1.0 Introduction

Earth Data Northeast, Inc. (EDN) has performed over one hundred groundwater investigations in Southeastern Pennsylvania. EDN's practice areas include:

- Groundwater exploration, new source development and permitting
- Downhole well testing and analysis
- Aquifer testing and analysis
- Well rehabilitation, redevelopment and reconstruction
- Groundwater contamination investigation and remediation
- Computer modeling
- Regulatory relations

EDN was retained by Plumstead Township to conduct a Groundwater Study. EDN has performed the study in accordance with the Township's Request for Proposal (RFP) solicitation dated June 6, 2007. EDN presented the results of the study to the Township Board of Supervisors on August 19, 2008.

2.0 Executive Summary

In conducting the study, EDN utilized information from public resources and databases including the United States Geological Survey (USGS), the Pennsylvania Department of Environmental Protection (PADEP), the United States Environmental Protection Agency (EPA) and the Delaware River Basin Commission (DRBC). Additional information sources include:

- Reports prepared by various consulting hydrogeologist's and engineers engaged by the Township
- Township Base flow Reports
- Township Act 537 Sewage Facilities Plan
- Township and Bucks County Water and Sewer Authority documents

The principal objectives of the Groundwater Study were as follows:

- Compile and organize information from multiple sources to create a database relative to the Township's groundwater resources, groundwater withdrawals, groundwater monitoring, aquifer characteristics and recharge.

- Evaluate data to assure consistency with the Township's land use policies.

- Develop a Site Conceptual Model to serve as the basis for numerical computer modeling.

- Assess the potential impact to the Township's water resources resulting from the installation and usage of new and existing sewer service by the Bucks County Water & Sewer Authority (BCWSA).

On May 6, 2008 EDN met with the Township Board of Supervisors to present a progress report and to discuss proposed scenarios for the numerical model to assure consistency with the Township's land use policies.

A review of information sources and inputs that comprise the database and a description of the numerical computer model developed specifically for this Groundwater Study were presented in a draft report submitted to the Township on June 26, 2008. On July 8, 2008 EDN met with the Township Manager and staff to review database inputs, numerical model assumptions and comments from Mercuri Associates, Inc. Modifications to the database and the numerical model were made as necessary and the model was calibrated to reflect current groundwater conditions. On August 19, 2008, EDN presented the results of the Groundwater Study to the Township Board of Supervisors.

The principal findings of the Groundwater Study were as follows:

- The Geologic formations underlying the Township exhibit minimal porosity and permeability. The degree of fracturing and interconnectivity of secondary openings within the bedrock is limited. These structural limitations need to be considered in the evaluation of the Township's available groundwater resources.

- The bedrock formations that underlie the Township weather to soils with high clay content. This condition coupled with limited secondary porosity and permeability within the bedrock results in low groundwater recharge rates. Recharge rates can also be influenced by urbanization and by the export of wastewater via sewers.

EDN concurs with the following statement from the Water Budget Report prepared for the Township by Pennoni Associates:

"the majority of the Township is underlain by bedrock with relatively low recharge and yield rates such as the Lockatong formation and diabase rock. It is clear that groundwater resources are limited and must be managed wisely to ensure continued groundwater supplies and sustain adequate natural stream flows."

However, despite the low recharge rates resulting from the characteristics of the geologic conditions underlying the Township, it is EDN's opinion that the export of groundwater via the BCWSA sewer system at the quantities contemplated by the Stipulation and Agreement will have a minimal impact on the groundwater resources of the Township.

Based on the results of the Groundwater Study EDN offers the following recommendations:

- The Township should continue to explore for and develop additional supply wells. New wells should be large diameter to expose and develop fractured zones.

- The Township should anticipate that future groundwater appropriation permit applications and monitoring data from existing wells will receive significant technical evaluation from regulators relative to potential well interference concerns and recharge.

- The Township should continue discussions with Doylestown Borough Authority relative to the amount of supply available through the existing interconnection for emergency situations.

- The Township should increase its above-ground storage capacity.

3.0 Current Groundwater Supply

Plumstead Township provides water service for residential commercial and industrial customers within the Township. Some residents obtain water from private or tract wells. All of the Township's water supply is derived from ground water resources. The Township's system is comprised of the following systems. The location of these systems is shown on Figure 1:

- Cabin Run (Production wells: CR-1, CR-2, CR-3)

- Country Green (Production Wells: MT-1 and MT-2)

- North Branch/Durham Ridge (Production Wells: NB-2, NB-3 and DR-1)

- Summer Hill/Summer Meadow (SH-5, SH-6 and SH-7)

These production wells have been consolidated under Delaware River Basin Commission (DRBC) Docket No. D-97-33 CP-2. An allocation has been established for each individual well and each of the four systems. The total system allocation from all wells is 15.31 million gallons per 30-day period.

A long-term monitoring program has been established to evaluate potential changes in ground water and surface water conditions in response to the pumping the production wells and residential wells within the Township. Thirty one (31) wells currently comprise the ground water monitoring network. This monitoring well data is collected, compiled, evaluated and reported by Mercuri Associates, Inc.

The database developed as a component of the Groundwater Study provides a means to catalog well drilling, construction and completion specifications. Groundwater withdrawal and water level monitoring data can be input on an ongoing basis. The numerical computer model provides a means to compare and evaluate monitoring data to identify changes or trends compared to

current baseline conditions. Enclosed is a compact disk containing the well data used in the model.

4.0 Wastewater

Much of the waste water generated within the Township is discharged through onsite septic systems. The remainder of the waste water generated in the Township, with the exception of the Timberly Farm Development (which is serviced by a small package plant), is collected by the Bucks County Water and Sewer System (BCWSA) and transported to the Chalfont New Britain Joint Sewer Authority Sewage plant for treatment.

In January 2008, the Township entered into a Stipulation and Agreement (S&A) with BCWSA regarding sewer systems within the Township. The purpose of the S&A was to confirm the agreement the Township and BCWSA regarding the manner in which public sewer service will be implemented by BCWSA within the Township.

The S&A provides the following information relative to the total EDUs to be served by the BCWSA system within the Sanitary Sewer District:

Development Name	Number of Equivalent Dwelling Units
Timberly Farm Subdivision	62
Plumstead Business Campus/Applebutter Development	10
Ferguson Tract Subdivision	8
Owls Nest Farm Subdivision	16
Nanni Tract Subdivision	20
Werner-Stump Road Subdivision	3
Urich Tract Land Subdivision	78
Autumn Preserve Subdivision	24
Lantern Ridge Subdivision	105
DiPalma Tract Land Development	8
Garden Village Subdivision	51
McGinnis Tract Subdivision	45
Center Club Land Development	6
Plumstead Pointe	10
Thompson Service Center Land Development	2
Authorized Individual Connections	26
Capacity Reservation	175
Total EDUs	**649**

The numerical model developed as part of the Groundwater Study, provides a means to document baseline conditions relative to water levels, recharge and other data. The model may also be used to monitor changes in these parameters to evaluate potential future impact to the

Township's groundwater resources resulting from increases in the transport of wastewater out of the Township via the BCWSA system.

5.0 Database Information Sources:

EDN compiled and evaluated data from multiple sources to construct the database. The database provides for the import of additional information as it becomes available or the deletion of data as necessary. Data was obtained from a variety of sources including Township records and files, the United States Geologic Survey (USGS), Delaware River Basin Commission (DRBC), and the Pennsylvania Department of Environmental Protection PADEP.

The following provides a partial listing of the information sources used to construct the database:

- Pennsylvania Topographic and Geologic Survey Groundwater Information System (PaGWIS);
- Pennsylvania Department of Environmental Protection (PADEP) eMapPa Electronic Mapping System;
- USGS report entitled: *Hydrogeology and Groundwater Quality of Northern Bucks County*
- Plumstead Township Act 537 Sewage Facilities Plan;
- United States Census Bureau records;
- Delaware River Basin Commission (DRBC) records;
- Township Base Flow Reports
- Township planning ordinances
- Reports prepared by the Township's consulting hydrogeologists and engineers relative to well construction, permitting, operation, monitoring and water budget analysis
- Additional records, correspondence and other information provided by the Township

6.0 Conceptual Site Model

During the data compilation process, information was evaluated to determine its usefulness in the formulation of conceptual model parameters. During this process, selected data was entered into HydroGeo Analyst (HGA) software to synthesize this information into a comprehensive Conceptual Site Model (CSM). HGA is a comprehensive data management, visualization, and reporting program developed by Schlumberger Water Services specifically for the management of groundwater and environmental data. HGA integrates mapping capabilities with ESRI GIS mapping compatibility, graphic and tabular data presentation, cross section interpretation incorporating geophysical logging data, and three-dimensional rendering and animation of data. HGA was utilized to interpolate available well drilling logs and construction details, to generate cross sections for use in the groundwater flow modeling portion of the project.

HGA is fully compatible with Visual MODFLOW, also developed by Schlumberger Water Services. Visual MODFLOW is a graphical user interface built on the USGS MODFLOW groundwater modeling package. Through this software system, the CSM created by HGA was imported directly into Visual MODFLOW along with available water level and hydraulic characteristic data for the development and calibration of the detailed groundwater flow model.

Model parameters and assumptions were formulated through analysis of available pumping test data from the Plumstead Township water supply system and other private subdivisions. Parameters for areas in which no public water supply wells are located were interpolated from the available data.

7.0 Numerical Model

7.1 Numerical Model Calibration and Optimization

During the creation of the CSM, model parameters were optimized via sensitivity analyses to calibrate the model in relation to “real-world” conditions. The WinPEST utility, an automated model calibration, sensitivity analysis, and predictive analysis package integrated with Visual MODFLOW, was utilized for the completion of this task. Once the model construction, calibration, and optimization were completed, Visual MODFLOW with MODPATH was utilized to model groundwater flow. The computer modeling results were compared to analytical models in areas in which sufficient hydrogeologic data is available.

7.2 Numerical Model Input Parameter: Topography and Drainage

The Township comprises of a total of approximately 27.7 square miles. A review of United States Geologic Survey (USGS) topographic maps (Bedminster, Lumberville, Buckingham, and Doylestown 7.5-minute quadrangles) indicates that elevations within the Township range from

approximately 620 feet above mean sea level (amsl) in the southwestern portion of the Township to approximately 110 feet amsl in the northeastern portion of the township adjacent to the Delaware River. Topographic highs and lows such as valleys and ridges generally are oriented along the strike of the geologic formations underlying the Township. The northern portion of the Township generally drains to the Tohickon-Geddes-Cabin Runs and to the Delaware River. The southern portion of the Township generally drains to the Tohickon-Deep Run, Pine Run and to the North Branch of the Neshaminy Creek. Figure 2 is a topographic map of the study area.

7.3 Numerical Model Input Parameter: Geology and Hydrogeology

The USGS reports the Township as being underlain by three primary geologic units: the Stockton and Lockatong Formations, and Diabase intrusions, of Triassic age. Figure 3 is a geologic map of the study area. The characteristics of each formation are described below

The Stockton formation consists of a diverse lithology, with a large variation in bedding, texture, and color. It is characterized by interbedded sandstone, arkose, arkosic sandstone, arkosic conglomerate, siltstone, and shale. The formation is characterized by fine-grained sandstone in the upper portion and coarse-grained conglomerate in the lower portion, with abundant arkose throughout, except for the uppermost few hundred feet. The Stockton formation strikes NE-SW, similar to the orientation of the township, and dips approximately 10 degrees NW.

The Stockton Formation is mapped in the southern corner of Plumstead Township. The Stockton Formation is the highest yielding and most transmissive formation within the Township, due to high primary porosity and a high concentration of interconnected joints and fractures. Additionally, the Stockton is highly weathered, thereby enhancing recharge to the aquifer.

The Lockatong Formation consists of laminated to thick-bedded, gray and black siltstone and shale. The Lockatong has been thermally metamorphosed in areas surrounding Diabase intrusions to a purplish-red, light grey, and dark gray fine-grained hornfels in a zone approximately 2,000 feet wide. The strike and dip of the Lockatong Formation are nearly identical to that of the Stockton Formation. The Lockatong Formation is mapped beneath the majority of Plumstead Township, from the southern interface with the Lockatong to the Delaware River. The Lockatong Formation is a low-yielding formation, due to lack of extensive primary porosity and limited fracturing and joint interconnectivity. Additionally, because the formation weathers to a clayey soil, recharge is restricted, further limiting the yield of the aquifer.

Diabase is characterized as a dark gray to black, fine to coarse grained, crystalline, plagioclase rock. This rock was intruded into the Lockatong Formation under high temperatures and low pressure, along bedding planes. Diabase sheets form hills and ring-like outcrop patterns over portions of the areas in which it is mapped. Diabase intrusions are mapped along the ridge in the eastern portion of the township, along Ferry Road, within the Lockatong Formation. Diabase is the lowest yielding formation within the Township, due to the lack of primary porosity and relatively few fractures. Wells can be installed within the diabase, but do not typically yield sufficient water for supply. Recharge to diabase is also limited by the clayey soil that typically

overlies the formation and lack of fracturing. Figure 3 is a geologic map of the Groundwater Study area.

7.4 Numerical Model Input: Aquifer Conditions

The groundwater resources within the Township are obtained exclusively from groundwater occurring within in these formations. The CSM assumes a heterogeneous, anisotropic, highly-fractured, multi-layer system fractured bedrock system:

Three-Layer Model

- Upper Zone 10 feet in thickness modeled using average transmissivity (2,784 gpd/ft), storage coefficient (9.44×10^{-5}), and hydraulic conductivity (0.91 ft/day) to allow for equal intake of recharge over the entirety of the model.

- Middle Zone of 10 feet to 400 feet modeled using data from individual tract and Plumstead supply wells. Hydraulic characteristics between wells interpolated based on distribution of data. Most transmissive/conductive wells installed at this depth range.

- Bottom Zone of 400 feet to 638 feet modeled using data from individual tract and Plumstead supply wells. Hydraulic characteristics between well interpolated based on distributions of data. Less transmissive/conductive wells installed at this depth range.

7.5 Numerical Model Input: Pumping Scenarios:

- Township supply wells and selected tract wells were modeled using actual known pumping rates and usage patterns for the wells, as documented in available reports.

- Other tract wells and individual wells were modeled based on the lateral distribution of the wells. The general distribution of wells is mapped in HGA based on wells for which accurate location data is available. It is assumed that the density concentration of the mapped wells is equivalent to the density concentration of all private wells within the Township. Based on the density of these wells, groundwater sinks/withdrawals were modeled to distribute the 1,816 EDUs over the model, assuming a daily withdrawal of 400 gpd/EDU.

- The model has been calibrated by entering available hydraulic data, withdrawal data, and individual well estimates to match, within an acceptable error range to match actual observed water levels from the 2007 monitoring report prepared by Mercuri Associates, Inc.

7.6 Numerical Model Input: Population

Population:

- 2000 Census: 11,409 residents
    - 2000 Census: 4,103 Equivalent Dwelling Units (EDUs)
    - 2007 Estimate (based on 4.41% growth rate): 11,912 residents
    - 2007 Estimate: 4,283 EDUs

7.7 Numerical Model Input: Water Use

- Served by Township Public Water Supply: 1,342 EDUs
    - System wide withdrawals (2007 data): 8.773mg/30 days (Mercuri)
    - Average Daily Withdrawal (2007 Data): 292,243 gallons
    - Average Annual Withdrawal: 106,738,150 gallons (17 gpd/acre)
- Served by Private or Tract Wells: 2,941 EDUs
    - Average Daily Withdrawal (400 gpd/EDU): 1,176,400 gallons
    - Average Annual Withdrawal: 429,386,000 gallons (67 gpd/acre)
- Industrial/Commercial Wells: 29 Commercial EDUs (CEDU)
    - Average Daily Withdrawal (5,000 gpd/CEDU): 145,000 gallons
    - Average Annual Withdrawal: 52,925,000 gallons (8 gpd/acre)
- Total Township Usage:
    - Average Daily Withdrawal: 1,613,643 gallons
    - Average Annual Withdrawal: 588,979,690 gallons (91 gpd/acre)

7.8 Numerical Model Input: Wastewater

- Sewer Connections
    - Served by Township Sewer: 1,342 EDUs
        - Average Daily Export (2007 data): 284,119 (Mercuri)
        - Average Annual Export (2007 data): 103,703,435 (Mercuri)
    - Total Planned BCWSA Connections: 639 EDUs
        - Average Daily Export (400 gpd/EDU): 255,600 gallons
        - Average Annual Export: 93,294,000 gallons
    - Industrial/Commercial Wells: 25 CEDUs
        - Average Daily Export (5,000 gpd/CEDU): 125,000 gallons
        - Average Annual Export: 45,625,000 gallons
    - Total Exported Wastewater
        - Average Daily Export: 664,719 gallons
        - Average Annual Export: 242,622,435 gallons
- Septic Discharges (assumes 80% of withdrawal returned via septic recharge)

- Residences Served by Septic Systems: 1,816 EDUs
  - Average Daily Discharge (400 gpd/EDU): 581,120 gallons
  - Average Annual Discharge: 212,108,800 gallons
- Industrial/Commercial Discharge: 4 CEDUs
  - Average Daily Discharge (5,000 gpd/EDU)
  - Average Annual Discharge: 5,840,000 gallons

7.9 Numerical Model Input: Groundwater Recharge

- Base Flow
  - Average Monthly Base flow (total): 169,880,000 gallons
  - Average Base flow: 535.5 gpd/acre
- Normal Precipitation (2007)
  - 3,542 gpd/acre (47.21 inches)
- Evapotranspriation (73% of precipitation)
  - 2,579 gpd/acre (34.53 inches)
- Runoff
  - 629 gpd/acre (8.42 inches)
- Recharge
  - 334 gpd/acre (4.47 inches)

7.10 Additional Numerical Model Inputs

- Well locations from registered wells within the Township have been entered into HGA. However, coordinates are not available for all existing wells. Therefore, the density of the plotted wells were used to project well distribution density within the model

- Population data obtained from the US Census Bureau has been used to determine groundwater usage of residences and subdivisions for which actual records do not exist.

- The total Equivalent Dwelling Units (EDU's) for the Township have been determined and assigned an average of 400 gallons per day/EDU in accordance with the township well ordinance

- Industrial withdrawals determined by PADEP eMapa service have been determined and plotted and assigned an average withdrawal of 5,000 gallons per day.

- The Township water budget has been calculated and entered into the database.

8.0 Numerical Model Output

8.1 Baseline Conditions

- Appendix A provides graphic illustrations of the numerical model output reflecting current baseline conditions. The head levels are base on monitoring data from a few specific areas of the township. Township-wide groundwater elevations for areas where there is no monitoring data are estimated based on surface elevation and hydraulic boundaries such as streams. The figures displayed in Appendix A represent model output under steady-state conditions.

- The water table elevation map represents groundwater elevations across the township. The levels are based on data from observed water levels from the 2007 monitoring report prepared by Mercuri Associates, Inc.

- The drawdown map represents the change in groundwater elevation based upon an initial estimate. Areas in which the greatest change in groundwater elevation is observed correspond to the location of mapped production wells.

- The groundwater flow direction map represents groundwater flow direction and velocity across the township. Larger arrows represent relatively greater flow velocity. Groundwater on this map is shown to flow generally from higher to lower elevations and towards the mapped production wells.

8.2 Impact of Water Use Changes in the Township

To model the impact of water use changes on township groundwater, 3 time-steps were created in the model. The first time-step represented current conditions as reported in Section 7.1. The second time-step represents the status of the model with additional sewer connections. The third time-step demonstrates the impact of pumping the township wells at their DRBC maximum allocations. All time-steps were run as steady-state models, so the length of each time-step was not a factor

8.2.1 Reduced Septic Infiltration

The impact of reduced septic infiltration through additional sewer connections was evaluated by reducing groundwater recharge rates in the model. Recharge rates were decreased in the area of the Sanitary Sewer System district by an amount equal to an addition of 649 sewer connections. The change in rate was calculated by using the previous estimates of 400 gpd/EDU and 80% of withdrawals being returned as septic discharge.

Changes in groundwater elevation were calculated in the model for 25 observation wells. The groundwater simulation indicated that reduced septic infiltration would result in an average decrease in groundwater elevation of 0.028 feet.

8.2.2 Increased Groundwater Withdrawals

The impact of future increases in groundwater use in the township was evaluated by increasing the groundwater withdrawals of existing production wells. All production wells were modeled with pumping rates equal to their DRBC maximum permitted allocations.

The pumping rates of the township public supply wells were increased from the actual 2007 reported flow rates to the maximum DRBC allocated rates. Changes in groundwater elevation were calculated in the model for 25 observation wells.

The groundwater simulation indicated that increasing groundwater withdrawals to the maximum allocated rates would result in an average decrease in groundwater elevation of 13.15 feet.

9.0 Findings

- The geologic formations underlying the Township exhibit minimal primary porosity and permeability. The degree of fracturing and interconnectivity of secondary openings within the bedrock is also limited. These structural limitations must be considered in the evaluation of the Township's available water resources.

- The bedrock formations that underlie the Township weather to soils with high clay content. These conditions result in low groundwater recharge rates.

- Despite the low recharge rates resulting from the characteristics of the geologic conditions underlying the Township, the export of groundwater via the BCWSA sewer system at the quantities contemplated by the Stipulation and Agreement will have a minimal impact on the groundwater resources of the Township.

10.0 Recommendations

- The Township should continue to explore for and develop additional supply wells. New wells should be large diameter to expose and develop fractured zones.

- The Township should anticipate that future groundwater appropriation permit applications and monitoring data from existing supply wells will receive significant technical evaluation by regulators relative to potential well interference and recharge.

- The Township should initiate discussions with the Doylestown Borough Authority relative to the amount of supply available through the existing interconnection

- The Township should increase its above-ground storage capacity.

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