.69
07/18/01	15.24
07/19/01	14.68
07/20/01	14.44
07/21/01	14.01
07/22/01	13.89
07/23/01	13.56
07/24/01	13.04
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07/26/01	12.23
07/27/01	28.36
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07/31/01	25.72
08/01/01	23.81
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08/21/01	12.37
08/22/01	11.92
08/23/01	11.52
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08/28/01	9.77
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08/30/01	8.99

08/31/01	8.68
09/01/01	8.45
09/02/01	8.05
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09/18/01	5.81
09/19/01	5.72
09/20/01	5.66
09/21/01	37.98
09/22/01	32.15
09/23/01	31.22
09/24/01	30.28
09/25/01	38.63
09/26/01	31.94
09/27/01	30.76
09/28/01	29.78
09/29/01	28.76
09/30/01	27.92

File Edit View Insert Format Tools Data Window Help Send

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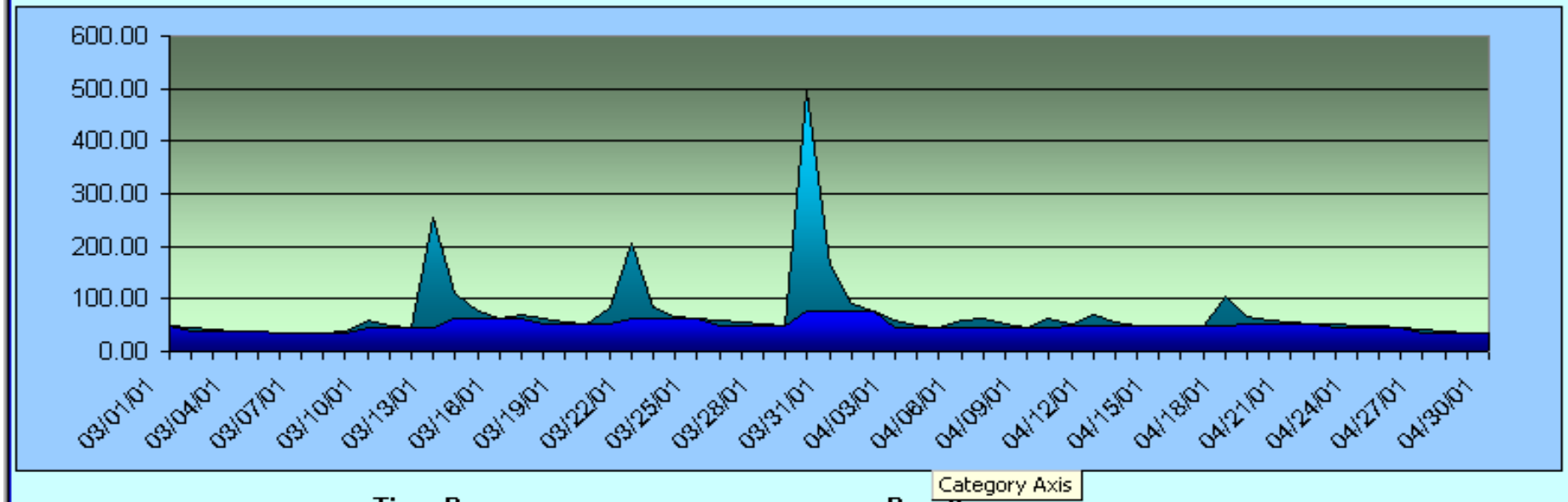
COOKS CREEK STREAM ANALYSIS

3/1/01 - 4/30/01



NEW DATA

PRINT

Time Base

All data		
Annual	2000	
Monthly	3	
Between	03/01/01	04/30/01
Last downloa		

Results

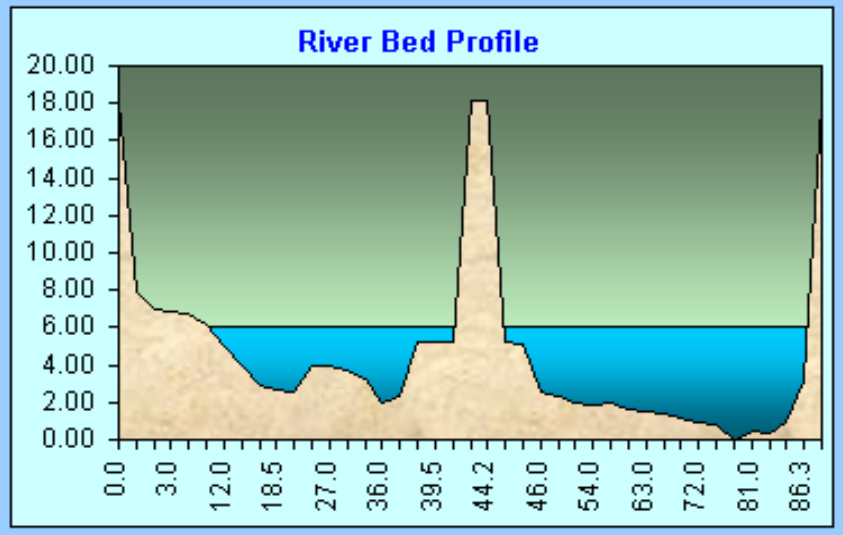
MIN	33.88
AVERAGE	70.34
MAX	495.41
BASEFLOW	70.18%
DIS. RATIO Q25/Q75	1.18

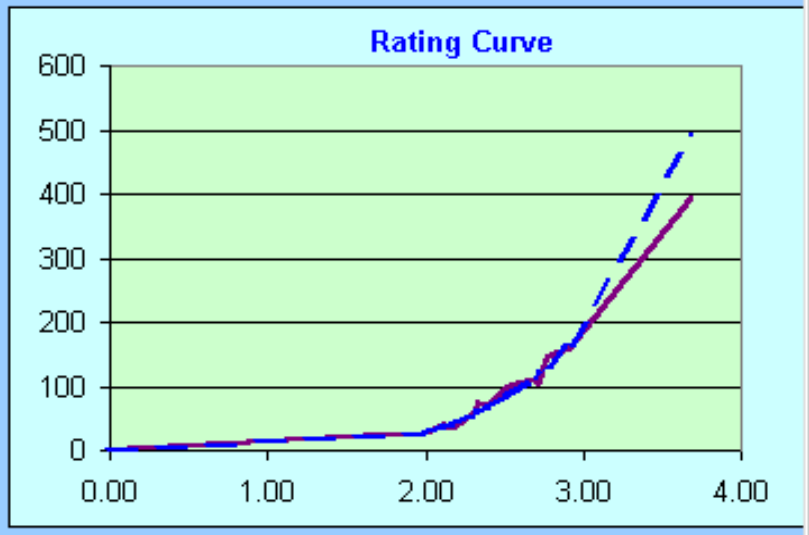
CALIBRATE

CALCULATE

File Edit View Insert Format Tools Data Window Help Send

Favorites Go C:\Projects\00-0023-DurhamRivers\Wamos\WAMOS 2.1R-F-09300





General Parameters

Flood Cross Sect. Area [ft^2]	1353.24
Drainage Area [mi^2]	30

Corelation Parameters

$Q = aH^b$	a =	1.1063
	b =	4.6725

River Bed Profile

Measurement Point	40
Distance from Ref. Point [ft]	86.26
Level on Staff Gage [ft]	0.00

Insert Point

Remove Point

Number of Measurement Points	41
River Bed Width [ft]	86.26
Highest Level Value [ft]	18.17

WATER BUDGET
(P=SF+dGWS+ET+GP)

SAMPLE DATA

ANALYSIS

USGS
science for a changing world

Potential Environmental Impacts of Quarrying Stone in Karst—A Literature Review

U.S. Geological Survey
Open-File Report OF-01-0484

U.S. Department of the Interior
U.S. Geological Survey

Potential Environmental Impacts of Quarrying Stone in Karst—A Literature Review

By William H. Langer

Open-File Report OF–01–0484

2001

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey (USGS) editorial standards nor with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the USGS.

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

Version 1.0 2002

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Layout and cover design by Carol Quesenberry

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Natural Formation of Karst 2
Quarrying Carbonate Rocks 6
Production and Use of Carbonate Rocks 7
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Potential Environmental Impacts of Quarrying Stone in Karst—A Literature Review

By William H. Langer

Introduction

Limestone, dolomite, and marble - the carbonate rocks - are the principal karst-forming rocks. Karst is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution that is characterized by sinkholes, caves, and underground drainage regions. Karst areas constitute about 10 percent of the land surface of the world (fig. 1) (Drew, 1999), and there is widespread concern for the effects that human activities have upon the karst environment. Much of the concern is motivated by the adverse environmental impacts of previous human activities in karst areas and the effects that those impacts have had on the quality of life. Many human activities can negatively impact karst areas, including deforestation, agricultural practices, urbanization, tourism, military activities, water exploitation, mining, and quarrying (Drew, 1999) (fig. 2).

Minerals associated with karst have been exploited for many years. Some carbonate rocks contain valuable supplies of water, oil, and gas, may weather to form bauxite deposits, and are associated with manganese and phosphate rock (guano). Coal is often found within thick carbonate rock sequences. Like other rocks, karst rocks may host ore deposits containing lead, zinc, iron, and gold.

Much of the resource extraction conducted in areas of karst is for the rock itself. Unweathered carbonate rocks provide crushed stone and dimension stone resources. The term “crushed stone” refers to the product resulting from the crushing of rocks such that substantially all faces are created by the crushing operation (ASTM, 2000). The term “dimension stone” is generally applied to masses of stone, either naturally occurring or prepared for use in the form of blocks of specified shapes and sizes, that may or may not have one or more mechanically dressed surface (Bowles, 1939: ASTM, 1998).

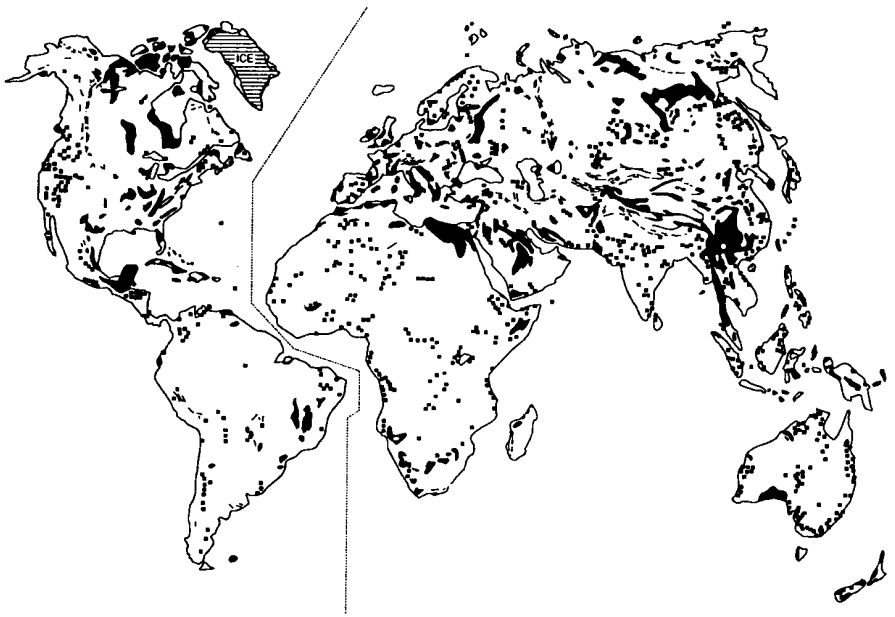

Figure 1. Major worldwide outcrops of carbonate rocks that exhibit at least some karstification *(after Ford and Williams, 1989).*

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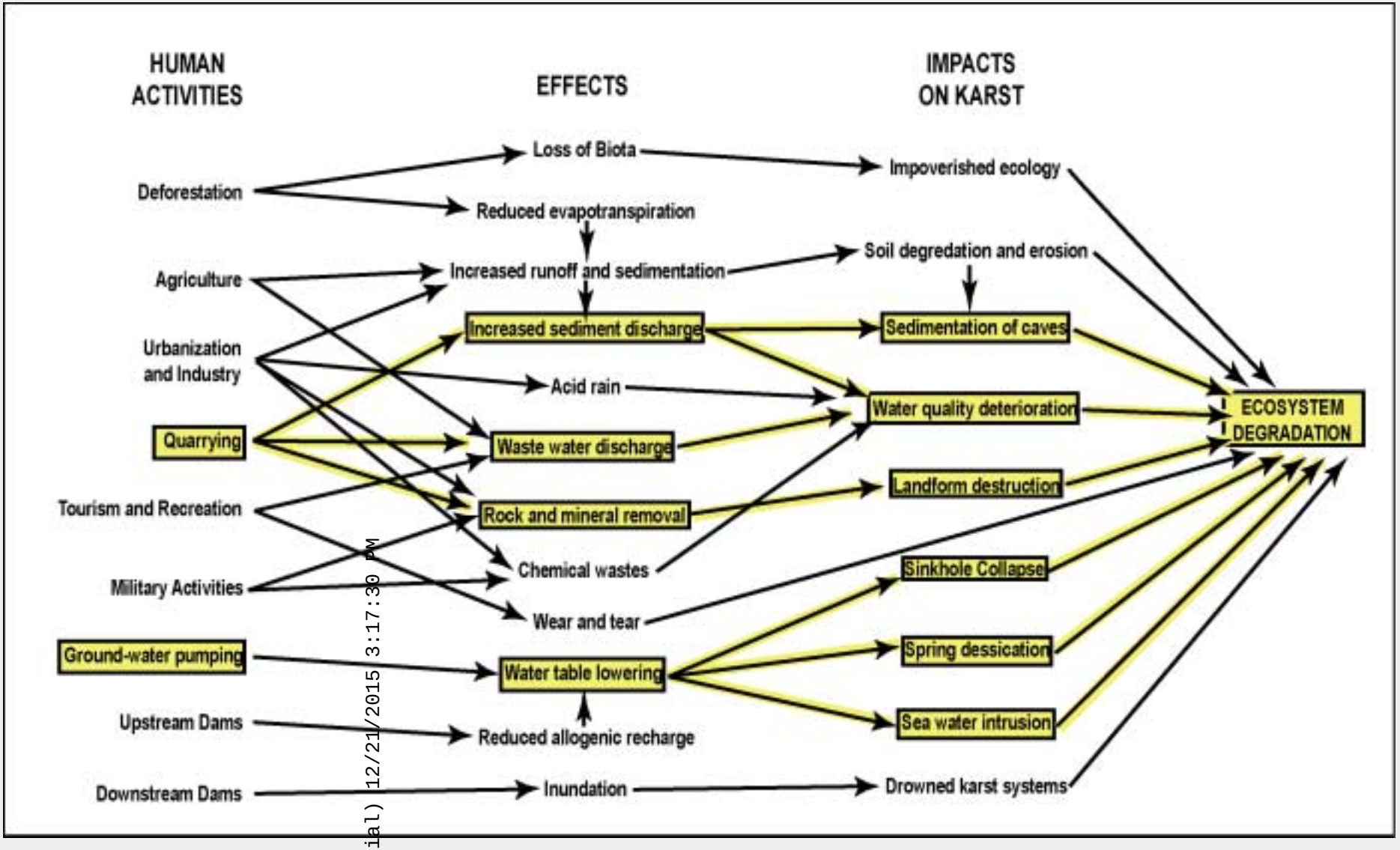

Figure 2. Summary of effects and impacts of various human activities on karst terrains. Effects and impacts from quarrying are highlighted in yellow. *(Modified from Williams, 1993a.)*

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Carbonate rocks provide dimension stone, aggregate resources, and raw materials for cement and other industrial and agricultural uses. Over 70 percent of crushed stone produced in the United States is made from carbonate rock. The products derived from carbonate rocks provide essential materials for society –materials that we need to maintain our current standard of living. Quarrying[1] carbonate rocks for use as crushed stone and dimension stone can be accomplished with no significant impacts to the environment, if done carefully and within the limits set by nature. However, if proper precautions are not taken many human activities in karst, including extraction of carbonate rocks, can result in damage to the environment and associated increases in costs for environmental compliance or liability.

Purpose

This report describes the state-of-the-knowledge regarding the environmental impacts from quarrying carbonate rocks in karst. Documentation of the relationships between carbonate rock quarries and environmental problems in karst has existed for nearly fifty years, but is scarce. There are numerous articles in the literature that describe environmental impacts on karst from human activities other than quarrying, but there are relatively few articles that specifically refer to impacts from quarrying.

[1]In this report, the term "quarrying" applies to both surface quarries and underground mines from which cabonate rocks are extracted.

The reported environmental impacts have occurred in a wide variety of karst terrains, under a wide variety of climatic conditions, where the natural systems have been stressed by a wide variety of human activities. It should not be assumed that impacts in one karst terrain under a particular set of natural and man-made conditions will also happen in a different karst terrain with a different set of natural and man-made conditions.

Previous work

In recent years numerous publications have addressed issues related to karst in general, as well as issues specifically related to human impacts on karst. Publications addressing human impacts on karst include a special supplement of the journal Catena entitled Karst Terraines: Environmental Changes and Human Impact (Williams, 1993); a special issue of Environmental Geology with the theme of addressing Environmental Change in Karst Areas (Ford, 1993); a special issue of Engineering Geology with the theme Sinkholes and the Engineering and Environmental Impacts of Karst (Beck, 1999), and the publication Karst Hydrogeology and Human Activities (Drew and Hötzl, 1999). The Florida Sinkholes Research Institute has held symposiums concerned with sinkholes in karst at approximately two-year intervals (Beck, 1984, 1989, 1993; Beck and Pearson, 1995; Beck and Stephenson, 1997; Beck and Wilson, 1987; Beck and others, 1999). The American Geological Institute Environmental Awareness Series 4, Living With Karst, is a non-technical discussion of environmental issues in karst (Veni and DuChene, 2001). Few of the reports in the publications listed above are primarily concerned with quarrying in karst; however, those publications do illustrate the complexities of cause and effects of human activities in karst.

Although a relationship between environmental damage and quarrying of carbonate rock has been well documented for over fifty years (Foose, 1953), there are only a few reports that include major discussions of the environmental impacts of quarrying in karst. These reports include *Development of Sinkholes Resulting from Man's Activities in the Eastern United States* (Newton, 1987), *Ground Subsidence*, which includes a chapter *Sinkholes on Limestones* (Waltham, 1989), and *Karst Hydrogeology and Human Activities* (Drew and Hötzl, 1999), which includes a chapter on *Extractive Industries Impact* (Hess and Slattery, 1999). There are a few individual reports scattered through the literature that address the environmental impacts of quarrying carbonate rocks in karst. In addition, there are reports that describe environmental impacts on karst from mining resources other than carbonate rock. Theories about how extraction of carbonate rock can impact the environment can be extrapolated from some of these reports.

Natural Formation of Karst

There is a tremendous variety of carbonate rocks and these rocks exist in a broad range of climatic situations. Weathering of carbonate rocks produces diverse types of karst landscapes (fig. 3), far too many types to be described here. Instead, this report gives a simplified description of the karst forming processes. Readers interested in learning the details of karst formation are encouraged to consult the numerous textbooks and research reports that describe the geohydrologic and geomorphic processes involved with karst development. For example, Karst Geomorphology (Sweeting, 1981) contains benchmark papers about karst, including excerpts from Das Karstphänomen (Cvijíc, 1893). Process geomorphology (Ritter and others, 1995), a recent textbook, discusses karst from a process / response perspective. Karst Geomorphology (Jennings, 1985) is a technical description of karst written for the non-scientific audience. Karst Lands (White and others, 1995) is a concise article in American Scientist that describes karst formation and hydrology. Sinkholes in Pennsylvania (Kochanov, 1999) is a non-technical description of karst prepared for non-scientific audiences. The International Geographical Union Commission on Sustainable Development and Management of Karst Terrains published eight annotated bibliographies of karst research studies (for example, Urushibara-Yoshino, 2000).

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Natural karst processes occur gradually over hundreds to thousands of years. The formation of karst includes interactions between carbonate rocks and slightly acidic water. (Actually karst can form on other soluble rocks such as gypsum; however, this report is restricted to carbonate rocks.) Carbonic acid is a mild acid formed when rainwater and carbon dioxide react. As the rainwater passes through the soil, the water absorbs more carbon dioxide and becomes more acidic. Carbonate rock contains openings between beds of rock and as fractures or joints created when the rocks were uplifted, uncovered, faulted, or folded (fig. 4). The slightly acidic water percolates into the rocks through these openings. The openings are enlarged by solvent action of acidic water. The dissolution process is self-accelerating: openings that are enlarged first will transmit more water, thus increasing the rate that acid is brought into contact with the rock, resulting in additional enlargement of the openings.

As underground flow paths controlled by joints, fractures, and bedding planes continue to enlarge over time, water movement changes from small volumes through many small, scattered openings in the rock to concentrated flow through a few well-developed conduits. As flow paths continue to enlarge, caves, conduits, and sinkholes may be formed (fig. 5). Surface streams may lose water to the subsurface or flow into cave entrances, only to reappear many miles away.

Figure 3. Shallow sinkhole typical of karst terrain in Cherokee County, Kansas. *(USGS photographic library - Pierce # 339, 340.)*

Unusual bedrock surfaces may be created as the carbonate rock is dissolved (fig. 6a and 6b). In temperate climates, some of the surfaces resemble abstract sculptures or contain pointed columns called pinnacles. A residual soil forms over the bedrock because there are minerals within limestone that are not affected by carbonic acid. As the process of dissolution continues, these insoluble minerals collect on top of the bedrock surface as clayey residual material. Some residual material is carried by water into openings in bedrock where they clog the openings. Other material, such as stream alluvium, may overly the clay. Depending on the climate, topography, and type of parent bedrock, soil on the bedrock surface can be non-existent or greater than 50 m thick.

Figure 4. Dimension stone quarry showing weathered outcrop (top) and smooth working face of quarry. Vertical solution channels following fractures and joints in the weathered outcrop extend down into the smooth working face. Horizontal solution features occur between beds of the rock. Notice ladder for scale. *(USGS photographic library - Loughlin 154.)*

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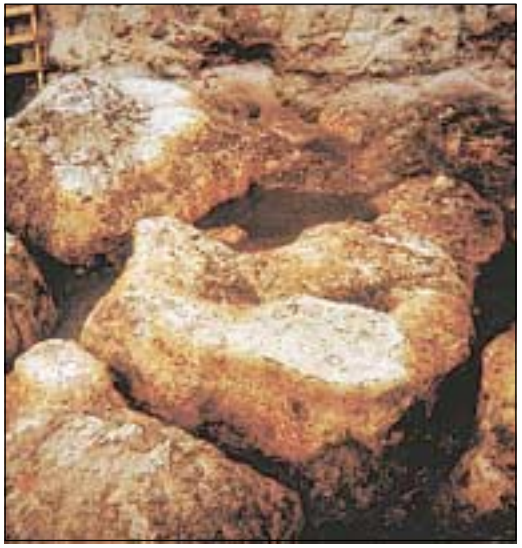

Figure 5 (above). Cave opening in karst terrain, Škocjan Cave, Slovenia.

Figure 6-a (right). Limestone surface in karst area with no soil cover.

Figure 6-b (far right, top and bottom). Removal of overburden has exposed the furrowed and pitted surface of carbonate rock. *(Photograph courtesy of Keith Bennett, Williams Earth Sciences, Inc.)*

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Quarrying Carbonate Rocks

The general objective of dimension-stone quarrying is to produce large rectangular blocks suitable for cutting into smaller, regularly-shaped products. The quarrying operation cuts a block of stone free from the bedrock mass by first separating the block on all four vertical sides and then undercutting or breaking the block away from the bedrock (fig. 7). Two of the oldest methods for quarrying are channel cutting and drilling and broaching. A channeling machine cuts a channel in the rock using multiple chisel-edged cutting bars that cut with a chopping action. In drilling and broaching, a drilling tool first drills numerous holes in an aligned pattern. The broaching tool then chisels and chops the web between the drill holes, freeing the block. Both channel cutting and drilling and broaching are slow and the cutting tool requires frequent sharpening. Both methods have generally been replaced with other more efficient methods.

Line drilling and sawing are more modern techniques for quarrying. Line drilling (also called slot drilling) consists of drilling a series of overlapping holes using a drill that is mounted on a quarry bar or frame that aligns the holes and holds the drill in position. Sawing can be accomplished with a variety of saws including wire saws, belt saws, and chain saws. The introduction of synthetic-diamond tools during the 1960's revolutionized stone working. A variety of explosive techniques may also be used to quarry dimension stone, but explosives generally are used in very small amounts, if at all, to avoid fracturing the stone block.

The general objective of crushed stone quarrying is to produce relatively small pieces of rock that are suitable for crushing into gravel-sized particles (fig. 8). To produce crushed stone, the rock is first drilled and blasted. Blasting commonly breaks the rock into pieces suitable for crushing. When the blasted material is dry, it can be extracted by using conventional earth-moving equipment, such as bulldozers, front loaders, track hoes, and scraper graders. Rock quarries that do not penetrate the water table, or where discharge from the water table naturally drains from the quarry, is offset by evaporation, or is otherwise insignificant, commonly are mined dry.

Figure 7. Working face of dimension stone limestone quarry in Lawrence County, Indiana, showing smooth surfaces from which large blocks have been removed. *(USGS photographic library – Burchard #556.)*

Where rock quarries penetrate the water table, the quarries commonly are dewatered by collection and pumping of the ground water. The rock is then mined by the procedures used in a dry quarry. Some operators may prefer not to dewater the quarry, or the inflow may be too great to be pumped. In those operations, the quarries are allowed to fill with water. The rock is drilled and blasted, and the rubble is extracted from under the water using draglines, clamshells, or other equipment. The aggregate may be processed wet or may be placed in windrows and allowed to dry before processing.

Carbonate rock is extracted from about 100 underground mines in the United States. Most of these mines are located in the Mid-Continent and produce crushed stone.

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Figure 8. Working face of crushed stone operation showing rubble created by blasting. *(Photograph courtesy Luck Stone.)*

Production and Use of Carbonate Rocks

Worldwide production of carbonate rocks ranks third in terms of volume and fourth in terms of value for all non-fuel mineral commodities (fig. 9) (Lüttig, 1994). Over 70 percent of the crushed stone produced in the United States comes from carbonate rock, and about three fourths of that is consumed by the construction industry. Crushed carbonate rock also has numerous agriculture and industrial uses. Agricultural uses include fertilizers and insecticides. Industrial uses include the manufacture of cement, pharmaceuticals, processed food, glass, plastics, floor coverings, paper, rubber, leather, synthetic fabrics, glue, ink, crayons, shoe polish, cosmetics, chewing gum, toothpaste, and antacids. During 1999, over one billion tons of crushed limestone, dolomite, and marble valued at over $5.5 billion were produced from about 2,200 quarries operating in 48 states. The top 10 states (in decreasing order of production) each produced over 45 millions tons of crushed carbonate rocks – Texas, Florida, Illinois, Ohio, Missouri, Pennsylvania, Tennessee, Kentucky, Indiana, and Alabama (Tepordei, 1999). All of these states contain areas of karst.

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Dimension stone has a large number of uses ranging from rustic walls and roughly-shaped paving stones to highly polished floor tile, counter tops, and building facades. The final use of the stone, as well as the methods to quarry and mill the stone, depend on the properties of the source rock. Today, stone is considered by many to be the premier building material and is experiencing resurgence in use for commercial and residential construction. During 1999, dimension limestone or dolomite were extracted from 33 quarries in 10 States. Production was 446,000 metric tons valued at $74.9 million. The top five producing states, in descending order by tonnage, were Indiana, Wisconsin, Texas, Minnesota, and Kansas. Other states producing dimension limestone or dolomite include Alabama, Arkansas, California, Ohio, and Vermont. Marble was extracted from 11 quarries in 5 states. Production was 40,300 metric tons valued at $9.5 million. Vermont was the leading producing State, followed by Tennessee, Georgia, Colorado, and Arkansas (Dolley, 1999).

Potential Environmental Impacts

Modern technology and scientific investigation methods have made it possible to reduce environmental impacts associated with extraction of carbonate rocks and manage impacts at acceptable levels that do not cause significant harm to the environment. Nevertheless, carbonate rock resources cannot be obtained from the landscape without causing some environmental impacts.

Engineering Impacts

Some of the environmental disturbance created by quarrying is caused directly by engineering activities during aggregate extraction and processing. The most obvious engineering impact of quarrying is a change in geomorphology and conversion of land use, with the associated change in visual scene. This major impact may be accompanied by loss of habitat, noise, dust, vibrations, chemical spills, erosion, sedimentation, and dereliction of the mined site. Some of the impacts are short-lived and most are easy to predict and easy to observe. Most engineering impacts can be controlled, mitigated, kept at tolerable levels, and restricted to the immediate vicinity of the aggregate operation by employing responsible operational practices that use available engineering techniques and technology (fig. 10). Some reports that generally describe engineering impacts include Barksdale (1991), Kelk (1992), Smith and Collis (2001), Lüttig (1994), Bobrowsky (1998), Primel and Tourenq, (2000) and Langer (2001).

Cascading Impacts

In karst environments, aggregate mining may alter sensitive parts of the natural system at or near the site thus creating cascading environmental impacts (Langer and Kolm, 2001). Cascading impacts are initiated by an engineering activity, such as the removal of rock, which alters the natural system. The natural system responds, which causes another impact, which causes yet another response by the system, and on and on. For example, aggregate mining in some karst might lower the water table, which will remove the buoyant support of rock that overlies water-filled caverns or other solution features, which might result in land collapse, which will create a sinkhole. Cascading impacts may be severe and affect areas well beyond the limits of the aggregate operation. Cascading impacts may manifest themselves some time after mining activities have begun and continue well after mining has ceased. Many of the impacts described below are cascading impacts.

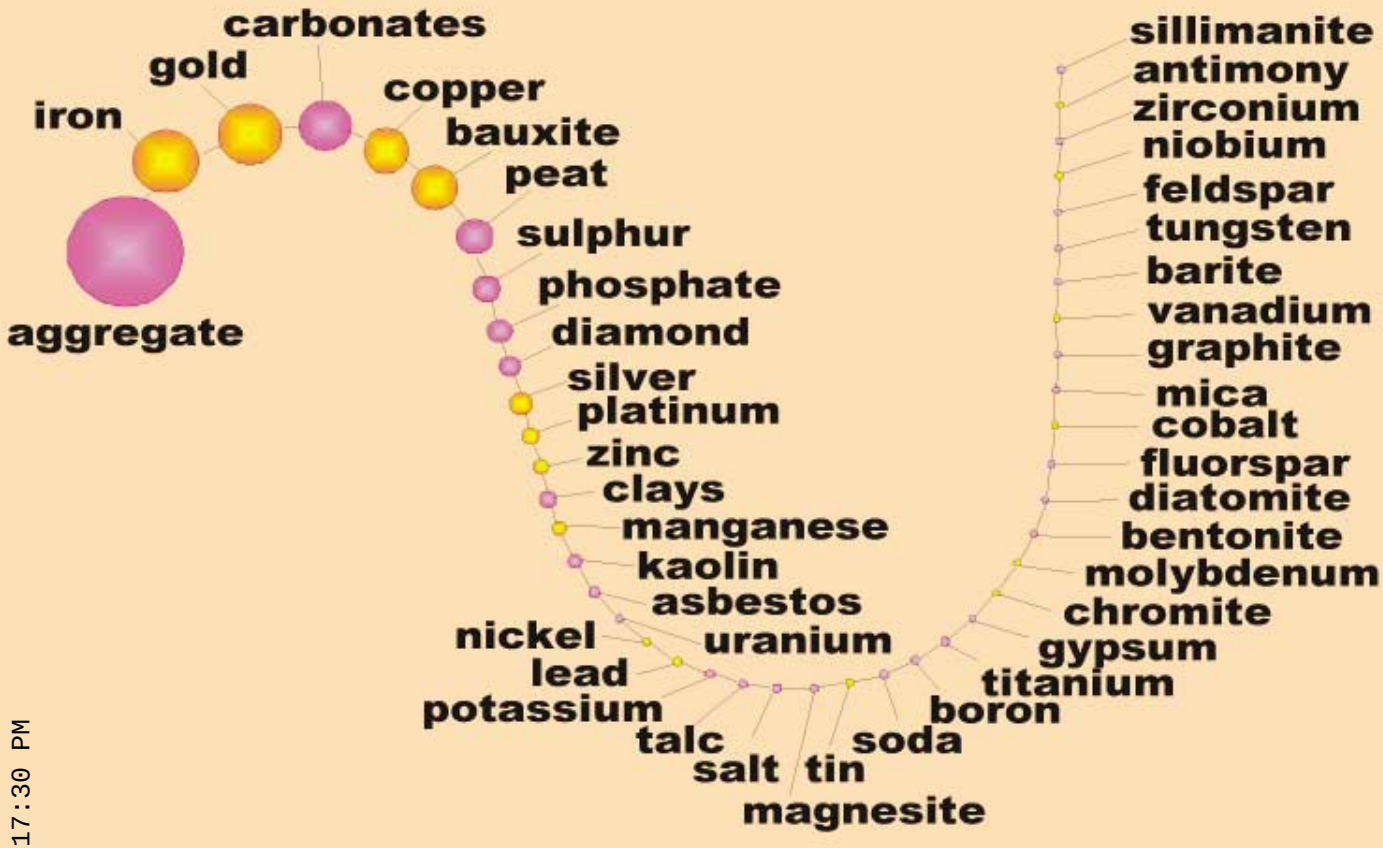

Figure 9. "Resource snake" graph showing relative values of non-fuel mineral resource production *(from Lüttig, 1994).*

Geomorphic Impacts

Quarrying has an associated, often dramatic, visual impact. Karst terrain is commonly considered to be of high scenic value, thus compounding the effects of visual impacts of quarrying. The principal geomorphic impact of quarrying is the removal of stone, which results in the destruction of habitat including relict and active caves and natural sinkholes (Gunn and Gagen, 1987).

The extent of the geomorphic impact is a function of the size of the quarry, the number of quarries, and the location of the quarry, especially with respect to the overall landscape and the local landforms (fig. 11). The influence of quarry size on environmental impact is obvious: all other things being equal, the larger the quarry, the larger the geomorphic impact. The size of quarries has increased over time, and so has their impact.

Great numbers of quarries in a karst region amplifies the geomorphic impact (Sauro, 1993). Stanton (1966) suggested that the disturbance created by numerous smaller quarries is greater than that created by one large quarry and recommended that geomorphic disturbance be minimized by maximizing reserves through deep quarrying. (See section on ground water regarding the impacts of deep quarrying.) Stanton (1990) later suggested that limestone has more value *in situ* as a source of water and for its scenic value than as a source of crushed stone and recommended avoiding extraction of limestone altogether when alternatives are available.

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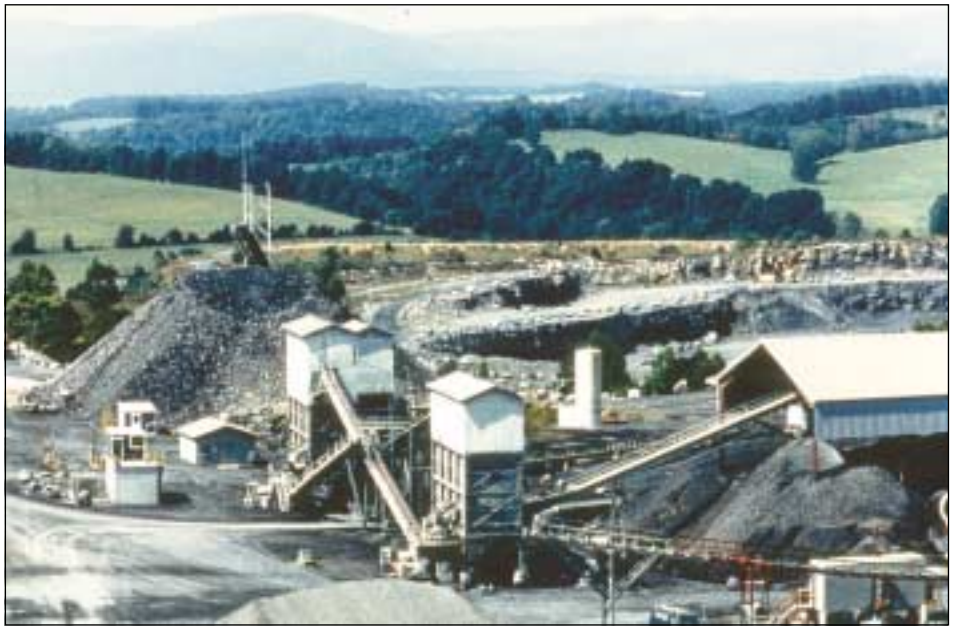

Figure 10. Engineering techniques, such as enclosing equipment and removing dust using vacuums, can mitigate impacts of noise and dust. *(Photograph courtesy of Luck Stone.)*

Figure 11. Quarries can occupy a significant part of the visual landscape.

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In broad terms there are three situations where quarries can be located: 1) on flat ground, 2) along or into the side of a valley, and 3) on the side of a hill (Gunn, 1993; Gunn and Bailey, 1993). In most situations, quarries excavated into flat ground have a relatively small impact on geomorphology, which is limited to the removal of sinkholes and cave passageways. Quarries on valley sides can extend laterally along the valley side causing large geomorphic impacts, or they can work back into the valley wall, where the impact is less (Gunn, 1993; Gunn and Bailey, 1993). Quarries on hills generally have a large geomorphic impact. Gunn (1993) reports that crushed stone quarrying has removed an entire karst hill and large portions of other nearby karst hills in the Mendip Hills, UK.

Blasting

One of the most frequent complaints the public makes to the crushed stone industry situated near population centers is about blasting noise (National Academy of Sciences, 1980). Blasting may occur daily or as infrequently as once or twice a year. The blasting techniques used in crushed stone operations are significantly different than those used in dimension stone quarrying. Whereas large amounts of explosives are used in crushed stone operations to produce appropriate-sized rubble (fig. 12), the dimension stone industry uses only small amounts of explosives to loosen large blocks of stone.

Figure 12. Rock is drilled and blasted for use as crushed stone. In some isolated areas where people are not located nearby, larger amounts of explosives may be used.

Geology, topography, and weather affect the impacts of blasting. Blasting noise generally increases with the amount of explosive, with specific atmospheric conditions, and with proximity to a blast. The area in front of a blast commonly receives more noise than an area behind a blast. People differ greatly in their response to blasting (National Academy of Sciences, 1980).

The technology of rock blasting is highly developed, and when blasting is properly conducted, most environmental impacts should be negligible. By following widely recognized and well-documented limits on ground motion and air concussion, direct impacts from ground shaking and air concussion can be effectively mitigated. Those limits and methods to measure them are discussed in Moore and Richards (1999), Bell (1992), Berger and others (1991), and National Academy of Sciences (1980).

When an explosive is detonated enormous amounts of energy are released. Most of the energy of a properly designed blast works to displace rock from the quarry face. The remaining energy is released as vibrations through and along the surface of the earth and through the air. Most of the energy that goes through the earth comes to the surface within a few meters of the detonation and travels as surface waves, which may cause ground shaking. A small amount of the energy is transmitted through the rocks as shear waves, which commonly are insignificant.

When a blast is detonated, some energy will escape into the atmosphere causing a disturbance in the air. Part of this disturbance is subaudible (air concussion) and part can be heard (noise). Air concussion is most noticeable within a structure, particularly when windows and doors are closed. The air concussion creates a pressure differential between the outside and inside the structure causing it to vibrate.

Poorly designed or poorly controlled blasts may cause rocks to be projected long distances from the blast site (flyrock), which can be a serious hazard. Flyrock is not commonly a problem with carefully designed and executed blasting plans, but is a situation that deserves careful attention. The pinnacled bedrock in karst can complicate blasting, increasing the risks for flyrock.

Blast-induced vibrations and shock waves can cause stalagmites and stalactites to break off and cause cave roofs to crack or collapse. Blasting may cause fracturing of quarry walls, increasing permeability and increasing drainage towards quarry face (Gagen and Gunn, 1987, Gunn and Bailey, 1993). The blast zone beneath the quarry floor in subwater table quarries may be considered as a separate aquifer with high fracture density, low primary porosity, and negligible conduit development (Smart and others, 1991).

Blasting-induced fracturing or aperture widening may play a role in initiating flooding events.

Lolcama and others (1999) describe a situation where blasting opened a conduit under the floor of a quarry. The conduit was connected to a nearby river and to a local water storage basin. Extensive grouting was required to stop the inflow of water from those sources.

Blasting can negatively impact karst biota and may cause problems with ground-water availability and quality (discussed below).

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Noise

The primary source of noise from extraction of aggregate and dimension stone is from earth-moving equipment, processing equipment, and blasting (see above). The truck traffic that often accompanies aggregate mining can be a significant noise source. The impacts of noise are highly dependent on the sound source, the topography, land use, ground cover of the surrounding site, and climatic conditions. The beat, rhythm, pitch of noise, and distance from the noise source affect the impact of the noise on the receiver (Langer, 2001). Topographic barriers or vegetated areas can shield or absorb noise. Sound travels farther in cold, dense air than in warm air and travels farther when it is focused by atmospheric inversions than when inversions are not present.

An important factor in determining a person's tolerance to a new noise is the ambient (background) noise to which one has adjusted. In general, the more a new noise exceeds the existing background noise level, the less acceptable the new noise will be. In an urban or industrial environment, background noise may mask noise from a quarry operation, whereas the same level of noise in a rural area or quiet, residential neighborhood may be more noticeable to people. Furthermore, ambient noise generally is an accumulation of noises and does not have a single, identifiable source. If the mining noise is identifiable, the perception of noise probably will be great. For example, the noise from a single backup alarm can often be picked out from an equally loud engine noise.

Crushed stone operators and dimension stone quarriers are responsible for assuring that the noise emitted from the quarry does not exceed levels set by regulations. The impacts of noise can be mitigated through various engineering techniques. Landscaping, berms, and stockpiles can be constructed to form sound barriers. Noisy equipment (such as crushers) can be located away from populated areas and can be enclosed in sound-deadening structures (fig. 13). Conveyors can be used instead of trucks for in-pit movement of materials. Noisy operations can be scheduled or limited to certain times of the day. The proper location of access roads, the use of acceleration and deceleration lanes, and careful routing of trucks can help reduce truck noise. Workers can be protected from noise through the use of enclosed, air-conditioned cabs on equipment and, where necessary, the use of hearing protectors. Worker safety may include regular health screening.

Noise can negatively impact karst biota (discussed below).

Figure 13. Noisy equipment can be located away from populated areas and can be enclosed in sound-deadening structures. *(Photograph courtesy Luck Stone.)*

Dust

Dust is one of the most visible, invasive, and potentially irritating impacts associated with quarrying, and its visibility often raises concerns that are not directly proportional to its impact on human health and the environment (Howard and Cameron, 1998). Dust may occur as fugitive dust from excavation, from haul roads, and from blasting, or can be from point sources, such as drilling, crushing and screening (Langer, 2001). Site conditions that affect the impact of dust generated during extraction of aggregate and dimension stone include rock properties, moisture, ambient air quality, air currents and prevailing winds, the size of the operation, proximity to population centers, and other nearby sources of dust. Dust concentrations, deposition rates, and potential impacts tend to decrease rapidly away from the source (Howard and Cameron, 1998).

A carefully prepared and implemented dust control plan commonly can reduce impacts from dust (Kestner, 1994). Federal, state, and local regulations put strict limits on the amount of airborne material that may be emitted during site preparation and operation. Controlling fugitive emissions commonly depends on good housekeeping practices rather than control systems. Techniques include the use of water trucks, sweepers, and chemical applications on haul roads, control of vehicle speed, and construction of windbreaks and plantings (fig. 14). The impacts from plant-generated dust commonly can be mitigated by use of dry or wet control systems. Dry techniques include covers on conveyors, vacuum systems, and bag houses, which remove dust before the air stream is released to the atmosphere. Wet suppression systems consist of pressurized water (or surfactant treated water) sprays located at dust generating sites

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throughout the plant. Fugitive dust from blasting can be controlled by proper design and execution of blasts. Workers are protected from dust through the use of enclosed, air-conditioned cabs on equipment and, where necessary, the use of respirators. Worker safety may include regular health screening.

In some situations, dust on quarry floors and nearby areas can clog pores in the ground (fig. 15), thus altering recharge rates. In other situations, dust can enter conduits and smaller openings, and can be transported and deposited into caves (Gunn and Hobbs, 1999).

Dust can negatively impact karst biota (discussed below).

Habitat and Biota

Caves develop one of the most peculiar terrestrial ecosystems. One determining factor for life in karst solution features is the lack of light. The karst environment can be divided into four zones based on the degree of darkness (Vermeulen and Whitten, 1999): 1) The twilight zone, near the entrance where light intensity, humidity, and temperature vary and a large and varied fauna are found, 2) The transition zone of complete darkness, variable humidity and temperature where a number of common species live, some of which make sorties to the outside world, 3) The deep zone of complete darkness, almost 100 percent humidity, and constant temperature where fully cave-adapted species that never venture outside the cave live, and 4) The stagnant zone of complete darkness, 100 percent humidity, where there is little air exchange and carbon dioxide concentrations may become high.

Many species of bats, including nectar-feeding bats and insectivorous bats, roost in the twilight zone or transition zone of caves. Insectivorous bats make up the largest known colonies of mammals in the world (Veni and DuChene, 2001). Birds, other animals, and plants also inhabit these zones.

To cope with the permanent darkness, extreme scarcity of food, and relatively constant climate of the underground voids in the deep and stagnant zones, animals have developed physiological, behavioral, and morphological adaptations (fig. 16), losing many of the essential functions of aboveground species. Eyes are reduced or absent, and they have little or no pigment. These animals are able to cope with the highly alkaline environment created by the abundance of soluble calcium carbonate. They have developed means of expelling water in 100 percent humidity without losing body salts. If their ancestors had wings, cave animals have lost them. Diurnal rhythms are lost. Their life span increases and their fertility decreases dramatically. These adaptations have confined cave species to their habitat; they cannot survive elsewhere (Vermeulen and Whitten, 1999).

Figure 14. Dust control techniques include the use of water trucks and sweepers on haul.

Figure 15 (right). Dust on quarry floors can clog pores in the ground, thus altering ground-water. recharge.

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The biodiversity of karst ecosystems is highly restrictive. Some species are restricted to single cave systems and are little known. For example, about 47 species of aquatic and terrestrial invertebrates have been collected from the Movile Cave and nearby springs in southern Romania. Thirty of the 47 species were previously unknown and appear to be endemic to the system (White and others, 1995).

As rock is removed by quarrying, any cave passage is destroyed, along with any sediments it may have contained. The habitat provided by the caves and passages will cease to exist. Animals that inhabit the twilight or transition zone, and are mobile and able to find new homes, might survive; the rest will die. Creatures that have adapted to the deep and stagnant zones will perish.

Figure 16a (top left). Karst inhabitant – Bamazomus. *(Photograph courtesy Elery Hamilton-Smith.)*

Figure 16b (bottom left). Karst inhabitant – Milyeringa. *(Photograph courtesy Elery Hamilton-Smith.)*

Quarrying may intersect active ground-water conduits, or cause their blockage, with adverse consequences for aquatic communities. Ground-water withdrawal and diversion of surface water may cause aboveground and underground hydrologic systems to dry up. Water bodies, which may be inhabited by small, site-endemic fish and snail species, will disappear and with them, the species. Alterations of flow volumes and patterns and the availability of nutrients can profoundly change the limestone environment and may lead to the extinction of whole communities (Vermeulen and Whitten, 1999). Lowering the water table will increase the thickness of the unsaturated zone, which can change the pH of the water in the unsaturated zone, which will change the biotic environment in small voids in the rock, which will kill species that live there.

Blasting can negatively affect karst habitat and biota. Blast-induced vibrations and shock waves can cause cave roofs to crack or collapse, and karst environmental conditions can be altered by just one new crack. Light may enter an otherwise dark cave or passage, or streams and ponds may suddenly drain into a new crack in the floor. Either situation can result in the death or displacement of cave communities (Vermeulen and Whitten, 1999).

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Noise and air concussion may disturb colonies of bats and swiftlets, causing them to leave their roosting sites. This type of disturbance can occur as far away as 1,500 meters from the quarry if the opening of the roosting cave happens to be facing in the direction of the blast (Vermeulen and Whitten, 1999). Noise can adversely affect wildlife by interfering with communication and masking the sounds of predators and prey, and in the extreme, result in temporary or permanent hearing loss (Fletcher and Busnel, 1978).

Dust, if uncontrolled, may spread over the surroundings during dry weather, leach into the soil during storms, and create harmful conditions for the flora and fauna (Vermeulen and Whitten, 1999). When dust smothers leaf surfaces, vegetation can be damaged through the blocking of leaf stomata, thus inhibiting gas exchange and reducing photosynthesis (Howard and Cameron, 1998).

Changes in the humidity of karst openings, presence of water, and quality of water (see below) can all impact karst biota. The impacts of quarrying on surface water and ground water (see below) can impact wetland riparian, and aquatic habitat which, in turn, can impact biota.

Water Quality

Karst systems have very low self-purification capabilities (Kresic and others, 1992), which makes karst water very susceptible to pollution. A major concern is that polluted materials, including pathogens, can be carried long distances without being filtered because of high flow velocities (several hundreds of thousands of meters per day) (Assad and Jordan, 1994).

The sources of pollutants do not necessarily have to be man-made; there also are natural sources of pollution (Kresic and others, 1992). Generally, karst occurs in areas that contain large amounts of organic material and bacteria, which can naturally degrade water quality. Erosion, especially at boundary areas between karst and nonkarst areas, and washout of terra rossa and clay residue from fissures can cause increased turbidity at karstic springs. Ground-water drainage from ore deposits act as natural pollutants.

Quarrying can substantially modify the routing of recharge and water quality may be degraded (Gunn and Hobbs, 1999). Commonly the first impact of quarrying is to remove the overlying vegetation and soil. In temperate areas removing vegetation and soil reduces evapotranspiration and increases the effective rainfall. Unless measures are taken to control runoff and sedimentation, deterioration of ground water is likely. In some karst areas the soil overlying the rock normally is a zone of filtration and water purification (Gunn and Hobbs, 1999). In aggregate mining, the target limestone, if unsaturated, may also act as a protective cover for the underlying aquifer. If the protective soil cover or unsaturated rock is removed, the hole created by the mining may focus surface water to the ground-water system. If the surface water is contaminated, the ground water can quickly become polluted (Hobbs and Gunn, 1998; Ekmekçi, 1993).

Quarrying can cause sinkhole collapse, which can result in capture of surface water. In the Tournaisis area, southern Belgium, about thirty sinkholes opened up along the Escaut River downstream from the city of Tournai. As a consequence, the ground water was polluted by an extensive loss of contaminated river water into the karst aquifer (Kaufmann and Quinif, 1999).

Dust can enter conduits and smaller openings and can be transported by ground water (Gunn and Hobbs, 1999). The fine debris produced by the cutting of marble can be worked through the ground-water system during storm events (Drysdale and others, 2001).

Blasting may cause problems with ground-water quality, but may also be erroneously identified as a cause of problems. Spigner (1978) reported that shock waves from blasting operations loosened clay particles from solution cavities causing “muddying” of the ground water. Elsewhere, Moore and Hughes (1979) investigated the impact of quarry blasting on ground-water quality and determined there was no relationship between blasting and quality of water in wells in the situation that they studied.

The risk of ground-water pollution may increase if the direction of ground-water flow is modified. New source areas of recharge may be introduced, and those sources may contain contaminated water. This situation can arise because of ground-water pumping (Adamczyk and others, 1988; Sedam and others, 1988) or can occur if old choked passages are flushed and become operational again. Ekmekçi (1993) reported that blasting associated with quarrying may close existing karst ground-water passages, or may open up new passage, resulting in a change in direction of ground-water flow.

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Figure 17a. Fuel oil spills can rapidly contaminate karst aquifers. *(Photograph courtesy Elery Hamilton-Smith.)*

Figure 17b. Properly constructed containment facilities can protect the aquifer from potential fuel spills. *(Photograph courtesy Lafarge.)*

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Large amounts of silt and other effluents from quarries (waste, fuel, oil) may pollute rivers as well as underground water bodies within and far beyond the boundaries of the limestone area (fig. 17a and b). Rivers in Indo-China, for example, host hundreds of species of large freshwater clams and snails, many of which are site endemic to a section of one stream. Development puts great pressure on these animals, which are very vulnerable because they are easily smothered in mud or killed by chemical pollution when silt is allowed to seep into a river. Fish communities are equally vulnerable (Vermeulen and Whitten, 1999).

Surface Water

Engineering activities associated with quarrying can directly change the course of surface water. Sinkholes created by quarrying (see below) can intercept surface water flow. Conversely, ground water being pumped from quarries changes streams from gaining streams to loosing streams and can drain other nearby surface water features such as ponds and wetlands. Similarly, blasting (see above) can modify ground-water flow, which ultimately can modify surface water flow. Discharging quarry water into nearby streams can increase flood recurrence intervals.

Ground Water

Overall, quarrying in the unsaturated zone is likely to result in relatively local impacts such as increased runoff, reduced water quality, rerouting of recharge water through the aquifer, and localized reduction in ground-water storage. In karst areas, the unsaturated zone commonly contains only a small percentage of storage, and where the unsaturated zone is thin, impact on ground-water quantity generally is minimal (Hobbs and Gunn, 1998). However, Smart and Friederich (1986), Dodge (1984), and Gunn (1986) all describe areas where a thick, well-developed unsaturated zone is present. In those areas, the unsaturated zone may store significant quantities of water. Following rainfall, water may be collected and temporarily stored in the unsaturated zone, until it subsequently joins the ground-water system.

The major impact of quarrying in the karst saturated zone relates to quarry dewatering and the associated decline of the water table. It should be noted that there are many human activities other than quarrying that can affect ground-water levels, including municipal, industrial, and private ground-water withdrawals, irrigation, use of ground water for freeze protection, and mine drainage from other mineral resource extraction activities. Drought is a natural cause for water table declines. Many of the reports of dramatic declines of the water table refer to underground mines, rather than surface quarries.

If quarrying intersects a phreatic conduit (a conduit in the saturated zone), the water-transporting function of that conduit will be severely impacted. Dye studies have demonstrated that, even without intersecting conduits, quarry dewatering can affect the function of a conduit by inducing leakage into diffuse flow zones (Edwards and others, 1991; Sedam and others, 1988). In cross section, the path of a conduit often has a wave shape. If the water table is lowered to where at least the crests of the waves no longer contain water, water will be trapped in the troughs of the waves and the conduits will no longer be able to transmit water.

If a quarry intersects the water table, ground water commonly will flow out of the rock into the quarry. Water may just trickle into the quarry or it may flow into the quarry at a rate of hundreds or thousands of liters per second (L/s), especially if quarrying intercepts a phreatic conduit. Foose (1953) reported an inrush of 500 to 630 L/s that occurred when an underground limestone quarry intersected a conduit, and Lolcama and others (1999) reported a flow of about 2,525 L/s when a surface quarry intersected a conduit that was in hydraulic connection to a nearby river. In some situations, it may be necessary to drain or pump the water from the quarry to protect people, quarry workings, and equipment.

Pumping from a quarry will reduce hydraulic head and, thus, draw down water levels in the rock draining into the quarry. In the simplest case, the part of the water table impacted by quarry dewatering would look like a downward-pointing cone that has been depressed into the water table, thus its name – cone of depression. If the quarry were the only major source of ground-water draw down in the area, it would be located over the apex of the cone of depression.

The actual shape of a cone of depression depends on many factors including the direction, volume, and velocity of water moving past the site; rock properties, including permeability of rock layers, attitude of rock layers, amount of fractures in the rock, size of fractures, fracture orientation, continuity of fractures, and regional stresses keeping fractures open or closed; other sources of ground-water withdrawals, natural or manmade discharge points, recharge points, conduits, whether conduits recharge or drain aquifer, and so forth. Homogeneous rocks yield a classic circular cone of depression, but the anisotropic nature of most limestones produces an irregular zone of depression, with preferential development along zones of highest permeability (Gunn and Hobbs, 1999). Depending on local conditions and quarrying practices, cones of depression can be almost as small as the quarry itself, or can be as large as 25 km^2.

Figure 18. Natural sinkhole near Ste. Genevieve, Missouri *(USGS photographic library-Shaw #891).*

Water pumped from a quarry is likely to be lost from the local ground-water system. Within the cone of depression, wells, springs, and streams can go dry or have their flows significantly reduced, and the overall direction of ground-water flow may be changed (Hobbs and Gunn, 1998). It is within this cone of depression that many human-induced sinkholes are formed.

Karst aquifers are often separate from overlying shallow surficial aquifers. Fraser and Grapes (1998) determined that a shallow aquifer in drift and the underlying karstic limestone aquifer in South Wales are separate hydraulic systems with distinct water chemistries and distinct responses to hydraulic stress. They determined that dewatering the deep aquifer would not affect plant communities supported by the shallow aquifer.

Sinkhole Collapse

Sinkholes are depressions formed in karst by either slow, downward solution or rapid collapse of the land surface. Sinkholes in carbonate rocks occur world wide, with notable concentrations in the eastern USA, southeast Asia, and parts of Europe. Sinkholes can occur naturally or can be induced by activities of man (Newton, 1976).

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Figure 19. Human-induced sinkholes formed during the development of an irrigation well affected a 20-acre area and ranged in size from less than 1 foot to more than 150 feet in diameter. *(Photograph courtesy Ann Tihansky, USGS.)*

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Natural sinkholes (fig. 18) can form through the dissolution of rock (solution sinkhole) or through the failure of a bedrock roof overlying a cavern (collapse sinkhole). The formation of both of these types of sinkholes occur over periods of geologic time, not within a human lifetime. The solution of rock has little to do with the final cause of sinkhole collapse, however, it can set the stage for some human-induced event in the future (Thorpe and Brook, 1984; White and White, 1995). Of an estimated 4,000 sinkholes formed in Alabama between 1900 and 1976, only 50 were natural collapses (Newton, 1976).

Human-induced sinkholes are those caused or accelerated by human activities and commonly are characterized by catastrophic subsidence (Newton, 1976; LaMoreaux and Newton, 1986; LaMoreaux, 1997). If human activities had not taken place, these sinkholes would not have occurred, would not have occurred when they did, or, under natural conditions, would have occurred as subsidence, not rapid collapse (Newton, 1987). Human-induced sinkholes (fig. 19) commonly form as a result of ground-water withdrawal, construction activities, or a combination of both.

Ground-Water Withdrawal

Human-induced sinkholes in karst commonly are caused by human activities that lower the water table below the rock/soil interface (fig. 20). Many human activities, in addition to quarrying, can lower the ground-water table. While quarrying commonly is restricted to relatively small areas, other activities tcan be spread out, which may increase their relative impacts on the environment. Regardless, in some situations quarrying includes ground-water withdrawals and should be carefully addressed.

A classic case of sinkhole development caused by dewatering an underground limestone quarry occurred in the Hershey Valley, Pennsylvania (Foose, 1953, 1969; Foose and Humphreville, 1979). In 1949, increased pumping from the quarry created a cone of depression covering 600 hectares. Nearly 100 subsidence sinkholes formed above the cone of depression within three months of the increased pumping. Sinkhole development ceased after quarrying dewatering stopped and the water table returned to normal.

Figure 20a. Hypothetical cross section showing karst area under conditions prior to quarry development. The water table (1) is generally above the soil / bedrock contact. Natural ground-water discharges to a spring (2), and a perennial stream (4), which support a wetland (3) and a riparian woodland (5). The surface of the bedrock is highly irregular (6), and is referred to as pinnacled bedrock. A natural sinkhole occurs where the water table is below the soil / bedrock contact (7).

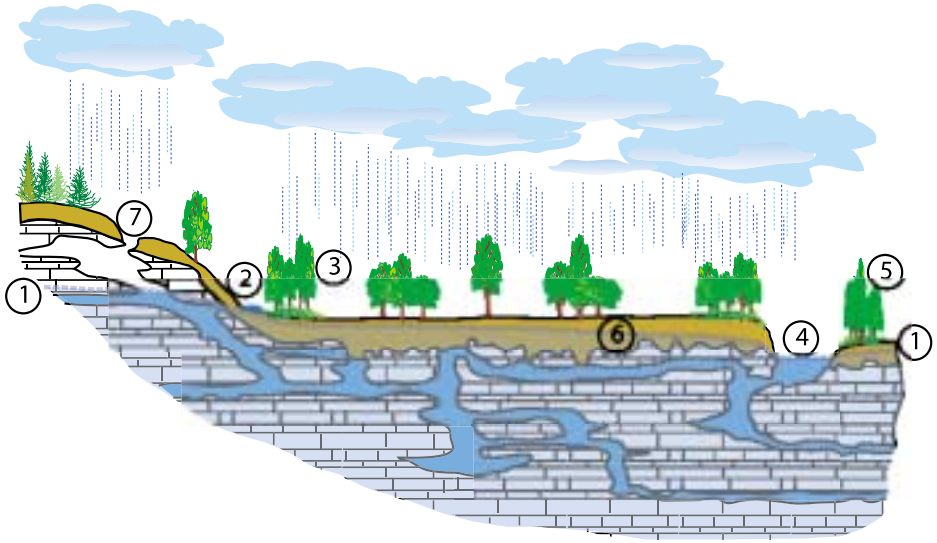
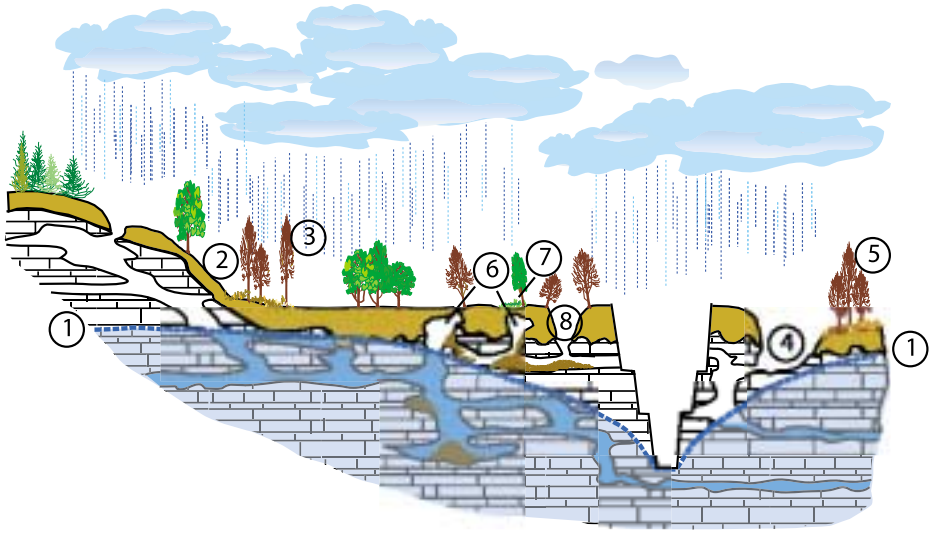


Figure 20b. Hypothetical cross section showing karst area under worst-case conditions after quarry development. Under actual conditions, none, some, or all of these conditions may exist. Quarry dewatering has lowered the water table (1) below the soil / bedrock contact. Natural ground-water discharge to a spring (2) and perennial stream (4) has stopped, resulting in destruction of the wetland (3), drying up of the stream (4) and destruction of the riparian woodland (5). Underground cavities formed in the soil in the area of the pinnacled bedrock due to loss of buoyant support and piping (6). The ground above the cavity has subsisded, resulting in the formation of a wet area, and the tilting of fence posts or trees (7). Ultimately these cavities could collapse, creating a collapse sinkhole (8).



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LaMoreaux and Newton (1986) document a similar occurrence in the Dry Valley area of Alabama where several thousand sinkholes formed above a cone of depression in the period 1967 – 1984. Ground-water withdrawals from two quarries in the Jamestown, South Carolina, area resulted in the formation of 42 sites of subsidence and collapse from 1976 – 1978 (Spigner, 1978; Newton, 1987). Ground-water withdrawal caused by limestone quarrying appears to be the cause of sinkhole collapse at Railtown in northwestern Tasmania (Kiernan, 1989). Other areas of sinkhole collapse related to quarry dewatering have been described by Newton (1976, 1986, 1987), and Newton and Hyde (1971).

Sinkhole collapse related to ground-water pumping can also result from some other dewatering activity in combination with quarrying. A number of sinkhole collapses near Calera, Alabama, occurred in an area dewatered by wells, quarries, and an underground mine (Warren, 1976). Intense pumping for domestic and industrial water supply, combined with dewatering of deep limestone quarries, has caused sinkhole development in the Tournaisis area, Belgium, since the beginning of the 20th century (Kaufmann and Quinif, 1999).

Quarrying begins at the top of bedrock and deepening occurs over a period of years. Sinkhole development may begin after quarrying penetrates the water table (fig. 20). When the depth below the water table is shallow, sinkhole development generally is confined to the vicinity of the quarry. As the quarry is deepened, the cone of depression enlarges and sinkholes occur further away (Newton, 1987). Sinkhole development following dewatering associated with subsurface mining commonly occurs more rapidly than that resulting from surface quarrying because the depth of dewatering and cones of depression are relatively large (Newton, 1987).

Triggering Mechanisms

The act of lowering the water table commonly does not by itself create a sinkhole. Most often land subsidence will occur only if support to overlying unconsolidated material is removed (Foose, 1967) and some other activity commonly “triggers” sinkhole formation. Triggering mechanisms include: 1) water level fluctuations, 2) loss of buoyant support by the water, 3) volume shrinkage, 4) piping or induced recharge, and 5) increased gradient and water velocity (fig. 21) (Newton and Hyde, 1971; Newton, 1987).

Subsidence or collapse of soil overburden into the fissures and caves of an underlying limestone creates subsidence sinkholes without involving failure of the rock (Waltham, 1989). Bedrock caves do exist beneath some sinkholes, but their role is merely to swallow the debris. Almost all sinkholes occur where cavities develop in unconsolidated deposits overlying solution openings in carbonate rocks (LaMoreaux and Newton, 1986), and given sufficient time, sinkholes can develop above bedrock containing only narrow rock fissures (Waltham, 1989).

Water Level Fluctuations

Pumping of ground water, particularly in seasonally-operated quarries, may result in ground-water fluctuations that are of greater magnitude than fluctuations that occur under natural conditions. The magnitude of fluctuation principally depends on the amount and duration of pumping and on the transmissivity and storage coefficient of the aquifer. The unconsolidated material bridging bedrock pinnacles can be weakened by the alternate wetting and drying, lubrication, and addition or subtraction of buoyant support brought about by fluctuating water levels (Newton and others, 1973).

Loss of Buoyancy Support

In some karst areas residual clay soil spans or fills space between bedrock pinnacles. If the soil is saturated, about 40% of the weight of the residual clay soil overlying a bedrock opening is supported by ground water (Newton and Hyde, 1971; Newton, 1987). When the ground-water level is lowered, buoyant support is lost (fig. 21, block B). The loss of buoyant support can trigger sinkhole collapse (fig. 21, block D) or cause spalling that ultimately trigger collapse. (Newton, 1984a, 1984b, 1984c, 1987).

In artesian areas, hydrostatic pressure provides support to the confining bed and to overlying material (Newton, 1987). Weakening of buoyant support in artesian carbonate rocks may be caused by a decline of piezometric levels of the confined aquifer system. A one meter decline in piezometric level corresponds to a 1 ton/m^2 increase of effective loading of overburden. Local or distant withdrawals of karst aquifer could cause such a decline (Prokopovich, 1985).

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Volume Shrinkage

As ground water is lowered in areas of pinnacle weathering, volume shrinkage due to compaction of the unconsolidated debris takes place. If two pinnacles are less than 10 – 15 m apart, the weight of the sediment load between the pinnacles can be carried as an arch (Foose, 1967). As spalling occurs, the cavity grows upward, enlarging the vaulted roof. There is a limit to the weight that the arch can hold, and when the ability of the arch to hold the load is exceeded, rapid upward propagation of the arch by continuous spalling results in sudden collapse of the surface.

Soils with low cohesive strength, such as dry sands, tend not to form a stable arch. There is a continuous flow of soil down the drain (raveling) and instead of an abrupt collapse, the sinkhole forms by a process of continuous subsidence. Human influences, particularly dewatering, can greatly modify the rate of soil transport (Newton and others, 1973).

Piping or Induced Recharge

When cavities in the soil or bedrock are filled with ground water (fig. 21, block A), surface water cannot flow into the cavities. When the water table is lowered, the cavities drain, thus allowing the inflow of surface water. Surface water passes through the residual soil, eroding it and carrying it downward into the air-filled cavities by a process called piping or subsurface mechanical erosion (LaMoreaux, 1997) (fig. 21, block C). Soil is piped down into the bedrock creating a void within the soil mantle. As time passes, more and more soil is piped down the drain and the void grows with an arched roof held up only by the cohesive strength of the soil. Eventually, the void becomes too large for the soil arch to support its own weight and there is a collapse (fig. 21 block D). The fallen roof may obscure the bedrock surface and the drain. The freshly-formed sinkhole is usually roughly circular in outline and has near vertical walls (Lolcama and others, 1999; White and White, 1995). Piping is well-documented by observations of the pumping of “muddy water” during quarry dewatering (Foose, 1953, 1967). Piping is most active during periods of heavy or prolonged rainfall.

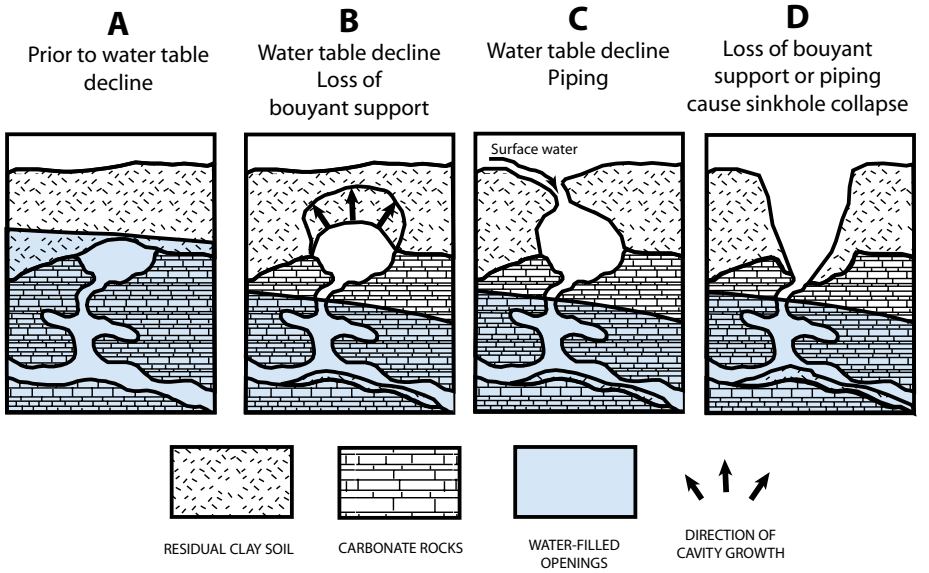

Figure 21. Diagram showing mechanics of sinkhole development.

Increased Velocity of Ground Water

Surface structures, such as storm drains, parking lots, and roof drains, concentrate recharge into a single inlet point in the carbonate rock, thus encouraging piping. Construction activities of various kinds can also raise hydraulic heads, increase velocities in the drain, and thus also enhance the rate of sediment transport leading to accelerated sinkhole development (Newton, 1986).

Ground-water withdrawal creates an increased hydraulic gradient, which results in an increased velocity of ground-water movement. Increased water velocity results in flushing of sediments filling openings in cavity systems. In turn, downward movement of overburden sediments into newly created bedrock openings, results in a sinkhole (Newton, 1976, 1984a, 1984b, 1984c).

A decline in potentiometric surface under artesian conditions produces increased head differential, which results in increased velocity of recharge through the confining bed. The energy of this movement is diffuse, and unless the confining bed is breached, will not be expected to contribute to sinkhole development (Newton, 1987).

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Figure 22. "A giant sink hole opened up on Thursday, September 19 [1975] at a drilling site near Tampa, Florida and swallowed up a well-drilling rig, a water truck, and a trailer loaded with pipe all valued at $100,000. The well being drilled was down 200 ft when the ground began to give way to what turned out to be a limestone cavern. Within 10 minutes all the equipment was buried way out of sight in a crater measuring 300 ft deep, and 300 ft wide. Fortunately, the drilling crew had time to scramble to safety and no one was hurt." -from National Water Well Association newsletter. *(Photograph courtesy Tom Scott.)*

Construction Activities

Some sinkhole failures are induced by construction activities and are of major significance because they directly affect the site being developed, either immediately or some years later. Construction activities that can trigger sinkholes include 1) diversion or impoundment of drainage, 2) removing overburden, 3) drilling, augering, or coring 4) blasting, 5) loading, and 6) removal of vegetation. A lowered water table may leave sections of ground in a critical state awaiting construction activity to triggers their failure; however, even without a water-table decline, the same activity may prompt failure, but statistically less often.

Diversion or Impoundment of Drainage

A major influence from construction is the diversion of natural drainage. Concentration of drainage at the surface, such as leaking pools, impoundments, pipes, canals, and ditches, can all create point discharge into the soil, inducing ground water to move through overburden into bedrock. This can result in an increased velocity of ground water, piping, saturation of overburden, and loss of cohesiveness of unconsolidated deposits (LaMoreaux, 1997). These effects can result in collapse of the overburden into openings below.

Runoff from roads or buildings commonly is disposed of into ditches, soakaway drains, or dry wells in soil over carbonate rock. Ditches and drainage wells cased into the limestone should perform safely, but, if poorly installed, leakage may cause adjacent or nearby failures (Crawford, 1986). In Pennsylvania, 7 km of highway induced 184 sinkholes along its associated drainage channels within 12 years (Meyers and Perlow, 1984).

Removing Overburden

Excavation of part of a soil cover may thin the roof of a soil cavity to a point of failure. Removal of a clay soil may permit drainage through previously sealed sands. Some Missouri railroads stand on banks made from soil excavated adjacent to them, and the marginal hollows frequently develop sinkholes (Aley and others, 1972).

Drilling, Augering, or Coring

These activities cause erosion of overburden into underlying openings. Unsealed boreholes can allow surface water to gain new access to the subsurface or may allow a perched soil aquifer to drain into a bedrock cavity. Drilling has resulted in collapses at or near working drill rigs (fig. 22) or the holes created (LaMoreaux, 1997). During 1960 an USGS driller was killed when a sinkhole formed around a test hole in Florida (Newton, 1987). Installation of wells at Westminster, Maryland, in 1940 and 1948 was associated with nearby sinkhole collapse (Newton, 1987). A sinkhole collapsed next to a USGS test well near Dickson, Tennessee, in May 1981 (Newton, 1987).

Blasting

Explosives create vibrations that can disturb the overburden and trigger its downward movement into solution openings in bedrock (Stringfield and Rapp, 1976; Ekmekçi, 1993; LaMoreaux, 1997). The village of Liangwu, in southern China, was abandoned when nearby blasting triggered 40 sinkholes, and another 100 followed soon after in an area 1800m long (Yuan, 1987).

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Loading

Heavy construction equipment and other traffic can disturb the overburden and trigger its downward movement into solution openings in bedrock (LaMoreaux, 1997). The weight of construction alone can trigger sinkholes (Newton, 1976).

Removal of Vegetation

The removal of vegetation permits increased infiltration and also deprives the soil of its root mat. In Alabama, sinkholes are more common in the parts of Dry Valley where timber has been cut (LaMoreaux and Newton, 1986) and failures occurred on a Birmingham, Alabama, construction site when foundation trenches stripped areas of topsoil (Newton and Hyde, 1971). Modern sinkhole development in Tasmania has been attributed to timber cutting and pasture development (Kiernan, 1989).

Analysis of Triggering Mechanisms

Two independent studies, one in Missouri and one in Florida, indicate that altered drainage is the triggering mechanism responsible for over half of the sinkhole collapses. Williams and Vineyard (1976) conducted a study of 46 reported sinkhole collapses in Missouri and determined the cause of collapse to be; altered drainage (52 percent, water impoundments (22 percent), dewatering (15 percent), highway construction (7 percent), and blasting (4 percent). The Florida Department of Transportation analyzed 96 roadway-related collapses and determined the triggering mechanisms to be related to; heavy rainfall (58 % percent), construction (11 percent), lowering of the water table (8 percent), blasting (5 percent), drilling (5 percent), and other (11 percent). (Numbers do not add to 100 due to rounding.) Runoff collected during heavy rainfall is concentrated by highway drainage, thus supporting the findings of Williams and Vineyard (1976) that altered drainage is the dominant triggering mechanism for collapse (Thorpe and Brook, 1984).

Sinkhole Size, Occurrence, and Area Impacted

Collapse sinkholes in fissured bedrock occur in the soil overlying cavernous bedrock, and the depth, therefore, is limited to the thickness of the soil. In cavernous bedrock the depth of collapse sinkholes is limited to the combined depth of the soil and the cavern. The width of a collapse sinkhole near the surface depends on the thickness of the soil and on the slope stability, which, in turn, relates to the cohesiveness of the soil (Waltham, 1989). Geometry dictates that thick soils develop sinkholes with greater diameters than thin soils (White and White, 1995). Cohesive clayey soils maintain steeper slopes that sandy soils with low cohesiveness and, consequently, maintain wider sinkholes.

Size

Data relating to the size of sinkholes resulting from ground-water withdrawals are limited and not all the figures below refer to sinkholes related to quarrying. Sinkhole collapses in general range from 1 m to 145 m in their longest dimension. One of the largest sinkholes resulting from the withdrawal of ground water from carbonate rocks in Alabama is about 145 m long, 115 m wide, and 50 m deep (LaMoreaux and Warren, 1973) (fig. 23). A study of an area in the Birmingham, Alabama, containing over 200 sinkhole collapses (Newton and Hyde, 1971) reported that the average sinkhole was 3.7 m long, 3 m wide, and 2.4 m deep. A similar study of an area near Greenwood, Alabama, containing over 150 sinkholes (Newton and others, 1973) reported that the average elongated sinkhole was about 6.1 m long, 4 m wide, and 2.1 m deep. Some sinkholes near Sylacauga, Alabama, (Newton, 1986) had surface diameters of 9 to 30 m. In Shelby County, Alabama, (Newton, 1986) six collapses had diameters approaching or exceeding 30 m. Collapse sinkholes near Orlando, Florida, have a mean diameter of 9.4 m and a mean depth of 4.7 m (Wilson and Beck, 1992). A collapse sinkhole in central

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Figure 23. The "December giant," a large sinkhole, developed rapidly in Shelby County, Alabama, in December 1972. The sinkhole measures 145 m long, 115 m wide, and 50 m deep. *(USGS Photographic Library-USGS #140.)*

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Maryland (Martin, 1995) was approximately 9 m in diameter and 6-7 m deep. Collapse sinkholes resulting from quarry dewatering in North Carolina are up to 5 m in diameter and 3 m deep (Strum, 1999). Sinkholes in Pennsylvania (Kochanov, 1999) generally range from 1.2 m to 6.1 m in diameter and have approximately the same range in depth. In Hershey Valley, Pennsylvania, (Foose, 1953) 100 new sinkholes were reported to be 0.3 to 6.1 m in diameter and 0.6 to 3 m deep. The largest of 42 sinkhole collapses described in South Carolina (Spigner, 1978) was over 8 m in diameter and the greatest depth exceeded 3 m. The largest of 64 sinkhole collapses near Tampa, Florida, also has these same dimensions (Sinclair, 1982).

Occurrence

The numbers of collapse sinkholes that occur in an area and the size of the effected area varies from a single sinkhole in (about 1 m) to about 1,000 sinkholes in area of about 45 km2. Seven sinkholes developed at a distance of 600 m from a quarry in North Carolina (Strum, 1999). Newton (1986) similarly reports that most induced sinkholes in Alabama related to quarry operations were found within 600 m of the point of withdrawal. In contrast, Sowers (1976) reports that quarries less than 60 m deep near Birmingham, Alabama, have been related to sinkhole development as far away as 1.6 km. Sinclair (1982) also reports that 64 collapses occurred within a 1.6 km radius of a well field near Tampa, Florida. In one area in Alabama, an estimated 1,700 collapses or related features have occurred in five areas with a combined area of 36 km2 (Newton, 1976). In another area of Alabama, it was estimated that 1,000 collapses or other related features formed in an area of about 41.5 km2 (Warren and Wielchowsky, 1973). Near Jamestown, South Carolina, 42 collapses occurred within a cone of depression (Spigner, 1978). In Pennsylvania, about 100 collapses occurred in a cone of depression near Hershey where the ground-water surface had been lowered in an area greater than 25.9 km2. Impacts were observes 2.4 km from the point of dewatering (Foose, 1969; Foose and Humphreville, 1979). At Friedensville, Pennsylvania, 128 sinkholes formed from 1953-57 in an area around the point of withdrawal at a zinc mine, and 25 new sinkholes were recorded during a four-month period ending January 1971 (Newton, 1987; Metsger, 1979). Sites of similar intense development, in addition to those described above, were identified in Alabama, Georgia, Maryland, North Carolina, Pennsylvania, South Carolina, and Tennessee (Newton, 1986).

Area Impacted

The size of the impacted areas varies with the amount of ground-water withdrawal. Rates of withdrawal at the Friedensville zinc mine were between 440 and 1,310 liters per second (L/s), and the cone of depression covered an area exceeding 10.3 km2 (Newton, 1987; Metsger, 1979). Pumping by wells, quarries, and an underground mine west of Calera, Alabama, exceeded 883 L/s, creating a cone of depression of about 26 km2 (Newton, 1976, 1987; Warren, 1976). Ground-water withdrawal from two quarries with a combined rate in excess of 1,575 L/s has lowered water levels in wells over 2.4 km from the quarries (Spigner, 1978). Near Hershey, Pennsylvania, an average of 347 L/s of water was pumped from the underground quarry, impacting areas 2.4 km away (Foose, 1953, 1969). In Craven County, North Carolina, a quarry pumped at a rate of about 440 L/s, which resulted in sinkholes 600 m away (Strum, 1999).

Predicting Collapse Sinkholes

It is only possible to predict sinkhole subsidence events in the broadest of terms. However, it is possible to identify zones where sinkhole risk is increased. A number of researchers have identified specific karst features that are diagnostic in pinpointing areas having a likelihood of collapse and subsidence. Williams and Vineyard (1976) cited nine features that can foretell of collapse or subsidence in karst terrain. Foose (1969) lists seven conditions that are common in areas of karst topography subject to collapse. Aley and others (1972) described seven features of karst terrain where catastrophic collapse had occurred, although they were primarily concerned with collapses induced by construction of impoundments.

The indicators cited may have limited regional usefulness because of the tremendous number of variables among various karst terrains and the various climatic conditions in those terrains. While this report is not intended to challenge the significance of the indicators, it is important to remember that the physical properties of karst are the result of local conditions.

Guidelines that repeatedly emerge from case studies is that sinkhole development most commonly occurs where four conditions exist: 1) residual soil overlies pre-existing fractures or cavities in pinnacled carbonate bedrock; 2) a solutionally widened fracture or shaft leading down into bedrock can act as a drain to transport sediment; 3) there is some provision to store or remove soil from the drain; and 4) the water table has declined past the bedrock/soil contact (Waltham, 1989; White and White, 1995).

Collapse sinkholes form most often where and when the water table first declines past the bedrock/soil contact. This condition occurs where the water level, previously above the bedrock/soil contact during all or most of the year, is maintained below the contact by ground-water withdrawal (Waltham, 1989; Newton, 1987; LaMoreaux and Newton, 1986; Foose, 1969). All the mechanisms that trigger sinkhole development in unconsolidated deposits can be activated by the decline in water table (LaMoreaux and Newton, 1986).

LaMoreaux and Newton (1986) state that sinkholes will not occur in areas where the water table was below the bedrock/soil contact prior to dewatering. However, Foose (1969), states that sinkholes have formed where the original water table was below the bedrock/soil contact as a consequence of flushing out underlying bedrock openings during ground-water lowering.

Wilson and Beck (1992) relate sinkhole occurrence in Florida to declines in the potentiometric surface. When the surface declines 3 m below its mode, more than 10 times as many collapse sinkholes as expected per unit of time begin to occur.

Many authors also pointed out that sinkholes occur where the bedrock weathering is irregular, where the bedrock is pinnacled, or where there are extensive cavernous openings and major structural elements in the underlying bedrock (Foose, 1968; Newton, 1984a, 1984b, 1984c; Waltham, 1989).

The thickness of the residual soil has some control on the likelihood of collapse sinkholes, although the actual values appear to be site and soil-type dependent. Williams and Vineyard (1976) pointed out that sinkhole collapses are more likely to occur in residual soil ranging in thickness from 12 to 30 m. Foose (1969) observed that few sinkholes occur where the overburden is less than 10 m thick. Waltham (1989) states that the most hazardous zone is where the soil is 2 to 20 m thick. Sinclair and Stewart (1985) state sinkhole collapses are rare where limestone is at surface or the ground is thinly covered with soil; sinkhole collapse is common where overlying material is 5-50 m thick, especially between 5 and 25 m thick; sinkhole collapses are found but are rare in areas of soil cover over 50 m thick. Williams and Vineyard (1976) pointed out that sinkhole collapses are more likely to occur in residual soil that retains the fabric of the parent material and in soil where the clay fraction has low plasticity common to kaolinitic and halloysitic clays.

Geomorphology influences collapse sinkhole formation. Newton (1984a) reports induced sinkhole formation is most common in terrain that is geomorphically youthful, exhibits little karstification, is usually a lowland area, has a water table above or near the top of bedrock, and contains perennial or near-perennial streams. Williams and Vineyard (1976) found that collapses are more likely to take place in valleys with losing streams and watersheds than in gaining ones. Waltham (1989) states that the most hazardous zone is a valley floor. Many collapse sinkholes occur where concentrations of surface water are greatest, such as streambeds, natural drains, or poorly drained areas. Wilson and Beck (1992) report that near Orlando, Florida, 85 percent of new sinkholes occur over high recharge areas on slightly elevated, sandy ridges. Few or no sinkholes occur in discharge areas where net downward erosion of surficial sediment is very unlikely. Kaufmann and Quinif, (1999) related sinkhole orientation in southern Belgium to structure, and reported that almost every sinkhole they investigated lies in three parallel linear zones that reflect the orientation of a shear fault about 1 km away.

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Hobbs and Gunn (1998) outline a method to characterize the nature of a karst aquifer in terms of the likelihood of impacts from carbonate rock extraction on the ground water. They classify carbonate aquifers into four groups based on storage, type of flow, and type of recharge. Storage ranges from high to low; flow ranges from conduit to diffuse, and recharge ranges from concentrated to dispersed.

- Group 1 represents aquifers with high storage, conduit flow, and variable recharge. Predicting the impact of quarry dewatering is very difficult and is dependent on the likelihood of the workings intersecting an active conduit.
- Group 2 represents aquifers with low storage, conduit flow, and variable recharge. Predicting the impact of quarry dewatering is very difficult, but with low storage, the number of water supplies and size of springs supported by the aquifer is likely to be small.
- Group 3 represents aquifers with low storage, diffuse flow, and dispersed recharge. These are thin limestones with seasonal springs and typically are minor or non-aquifers. These aquifers present no problem from a geohydrologic point of view, and the potential impact can easily be predicted by treating them as homogenous aquifers.
- Group 4 represents aquifers with high storage, diffuse flow, and variable recharge. These aquifers provide a useful resource and may support moderately large springs that may, in turn, provide stream base flow. The potential impact can easily be predicted by treating them as homogenous aquifers.

A holistic systems analysis technique to investigate impacts of aggregate extraction on the environment is described by Langer and Kolm (2001). The method requires analyzes of various systems making up the environment, including land surface, geomorphic, subsurface, and ground-water systems (Kolm, 1996). After system characterization is complete, the method focuses on risk analysis techniques for identifying and evaluating potential environmental impacts to determine acceptable mining strategies (Langer, in press).

There may be warning signs of impending sinkhole collapse. There may be slow localized subsidence and, although new depressions may be hard to identify, the depressions may be enhanced by the ponding of water. Circular cracks may appear in the soil or pavement. Fence posts or other objects may be tilted from the vertical. Vegetation may be distressed due to lowering of the water table. Muddy water in wells may indicate the early stages of a nearby developing sinkhole.

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Reclamation

Reclamation commonly is considered to be the start of the end of environmental impacts from mining. The development of mining provides an economic base and use of a natural resource to improve the quality of human life. Equally important, properly reclaimed land can also improve the quality of life. Wisely shaping mined out land requires a design plan and product that responds to a site's physiography, ecology, function, artistic form, and public perception.

There are numerous examples of successfully reclaimed aggregate quarries, including residential, commercial, recreational, and natural uses (Arbogast and others, 2000). Many of the examples are independent of rock type. However, there are a few studies that relate specifically to reclamation of carbonate rock quarries to near natural conditions.

The oldest design approach around is nature itself. Given enough geologic time, a suitable small site scale, and stable adjacent ecosystems, disturbed areas may recover without mankind's input. Ursic and others (1997) studied the Niagara Escarpment and recognized natural cliffs as special places that provide refuge for rare species of plants and animals. They also inventoried vegetation on the walls of 18 carbonate rock quarries abandoned from 20 to 100 years ago and discovered that many of the older quarry walls naturally revegetated in such a way as to replicate the biodiversity of natural landforms.

In other areas, long-term natural recovery alone may not bring about the specific changes people find desirable. The natural reclamation process of abandoned quarries can be accelerated through a process called landform replication. Through carefully designed blasting, referred to as restoration blasting, talus slopes, buttresses, and headwalls of carbonate rock quarries can be created that can be revegetated to produce landform and plant assemblages similar to those that occur on natural valley sides (fig. 24) (Gunn and Bailey, 1993; Gunn and others, 1997).

Gillieson and Houshold (1999) describe reclamation projects in Australia that are specifically designed to return carbonate rock quarries to as close as possible to their original state. The key issues were the integrity of the underground drainage, its water quality, and the cave invertebrate populations.

Legal Aspects

The legal situation concerning induced sinkholes and other environmental impacts in karst is reviewed by Quinlan (1986), LaMoreaux (1997), and LaMoreaux and others (1997).

Quinlan (1986) summarizes case law, legal concepts of ground water and surface water, liability, and law review articles. He reviews the rationales of plaintiffs and defendants, including the allegations that serve as the basis of liability for damages and the defenses against those allegations.

LaMoreaux (1997), and LaMoreaux and others (1997) primarily discuss regulatory standards and the geologic and hydrologic conditions that lead to legal disputes. The authors point out that nearly every State in the United States has implemented legislation, rules, and regulations that apply in part or totally to karst terrain and give examples of State and local laws.

An example of the difficulties in determining the proximate cause of a sinkhole is demonstrated by the investigation of a catastrophic sinkhole that occurred near Westminster, Maryland (Gary, 1999). On March 31, 1994, a sinkhole opened up in the middle of a State road. The sinkhole measured approximately 8 m by 6 m, and was 4.5 m deep. A man drove into the sinkhole and was killed. An active quarry operation was located about 600 m away, and two municipal water supply wells were within 1.6 km of the sinkhole. An isolated pinnacle of limestone occurred in the center of the roadway alignment. A dye trace was conducted to determine if there was a hydraulic connection between the sinkhole and the quarry or other pumping locations. Sampling stations were placed throughout the surrounding valley and in the nearby quarry. There was no dye recovered in the sample sites, therefore, there was no conclusive evidence that quarry dewatering was the cause for the sinkhole.

Figure 24. Face of limestone quarry after restoration blasting and habitat reclamation. *(Photograph courtesy John Gunn.)*

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Case Studies

There are numerous causes of environmental damage in karst, many that do not relate to quarrying. These case studies are primarily those directly related to quarrying or engineering activities, such as drilling and blasting, that are used by a number of activities, including quarrying. Units of measurements in case studies are as reported by the original authors.

Blasting - A sinkhole collapse occurred in 1983 while blasting for new highway construction near Erwin in Unicoi County, Tennessee (Newton and Tanner, 1987).

Blasting - A number of rural residents near Oxford, Alabama, reported recurring problems in turbidity of water from their individual water-supply wells and, occasionally, decreases in yield. Many residents associated the problems with blasting operations in a local rock quarry. Research identified no relationship between blasting events and the quality of water in wells. Most turbidity problems occurred during the dry period of the year (October—December) when water levels in some wells are as much as 40 feet lower than during summer months. Turbid or muddy water in some wells resulting from heavy rainfall and heavy use of ground water, particularly during extended dry periods, contributes significantly to the problem (Moore and Hughes, 1979).

Blasting - Collapse sinkholes formed at a quarry (location not given) in Paleozoic dolomitic limestone following a routine blasting event. Ground water entered through the floor of the quarry from an unsuspected conduit. The conduit connected the quarry with a karst cavern network that extended to a nearby river. Immediately following the blasting event, water flowed into the quarry at a rate of about 15,000 gpm, carrying with it eroded karst-fill from the cavern. For the first few weeks, the inflow decreased in response to a rapid decline of the water table within the karst aquifer. The drainage may have led to enlargement of subsurface voids, creating a continuous connection between the river and the quarry. Subsequent river inflow to the pit further eroded fill material from the conduit and the rate of inflow increased over the next several months to over 40,000 gpm (Lolcama and others, 1999).

Drilling - Collapse at a U.S. Geological Survey test well near Keystone Heights, Florida, in 1959-60 buried a driller's helper to a depth of 30 feet and partially buried the geologist at the site. Drilling was at a depth of about 80 feet near the contact between the unconsolidated surficial material and the underlying limestone aquifers. Water level in the shallow aquifer was reportedly higher than in underlying aquifer. The well being drilled was a replacement for another recently completed and abandoned well about 12 feet away. Blasting in the abandoned well to increase yield had damaged the bottom of the casing set at depth of about 80 feet. The casing was removed prior to drilling the new well (Newton, 1987).

Drilling - Installation of wells at Westminster, Maryland, in 1940 was associated with nearby sinkhole collapse. In 1948, the well was replaced by two new wells. During a 72-hour test, the two wells were pumped at a combined rate of 950 to 1050 gpm. A sinkhole formed near the wells and cracks reportedly formed in two nearby buildings (Newton, 1987).

Drought - As many as 40 collapses sinkholes formed in downtown Sylacauga, Alabama, during a prolonged drought in 1953-56. The largest sinkhole was as much as 30 to 40 feet in diameter and 30 to 40 feet in depth. Collapses occurred under streets, water lines, drains, and other structures including a church and football field. Sinkhole activity ceased with recovery of the water table at the end of the drought. Limited activity occurred briefly in 1981 during similar decline in water table. Some water withdrawals contributed to declines during both periods (Newton, 1987)

Freeze Protection – Collapse sinkholes formed near Pierson, Florida, during the period 1973-1979 in the cone of depression created by ground-water withdrawals. Most of the sinkholes are known to have occurred during periods of drawdown caused by irrigation for freeze protection. The remainder formed in secluded locations, but were discovered soon after periods of freeze protection pumping (Rutledge, 1982).

Mine - Many sinkholes developed coincidently with major dewatering (started 1960) of a portion of the Far West Rand mining district near Johannesburg, South Africa. Between December 1962 and February 1966, eight sinkholes greater than 50 m in diameter and 30 m in depth formed. The area is characterized by deep weathering and a thick mantel of surficial material. The depth to bedrock is as much as 400 m and commonly is about 100 m. Ground water was lowered from about 100 m below surface to 550 m below surface in July of 1966. Eight large sinkholes formed after ground water was lowered to 160 m or more. Smaller sinkholes formed in the outer part of the cone of depression where the drawdown was between 60 and 160 m. Several sinkholes formed where rapid seepage of water from the surface hastened the process of roof spalling and cavern enlargement. The largest of the sinkholes formed after a few days of torrential rainfall (Foose, 1967).

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Mine - Dewatering a zinc mine near Friedensville, Pennsylvania began in 1953. Active sinkhole collapse occurred in an area of large ground-water withdrawals. Records indicate that 128 sinkholes formed around the dewatering site during period 1953-57. Twenty-five new sinkholes occurred from October 1970 to January 1971. The number of sinkholes occurring during the intervening 13 years was not inventoried. The water table in lowland areas prior to withdrawals was generally at a depth of less than 30 feet. Depth to top of bedrock exceeds 30 feet in numerous areas. Rates of withdrawal between 1953 and 1977 varied between 10 and 30 million gallons per day. The cone of depression in 1967 exceeded 4 mi^2 in area (Metsger, 1979).

Multiple Causes - Collapse sinkholes have been reported since the beginning of the 20th century in the Tournaisis area, southern Belgium. The sinkholes developed from reactivated paleokarsts. Intensive pumping for domestic and industrial water supply, combined with the dewatering due to deep limestone quarries, resulted in the lowering of ground-water levels. This triggered the reactivation of paleokarstic systems resulting in sinkhole collapse (Kaufmann and Quinif, 1999).

Multiple Causes – An estimated 1,000 collapses west of Calera, Alabama include sites of subsidence, fracturing, and significant piping. One collapse, the "December Giant" (fig. 23), measures 145 m long, 115 m wide, and 50 m deep (LaMoreaux and Warren, 1973). The area was dewatered by wells, quarries, and an underground mine. The cone of depression in October 1973 was about 10 mi^2 (26 $km^{2)}$ in area. Pumpage at that time exceeded 14,000 gallons per minute (883 liters per second). Significant sinkhole development began about 1964. The greatest hazards in this ural area were collapses beneath highways and major gas pipelines. Sinkholes in part of the area were still active in 1981 (Newton, 1976, 1987; Warren, 1976).

Multiple Causes - More than 150 sinkholes, depressions, and related features formed in and adjacent to the proposed right-of-way of Interstate Highway 459 near the community of Greenwood in Bessemer, Alabama. Sinkhole collapse began about 1950 and continued through March 1972. A general lowering of the water table occurred during the early 1950's, or the preceding decade de to large withdrawals of ground water from more than 1,070 wells (1,500 gpm) and deep mines (9,500 gpm), compounded with a prolonged drought during the 1950's (Newton and others, 1973).

Quarry and underground mining - Quarry and mine dewatering extended to within 1.5 miles (2 km) of Farmington, Missouri. Collapses were recorded at least 30 years prior to quarrying and mining and have continued for 10 years subsequent to the completion of mining activities. Although deep mines exist in areas subject to catastrophic collapse in Missouri, and continuous dewatering is required for mining, only minor surface effects have been noted (Williams and Vineyard, 1976).

Quarry and underground quarry, Hershey, Pa. – A series events in surface and underground quarrying near Hershey, Pennsylvania, between 1946 and 1953 altered ground-water levels over an area of 10 mi. About 100 new sinkholes formed within the area where there was a drastic lowering of the water table. Recovery of water levels to nearly normal conditions in 1950 was accompanied by a cessation of sinkhole development (Foose, 1953, 1969).

A blast of August 1946, Hershey, Pa. - Blast in the hanging wall of the underground quarry near Hershey, Pa. exposed a 6-inch-wide solution channel about 275 or 375 feet below the surface. Water flowed at 8,000 to 10,000 gpm, flooding the quarry in one day. Near-by wells dried up, ground-water seepage into a nearby quarry ceased, Derry Spring 1½ miles to the southwest dried up on second day, and water in two nearby wells at the Hershey Chocolate Corporation (1½ miles northeast) rapidly declined. After many months the opening was sealed. Adjacent wells had water in them again, and flow at spring and water levels in corporate wells were restored (Foose, 1953, 1969).

Pumping Test of August 1948, Hershey, Pa. - From August 30 to September 4, 1948, an average of 5,500 gpm was pumped from the underground quarry near Hershey, Pa. as a test preliminary to permanent installation of pumps for deeper quarry operations. The water level was maintained at about 200 feet below the quarry floor. On September 2 the newly drilled Derry Spring well 1½ miles southwest (yield of 2100 gpm) dried up; water level fell from an elevation of 355 ft to 313 ft, which was below the pump intake. On September 8, water level began to rise, and within a couple of days normal pumping operations resumed (Foose, 1953, 1969).

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Increased pumping during May 1949, Hershey, Pa. - The quarry operation near Hershey, Pa. inaugurated its new pumping program at about 6,500 gpm normal discharge from pumps with the intake at 340 ft. below the land surface. Derry Spring well dried up. Spring Creek dried up. Many wells throughout the valley went dry. During the second month of the new pumping program, sinkholes began to form in the valley of Spring Creek. The size of the sinkholes ranged from 1 to 20 ft in diameter and 2 to 10 ft deep. Nearly 100 sinkholes formed. More new sinkholes formed during the late summer of 1949 than had previously existed in the areas. During February and March of 1950, grouting in the underground quarry reduced flow into the quarry (flow had reached 8,000 gpm). Springs began to flow again, wells could be pumped, and Spring Creek began to flow. In 1953, the quarry was allowed to flood and became a water storage reservoir. Sinkhole formation ceased after dewatering stopped and the water table had recovered (Foose, 1969).

Quarry - In 1950, a quarry at Pelham, Alabama, was in its early stages of development and sinkholes were not actively occurring. As the excavation progressed, it became necessary to dewater. In 1959, 11 open collapses were observable on aerial photographs and by 1967 34 open collapses were observable. The total distance of sinkhole migration was about 0.4 mile. At some time prior to October 1967, the quarry was abandoned and ground-water pumping stopped, along with sinkhole formation (Newton, 1976).

Quarry - More than 18 sinkhole collapses occurred along a planned highway corridor near Castle Hayne, North Carolina in 1980-81. These sinkholes were under the pavement of an existing road and in or adjacent to its right-of-way near a dewatered quarry. Four sinkholes were triggered by torrential rains in August 1981 (Newton, 1987).

Quarry - In August and September 1994, seven sinkholes up to 5 m in diameter and 3 m deep developed at a residential property adjacent to a limestone quarry in Craven County, North Carolina. The quarry operates about 600m southeast of the sinkholes and pumps water at a rate of 38 million liters per day. Water levels in wells on the perimeter of the quarry site have declined by as much as 5 meters below pre-pumping conditions. Large changes in hydraulic head were observed in monitoring wells at the quarry as the active pit was developed across the quarry site. The collapse of the sinkholes concurrent with large changes in water levels at the quarry suggests that head changes in the limestone aquifer may have been a triggering mechanism for sinkhole collapse (Strum, 1999).

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Quarry - In about 1986, a limestone quarry in the Valley and Ridge Province in the southeastern United States began expansion by deepening the quarry to a new level about 60 m (200 ft) below the original water table. Extensive dewatering triggered sinkhole development in a nearby town and along a local railroad track. The ground-water surface was depressed in and around the quarry and appeared to affect the ground-water flow regime in and around the quarry and town. Ground-water levels were lowered 18 to 24 m (60 to 80 ft) at a distance of about 0.8 km (one half mile) from the quarry. Collapse sinkholes began to develop around the quarry, occurring as much as 1.6 km (one mile) from the quarry. A perennial stream was captured by a sinkhole, a sinkhole drained a local wastewater treatment pond, and sinkholes and ground subsidence began to threaten the local railroad track. The summer of 1987 was a drought year for the region, and the likely impact of the drought on sinkhole development in the area was investigated. The investigation concluded that quarry dewatering related to quarry expansion was the primary cause of the sinkholes and subsidence that occurred around the town that year. A few years after the expansion, quarry operations ceased and the quarry naturally filled with water. The writers did not document any further sinkhole or subsidence activity since that time (Kath and others, 1995).

Quarry - Artificial drawdown is the probable cause of a sinkhole problem at Railton in northwestern Tasmania where limestone is excavated from a deep quarry on the floor of a broad valley beneath about 20m of overburden. Prior to quarrying there was little evidence of sinkholes. Local anecdotes suggest minor sinkhole problems arose during the early years of the operation. A new bench was developed in the quarry during the early-mid 1980's, deepening the quarry by 15-20m, and sinkhole collapses increased. The sinkholes appeared to occur within a cone of ground-water depression around the quarry. The town sewage main was ruptured by one sinkhole. A nearby abandoned water-filled quarry drained rapidly. Other sinkholes appeared in pasture close to the quarry and in the backyards of at least two village dwellings. Exposures in the quarry reveal that the limestone surface beneath the overburden consists of pinnacles with a relief of 10 – 15 m. At least two small caves and one major spring were encountered at depth in the quarry. Artificial lowering of the ground-water table due to the quarrying together with differential settlement of the overburden between the limestone pinnacles was reported as the most likely cause of the problem. Inadequate drainage of runoff from the roofs of houses and outbuildings contributed to at least one collapse (Kiernan, 1989).

Quarry - Numerous sinkholes and sites of subsidence developed in a borrow pit area near Andrew Johnson Highway west of Morristown, Tennessee. The borrow pit was active as early as April 1976. Most sinkholes occurred between 1983 and 1986. The site exhibits three distinct levels of excavating with sinkholes occurring on all levels. Ten sinkholes occurred on the lower level, two sinkholes on the middle level, and one sinkhole on the upper level. The number of sinkholes occurring on each level was correlative with amounts of drainage received by each. Three additional sinkholes occurred across a road adjacent to the borrow pit, and collapses in the road have reportedly occurred on more than one occasion (Newton and Tanner, 1987).

Quarries – Ground-water withdrawals from two quarries in the Jamestown, South Carolina area resulted in 42 sites of subsidence and collapse in 1976-78. Collapses range in size from less than 1 ft to over 24 ft in diameter. Most dramatic collapses occur within 5,000 ft of, the point of largest ground water withdrawal. About 20 feet of unconsolidated sands and clays overlie the cavernous limestone that was being quarried. Pumpage was estimated to periodically be in excess of 36 million gallons per day, causing a water level decline of over 35 feet. Water levels in wells over 1.5 miles from the center of pumping have been affected. Blasting has caused "muddying" of water (Spigner, 1978).

Quarries – Ground-water withdrawal from two deep quarries in Birmingham, Alabama, resulted in two overlapping cones of depressions, with apexes being at quarries. More than 200 sinkholes formed in an area of less than 0.5 mi^2 during a period of about 8 years. The formation of many of the sinkholes coincided with periods of heavy rain. Movement of water to one quarry was verified by dye tests. Estimated total average discharge from both quarries exceeds 1.0 mgd. Withdrawals from other sources were not identified (Newton and Hyde, 1971).

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Brook Trout Study Identifies Top Climate Change Pressure Factor [1]

UMass Amherst, Forest Service, USGS scientists track more than 15,000 brook trout
November 30, 2015
Contact: Janet Lathrop [2] 413/545-0444

brook trout

AMHERST, Mass. – Results from a 15-year study of factors affecting population levels of Eastern brook trout in the face of climate change show that high summer air temperatures have a large influence, in particular on the smallest fry and eggs, which are most important to wild trout abundance in streams.

Co-author Ben Letcher, fisheries biologist at the U.S. Geological Survey and adjunct faculty in environmental conservation at the University of Massachusetts Amherst, says, “It took years of sampling four streams and tracking more than 15,000 individual fish, but we feel we can account for about 90 percent of the yearly variation in abundance. The bottom line is that high summer temperatures are bad. That is unfortunate because summer air temperature is expected to increase with climate change and extreme rain is also expected to increase, especially in the spring when vulnerable eggs are hatching and fry are emerging.”

“Those two things are heading in the wrong direction for this particular species,” he adds. Letcher and his colleagues predict that if climate warming proceeds as projected and the trout don’t evolve, in as soon as 15 years these sentinel fish of cold water streams could be gone from the study stream. “If they can evolve, they may at least double their ability to stay in the stream,” he notes.

Findings reported this week in the current issue of the *Global Change Biology* are expected to help nonprofit watershed conservation groups and state and federal wildlife managers identify, prioritize and protect habitat at sites most likely to have

fish in the future.

To identify how climate influences fish abundance in streams, Letcher and colleagues at UMass Amherst, USGS, the USDA Forest Service and the University of Oxford, England, studied native brook trout in a small cold water main stream with three tributaries, perhaps “the most studied trout stream in the world” he says, about 1 kilometer long, in western Massachusetts.

Since 2000, they have sampled populations and tagged individual trout to understand the relationship between fish deaths, births, their movement into and out of the stream and factors such as air and water temperature, stream flow, rainfall and drought by season. Using small pieces of fin from thousands of individual fish, the researchers also are studying generations to see if they might evolve their way out of this problem.

Letcher explains that this group’s recent paper represents step two of their quantitative model of this stream system. It puts fish growth, movement and survival data together with stream temperature and flow in each of the four streams in each of the four seasons per year.

“Climate works through rain and stream flow, and air temperature and stream temperature. Our challenge is to get from climate, to stream, to fish,” he points out. “Put simply, the two main drivers are stream flow and temperature. If we can understand the link, then we can predict from climate back to fish. This paper boils all that down into one complicated but integrated model that takes all those things into account. The result is a forecast based on best available knowledge.”

The data points are tight, he adds. “It’s very hard to detect contemporary climate change effects, but we’ve done that. It took a study of this complexity to be able to uncover these very complicated relationships, but because we can account for a lot of the variability in the system, I have confidence in the results.”

“If we were looking at just this study by itself I’d have less confidence in the conclusion. But we also have data from studies in other areas and they all point to the same general conclusions. Data from other states and other experiments fit our model and match the abundance decline we see with higher summer air temperatures and more extreme spring floods.”

Letcher says there is much that can be done by wildlife managers, land trusts and conservation groups to help the Eastern brook trout in the future, including putting more shade-producing trees along river banks, adding logs into streams and making sure there are not too many wells removing cold spring water from the watershed. He is designing a web application to help such groups interpret and understand this study and others from the same research group.

Letcher’s collaborators include Keith Nislow, project leader in the U.S. Forest Service’s Northern Research Station, conservation geneticist Andrew Whiteley and postdoctoral researcher Jason Coombs at UMass Amherst, evolutionary ecologist Ron Bassar currently at Oxford University, and Matt O’Donnell and Todd Dubreuil at the USGS.

Funding for this work is from USGS, the U.S. Forest Service, The Nature Conservancy and the U.S. Fish and Wildlife Service’s North Atlantic Landscape Conservation Cooperative in Hadley, Mass.

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SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS
CC2a	25,376,041.98	24637.77	Leithsville Fm	Limestone
CC2a	25,376,041.98	24637.77	Allentown Fm	Limestone
				Total (sq-ft):
				Total (acres):
				Percentage
CC2a	25,376,041.98	24637.77	Hardyston Fm	Crystalline
CC2a	25,376,041.98	24637.77	Hornblende Gneiss	Crystalline
CC2a	25,376,041.98	24637.77	Hardyston Fm	Crystalline
CC2a	25,376,041.98	24637.77	Granitic Gneiss	Crystalline
				Total (sq-ft):
Area CC2a:	**634.40**	**acres**		**Total (acres):**
				Percentage
CC6a	24,490,315.07	22505.85	Leithsville Fm	Limestone
CC6a	24,490,315.07	22505.85	Allentown Fm	Limestone
				Total (sq-ft):
				Total (acres):
				Percentage
CC6a	24,490,315.07	22505.85	Hornblende Gneiss	Crystalline
CC6a	24,490,315.07	22505.85	Hardyston Fm	Crystalline
CC6a	24,490,315.07	22505.85	Granitic Gneiss	Crystalline
CC6a	24,490,315.07	22505.85	Granitic Gneiss	Crystalline
CC6a	24,490,315.07	22505.85	Granitic Gneiss	Crystalline
CC6a	24,490,315.07	22505.85	Hornblende Gneiss	Crystalline
CC6a	24,490,315.07	22505.85	Hornblende Gneiss	Crystalline
				Total (sq-ft):
				Total (acres):
Area CC6a:	**612.26**	**acres**		**Percentage**
CC9a	26,488,883.19	26615.98	Leithsville Fm	Limestone
CC9a	26,488,883.19	26615.98	Allentown Fm	Limestone
				Total (sq-ft):
				Total (acres):
				Percentage
CC9a	26,488,883.19	26615.98	Hardyston Fm	Crystalline
CC9a	26,488,883.19	26615.98	Granitic Gneiss	Crystalline
CC9a	26,488,883.19	26615.98	Granitic Gneiss	Crystalline
CC9a	26,488,883.19	26615.98	Hornblende Gneiss	Crystalline
CC9a	26,488,883.19	26615.98	Hornblende Gneiss	Crystalline

CC9a	26,488,883.19		26615.98	Hornblende Gneiss	Crystalline
					Total (sq-ft):
					Total (acres):
Area CC9a:	**662.22**	**acres**			**Percentage**
CCT33a	8,825,954.40		14812.85	Leithsville Fm	Limestone
	220.65				**Total (sq-ft):**
					Total (acres):
					Percentage
CCT33a	8,825,954.40		14812.85	Hardyston Fm	Crystalline
CCT33a	8,825,954.40		14812.85	Granitic Gneiss	Crystalline
CCT33a	8,825,954.40		14812.85	Hornblende Gneiss	Crystalline
CCT33a	8,825,954.40		14812.85	Hornblende Gneiss	Crystalline
					Total (sq-ft):
					Total (acres):
Area CCT33a:	**220.65**	**acres**			**Percentage**
CCT34a	10,761,744.62		18319.80	Leithsville Fm	Limestone
	269.04				**Total (sq-ft):**
					Total (acres):
					Percentage
CCT34a	10,761,744.62		18319.80	Hardyston Fm	Crystalline
CCT34a	10,761,744.62		18319.80	Granitic Gneiss	Crystalline
CCT34a	10,761,744.62		18319.80	Hornblende Gneiss	Crystalline
CCT34a	10,761,744.62		18319.80	Hardyston Fm	Crystalline
					Total (sq-ft):
					Total (acres):
					Percentage
Area CCT34a:	**269.04**	**acres**			

AREA (sq-ft)
4,120,395.52
4,555,786.12
8,676,181.64
216.90
34.19%
408,229.27
11,754,892.65
4,023,001.62
513,736.80
16,699,860.34
417.50
65.81%
4,227,500.14
595,593.75
4,823,093.89
120.58
19.69%
7,730,984.69
2,432,331.73
6,748,225.49
661,328.48
79,424.76
23,208.45
1,991,717.57
19,667,221.17
491.68
80.31%
1,422,848.46
652,289.71
2,075,138.17
51.88
7.83%
1,185,082.60
14,219,264.38
415,011.80
3,667,019.50
3,666,268.78

1,261,097.96
24,413,745.02
610.34
92.17%
327,691.73
327,691.73
8.19
3.71%
544,862.38
3,699,032.81
1,941,053.13
2,313,314.34
8,498,262.66
212.46
96.29%
1,826,521.19
1,826,521.19
45.66
16.97%
246,177.09
6,073,595.21
1,770,749.73
844,701.39
8,935,223.42
223.38
83.03%

SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
CC1	105,710,096.94	97,925.06	Leithsville Fm	Limestone	43,269,196.00
CC1	105,710,096.94	97,925.06	Allentown Fm	Limestone	11,862,652.00
				Total (sq-ft)	**55,131,848.00**
				Total (acres)	**1,378.30**
				Percentage	**52.15%**
CC1	105,710,096.94	97,925.06	Hardyston Fm	Crystalline	3,955,274.00
CC1	105,710,096.94	97,925.06	Granitic Gneiss	Crystalline	19,011,499.00
CC1	105,710,096.94	97,925.06	Hornblende Gneiss	Crystalline	3,088,219.00
CC1	105,710,096.94	97,925.06	Hornblende Gneiss	Crystalline	8,456,640.00
CC1	105,710,096.94	97,925.06	Hardyston Fm	Crystalline	307,117.00
CC1	105,710,096.94	97,925.06	Hardyston Fm	Crystalline	11,758,400.00
CC1	105,710,096.94	97,925.06	Granitic Gneiss	Crystalline	612,512.00
CC1	105,710,096.94	97,925.06	Hardyston Fm	Crystalline	2,071,251.00
CC1	105,710,096.94	97,925.06	Granitic Gneiss	Crystalline	1,317,336.00
				Total (sq-ft)	**50,578,248.00**
				Total (acres)	**1,264.46**
Area CC1:	**2,642.75**	**acres**		**Percentage**	**47.85%**
CCT10	2,435,679.89	7,352.41	Hornblende Gneiss	Crystalline	1,153,973.00
CCT10	2,435,679.89	7,352.41	Granitic Gneiss	Crystalline	497,257.00
				Total (sq-ft)	**1,651,230.00**
				Total (acres)	**41.28**
				Percentage	**67.80%**
CCT10	2,435,679.89	7,352.41	Brunswick Fm	Brunswick	784,450.00

					Total (sq-ft)	**784,450.00**
					Total (acres)	**19.61**
Area CCT10:	**60.89**	**acres**			**Percentage**	**32.21%**
CCT8	21,572,375.14		21,406.52	Leithsville Fm	Limestone	3,126,779.00
	539.31				**Total (sq-ft)**	**3,126,779.00**
					Total (acres)	**78.17**
					Percentage	**14.49%**
CCT8	21,572,375.14		21,406.52	Hornblende Gneiss	Crystalline	10,394,592.00
CCT8	21,572,375.14		21,406.52	Hardyston Fm	Crystalline	4,014,901.00
CCT8	21,572,375.14		21,406.52	Granitic Gneiss	Crystalline	1,070,075.00
					Total (sq-ft)	**15,479,568.00**
					Total (acres)	**386.99**
					Percentage	**71.76%**
CCT8	21,572,375.14		21,406.52	Quartz Fanoglomerat	Brunswick	999,237.00
CCT8	21,572,375.14		21,406.52	Brunswick Fm	Brunswick	1,966,791.00
					Total (sq-ft)	**2,966,028.00**
					Total (acres)	**74.15**
Area CCT8:	**539.31**	**acres**			**Percentage**	**13.75%**

Table 5

Subwatershed Area By Hydrogeologic Units

SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
CC11a	22,091,306.83	19,258.44	Leithsville Fm	Limestone	8,768,562.00
				Total (sq-ft)	**8,768,562.00**
				Total (acres)	**219.21**
				Percentage	**39.69%**
CC11a	22,091,306.83	19,258.44	Hornblende Gneiss	Crystalline	2,713,953.00
CC11a	22,091,306.83	19,258.44	Hardyston Fm	Crystalline	8,922,216.00
CC11a	22,091,306.83	19,258.44	Granitic Gneiss	Crystalline	518,551.00
CC11a	22,091,306.83	19,258.44	Granitic Gneiss	Crystalline	1,003,749.00
CC11a	22,091,306.83	19,258.44	Granitic Gneiss	Crystalline	164,275.00
				Total (sq-ft)	**13,322,744.00**
				Total (acres)	**333.07**
Area CC11a:	**552.28**	**acres**		**Percentage**	**60.31%**
CC12a	17,870,381.40	22,023.29	Leithsville Fm	Limestone	2,502,474.00
				Total (sq-ft)	**2,502,474.00**
				Total (acres)	**62.56**
				Percentage	**14.00%**
CC12a	17,870,381.40	22,023.29	Hornblende Gneiss	Crystalline	12,535.00
CC12a	17,870,381.40	22,023.29	Hardyston Fm	Crystalline	8,725,963.00
CC12a	17,870,381.40	22,023.29	Granitic Gneiss	Crystalline	2,434,375.00
				Total (sq-ft)	**11,172,873.00**
				Total (acres)	**279.32**
				Percentage	**62.52%**
CC12a	17,870,381.40	22,023.29	Quartz Fanoglomerate	Brunswick	4,195,035.00
				Total (sq-ft)	**4,195,035.00**
				Total (acres)	**104.88**
Area CC12a:	**446.76**	**acres**		**Percentage**	**23.48%**
CC4a	4,965,003.03	9,168.44	Leithsville Fm	Limestone	1,225,122.00
				Total (sq-ft)	**1,225,122.00**
				Total (acres)	**30.63**
				Percentage	**24.67%**
CC4a	4,965,003.03	9,168.44	Hornblende Gneiss	Crystalline	3,739,881.00

				Total (sq-ft)	**3,739,881.00**
				Total (acres)	**93.50**
Area CC4a:	**124.13**	**acres**		**Percentage**	**75.33%**
CCT23a	5,631,663.82	10,726.10	Hornblende Gneiss	Crystalline	49,486.00
				Total (sq-ft)	**49,486.00**
				Total (acres)	**1.24**
				Percentage	**0.88%**
CCT23a	5,631,663.82	10,726.10	Brunswick Fm	Brunswick	3,166,065.00
CCT23a	5,631,663.82	10,726.10	Quartz Fanoglomerate	Brunswick	1,168,454.00
CCT23a	5,631,663.82	10,726.10	Quartz Fanoglomerate	Brunswick	1,247,660.00
				Total (sq-ft)	**5,582,179.00**
				Total (acres)	**139.55**
Areas CCT23a:	**140.79**	**acres**		**Percentage**	**99.12%**
CCT24a	6,196,518.42	13,630.14	Granitic Gneiss	Crystalline	3,133.00
				Total (sq-ft)	**3,133.00**
				Total (acres)	**0.08**
				Percentage	**0.05%**
CCT24a	6,196,518.42	13,630.14	Brunswick Fm	Brunswick	1,090,176.00
CCT24a	6,196,518.42	13,630.14	Quartz Fanoglomerate	Brunswick	5,103,210.00
				Total (sq-ft)	**6,193,386.00**
				Total (acres)	**154.83**
Areas CCT24a:	**154.91**	**acres**		**Percentage**	**99.95%**
CCT25a	10,471,143.28	13,658.40	Hornblende Gneiss	Crystalline	1,528,292.00
CCT25a	10,471,143.28	13,658.40	Hardyston Fm	Crystalline	103,485.00
CCT25a	10,471,143.28	13,658.40	Granitic Gneiss	Crystalline	2,957,431.00
CCT25a	10,471,143.28	13,658.40	Hornblende Gneiss	Crystalline	380,135.00
				Total (sq-ft)	**4,969,343.00**
				Total (acres)	**124.23**
				Percentage	**47.46%**
CCT25a	10,471,143.28	13,658.40	Brunswick Fm	Brunswick	744,703.00
CCT25a	10,471,143.28	13,658.40	Quartz Fanoglomerate	Brunswick	4,757,096.00

				Total (sq-ft)	**5,501,799.00**
				Total (acres)	**137.54**
Areas CCT25a:	**261.78**	**acres**		**Percentage**	**52.54%**
CCT26a	15,559,999.47	17,743.82	Leithsville Fm	Limestone	222,935.00
CCT26a	15,559,999.47	17,743.82	Limestone Fanoglomer	Limestone	384,793.00
				Total (sq-ft)	**607,728.00**
				Total (acres)	**15.19**
				Percentage	**3.91%**
CCT26a	15,559,999.47	17,743.82	Hardyston Fm	Crystalline	5,592,891.00
CCT26a	15,559,999.47	17,743.82	Granitic Gneiss	Crystalline	3,486,761.00
				Total (sq-ft)	**9,079,652.00**
				Total (acres)	**226.99**
				Percentage	**58.35%**
CCT26a	15,559,999.47	17,743.82	Quartz Fanoglomerate	Brunswick	4,532,752.00
CCT26a	15,559,999.47	17,743.82	Brunswick Fm	Brunswick	1,339,867.00
				Total (sq-ft)	**5,872,619.00**
				Total (acres)	**146.82**
Area CCT26a:	**389.00**	**acres**		**Percentage**	**37.74%**
CCT27a	5,156,819.33	11,639.43	Brunswick Fm	Brunswick	2,779,112.00
				Total (sq-ft)	**2,779,112.00**
				Total (acres)	**69.48**
				Percentage	**53.89%**
CCT27a	5,156,819.33	11,639.43	Diabase	Diabase	2,377,708.00
				Total (sq-ft)	**2,377,708.00**
				Total (acres)	**59.44**
Area CCT27a:	**128.92**	**acres**		**Percentage**	**46.11%**
CCT29a	6,287,733.97	10,797.57	Quartz Fanoglomerate	Brunswick	959,464.00
CCT29a	6,287,733.97	10,797.57	Brunswick Fm	Brunswick	5,328,270.00
				Total (sq-ft)	**6,287,734.00**
				Total (acres)	**157.19**
Area CCT29a:	**157.19**	**acres**		**Percentage**	**100.00%**
CCT30a	4,339,722.76	9,563.43	Brunswick Fm	Brunswick	1,992,547.00
				Total (sq-ft)	**1,992,547.00**
				Total (acres)	**49.81**
				Percentage	**45.92%**

CCT30a	4,339,722.76	9,563.43	Diabase	Diabase	2,347,176.00
				Total (sq-ft)	**2,347,176.00**
				Total (acres)	**58.68**
Area CCT30a:	**108.49**	**acres**		**Percentage**	**54.08%**
CCT31a	4,609,981.03	12,135.14	Quartz Fanoglomerate	Brunswick	2,221,663.00
CCT31a	4,609,981.03	12,135.14	Brunswick Fm	Brunswick	2,388,318.00
				Total (sq-ft)	**4,609,981.00**
				Total (acres)	**115.25**
Area CCT31a:	**115.25**	**acres**		**Percentage**	**100.00%**
CCT32a	7,351,739.98	14,779.17	Quartz Fanoglomerate	Brunswick	2,472,367.00
CCT32a	7,351,739.98	14,779.17	Brunswick Fm	Brunswick	3,834,044.00
CCT32a	7,351,739.98	14,779.17	Lockatong Fm	Brunswick	1,045,329.00
	183.79			**Total (sq-ft)**	**7,351,740.00**
Area CCT32a:	**183.79**	**acres**		**Total (acres)**	**183.79**
				Percentage	**100.00%**

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Table 5

Subwatershed Area By Hydrogeologic Units

SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
SC2a	12,321,788.43	18,983.31	Leithsville Fm	Limestone	492,641.00
				Total (sq-ft)	**492,641.00**
				Total (acres)	**12.32**
				Percentage	**4.00%**
SC2a	12,321,788.43	18,983.31	Granitic Gneiss	Crystalline	11,829,148.00
				Total (sq-ft)	**11,829,148.00**
				Total (acres)	**295.73**
Area SC2a:	**308.04**	**acres**		**Percentage**	**96.00%**
SC3a	4,460,811.92	12,547.89	Leithsville Fm	Limestone	406,948.00
				Total (sq-ft)	**406,948.00**
				Total (acres)	**10.17**
				Percentage	**9.12%**
SC3a	4,460,811.92	12,547.89	Granitic Gneiss	Crystalline	4,053,864.00
				Total (sq-ft)	**4,053,864.00**
				Total (acres)	**101.35**
Area SC3a:	**111.52**	**acres**		**Percentage**	**90.88%**
SCN2a	17,767,983.94	22,557.99	Leithsville Fm	Limestone	5,440,529.00
	444.20				
				Total (sq-ft)	**5,440,529.00**
				Total (acres)	**136.01**
				Percentage	**30.62%**
SCN2a	17,767,983.94	22,557.99	Granitic Gneiss	Crystalline	2,191,374.00
SCN2a	17,767,983.94	22,557.99	Hornblende Gneiss	Crystalline	638,324.00
				Total (sq-ft)	**2,829,698.00**
				Total (acres)	**70.74**
				Percentage	**15.93%**
SCN2a	17,767,983.94	22,557.99	Quartz Fanoglomerate	Brunswick	9,497,757.00

					Total (sq-ft)	**9,497,757.00**
					Total (acres)	**237.44**
Area SCN2a:	**444.20**	**acres**			**Percentage**	**53.45%**
SCN3a	4,785,559.01		10,933.15	Leithsville Fm	Limestone	1,098,969.00
					Total (sq-ft)	**1,098,969.00**
					Total (acres)	**27.47**
					Percentage	**22.96%**
SCN3a	4,785,559.01		10,933.15	Quartz Fanoglomerate	Brunswick	3,686,590.00
					Total (sq-ft)	**3,686,590.00**
					Total (acres)	**92.16**
Area SCN3a:	**119.64**	**acres**			**Percentage**	**77.04%**
SCS2a	6,894,998.12		12,280.80	Quartz Fanoglomerate	Brunswick	6,325,995.00
SCS2a	6,894,998.12		12,280.80	Brunswick Fm	Brunswick	569,003.00
					Total (sq-ft)	**6,894,998.00**
					Total (acres)	**172.37**
Area SCS2a:	**172.37**	**acres**			**Percentage**	**100.00%**
SCS3a	23,636,950.47		25,581.02	Quartz Fanoglomerate	Brunswick	19,823,338.00
SCS3a	23,636,950.47		25,581.02	Brunswick Fm	Brunswick	3,813,613.00
	590.92				**Total (sq-ft)**	**23636951**
					Total (acres)	**590.92**
Area SCS3a:	**590.92**	**acres**			**Percentage**	**100%**

Table 5

Subwatershed Area By Hydrogeologic Units

SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
CC14	67,282,517.85	64,252.49	Leithsville Fm	Limestone	5,680,276.00
CC14	67,282,517.85	64,252.49	Limestone Fanoglomerate	Limestone	2,021,236.00
				Total (sq-ft)	**7,701,512.00**
				Total (acres)	**192.54**
				Percentage	**11.45%**
CC14	67,282,517.85	64,252.49	Hardyston Fm	Crystalline	892,870.00
CC14	67,282,517.85	64,252.49	Granitic Gneiss	Crystalline	354,149.00
CC14	67,282,517.85	64,252.49	Hardyston Fm	Crystalline	1,122,274.00
CC14	67,282,517.85	64,252.49	Granitic Gneiss	Crystalline	5,023,488.00
				Total (sq-ft)	**7,392,781.00**
				Total (acres)	**184.82**
				Percentage	**10.99%**
CC14	67,282,517.85	64,252.49	Brunswick Fm	Brunswick	49,726,595.00
				Total (sq-ft)	**49,726,595.00**
				Total (acres)	**1,243.16**
				Percentage	**73.90%**
CC14	67,282,517.85	64,252.49	Diabase	Diabase	1,483,021.00
CC14	67,282,517.85	64,252.49	Diabase	Diabase	978,608.00
				Total (sq-ft)	**2,461,629.00**
				Total (acres)	**61.54**
Area CC14:	**1,682.06**	**acres**		**Percentage**	**3.66%**
CCT13	6,950,666.14	17,397.31	Leithsville Fm	Limestone	2,255,027.00
CCT13	6,950,666.14	17,397.31	Limestone Fanoglomerate	Limestone	1,696,295.00
				Total (sq-ft)	**3,951,322.00**
				Total (acres)	**98.78**
				Percentage	**56.85%**
CCT13	6,950,666.14	17,397.31	Hardyston Fm	Crystalline	607,898.00
CCT13	6,950,666.14	17,397.31	Granitic Gneiss	Crystalline	118,853.00
CCT13	6,950,666.14	17,397.31	Granitic Gneiss	Crystalline	18,055.00
				Total (sq-ft)	**744,806.00**
				Total (acres)	**18.62**
				Percentage	**10.71%**
CCT13	6,950,666.14	17,397.31	Brunswick Fm	Brunswick	2,254,539.00

				Total (sq-ft)	**2,254,539.00**
				Total (acres)	**56.36**
Area CCT13:	**173.77**	**acres**		**Percentage**	**32.44%**
CCT28	13,483,712.46	24,540.52	Brunswick Fm	Brunswick	9,973,263.00
				Total (sq-ft)	**9,973,263.00**
				Total (acres)	**249.33**
				Percentage	**73.97%**
CCT28	13,483,712.46	24,540.52	Diabase	Diabase	3,510,449.00
				Total (sq-ft)	**3,510,449.00**
				Total (acres)	**87.76**
Area CCT28:	**337.09**	**acres**		**Percentage**	**26.03%**
SC1	14,751,635.81	22,566.00	Leithsville Fm	Limestone	9,508,368.00
				Total (sq-ft)	**9,508,368.00**
				Total (acres)	**237.71**
				Percentage	**64.46%**
SC1	14,751,635.81	22,566.00	Granitic Gneiss	Crystalline	1,563,932.00
SC1	14,751,635.81	22,566.00	Hardyston Fm	Crystalline	2,877,834.00
SC1	14,751,635.81	22,566.00	Granitic Gneiss	Crystalline	801,503.00
				Total (sq-ft)	**5,243,269.00**
				Total (acres)	**131.08**
Area SC1:	**368.79**	**acres**		**Percentage**	**35.54%**
SCN1	34,579,629.51	25,082.55	Leithsville Fm	Limestone	12,570,198.00
				Total (sq-ft)	**12,570,198.00**
				Total (acres)	**314.25**
				Percentage	**36.35%**
SCN1	34,579,629.51	25,082.55	Granitic Gneiss	Crystalline	14,266,082.00
SCN1	34,579,629.51	25,082.55	Hornblende Gneiss	Crystalline	2,977,763.00
SCN1	34,579,629.51	25,082.55	Hardyston Fm	Crystalline	736,217.00
SCN1	34,579,629.51	25,082.55	Hornblende Gneiss	Crystalline	5,641.00
				Total (sq-ft)	**17,985,703.00**
				Total (acres)	**449.64**
				Percentage	**52.01%**
SCN1	34,579,629.51	25,082.55	Quartz Fanoglomerate	Brunswick	4,023,728.00

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				Total (sq-ft)	**4,023,728.00**
				Total (acres)	**100.59**
Area SCN1:	**864.49**	**acres**		**Percentage**	**11.64%**
SCS1	17,686,242.50	25,211.81	Leithsville Fm	Limestone	7,316,628.00
SCS1	17,686,242.50	25,211.81	Limestone Fanoglomerate	Limestone	1,169,022.00
				Total (sq-ft)	**8,485,650.00**
				Total (acres)	**212.14**
				Percentage	**47.98%**
SCS1	17,686,242.50	25,211.81	Hardyston Fm	Crystalline	1,563,579.00
SCS1	17,686,242.50	25,211.81	Hardyston Fm	Crystalline	1,112,447.00
SCS1	17,686,242.50	25,211.81	Hornblende Gneiss	Crystalline	201,683.00
				Total (sq-ft)	**2,877,709.00**
				Total (acres)	**71.94**
				Percentage	**16.27%**
SCS1	17,686,242.50	25,211.81	Quartz Fanoglomerate	Brunswick	4,924,875.00
SCS1	17,686,242.50	25,211.81	Brunswick Fm	Brunswick	1,398,008.00
				Total (sq-ft)	**6,322,883.00**
				Total (acres)	**158.07**
Area SCS1:	**442.16**	**acres**		**Percentage**	**35.75%**

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Table 5

Subwatershed Area By Hydrogeologic Units

SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
CC18a	20,926,830.09	18,260.54	Brunswick Fm	Brunswick	14,009,329.00
				Total (sq-ft)	**14,009,329.00**
				Total (acres)	**350.23**
				Percentage	**66.94%**
CC18a	20,926,830.09	18,260.54	Diabase	Diabase	6,917,501.00
				Total (sq-ft)	**6,917,501.00**
				Total (acres)	**172.94**
Area CC18a:	**523.17**	**acres**		**Percentage**	**33.06%**
CC19a	21,358,039.35	22,496.85	Brunswick Fm	Brunswick	20,986,857.00
				Total (sq-ft)	**20,986,857.00**
				Total (acres)	**524.67**
				Percentage	**98.26%**
CC19a	21,358,039.35	22,496.85	Diabase	Diabase	371,183.00
				Total (sq-ft)	**371,183.00**
				Total (acres)	**9.28**
Area CC19a:	**533.95**	**acres**		**Percentage**	**1.74%**
CC20a	101,454,375.26	62,795.67	Quartz Fanoglomerate	Brunswick	21,580,179.00
CC20a	101,454,375.26	62,795.67	Brunswick Fm	Brunswick	67,559,596.00
				Total (sq-ft)	**89,139,775.00**
				Total (acres)	**2,228.49**
				Percentage	**87.86%**
CC20a	101,454,375.26	62,795.67	Diabase	Diabase	3,843,843.00
CC20a	101,454,375.26	62,795.67	Diabase	Diabase	8,470,758.00
				Total (sq-ft)	**12,314,601.00**
				Total (acres)	**307.87**
Area CC20a:	**2,536.36**	**acres**		**Percentage**	**12.14%**
CC21a	30,114,438.51	40,419.57	Quartz Fanoglomerate	Brunswick	12,574,232.00
CC21a	30,114,438.51	40,419.57	Brunswick Fm	Brunswick	17,540,206.00

				Total (sq-ft)	**30,114,438.00**
				Total (acres)	**752.86**
Area CC21a:	**752.86**	**acres**		**Percentage**	**#DIV/0!**
CC22a	33,456,702.23	26,082.35	Quartz Fanoglomerate	Brunswick	10,770,158.00
CC22a	33,456,702.23	26,082.35	Brunswick Fm	Brunswick	22,686,545.00
				Total (sq-ft)	**33456703**
				Total (acres)	**836.42**
Area CC22a:	**836.42**	**acres**		**Percentage**	**100.00%**

SUBBASIN ID	SUBBASIN AREA_ (sq-ft)	SUBBASIN PERIMETER_ (ft)	GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
CC15a	20,458,437.17	19,858.70	Leithsville Fm	Limestone	1,686,504.00
CC15a	20,458,437.17	19,858.70	Limestone Fanoglomerate	Limestone	2,731,719.00
				Total (sq-ft)	**4,418,223.00**
				Total (acres)	**110.46**
				Percentage	**21.60%**
CC15a	20,458,437.17	19,858.70	Hardyston Fm	Crystalline	906,397.00
				Total (sq-ft)	**906,397.00**
				Total (acres)	**22.66**
				Percentage	**4.43%**
CC15a	20,458,437.17	19,858.70	Brunswick Fm	Brunswick	15,133,817.00
				Total (sq-ft)	**15,133,817.00**
				Total (acres)	**378.35**
Area CC15a:	**511.46**	**acres**		**Percentage**	**73.97%**
CC16a	32,247,017.72	27,354.26	Quartz Fanoglomerate	Brunswick	6,430,055.00
CC16a	32,247,017.72	27,354.26	Brunswick Fm	Brunswick	25,816,963.00
				Total (sq-ft)	**32,247,018.00**
				Total (acres)	**806.18**
AreaCC16a:	**806.18**	**acres**		**Percentage**	**100.00%**
CC17a	7,068,638.71	11,257.63	Brunswick Fm	Brunswick	7,068,639.00
				Total (sq-ft)	**7,068,639.00**

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			Total (acres)	**176.72**
Area CC17a:	**176.72**	**acres**	**Percentage**	**100.00%**

GEOLOGIC FORMATION	HYDROGEOLOGIC UNITS	AREA (sq-ft)
Leithsville Fm	Limestone	117,497,476.00
Allentown Fm	Limestone	17,666,321.00
Limestone Fanoglomerate	Limestone	3,900,741.00
Limestone Fanoglomerate	Limestone	4,102,324.00
	Total (sq-ft)	**143,166,862.00**
	Total (acres)	**3,579.17**
	Percentage	**17.29%**
Hardyston Fm	Crystalline	408,229.00
Hornblende Gneiss	Crystalline	19,485,877.00
Hardyston Fm	Crystalline	12,386,729.00
Granitic Gneiss	Crystalline	84,169,753.00
Granitic Gneiss	Crystalline	1,076,340.00
Granitic Gneiss	Crystalline	79,425.00
Hornblende Gneiss	Crystalline	23,208.00
Hornblende Gneiss	Crystalline	5,658,737.00
Hornblende Gneiss	Crystalline	8,695,541.00
Hornblende Gneiss	Crystalline	5,345,162.00
Hornblende Gneiss	Crystalline	28,049,352.00
Hardyston Fm	Crystalline	307,117.00
Hardyston Fm	Crystalline	40,618,624.00
Granitic Gneiss	Crystalline	2,201,139.00
Hardyston Fm	Crystalline	2,915,953.00
Hornblende Gneiss	Crystalline	3,616,088.00
Granitic Gneiss	Crystalline	12,173,044.00
Granitic Gneiss	Crystalline	164,275.00
Hornblende Gneiss	Crystalline	380,135.00
Hardyston Fm	Crystalline	6,470,083.00
Granitic Gneiss	Crystalline	5,843,045.00
Hardyston Fm	Crystalline	1,848,664.00
Hornblende Gneiss	Crystalline	207,324.00
	Total (sq-ft)	**242,123,844.00**
	Total (acres)	**6,053.10**
	Percentage	**29.25%**
Brunswick Fm	Brunswick	7,752,185.00
Quartz Fanoglomerate	Brunswick	2,167,691.00
Quartz Fanoglomerate	Brunswick	25,489,247.00
Quartz Fanoglomerate	Brunswick	99,636,906.00
Brunswick Fm	Brunswick	276,199,192.00
Lockatong Fm	Brunswick	1,045,329.00
	Total (sq-ft)	**412,290,550.00**
	Total (acres)	**10,307.26**

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	Percentage	**49.80%**
Diabase	Diabase	8,400,522.00
Diabase	Diabase	9,213,941.00
Diabase	Diabase	3,843,843.00
Diabase	Diabase	8,841,940.00
	Total (sq-ft)	**30,300,246.00**
	Total (acres)	**757.51**
	Percentage	**3.66%**

Hydrogeologic Units	Percentage
Limestone	**17.29%**
Crystalline	**29.25%**
Brunswick	**49.80%**
Diabase	**3.66%**

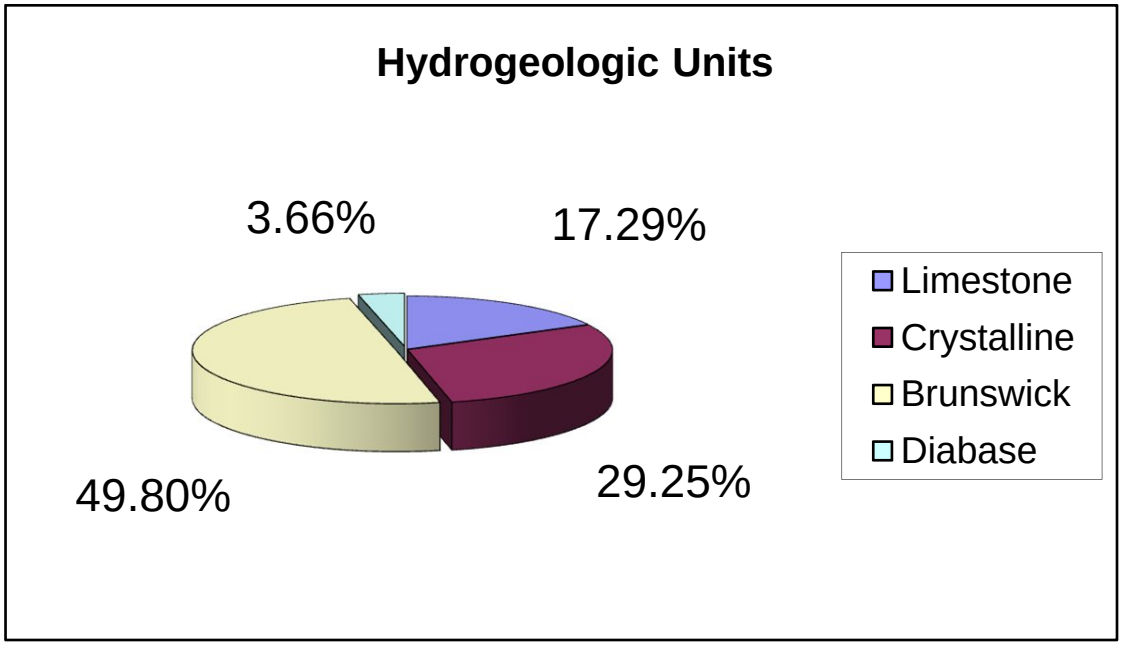

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Table 6

BASE-FLOW RECURENCE INTERVALS FOR GEOLOGIC UNITS OR GROUPS IN THE NESHAMINY

[(gal/d)/sq.mi., million gallons per day per square mile]
[gpd/acre, gallons per day per acre]

Geologic Unit or Group	Base-flow Recurence Interval					
	2-year	5-year	10-year	25-year	50-year	2-year
	Discharge [(gal/d)/sq.mi.]					
Brunswick Group and Lockatong Formation	0.314	0.241	0.189	0.154	0.144	219
Carbonate Rocks	0.706	0.481	0.408	0.289	0.278	492
Crystalline Rocks	0.524	0.381	0.302	0.299	0.206	365

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Base-flow Recurence Interval			
5-year	10-year	25-year	50-year
	Discharge [gpd/acre]		
168	132	107	100
335	284	201	194
266	210	208	144

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Table 7

BASE-FLOW RATIO FOR GEOLOGIC UNITS OR GROUPS IN THE NESHAMINY CREE
PENNSYLVANIA

[(gal/d)/sq.mi., million gallons per day per square mile]
[gpd/acre, gallons per day per acre]

Geologic Unit or Group	Discharge Q7-10 [gpd/acre]	Discharge Q7-10 Average [gpd/acre]
Brunswick Group	230	239
Carbonate Rocks	284	239
Crystalline Rocks	210	239
Diabase	80	239

Average Q7-10 for Cooks Creek = 222 GPD/Acre

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Ratio to Q7-10 Average	Discharge Inferred for Cooks Creek [gpd/acre]
0.96	214
1.19	264
0.88	196
0.33	74

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RECORD_NO	LAT_DD	LON_DD	ELEVATION	MUNICPAL
5968	40.52	-75.25306	600	SPRINGFIELD
6210	40.52028	-75.24361	530	SPRINGFIELD
5972	40.52139	-75.29389	470	SPRINGFIELD
5973	40.52222	-75.25972	470	SPRINGFIELD
5976	40.52306	-75.25722	580	SPRINGFIELD
5975	40.52306	-75.22583	530	NOCKAMIXON
5980	40.52333	-75.25667	570	SPRINGFIELD
5984	40.52389	-75.30278	520	SPRINGFIELD
5983	40.52389	-75.29778	485	SPRINGFIELD
6490	40.52417	-75.2275	540	NOCKAMIXON
5987	40.52444	-75.29278	495	SPRINGFIELD
5988	40.52472	-75.32417	800	SPRINGFIELD
5989	40.525	-75.33389	850	SPRINGFIELD
5990	40.52528	-75.31833	665	SPRINGFIELD
5993	40.52556	-75.28722	480	SPRINGFIELD
5992	40.52556	-75.27167	520	SPRINGFIELD
5991	40.52556	-75.25472	600	SPRINGFIELD
5996	40.52583	-75.28861	485	SPRINGFIELD
5995	40.52583	-75.27028	620	SPRINGFIELD
5994	40.52583	-75.24472	570	SPRINGFIELD
5999	40.52667	-75.24528	570	SPRINGFIELD
6000	40.52722	-75.32417	820	SPRINGFIELD
6519	40.52722	-75.2175	580	NOCKAMIXON
6907	40.52722	-75.21639	580	NOCKAMIXON
6383	40.52722	-75.21389	605	NOCKAMIXON
6518	40.52778	-75.21556	600	NOCKAMIXON
6006	40.52889	-75.25861	615	SPRINGFIELD
6008	40.52917	-75.31944	780	SPRINGFIELD
6007	40.52917	-75.23389	610	SPRINGFIELD
6013	40.53	-75.24028	560	SPRINGFIELD
6479	40.53	-75.21083	565	NOCKAMIXON
6016	40.53056	-75.30639	560	SPRINGFIELD
6015	40.53056	-75.21861	600	NOCKAMIXON
6021	40.53111	-75.32417	760	SPRINGFIELD
6020	40.53111	-75.22528	610	SPRINGFIELD
6019	40.53111	-75.21083	540	NOCKAMIXON
6031	40.53222	-75.31389	580	SPRINGFIELD
6035	40.53278	-75.29917	500	SPRINGFIELD
6038	40.53306	-75.30667	535	SPRINGFIELD
6897	40.53306	-75.21667	540	SPRINGFIELD
6919	40.53333	-75.23639	610	SPRINGFIELD
6040	40.53361	-75.2225	560	SPRINGFIELD
6043	40.53417	-75.27028	490	SPRINGFIELD
6042	40.53417	-75.225	520	SPRINGFIELD
5855	40.48167	-75.39361	660	SPRINGFIELD
5857	40.48222	-75.39361	670	SPRINGFIELD
5862	40.48306	-75.38361	620	SPRINGFIELD
5864	40.48444	-75.39417	670	SPRINGFIELD
5866	40.48833	-75.39861	680	SPRINGFIELD
5871	40.48972	-75.35139	590	SPRINGFIELD
5874	40.49083	-75.37944	620	SPRINGFIELD

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5876	40.49111	-75.37972	620	SPRINGFIELD
5878	40.49167	-75.36889	670	SPRINGFIELD
5880	40.49222	-75.35833	560	SPRINGFIELD
5886	40.49361	-75.36861	680	SPRINGFIELD
5885	40.49361	-75.33222	630	SPRINGFIELD
5888	40.49389	-75.32417	610	SPRINGFIELD
5887	40.49389	-75.31472	600	SPRINGFIELD
5892	40.49556	-75.34278	650	SPRINGFIELD
5893	40.49583	-75.36139	640	SPRINGFIELD
5894	40.49611	-75.28944	560	HAYCOCK
5904	40.49917	-75.3375	630	SPRINGFIELD
5903	40.49917	-75.33139	640	SPRINGFIELD
5907	40.49972	-75.33194	640	SPRINGFIELD
5912	40.50167	-75.32361	580	SPRINGFIELD
5914	40.50222	-75.3	470	SPRINGFIELD
5915	40.50389	-75.27306	620	SPRINGFIELD
5916	40.50417	-75.35139	645	SPRINGFIELD
5917	40.50444	-75.33028	620	SPRINGFIELD
5918	40.505	-75.36806	645	SPRINGFIELD
5925	40.50667	-75.27472	605	SPRINGFIELD
5927	40.50722	-75.28639	485	SPRINGFIELD
5933	40.50972	-75.34056	700	SPRINGFIELD
5934	40.51	-75.33222	625	SPRINGFIELD
5935	40.51056	-75.31111	530	SPRINGFIELD
5937	40.51139	-75.275	580	SPRINGFIELD
5939	40.51278	-75.31972	595	SPRINGFIELD
5942	40.51306	-75.23833	530	HAYCOCK
5943	40.51333	-75.34944	765	SPRINGFIELD
5944	40.51389	-75.29639	440	SPRINGFIELD
5946	40.51417	-75.35722	650	SPRINGFIELD
5945	40.51417	-75.32833	635	SPRINGFIELD
5948	40.51444	-75.3575	660	SPRINGFIELD
5949	40.51472	-75.27028	645	SPRINGFIELD
5955	40.51778	-75.24722	560	SPRINGFIELD
5956	40.51806	-75.33333	715	SPRINGFIELD
5959	40.51861	-75.31583	535	SPRINGFIELD
5962	40.51917	-75.29028	435	SPRINGFIELD
5965	40.51944	-75.32889	730	SPRINGFIELD
6046	40.53444	-75.3	500	SPRINGFIELD
6918	40.53444	-75.23806	610	SPRINGFIELD
6047	40.53472	-75.28694	455	PLUMSTEAD
6048	40.535	-75.23	500	SPRINGFIELD
6051	40.53583	-75.24167	580	SPRINGFIELD
6054	40.53611	-75.22583	530	NOCKAMIXON
6053	40.53611	-75.22361	500	SPRINGFIELD
6056	40.53639	-75.32028	680	SPRINGFIELD
6061	40.53694	-75.2825	395	SPRINGFIELD
6491	40.5375	-75.21917	470	NOCKAMIXON
6069	40.53806	-75.24722	530	SPRINGFIELD
6075	40.53944	-75.23139	600	SPRINGFIELD
6081	40.54056	-75.23639	720	SPRINGFIELD
6084	40.54167	-75.27611	335	SPRINGFIELD

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6091	40.54333	-75.30389	470	SPRINGFIELD
6090	40.54333	-75.23139	770	SPRINGFIELD
6093	40.54361	-75.22083	480	NOCKAMIXON
6092	40.54361	-75.21667	480	NOCKAMIXON
6095	40.54389	-75.30556	450	SPRINGFIELD
6098	40.545	-75.28194	350	SPRINGFIELD
6100	40.54583	-75.28667	465	SPRINGFIELD
6101	40.54611	-75.21306	480	NOCKAMIXON
6105	40.54694	-75.30056	410	SPRINGFIELD
6104	40.54694	-75.22306	590	DURHAM
6107	40.54806	-75.20417	520	NOCKAMIXON
6724	40.54944	-75.20972	540	DURHAM
6115	40.55028	-75.25361	470	SPRINGFIELD
6116	40.55056	-75.24194	560	SPRINGFIELD
6117	40.55083	-75.19111	360	NOCKAMIXON
6118	40.55139	-75.2375	580	SPRINGFIELD
6121	40.55389	-75.26583	380	SPRINGFIELD
6120	40.55389	-75.26028	450	SPRINGFIELD
6123	40.55444	-75.24556	480	SPRINGFIELD
6125	40.555	-75.29167	340	SPRINGFIELD
6124	40.555	-75.27306	290	SPRINGFIELD
6126	40.55667	-75.19028	250	DURHAM
6166	40.55722	-75.27778	310	SPRINGFIELD
6130	40.5575	-75.21889	440	DURHAM
6197	40.55778	-75.17944	280	NOCKAMIXON
6132	40.55806	-75.27306	315	SPRINGFIELD
6131	40.55806	-75.175	375	NOCKAMIXON
6135	40.55833	-75.275	325	SPRINGFIELD
6134	40.55833	-75.25139	330	SPRINGFIELD
6133	40.55833	-75.17944	160	NOCKAMIXON
6136	40.55889	-75.28667	370	SPRINGFIELD
6137	40.55889	-75.28667	360	SPRINGFIELD
6138	40.55917	-75.17583	320	NOCKAMIXON
6545	40.55917	-75.17333	365	NOCKAMIXON
6141	40.56194	-75.24944	280	SPRINGFIELD
6142	40.56222	-75.23667	320	DURHAM
6144	40.56361	-75.27944	490	SPRINGFIELD
6143	40.56361	-75.25361	295	SPRINGFIELD
6146	40.56528	-75.2625	405	SPRINGFIELD
6152	40.5725	-75.1925	180	DURHAM
6153	40.57306	-75.20583	320	DURHAM
6154	40.575	-75.225	220	DURHAM
6155	40.57611	-75.22389	200	DURHAM
6932	40.57722	-75.24	285	DURHAM
6157	40.57889	-75.22806	220	DURHAM
6158	40.57972	-75.19806	150	DURHAM
6159	40.58	-75.20028	150	DURHAM
6161	40.58028	-75.20194	160	DURHAM
7155	40.60194	-75.19667	180	RIEGELSVILLE

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FORMNAME	WELL DEPTH	HYDROLOGIC UNIT	WATER_USE
DIABASE DIKES AND SILLS	300	02040105	DOMESTIC
DIABASE DIKES AND SILLS	67	02040105	UNUSED
BRUNSWICK FORMATION	200	02040105	COMMERCIAL
BRUNSWICK FORMATION	300	02040105	INSTITUTIONAL
DIABASE DIKES AND SILLS	8	02040105	DOMESTIC
BRUNSWICK FORMATION	320	02040105	DOMESTIC
DIABASE DIKES AND SILLS	17	02040105	DOMESTIC
BRUNSWICK FORMATION	185	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	225	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	140	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	84	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	100	02040105	DOMESTIC
BRUNSWICK FORMATION	225	02040105	STOCK
BRUNSWICK FORMATION	210	02040105	DOMESTIC
DIABASE DIKES AND SILLS	28	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	UNUSED
DIABASE DIKES AND SILLS	300	02040105	DOMESTIC
BRUNSWICK FORMATION	105	02040105	DOMESTIC
BRUNSWICK FORMATION	222	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	195	02040105	DOMESTIC
BRUNSWICK FORMATION	220	02040105	DOMESTIC
BRUNSWICK FORMATION	96	02040105	DOMESTIC
BRUNSWICK FORMATION	180	02040105	DOMESTIC
BRUNSWICK FORMATION	240	02040105	DOMESTIC
DIABASE DIKES AND SILLS	200	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	400	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	215	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	400	02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	140	02040105	DOMESTIC
BRUNSWICK FORMATION	110	02040105	DOMESTIC
BRUNSWICK FORMATION	220	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	300	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK FORMATION	27	02040105	DOMESTIC
BRUNSWICK FORMATION	130	02040105	DOMESTIC
BRUNSWICK FORMATION	320	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040203	DOMESTIC
BRUNSWICK FORMATION	360	02040203	DOMESTIC
BRUNSWICK FORMATION	122	02040105	DOMESTIC
BRUNSWICK FORMATION	148	02040105	DOMESTIC
BRUNSWICK FORMATION	198	02040105	DOMESTIC
DIABASE DIKES AND SILLS	180	02040105	DOMESTIC
DIABASE DIKES AND SILLS	92	02040105	COMMERCIAL

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DIABASE DIKES AND SILLS	33	02040105	COMMERCIAL
DIABASE DIKES AND SILLS	400	02040105	DOMESTIC
DIABASE DIKES AND SILLS	100	02040105	DOMESTIC
DIABASE DIKES AND SILLS	350	02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK FORMATION	200	02040105	DOMESTIC
DIABASE DIKES AND SILLS	150	02040105	DOMESTIC
BRUNSWICK FORMATION	80	02040105	DOMESTIC
BRUNSWICK FORMATION	175	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	150	02040105	DOMESTIC
BRUNSWICK FORMATION	160	02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040105	DOMESTIC
DIABASE DIKES AND SILLS	352	02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK FORMATION	460	02040105	DOMESTIC
DIABASE DIKES AND SILLS	300	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	340	02040105	DOMESTIC
BRUNSWICK FORMATION	160	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK FORMATION	120	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
DIABASE DIKES AND SILLS		02040105	DOMESTIC
BRUNSWICK FORMATION	400	02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040105	DOMESTIC
BRUNSWICK FORMATION	250	02040106	PUBLIC SUPPLY
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	200	02040106	PUBLIC SUPPLY
DIABASE DIKES AND SILLS	250	02040105	DOMESTIC
DIABASE DIKES AND SILLS		02040105	INSTITUTIONAL
BRUNSWICK,QUARTZ FANGLOMERATE	300	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	250	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE		02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	100	02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040105	DOMESTIC
BRUNSWICK FORMATION	150	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	200	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE		02040105	DOMESTIC
BRUNSWICK FORMATION	225	02040105	DOMESTIC
BRUNSWICK FORMATION	300	02040105	DOMESTIC
BRUNSWICK FORMATION	500	02040105	PUBLIC SUPPLY
BRUNSWICK,QUARTZ FANGLOMERATE	220	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE		02040105	
BRUNSWICK,LIMESTONE FANGLOMERATE	200	02040105	DOMESTIC

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BRUNSWICK,LIMESTONE FANGLOMERATE	39	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	340	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	80	02040105	DOMESTIC
BRUNSWICK FORMATION	250	02040105	DOMESTIC
BRUNSWICK,LIMESTONE FANGLOMERATE	42	02040105	DOMESTIC
GRANITE & GRANITE GNEISS		02040105	UNUSED
GRANITE & GRANITE GNEISS		02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	150	02040105	DOMESTIC
GRANITE & GRANITE GNEISS		02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	90	02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	100	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE	280	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	110	02040105	DOMESTIC
BRUNSWICK FORMATION	350	02040105	DOMESTIC
BRUNSWICK,QUARTZ FANGLOMERATE	460	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE	80	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE	320	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE		02040105	DOMESTIC
LEITHSVILLE FORMATION	158	02040105	UNUSED
LEITHSVILLE FORMATION	180	02040105	DOMESTIC
BRUNSWICK FORMATION	125	02040105	DOMESTIC
LEITHSVILLE FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	98	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE	123	02040105	DOMESTIC
BRUNSWICK FORMATION	500	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE		02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE	225	02040105	STOCK
BRUNSWICK FORMATION	82	02040105	COMMERCIAL
HARDYSTON FORMATION-QUARTZITE	600	02040105	PUBLIC SUPPLY
HARDYSTON FORMATION-QUARTZITE	55	02040105	UNUSED
BRUNSWICK FORMATION	560	02040105	PUBLIC SUPPLY
BRUNSWICK FORMATION	460	02040105	DOMESTIC
LEITHSVILLE FORMATION	127	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE		02040105	UNUSED
GRANITE & GRANITE GNEISS	180	02040105	DOMESTIC
LEITHSVILLE FORMATION	300	02040105	DOMESTIC
LEITHSVILLE FORMATION		02040105	DOMESTIC
BRUNSWICK FORMATION	93	02040105	DOMESTIC
HARDYSTON FORMATION-QUARTZITE		02040105	DOMESTIC
LEITHSVILLE FORMATION	85	02040105	DOMESTIC
LEITHSVILLE FORMATION	90	02040105	STOCK
LEITHSVILLE FORMATION		02040105	UNUSED
ALLENTOWN FORMATION	134	02040105	INSTITUTIONAL
LEITHSVILLE FORMATION	95	02040105	INDUSTRIAL
LEITHSVILLE FORMATION	94	02040105	INDUSTRIAL
LEITHSVILLE FORMATION	317	02040105	INDUSTRIAL
GLACIAL OUTWASH	207	02040105	PUBLIC SUPPLY

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DATE DRILLED	YIELD_MAX	SWL_MAX	OWNER	TEMPERATURE (C)
198812	2	14.7	FONDER, EDWARD	
		16.5	HAYCOCK CAMPING MINISTRIES	
19400101			FRITZ, C	
19450101	50	68	SPRINGFIELD HIGH SCHOOL	
19370101			BOER , PAUL	
198810			CARROL	
19460101		1	BOER , PAUL	
19480101			HOLTON , OLIVER	
		56.6	QUEEN, BEN	
	150	8.47	HOFF, JAMES	
199008	15	96.4	CRUM, RANDY	
198303	35	79.6	WENHOLD, C	
19390101	20	38	ELBERT , ARTHUR	13
197607		13.2	STACKHOUSE, NEIL	
19801201	30	35.3	SINGER, WEBSTER	
1978		23.5	BAUDER, L	
			BOER , PAUL	
		9.8	MILLER, ALLEN	
198608	7	35	FRANKLIN, J	
19500101			MAKL , HENRY	
198506	20	62	GELLETICH, R	
198606	50	75.7	ZANGHI, TONY	
198404	16	82	COULBY, F & CLARK, RON	
1940	5.4	22.6	RICK , EDWARD	13
1975		126	MCNICHOL, ANN	
1963	7	77.6	RICK, TIMOTHY	
198501	15	33.4	MCCARTY, J	
198710	8	105	CLEMENT, G	
		12.5	BELL	
198707	20	14.2	CAMPEAU, D	
1972		110	SHICK, HAROLD	
		61.4	BALLIET	
198904	5	116	BENNETT, RANDY	
		100	HANGEY, CARL	
1968		42.2	NIEMI, BRUCE	
198208	18	101	MANSLEY, RONALD	
		26	KURTESON	
19521209			FINADY , W	
1976		10	DERENICK, GENE	
198905	15	88.6	BERGER, CLARENCE	
		7.1	SCHULBERGER , ANTHONY	
1970		92.9	VIRTUE, WILLIAM	
198305	10	31.7	SMITH, J	
1970		48.3	CAFFEY, CHARLES	
1940	4.3	62.4	TRUMBOWER , EARL	14
198303	5	73.2	BINNER, WALTER	
19770728	20	22.6	ERNEY, RON	
19520101	10	22.17647	R B HARWICK & SONS	
	0.5		LOB & FENESSY	
199010	20	-0.1	DOLLMAN, JOHN	
19521001		6	BERGER, VICTOR	12

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		5.07	BERGER, VICTOR	8
198508	2	72.1	HORN, GRANT	
197710	27	9	GROSS, WILLIAM	
198109	0.5	142	WEAVER, JEFF	
1976		65.7	PRESTON	
198009	14	54.3	FRY, R	
199102	25		KRUPP, NANCY	
199008	15	51.8	KNIBBS, WAYNE	
19840731	4	49.2	POVINSKY, JOHN	
197807	20	4.7	HAYDEN, DAISY	
198009	10	66	SPARANGO, TONY	
19470101			VORNDRAN , ADAM	
1961		44.1	WEIERBACH, WILLARD	
		26.4	RUMSEY, JOHN	
1950		25	VISSER, C	
1978		101	FULMER, PATRICIA	
198605	10	19.8	KOWALENKO, P	
198911	2	80	MAGARGAL, JENNIFER	
198505		22.1	RIEDLER	
		97.5	KUCHER, DON	
197809		1.59	JAMANN, HERBERT	
198803	32	65.9	MITCHELL, DAVID	
		21.4	GALBRAITH, JOANNE	
198506	20	93.6	BILGER, RAY	
198901	37	14.2	KRCHNAVI, PAUL	
		54.2	SHEETS, JIM	
		10.9	BAILEY	
198908		63.2	DANNENHOWER, PAUL	
		22.7	AHLUM, HENRY	
19360101	240	55	COOPERSBURG BOROUGH	
		30.9	STAROSKY, JACK	
19360101	150		COOPERSBURG BOROUGH	
1987		12.6	INDIERO, JOHN	
		16.4	HAYCOCK MINISTRY CAMP	
198208	15	51.8	BERENZY, JOHN	
		16.5	WOODSON, GEORGE	
198306	12	45.3	BILGER	
		96.3	ANDREWS, EVERETT	
1983		25.4	BROMWELL, JOHN	
19500101		2	FREEH , LEWIS	
		55	RIEHMAN, RICHARD	
198704	30	21.1	HUNTER, ROBERT	
198708	30	32.1	FERENCE, JOHN	
1974		51.4	VITALE, DOMINICK	
198605	15	46.7	JOHNSON, W	
		19.2	YOUNGKEN, PHILIP	
1985		57.4	MYERS, GARY	
		49	SAMKAVITZ, VICTOR	
		3.42	BERENBAUM'S FARM	
198408	3	29.3	WARD, DAVE	
19460101			LANGE , J	
198309	25	25	LOVEKIN, V	

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19521201		4	FLUCK , LEROY	
19781120		60.2	SCOTCHELL, GEORGETTE	14
1969		33.2	PARAISH, IRENE	
198412	20	52.1	LYNCH, JACK	
19480101			QUIER , MARVIN	
		1.02	MESKO	
198406	16	69.3	REISS, C	13
198707	15	63.2	CHAPMAN, PAUL	
1986		15.9	BIELANSKI, STANLEY	135
1954	4.6	72.84	CORRELL, SYLVESTER	10.5
1978		55.7	NICHOLAS, KURT	
198002	15	43.3	DIBLASIO, SUE	
197908	20	100	MORAN, THOMAS	16
		6	DE SILVER , FRANK	
1976		41.8	GROSS, MARK	
1976		72.5	LABS, ROBERT	
19420101			HOOPER , GEORGE	
		164	CHASE, ROBERT	12
		97.2	MERTZ, CHARLES	
1968	750	3.54	BUCKS CO DNR	
		13.8	SCHRETLIN, HENRY	
1961		6.56	STANGIL, BRAD	
		17.8	HAWKINS, LENDRUM	
19520401		12	KIRKPATRICK , EUGENE	
1951		27.5	WILLIAMS, RICHARD	
		43.1	BAINBRIDGE, D	
1984	9	210	RUFE, DANIEL	
1976		8.8	WERGE, TOM	
19370101			BODDER , LESTER	
19480101	22	15	LEHR'S GENERAL STORE	
19570312	60	26	SPRINGTOWN WATER CO	
19561013			SPRINGTOWN WATER CO	
1984	50	232	SAUTER, DAVE	
198203	7.5	249	MURDOCH, GUY	
19500101		42	SACHENBACK , GEORGE	
		24.5	GERENSER, ERVIN	
197807		53.5	SEIFERT, HARRY	
1983		47	MILLET, V	
		68.1	BERSETH, LYNN	
19500101	35	20	PAGLIARO BROS CHEVROLET	
19510101			PAVLICA , JOSEPH	
19470101		30	RIEGEL , FLOYD	
19490101		30	RIEGEL FEED AND GRAIN CO	
		52.4	BOYER	
		34	DURHAM SCHOOL	
19320101	600	21	DURHAM PAPER BOARD CO	4.5
19320101	600	77	DURHAM PAPER BOARD CO	
19510101	750	33	DURHAM PAPER BOARD CO	
19661201	239	28.5	RIEGELSVILLE WATER AUTH	

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CONDUCTANCE	HARDNESS, TOTAL (mg/l as CACO3)
555	260
450	150

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340

130

530
128 51

300

245

130

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ALKALINITY, WATER,WHOLE,TOTAL (mg/l as CACO2) pH DISSOLVED OXYGEN (mg/l)

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166	7.1	6.1
18	6.1	9.2
220	7.8	8
	6.6	
	6.4	
	7.2	
	7.6	

Document Content(s)

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