

# Quantifying Urban Groundwater in Environmental Field Observatories: A Missing Link in Understanding How the Built Environment Affects the Hydrologic Cycle

**PI: Claire Welty, UMBC (University of Maryland, Baltimore County)**

## Introduction

The goal of this proposal is to contribute to the design of WATERS environmental field observatories by establishing a methodology to quantify flowpaths, fluxes, and stores of groundwater in urban areas. While certain aspects of interactions between the built environment and the hydrologic cycle have received a great deal of attention in an applied sense (stormwater management, etc.), there have been few efforts that have taken a comprehensive approach to evaluate how urban infrastructures affects groundwater on a watershed scale.

The objective of the current proposal is not to answer all of the many relevant research questions; rather, we intend to develop a set of tools to address these questions that can be used by environmental observatories containing an urban component.

An advantage of using field sites in Baltimore as a test bed is that extensive instrumentation is already in place and a number of spatial data sets have been collected that can be utilized for the project. Baltimore is an ideal test site because it is already a part of LTER, NEON (planning), CLEANER (planning) and proposed CZO field observatories; methodology developed from this effort will be transferable to other urban areas both in the region and in other parts of the US and the world.

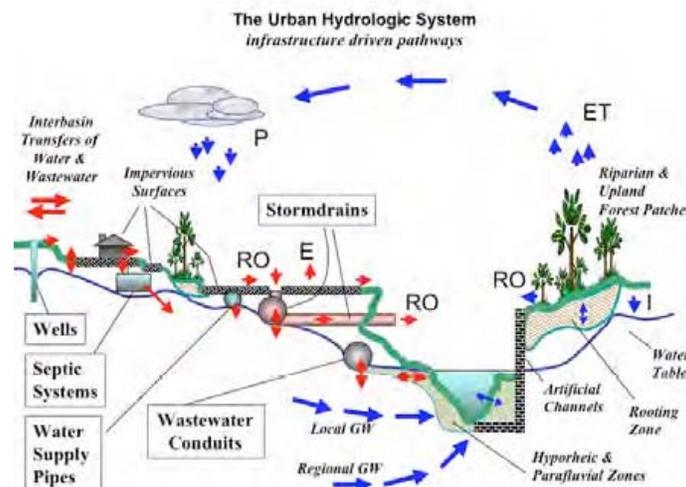


Figure 1. The urban hydrologic cycle.

Elements of the planned work include synoptic field surveys, remote sensing, numerical modeling, data mining and visualization tools. We will: (1) compare base flow behavior from stream gauges in a nested set of watersheds at four different spatial scales from 0.8

to 170 km<sup>2</sup>, with diverse patterns of impervious cover and urban infrastructure; (2) conduct a synoptic survey of well water levels to characterize the regional water table; (3) use airborne thermal infrared imagery to identify locations of groundwater seepage into streams across a range of urban development patterns; (4) use seepage transects and tracer tests to quantify the spatial pattern of groundwater fluxes to the drainage network in selected subwatersheds; (5) develop a mass balance for precipitation over a 170 km<sup>2</sup> area on a 1x1 km<sup>2</sup> grid using recording rain gages for bias correction of weather radar products; (6) calculate urban evapotranspiration using the Penman-Monteith method compared with results from an eddy correlation station; (7) use numerical groundwater model in a screening mode to estimate depth of groundwater contributing surface water flow; (8) mine data from public agency records of potable water and wastewater flows to estimate leakage rates and flowpaths in relation to streamflow and groundwater fluxes; and (9) evaluate the CUAHSI Hydrologic Information Systems data modeling tools for application to urban environments.

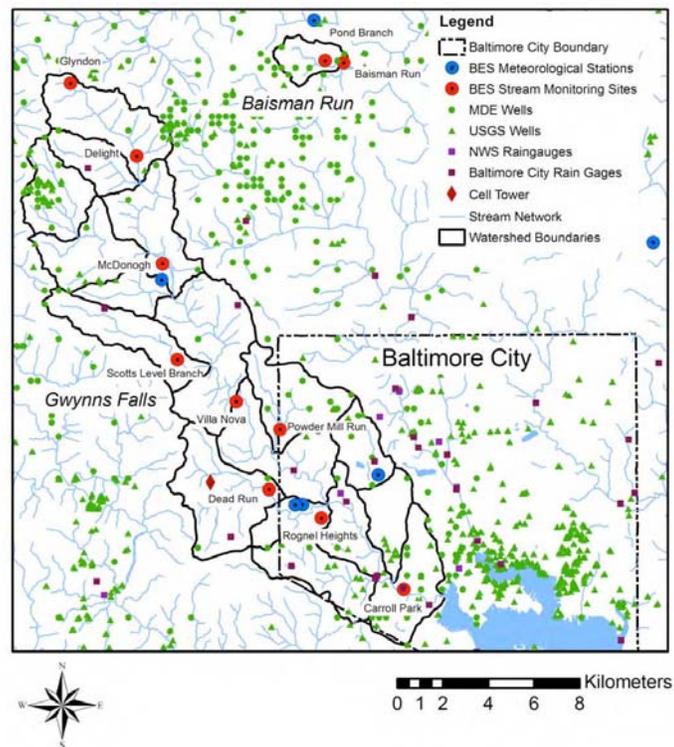


Figure 2. Streamflow, meteorological stations, and wells in the Gwynns Falls watershed.

Of particular interest, when considering the added value that integration of geophysical methods would bring, is point (2) above. The behavior of urban groundwater is generally not well documented, and this is certainly true for the Baltimore area. In the Piedmont and fall zone, groundwater flows through unconsolidated saprolite (weathered bedrock) and alluvium and fractured bedrock. The saprolite has a high porosity (20-30%); the porosity of the fractured rock is 0.01 - 2%. The unconsolidated and fractured formations can be considered separate but interconnected flow systems (Greene et al., 2004). Due to its high porosity and storage characteristics, the unconsolidated system is not very

responsive to recharge. It feeds the underlying low-porosity fractured bedrock, which owing to its low porosity is extremely responsive to recharge, resulting in significant changes to water levels in wells. The thickness of the saprolite is highly variable and sometimes extends to depths on the order of 15-20m; response of well levels and baseflow in streams to cycles of wetting and drying suggests that the saprolite may play an important role in buffering the response of the groundwater reservoir to these cycles, but that role is not well understood. Increases in impervious surfaces would be expected to reduce recharge in urban areas, which in turn would be expected to reduce base flow to streams, but the behavior of the saprolite in this regard has not been quantified. It may very well be that if the saprolite is not sensitive to recharge, the surficial groundwater reservoirs are also relatively insensitive to hydrologic extremes.

Characterizing the urban groundwater flow system is difficult, due to the low spatial density of wells in this urban area that relies on surface water distribution for potable water supply. Nonetheless, locations of existing wells have been obtained from USGS and MDE data bases (Figure 2), and there are an additional 30,000 wells in the Baltimore County data base that can be mined to determine locations within the study area. USGS personnel will open approximately 100 (total) of these wells within and outside of the Gwynns Falls boundary to obtain a snapshot of the deep and shallow potentiometric surface elevations under wet (late winter/early spring) and dry (late summer) conditions. These measurements will be used to contour heads for shallow (e.g., 50 ft) and deep (e.g., 300 ft) well elevations. Comparison of the two potentiometric surfaces will provide an indication of regions of downward vs upward flow exchange from the deep bedrock to the overlying saprolite and alluvium. An approximate indication of shallow lateral flow directions can be determined from the potentiometric head map derived from the shallow wells. The regional depiction of hydraulic head is expected to be too coarse to be very meaningful at the small subwatershed scale; additional methods can be employed to refine the groundwater flow field as needed.

The extent to which deep groundwater is contributing to stream base flow can be determined through model calibration to measured heads and stream-groundwater flux rates, plus any available information on hydraulic conductivity from aquifer pumping tests. We will use a three-dimensional numerical groundwater model (e.g., MODFLOW) in a screening mode where we will adjust the fluxes to the streams to match those measured with seepage tests to determine the possible range of groundwater depths and the range of average aquifer hydraulic conductivities that will yield fluxes of the appropriate order of magnitude.

In addition to describing the regional groundwater system, we wish to begin to explore methods for determining local recharge rates; this information can also be incorporated into the groundwater model. Opportunities for infiltration of precipitation in urban areas are severely reduced by the presence of impervious surfaces, hardened soils, and even turfgrass in some cases. Even in the event that infiltration does occur, this may not be directly correlated to the amount of water that reaches the saturated zone as recharge. Infiltrating groundwater is subject to high evaporation rates in areas lacking canopy

vegetation, and to shortcuts and short circuiting through and around buried pipes that can serve as infiltration galleries and subsurface preferential flowpaths.

## Geophysical survey design

There are two related aims that the geophysical surveys are targeted towards: 1) to image the spatial variability of the depth to the water table to fill in the blanks between the limited point source measurements from wells; and 2) to characterize the subsurface spatially, enabling the variation in the thickness of the overlying saprolite layer to be determined. The results obtained from both of these aims would enable an improved constraint on the hydrogeological models. By considering both these aims we also hope to add to the understanding the role this weathered layer has on the control of the hydrological responses in this urban system.

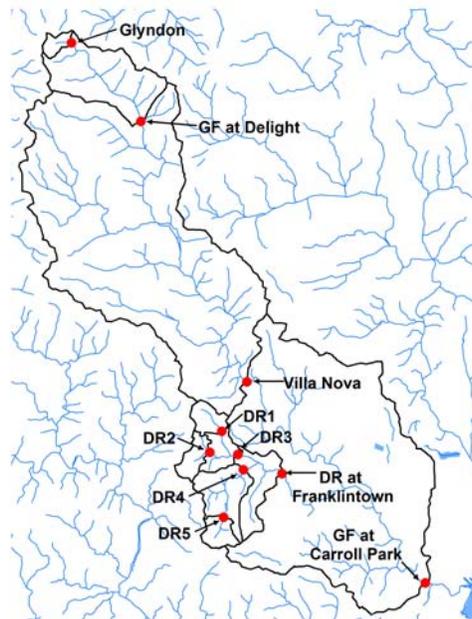


Figure 3. Sub-watersheds within the Gwynns Fall watershed.

Proposed dates for this survey are confirmed for between 1<sup>st</sup> July 2007 and 18<sup>th</sup> July 2007.

The urban environment is a challenging one for any geophysical survey, both in terms of signal interference from infrastructure and also locating sufficient suitable areas to conduct meaningful surveys. To improve our chances of success we propose using a number of techniques to address the above aims. The majority of the surveys will be conducted using a combination of electrical resistivity imaging (ERI), ground-penetrating radar (GPR), and seismic refraction as ground conditions dictate.

A number of sub-watersheds have been proposed for these surveys, including DR1, DR2, DR3, DR4, DR5, Glyndon and Delight (Figure 3). Aerial photography, provided on the Baltimore Ecosystem Study website, indicates that it should be possible to concentrate

the geophysics in green areas, such as parks, open spaces, wooded areas, gardens, etc., whilst still maintaining a suitable spatial distribution to capture the variations. This would minimize the impact of urban infrastructure on the results, and reducing the logistical difficulties created by surveying on public roads, etc.

The proposed methodology would be to identify a suite of suitable 'green' sites that would best capture the spatial variability within these sub-watersheds. A number of transects of ERI, GPR, and seismic refraction would be conducted to image the water table and characterize the subsurface at each site. The exact design and number of these transect will be site specific depending on area available and any physical constraints present. This will produce a series of well characterized 'little oases' which can be incorporated into the hydrogeological models. The spatial distribution of these sites can be tuned, allowing concentrations around wells or stream channels for a more detailed characterization for example, depending on the requirements.

An initial microgravity survey across the watershed will also be conducted to investigate the suitability of this technique. If successful, a repeat survey could be conducted at a later date in an attempt to determine storage changes in the underlying aquifer, this would hopefully aid in improving the understanding of spatial variations in recharge in this urban area.

In addition, we propose to conduct a test of a variety of geophysical techniques aimed at the detection of utilities in this urban environment. This is of interest to this WATERS Test Bed proposal for a number of reasons; firstly the basic fact is the location of these utilities is often poorly recorded. By knowing the locations of such pipelines can aid in the understanding of preferential flow paths created by their presence and installations. Secondly, leaking water and sewer lines have the potential to act as sources of recharge to the groundwater system. We aim to test whether the geophysical techniques have the potential for detecting such leakages.

This will not be an exhaustive survey of the selected sub watersheds, instead we aim to test a number of techniques (ERI, GPR, electromagnetic induction, magnetics), at 1 or 2 specific sites. These results could then be used to determine the best combination of techniques for any potential future surveys, possibly conducted by one of the many geophysical service companies.

## **Infrastructure**

There are a number of groundwater monitoring wells available (Figure 2) that we can use for ground truthing of the geophysics. Although continuous down-hole water table measurements are limited, part of the proposal calls for a comprehensive survey of water table levels within a subset of these wells at several time periods. We also have access to any logs, geological and geophysical for example, that were recorded at the time of completion.

## Budget

We would be out in the field for a total of 18 days; this includes 2 days travel, 1 day to set up and 1 day to pack away, and 14 days on site to carry out the surveys (10 days for the ERI and 2 days for the utility surveying, with 2 days spare for downtime, etc.).

The plan is to fly out to Baltimore, using a rental car from one of the airport rental companies. All accommodation and subsidence costs need to be accounted for, with consideration of this being an urban environment and the associated elevated costs. We have all the geophysical equipment needed for the surveys, this will need to be shipped out to Baltimore in advance.

### On-site support to be provided by UMBC

We are receiving on-site support in the following way:

- Personnel to assist with the acquisition of the geophysical data is being provided for the duration of the proposed field work.

### Additional costs

		Unit price	Taxes & extras	Total price
<b>TRANSPORTATION</b>				
<b>Flights</b>	SFO to BWI Estimate for proposed dates; Sun 24 <sup>th</sup> Jun to Wed 11 <sup>th</sup> Jul	\$700.00	included	\$700.00
<b>Rental Car</b>	18 days rental Intermediate sized SUV Includes LDW and supplementary liability insurance	\$1500.00	\$250.00	\$1750.00
<b>Fuel Charge</b>	Assuming 50 miles per day, vehicle running at 18 mpg, and a fuel price of \$3.00 per gallon.	\$150.00	included	\$150.00
<b>ACCOMMODATION</b>				
<b>Hotel</b>	17 nights stay Extended Stay Hotels – BWI airport (studio room)	\$1700.00	\$316.00	\$2016.00
<b>Subsidence</b>	19 days @ \$45 per day	\$855.00	included	\$855.00
<b>SHIPPING COSTS</b>				
<b>Fedex shipping</b>	Shipping the follow from; Stanford, CA 94305 – Baltimore, MA 21090 (estimated 4 day delivery time) PE100 GPR system (15kg) Syscal resistivity imaging system (40kg) Dualem 1S EM system (10kg) Magnetometer (3kg)	\$700.00 (1-way)	\$200.00	\$1600.00
<b>CONSUMABLES</b>				
	Includes: replacing batteries in each	\$600.00	included	\$600.00

	system, cover any minor breakages (cables and connectors for example, on site purchase of tools, etc.			
<b>GRAND TOTAL</b>				<b>\$6671.00</b>