INGHAM SPRING EVALUATION
SOLEBURY TOWNSHIP, PENNSYLVANIA

Prepared for:

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June 2008

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TABLE OF CONTENTS

INGHAM SPRING EVALUATION
SOLEBURY TOWNSHIP, PENNSYLVANIA

TABLE OF CONTENTS (CONTINUED)

TABLES

FIGURES

APPENDIX

INGHAM SPRING EVALUATION
SOLEBURY TOWNSHIP, PENNSYLVANIA

LIST OF PHOTOGRAPHS

INGHAM SPRING EVALUATION
SOLEBURY TOWNSHIP, PENNSYLVANIA

1.0 INTRODUCTION

Ingham Spring is one of the largest springs in southeast Pennsylvania and forms the headwaters of Aquetong Creek in Solebury Township. Uhl, Baron, Rana & Associates, Inc. (UBR) was retained by the Township in 2006 to conduct a study to assess the groundwater contribution area and flow to Ingham Spring. This study is a step in the Township's plan to develop and implement policies and practices to protect the quantity and quality of water issuing from this spring.

Photo 1: Ingham Spring Outlet

2.0 STUDY ELEMENTS

The principal elements of the Ingham Spring evaluation included:

1. Delineation of the surface-water drainage basins/watersheds within the project area;

2. Evaluation of the geologic framework and major geologic structural features within the project watersheds;

3. Identification and quantification of the major groundwater pumping centers in the project area;

4. A field-based evaluation of groundwater flow conditions involving the collection of water levels in over 200 wells, and the development of a water-level contour map (potentiometric surface map) for the project area;

5. Delineation of groundwater divides and determination of the groundwater contribution area to Ingham Spring, on the basis of the field-collected water level data and potentiometric surface map interpretation;

6. Measurement of Ingham Spring discharge rates on a monthly basis from May of 2007 to May 2008;

7. Evaluation of groundwater recharge for years of normal and below-normal (drought) precipitation within the contribution area to Ingham Spring on the basis of published recharge quantities developed by the United States Geological Survey and others; and

8. A comparison of the spring discharge measurements, particularly during the summer and fall months, to the calculated groundwater recharge for the Ingham Spring contribution area.

The Furlong Fault, which has a northeast to southwest orientation, represents the principal fault in the project area and separates the carbonate rock aquifer system from the Brunswick sandstone/shale aquifer system to the southeast. Ingham Spring issues from this contact fault and flows into Aquetong Lake forming the southern tributary of Aquetong Creek. The carbonate rock area to the southwest of Ingham Spring in Buckingham Township is characterized by numerous sinkholes as is evident on **Figure 1** by the closed depressions and numerous outcrops of the water table in the form of ponds. These occur in the area bounded by the Furlong Fault to the southeast; Holicong Road to the southwest, Route 202 to the northwest and Street Road to the northeast.

The major pumping centers in the project area include the New Hope Crushed Stone Quarry pumping center in the Primrose Creek Basin; the Bucks County Water & Sewer Authority water supply production wells in New Hope and along the Route 202 corridor in Solebury Township within the Aquetong Basin; and a smaller pumping center proximate to Lahaska Creek that supplies Lahaska and Peddlers Village. Aqua America also maintains a well for the residential development at the intersection of Street and Upper Mountain Roads.

Photo 2: Ingham Spring Pond

3.0 BACKGROUND AND SITE SETTING

In 1701, William Penn granted 600 acres of land to James Logan which contained what was then referred to as the "Great Spring Tract", or by the local Lenape Native Americans as "Aquetong" loosely translated by George Mac Reynolds in "Place Names in Bucks County, Pennsylvania, Alphabetical Arranged in an Historical Narrative," to mean "at the spring among the bushes". The land was sold to Jonathan Ingham in 1747 and was owned by the Ingham family for 113 years. During this time, the sizable flow of the spring was used to power a fulling mill (for cleaning and thickening of woolen cloth) and later a paper mill.

Many legends surround the origin of Ingham Spring; some dating as far back as the 1600's when the area was inhabited primarily by the Lenape Indians. One story is that of a pursued deer falling into a spring referred to as Konkey Hole located in Holicong, or Hollekonk as it was named at the time, in Buckingham Township only to resurface unharmed at Ingham Spring approximately 3 miles away. Other stories involve objects such as barley leaves and handkerchiefs falling into the Holicong Spring that resurfaced at Ingham Spring.

The spring and its surrounding area are currently owned by the Pennsylvania Fish and Boat Commission and the process is underway for transfer of ownership to Solebury Township. The United States Fish and Wildlife Service approved the property transfer in 2007, and the Township is currently awaiting final approval from the Pennsylvania State Legislature.

3.1 Surrounding Land Use

Land use in Solebury Township consists largely of residential development, small-scale farms and nurseries, and commercial development concentrated along Route 202. A portion of northeast Buckingham Township, which borders Solebury Township to the west, was included in the groundwater elevation study. This area primarily consists of rural residential development, small farms and nurseries, and the Peddler's Village commercial development located in Lahaska at the Solebury Township boundary.

Ingham Spring (**Figure 1 and Photo 1**) is located in Solebury Township just east of the intersection of Route 202 (Lower York Road) and Lower Mountain Road. The spring is located slightly south of Route 202, between Lower Mountain Road and Silver Tail Road. The spring is made up of a number of springs within a few feet of each other that discharge to a pond (**Photo 2**) and flow over an old dam structure to a creek (**Photo 3**). The spring discharge serves to fill Aquetong Lake a few hundred feet to the east of the spring. Aquetong Lake is approximately 15 acres in area and the outlet from this lake forms one of the two main tributaries of Aquetong Creek. The spring is bordered to the east by Deer Park Camp, which is mainly undeveloped forested land; to the north-northwest by Route 202 and the residential developments Fox Run and Fox Run Estates; to the south by residential development along Heather Lane; and to the east by undeveloped land owned by the Commonwealth of Pennsylvania.

Photo 3: Dam (enclosing Ingham Spring Pond) and Waterfall

Photo 4: Ingham Spring Outlet Creek Leading to Aquetong Lake

3.2 Topography and Drainage

The Aquetong Creek Drainage Basin is 7.5 square miles in area and drainage occurs from west to east in two main tributaries. The northern tributary parallels Meetinghouse Road and then turns south and joins the southern tributary which heads at Ingham Spring, just south of Route 202.

Ingham Spring has an approximate surface elevation of 167.25 ft, amsl. The spring flows into Aquetong Lake, formed by an earthen dam approximately 500 feet in length. The lake outflow joins the northern tributary of Aquetong Creek, and flows northeast through Solebury Township and into the Borough of New Hope, to its confluence with the Delaware River.

The proximate stream drainage basins include:

- Primrose Creek and Rabbit Run to the north;
- Pannacussing and Cuttalossa Creeks to the north-northwest, and
- Lahaska and Pidcock Creeks and Dark Hollow Run to the southwest and southeast.

Primrose, Pannacussing, Cuttalossa and Pidcock Creeks, and Rabbit and Dark Hollow Runs drain to the Delaware River within the Township; and Lahaska Creek is tributary to the Neshaminy River which also is confluent with the Delaware River in southern Bucks County. Wells were identified in all of these drainage basins for water-level measurement purposes.

3.3 Geologic Framework and Structure

The study area, and in particular the Aquetong Creek Drainage Basin, is underlain by the following units from southeast to northwest (**Figure 2**):

- Jurassic Age diabase rocks to the south that form Solebury Mountain (Jd);
- Triassic Age red shale and sandstone rocks of the Brunswick Formation (Brunswick Aquifer) that underlie the area along the Route 202 Corridor where commercial and residential development is concentrated (TrB);
- Cambrian Age rock formations including the Allentown (Cal) and Leithsville (Clv) carbonate rock formations that lie northwest of the Furlong Fault and abut the Triassic Age Brunswick rocks.
- The Ordovician Age Beekmantown Group (Ob) which is a carbonate rock formation; and
- The sandstone rocks of the Stockton Formation (Trs and Trsc) which underlie the west-northwest part of the basin

The Allentown, Leithsville and Beekmantown rock units are collectively referred to as the Carbonate Rock Aquifer system in the area. Ingham Spring is located on the Furlong Fault which lies at the contact between the Allentown Formation limestone and the Brunswick Formation sandstone. The Furlong Fault provides a permeability contrast between the more permeable Allentown and Leithsville Formations (carbonate rock) and the less permeable Brunswick Formation (sandstone and shale), resulting in the back-up of groundwater behind (to the west) of the fault and the resultant spring discharge.

The diabase, and Triassic Rocks belong to the Newark Group of rocks (Triassic to Jurassic). There is large gap (unconformity) between the Cambrian Rocks and Newark Group of Rocks (about 260 million years). The rocks abut on the surface but the Cambrian rocks underlie the Triassic rocks, as such the unconformity. The Furlong Fault obviously separates the Newark Basin Rocks from the Cambrian.

4.0 STUDY METHODOLOGY

4.1 Groundwater-Level Measurements

Approximately 900 well survey forms were mailed to homeowners in Solebury and Buckingham Townships who live within and proximate to the Aquetong and Primrose Creek Drainage Basins. Homeowners were asked for various well details including well depth, date of well completion, any experience of well operational problems, and if permission would be granted for a representative from UBR to obtain a water-level measurement. The survey form is included in **Appendix A**.

An extensive water-level measurement event was conducted in the fall of 2006, with a supplemental event in the fall of 2007 to obtain more definition in the area to the southwest of Ingham Spring in Buckingham Township. In total, 230 water-level measurements were made and are included in the study. Additional water-level measurement data were obtained for wells managed by Bucks County Water and Sewer Authority, and wells monitored by New Hope Crushed Stone.

Two types of instruments were utilized to conduct the water-level measurements:

1. An M-Scope or electronic water-level indicator which consists of a small diameter steel sensor attached to a thin wire cable. When the sensor is lowered into the well, it signals (by sound and light indicator) when it reaches the water table. The depth to water from the top of the measuring point is read from markings on the graduated wire cable; or

2. A sonic measuring device. The sonic device functions by sending sound waves into the well and analyzing the wave reflected from the water surface to determine the depth to water.

Both instruments were used to read measurements on selected wells and were found to produce comparable results.

Whenever possible, homeowner wells were measured at an appointed time agreed to by the residents, who were asked to minimize water use within a few hours before the appointment, so as to obtain measurements representing static water levels.

Additional recorded data included the measurement of the stickup height of the well casing above ground surface, the well's global positioning system (GPS) coordinates (latitude and longitude), the date and time of the water-level measurement, and any additional comments.

The depth-to-water measured in each well and the corresponding groundwater level elevation (in feet above mean sea level (ft, amsl)), are summarized in **Tables 1 and 2** for the wells measured in 2006 and 2007, respectively. The location of each well and its associated groundwater level elevation (ft, amsl) are shown on **Figures 1 and 2**.

4.2 Spring Flow Measurements

Spring flow measurements were obtained from a location in the outlet creek downgradient of Ingham Spring pond on a monthly basis from May 2007 to May 2008 (**Figure 1**). The stream flow measurements were initiated by measuring the width of the stream and then dividing the stream up into six 1-foot sections. A Global Flow Probe FB101-EP201 current meter was then used to measure the maximum and average velocity of the water flow in each 1-foot measurement section. The probe was held at each measurement location for approximately 40 seconds to account for surging. True velocity averaging was recorded by slowly moving the probe back and forth through the entire water column in a vertical line (from bottom to top) for approximately one minute. **Photo 5** shows a flow measurement in May of 2008 and **Photo 6** is a close up of the current meter measurement instrument.

During each measurement event, the cross-sectional area of the outlet creek was measured for each of the 1-foot sections. The average velocity in feet per second (ft/sec) recorded for each 1-foot measurement section was multiplied by its area in square feet (ft^2) to calculate the flow in that section in cubic feet per second (ft^3/sec); and the six sections were summed to determine the total flow (discharging from the spring). The spring flow was then converted to units of gallons per minute (gpm) and gallons per day (gpd).

An example calculation for the spring outlet creek flow is provided below and the creek cross-sectional area profile is shown on **Figure 3**.

Ingham Spring Flow Measurement (June 14, 2007)

Section	A	B	C	D	E	F	Total Q (gpm)	Total Q (MGD)
Area	0.48	1.090	1.257	1.185	0.807	0.538		

(ft^2)								
V_{tavg} (ft/sec)	0.70	1.90	2.13	1.34	0.39	0.00		
Q (gpm)	150.80	929.46	1201.62	712.65	141.25	0.00	3135.78	4.5

Example Calculation:

Section A: *0.48 ft² * 0.70 ft/sec * 7.48 gal/ft³ * 60 sec/min = 150.80 gpm*

Section A + B + C + D + E + F + G = 3,135.78 gpm

*3,135.78 gpm * 1440 minutes per day = 4.5 MGD*

A stream staff gauge was installed in June 2007 in the outlet creek at the flow measurement location, and staff gauge readings were taken simultaneously with the monthly flow measurements. The staff gauge readings ranged from 1.96 feet from the top of the staff gauge in June 2007 to 2.06 feet from the top of the staff gauge in January 2008. These readings correspond with the second highest discharge of 4.5 MGD in June 2007 (excluding May 2007 because the staff gauge had not yet been installed) and the lowest discharge of 2.7 MGD in January 2008.

In addition, field measurements were made of the outlet creek water's pH, total dissolved solids and temperature. The Spring outlet creek flow rates, pH, total dissolved solids, and temperature measurements are provided in **Table 3**.

Photo 5: Ingham Spring Outlet Stream Flow Measurement Location and Staff Gauge

Photo 6: Flow Meter Screen Reading Maximum Velocity

5.0 ANALYSIS AND RESULTS

5.1 Groundwater Flow Evaluation

The groundwater level elevations obtained from the 2006 and 2007 well measurement events were utilized to construct the groundwater-level contour map (Potentiometric Surface Map) shown on the USGS topographic quadrangle base on **Figure 1**, and overlain on the geologic map of the area on **Figure 2**. Individual water-level contours, which represent points of equal head or elevation of the water table above mean sea level, are depicted in black on the map. These individual contours show a decrease from higher water elevations to lower elevations in the direction of stream/spring discharge areas/points in areas/drainage basins, where there are no major pumping stresses. In areas where there are major pumping stresses, such as in the Primrose Creek Basin, water-level contours are configured in a cone-of-depression around the pumping center as indicated on **Figures 1 and 2** in the Primrose Creek basin. A second set of lines, referred to as groundwater flow lines, are drawn perpendicular to the contour lines, and depict the pathways followed by particles of water as they move through the aquifer from areas of higher water elevation (head) to areas of lower water elevation and ultimately to groundwater discharge points such as streams and springs or major pumping centers.

5.2 Groundwater Contribution Area to Ingham Spring

Boundaries of the groundwater contribution area to Ingham Spring were delineated via interpretation of the groundwater elevations and principal groundwater divides as shown on the Potentiometric Surface Map **(Figures 1 and 2)**. The Ingham Spring discharge is at an approximate elevation of 167.25 ft, amsl, and as such groundwater occurring at elevations below this altitude could not feasibly contribute to the output of the spring.

The Furlong Fault represents the southeastern boundary of the groundwater contribution area to the spring. Groundwater divides were determined from an analysis of the water-level measurement data and groundwater level contours for the remaining boundaries of the contribution area.

- The area to the west - southwest of Ingham Spring is underlain by a carbonate rock aquifer system (Allentown and Leithsville Formations) and is characterized by numerous sinkholes and subsurface solution openings. The groundwater divide in this area, as shown on **Figures 1 and 2**, extends between Holicong and Byecroft Roads in Buckingham Township. This divide is evident from a review of groundwater elevations proximate to measurement point BY1 (Byecroft Road). BY1 shows the highest groundwater level in this area and forms the divide wherein groundwater levels to the southwest are lower (e.g. water level elevations in wells HO1, HO2 and HO3 along Holicong Road). Northeast of this divide, groundwater levels drop off in the direction of Ingham

Spring. Groundwater to the west-southwest of this divide contributes to Lahaska Creek.

- The area to the north - northwest in the study area is characterized by a classic groundwater divide (note the closed 430 ft, amsl water-level contour) wherein the groundwater and surface water divides are coincident. Groundwater to the north-northwest of the divide flows to Pannacussing and Cuttalossa Creeks, and groundwater to the south of the divide flows to Lahaska Creek and to the southeast flow off of this divide is within the Contribution Area of Ingham Spring as demarcated on Figures 1 and 2.

- Between the Ingham Spring Contribution Area and the Primrose Creek Basin, there is an area that contributes to Aquetong Creek that is outside of both the Ingham Spring Contribution Area and the contribution area to the Quarry pumping (> 2 MGD pumpage) within the Primrose Creek Basin. This area, outside the influence of these two principal discharge points (the natural Ingham Spring discharge and the pumping-induced discharge at the Quarry), widens to the east and northeast up to the Aquetong Creek's confluence with the Delaware River.

The total area contributing to Ingham Spring is estimated to be 6.32 mi^2. **Table 4** below outlines the area and the recharge estimate for each geologic formation within the Ingham Spring Contribution Area.

5.3 Spring Flow Rates

The Ingham Spring flow rate, as measured at the outlet creek downgradient of the pond (Photo 5), ranged from a minimum of 2.7 million gallons per day (MGD) in January 2008 to a maximum of 5.4 MGD in May 2007; 1,875 gpm to 3,750 gpm. For the 12 month period from June 2007 to May 2008, the average spring discharge was 3.53 MGD (2,450 gpm). There was a decline in spring flow from May 2007 to October 2008 which is reflective of the natural decrease in groundwater recharge that occurs from the wetter spring months to the drier summer and early fall/winter seasons due to higher temperatures and increased rates of evapo-transpiration.

The difference in the corresponding staff gauge readings between highest (4.5 MGD in June 2007) and lowest (2.7 MGD in January 2008) measured flow rates in the spring outlet creek (1.96 feet and 2.06 feet from the top of the staff gauge) was just 0.10 feet. This indicates that the rise and fall in stage of the creek with the range of flow is not great enough to be able to develop a rating curve (whereupon flow could be related to the staff gauge readings), and that continued flow measurements will be necessary to monitor spring flow in the outlet creek.

Photo 7: Ingham Spring Outlet to Aquetong Lake

Table 3: Ingham Spring Flow Measurements: May 2007 – May 2008.

Date	pH	Temperature °C	Conductivity uS	Spring Flow MGD
5/9/2007				5.4
6/7/2007				4.0
6/15/2007		14.4	375	4.5
8/16/2007		16.9	391	3.2
8/20/2007		13.1	382	3.1
9/10/2007		14.2	370	2.9
10/3/2007		16.4	340	3.1
10/16/2007		15.7	368	2.9
1/9/2008		11.6	401	2.7
2/26/2008	8.00	9.2	403	4.1
3/27/2008	8.40	10.3	385	4.7
4/24/2008	7.90	14.9	386	3.8
5/13/2008	8.00	12.1	390	3.4
Average				**3.53 (June to May 2008)**

Photo 8: Aquetong Lake

5.4 Recharge Estimate and Spring Flow Comparison

The recharge estimate for each geologic formation within the contribution area to Ingham Spring in square miles (mi^2) is shown on **Table 4** for years of average or normal precipitation, and for drought years. The estimated recharge to the spring contribution area is 4.08 million gallons per day (MGD) for a year of average precipitation. This translates to 2,833 gallons per minute (gpm). For a drought year, the recharge is estimated to be 1.48 MGD or 1,028 gpm.

The spring flow measurements for the 12 measurement events from June 2007 to May 2008, yield an average spring flow of 3.53 MGD which is comparable to the calculated groundwater recharge for a year of normal or average precipitation/recharge for the 6.32 square mile Contribution Area to the Spring of 4.08 MGD. The differential between the calculated groundwater recharge for the Contribution Area and measured spring flow of 0.55 MGD likely reflects dry weather baseflow contribution to the stream systems (principally the north branch of Aquetong Creek) within the Contribution Area. A longer period of record will assist in evaluating seasonal as well as drought impacts to spring flow.

Table 4: Ingham Spring Contribution Area Groundwater Recharge Estimates Normal and Drought Years

Geologic Units	Area (mi^2)	Normal Year Recharge (MGD/mi^2)	Normal Year Recharge (Total MGD)	Drought Year Recharge (MGD/mi^2)	Drought Year Recharge (Total MGD)
Stockton Formation	2.45	0.627	**1.54**	0.189	**0.46**
Stockton Conglomerate	0.37	0.627	**0.23**	0.189	**0.07**
Allentown Formation (Carbonate)	1.95	0.706	**1.38**	0.289	**0.56**
Beekmantown Formation (Carbonate)	0.34	0.706	**0.24**	0.289	**0.10**
Leithsville Formation (Carbonate)	0.80	0.706	**0.56**	0.289	**0.23**
Hardyston Formation (Sandstone)	0.41	0.314	**0.13**	0.154	**0.06**
Total	**6.32**		**4.08 MGD**		**1.48 MGD**

6.0 RECOMMENDATIONS

6.1 Spring Discharge (Flow and Quality) Measurements

Monthly measurements of the Ingham Spring discharge flow rate should be continued, along with the field measurement of water quality parameters including pH, conductivity and temperature. Ultimately, a discharge weir should be incorporated into the dam re-construction at the spring outlet pond.

Seasonal water samples should also be collected from the spring for a more detailed laboratory analysis of common anions and cations; metals and organic constituents.

6.2 Creation of a Contribution Area to Ingham Spring Overlay District

An Ingham Spring Contribution Area Overlay District should be created. Zoning and existing land usage within this district should be defined via the use of available Geographic Information System (GIS) databases. Existing land uses which have impacted or have the potential to impact groundwater should be identified, and certain potential future land uses should be prohibited.

6.3 Preservation of Property Within the Contribution Area (CA)

Solebury residents have been involved with land preservation for many years and in recent years most notably with the formation of the Land Preservation Committee in 1987 (formerly the Land Use Committee). Along with the State of Pennsylvania, Bucks County, and various preservation oriented groups such as the Heritage Conservancy and the Natural Lands Trust, Solebury Township has preserved 5,341 acres or 30% of its total area.

Many of the preserved lots/properties in Solebury Township have been protected via conservation easements. A conservation easement is a legal agreement between the landowner and a government entity or nonprofit organization in which the landowner retains some rights but the land is protected from various forms of development. Each conservation easement is specifically tailored. The owner may sell the land, but the land use and development restrictions remain with that parcel forever. The Bedminster Land Conservancy is the local, nonprofit, independent land trust that assists Solebury with conservation easements, while The Bucks County Agricultural Land Preservation Program aids with agricultural easements.

Photo 9: Aquetong Lake Earthen Dam and Lake Outlet to Aquetong Creek

Some of the lots to the west and north of Ingham Spring are preserved by The Heritage Conservancy, Natural Lands Trust, and Solebury Township, but the majority of lots surrounding Ingham Spring are not. To maintain groundwater recharge and sustain the high quantity and quality of spring flow, it is encouraged to promote open space and preserve lots within the Contribution Area.

6.4 Development of Tiered Spring Protection Areas

As with a tiered well-head protection area (WHPA) system in which the area around a water-supply production well is assigned a high level of protection and areas further away from the well have relatively lower levels of protection, a similar system can be developed around Ingham Spring. First tier Spring Protection Areas (SPAs) would comprise areas with groundwater travel times to the spring within a 1-year window and those areas underlain by limestone/carbonate rock because of their high recharge rate and potential for sinkhole and solution-opening development. The second tier of protection could include the remaining areas in the Contribution Area. A third level of protection could be a 500+ foot buffer on the fringes of the defined Contribution Area.

Photo 10: Aquetong Lake Outlet to Aquetong Creek

6.5 General Recommendations

Development of an Ingham Spring Advocacy Organization: A local group could be formed with the purpose of protecting Ingham Spring in collaboration with the Land Preservation Committee.

Rainwater Catchment and Recharge Promotion: Practices to maximize recharge should be encouraged and/or required for new construction in the Contribution Area. Roof top collection and dry well systems and creative stormwater basins (e.g. rain gardens) are two examples of rainwater catchment and recharge enhancement which would assist with groundwater replenishment.

Recommended Best Management Practices: Best Management Practices (BMPs) developed by The Pennsylvania Department of Environmental Protection (PADEP) for the protection of groundwater resources and the health and safety of a household should be incorporated via public education programs.

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