FINAL REPORT: INVENTORY OF EXISTING STORMWATER MANAGEMENT FACILITIES WITH RETROFIT POTENTIAL WITHIN THE WISSAHICKON CREEK WATERSHED

(Photo by PWD Field Team, Pheasant Hill Basin in Upper Dublin Township)

Philadelphia Water Department
Office of Watersheds

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104b3 Grant Program

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Pennsylvania Department of Environmental Protection

NARRATIVE DESCRIPTION OF PROJECT:

The purpose of this initiative was to develop and implement a replicable approach for generating an inventory of existing stormwater management facilities within a watershed drainage area and constructing a process by which inventoried basins could be prioritized for retrofit with structural and nonstructural stormwater best management practices aimed at enhancing groundwater recharge and water quality treatment of stormwater runoff. This initiative established a prioritized inventory of existing sites where retrofits will provide the most benefit for reducing stormwater runoff impacts to the creek and increasing stream baseflow. The pilot study for this initiative focused on dry-bottom detention basins within the chosen study area, the Wissahickon Creek Watershed located in Southeastern Pennsylvania.

The project will result in a document available to municipal officials, targeted landowners, watershed organizations and the general public that can be used as a resource to identify priority projects for implementation through PA's Growing Greener Grants and other funding sources. The priority projects will directly address the Wissahickon Creek Total Maximum Daily Load (TMDL) recommendations for reduction of stormwater point and non point source impacts.

The study area for this initiative was limited to the subwatershed drainage areas of the tributary streams flowing to the Wissahickon Creek mainstem – specifically excluding basins within the mainstem drainage area. (Figure 1) The study was focused on first and second order streams where implementation benefits would be maximized.

For the purposes of this study, dry bottom detention basins were assumed to have the following characteristics:

- Designed to completely dewater after having provided its planned detention of runoff; normally dry over the majority of its bottom area.
- Designed to control peak discharge rates but do little to treat runoff for water quality improvements.

Water Quality Retrofitting: Upgrades to a facility, which would improve the water quality of stormwater runoff leaving the site.

Groundwater Recharge Retrofitting: Upgrades to a facility, which would increase groundwater infiltration of stormwater runoff within the basin footprint.

WHAT THIS PROJECT IS – AND WHAT IT IS NOT

The purpose of this initiative was to develop a tool to assist Wissahickon stakeholders and municipalities in the first phase of an implementation strategy - to help them assess and prioritize their options in order to ultimately develop an adequate long-term approach; this is not a list of retrofit priorities deemed appropriate and/or ready for implementation at this time. All basins considered for retrofit implementation will require a detailed site specific feasibility study and engineering design in order to proceed. Existing on-the-ground conditions such as flooding issues, groundwater contamination, underlying karst geology, proximity to drinking water, groundwater source (i.e. a well, or spring) as well as many other factors must be considered in order to deem the basin appropriate for retrofit implementation. This initiative did not result in a series of "recommendations" – but rather a resource for partners to utilize in developing their own implementation approach.

Additionally, all implementation work must be done in accordance with any and all (Municipal, County, State and/or Federal) applicable rules, regulations, permits, codes and guidance (examples: Act 167 Stormwater Management Plan and Ordinance, Pennsylvania State Best Management Practices Manual, Erosion and Sediment Control Plans, NPDES permitting, Chapter 105 requirements, wetlands regulations, etc.).

SCOPE OF WORK AS DETAILED IN THE 104B3 GRANT PROPOSAL

The Scope of Work for the 104b3 Grant included the following tasks:

Task 1: Data Collection

Currently, no database exists with all stormwater management facilities in the Wissahickon Creek Watershed. Under this task, an inventory of facilities associated with the 1st and 2nd order streams within the watershed was created based upon the following sources of data:

- Existing inventories of PWD and watershed municipalities
- NPDES permit annual reports
- Aerial photographs
- Up to 12 interviews with municipal officials and county officials
- Information contained in existing Act 167 plans

For each facility, existing information was collected and utilized to populate a dataset. Information included soils, land use, basin area, inlet/outlet structure, ownership, etc.

Task 2: Prioritization Procedure Development

A screening prioritization procedure was developed based upon the data collected in task 1. The procedure was designed to prioritize existing facilities for retrofit to increase recharge and reduce sediment load to the creek.

The prioritization procedure developed by the PWD Project Team and submitted, reviewed and approved by DEP.

Task 3: Facility Prioritization
The prioritization approach designed in task 2 was applied to the basin inventory developed under task 1. The task resulted in an ordered list of facilities based on retrofit priority.

Task 4: Demonstration of Conceptual Retrofit Designs
This task produced documentation of costs and benefits associated with three types of retrofits deemed appropriate and "implementable" within the Wissahickon Creek Watershed.

Deliverable
Upon completion of this initiative, a final report detailing estimated benefits and costs associated with each retrofit type and a list of the top 20 "best candidate" basins for retrofit was produced; this and all data layers developed through this initiative were shared with Wissahickon Watershed Partners.

STUDY AREA

The Wissahickon Creek Watershed study area included an almost completely developed suburbanized drainage basin. With a total drainage area of approximately 64 square miles, this watershed spanned portions of fifteen Montgomery County municipalities and the City of Philadelphia. According to 2000 DVRPC land use data, more than half of the Wissahickon Creek Watershed was covered by residential development with parking lots, roadways, commercial and industrial uses making up another roughly 13% of the watershed land use – meaning that more than 65% of this watershed area was developed with into mostly impervious cover! Furthermore, the headwaters of the Wissahickon Creek emerge from just below a parking lot at the Montgomeryville Mall complex in Montgomery Township. Over the past hundred years, many small ephemeral streams and first order tributaries of the Wissahickon have been lost to land development (i.e. buried or encapsulated). The total number of stream miles contributing to Wissahickon Creek drainage was roughly 114.6 miles.

Impervious cover, especially directly connected impervious cover (DCIA), decreases groundwater recharge and the percent of annual streamflow represented by groundwater fed baseflow. According to the Nutrient and Siltation TMDL Development for Wissahickon Creek, Pennsylvania – Final Report, "several portions of the headwaters and tributaries have exhibited no baseflow during PA DEP 1997 inspections conducted in conjunction with the Unassessed Waters Program, an August 2001 site visit conducted by PA DEP and EPA Region 3, and PA DEP data collection of Summer 2002." The TMDL listed some potential sources of Wissahickon Creek baseflow reduction including the increase of impervious area and subsequent loss of groundwater recharge resulting from urbanization, as well as groundwater pumping and drawdown. Under these conditions, during wet weather events the streams in the watershed have become "flashy" – meaning that they exhibit significantly increased flows immediately following the onset of the wet weather event followed by a rapid return to the low-flow pre-wet weather conditions shortly after the event. These flashy conditions carry erosive forces and can cause habitat destruction within the waterway.

Numerous studies and research efforts have linked impervious cover with watershed health. According to Schueler (1995), a watershed with more than 26% impervious cover will have highly unstable stream channels, water quality issues, bacterial pollution and poor stream biodiversity – all of which have been observed in the Wissahickon Creek Watershed. The Wissahickon Creek Comprehensive Characterization Report (WCWCCR, 2007) stated that "while there are a few isolated regions with less impervious cover, such as Prophecy Creek and other small tributary subwatersheds, the Wissahickon Creek Watershed as a whole had greater than 26% impervious cover, placing it in the "Non-Supporting" category of stream health".

Wissahickon Creek Watershed was listed by PADEP as impaired due to siltation with twenty-one stream segments in the watershed included on Pennsylvania's 303(d) list. In 2003, the U.S. Environmental Protection Agency (EPA) Region III established a Total Maximum Daily Load (TMDL) for siltation in the Wissahickon Creek Watershed. This TMDL lists sources of the Wissahickon Creek siltation as urban runoff/storm sewers and habitat modification generally associated with nonpoint sources and wet weather streamflows.

Retrofits recommended by this initiative should be considered as a part of a broad municipal approach for addressing the diminished stream baseflow exhibited in many headwater tributaries, as well as addressing the Waste Load Allocations (WLAs) outlined by the Siltation TMDL for the Wissahickon Creek Watershed.

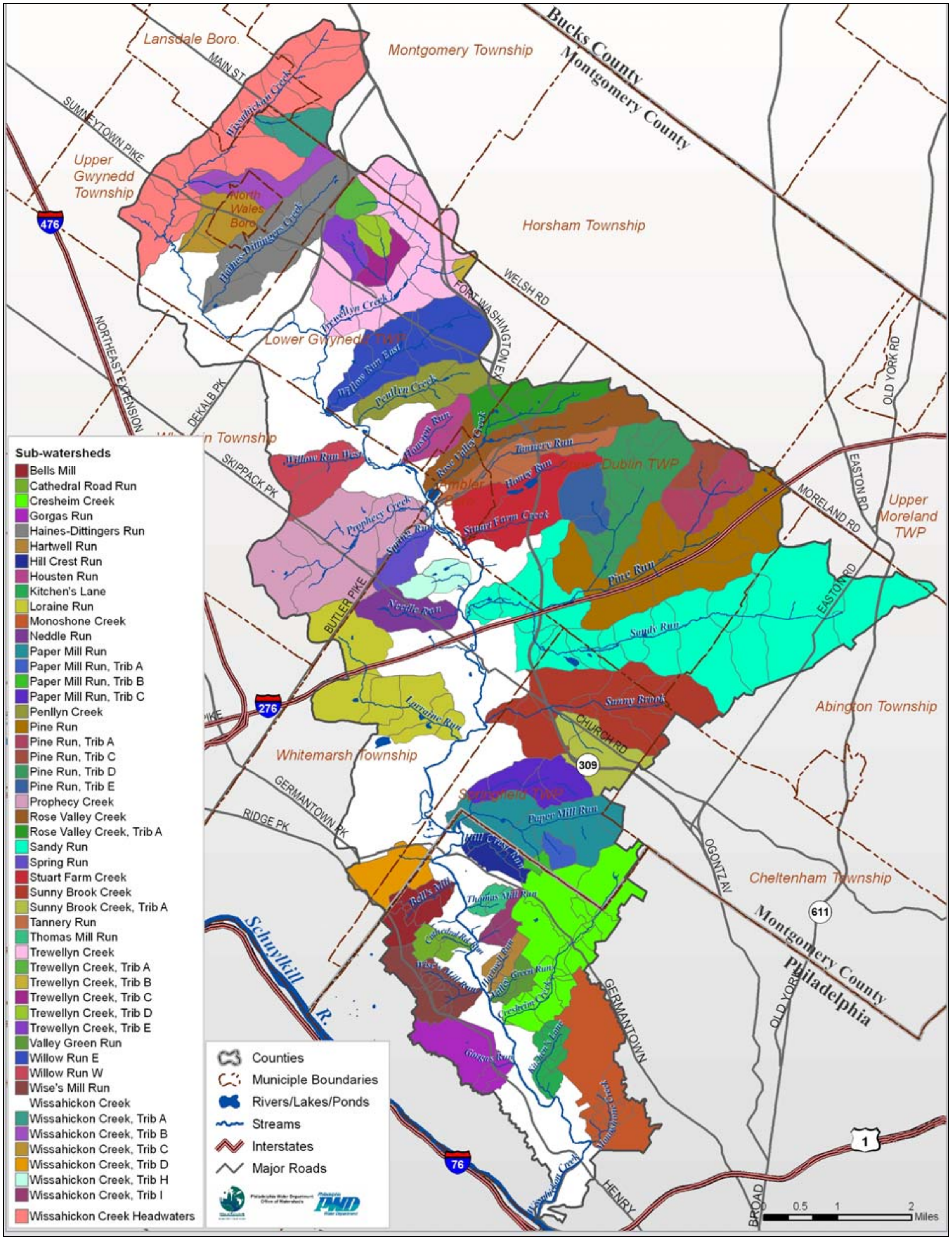


Figure 1: Study Area for Wissahickon Creek Detention Basin Inventory and Retrofit Program (excluding mainstem drainage area illustrated in white)

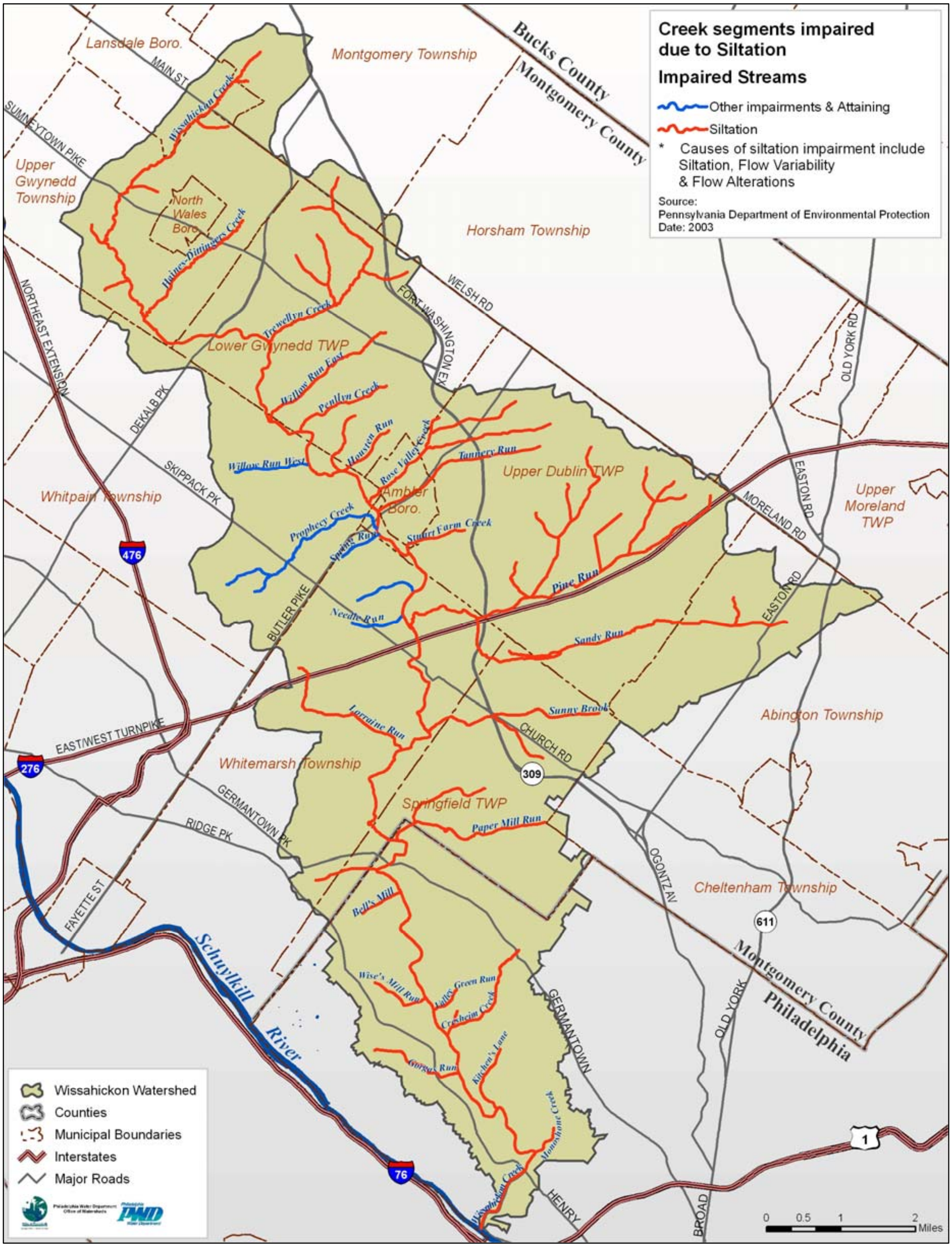


Figure 2: 303d listed streams impaired due to Siltation in the Wissahickon Creek Watershed

History of Stormwater Management within the Wissahickon Creek Watershed
As previously described, the Wissahickon Creek Watershed had a high percentage of impervious cover, which had altered the peak flow and volume of water entering the stream. This alteration of peak flow and volume has modified the hydrology of the stream. Natural stream channels do not have the capacity to handle the peak flows associated with extreme increases in stormwater runoff volumes. As a result, the stream morphology has become altered as erosive velocities cut a new flow path – thereby causing a great deal of habitat degradation as this takes place. Land development also impacted the water quality of stormwater entering the creek as runoff collected pollutants – such as nutrients, pathogens, oil, grease, pesticides, and sediment in its path to the waterway.

Additionally, not only did large portions of the Wissahickon Creek Watershed experience extensive land development pressures, but most of the "suburbanization" of this watershed appears to have taken place prior to the initiation of stormwater management controls required by the Pennsylvania Stormwater Management Act of 1978. According to the Wissahickon Creek River Conservation Plan (2002), approximately 60% of the watershed area was developed prior to the adoption of runoff control ordinances that limit impervious area or require detention of stormwater runoff.

Retrofits considered for this program should address some of the existing water quality and quantity issues described below:

Sediments and Erosion of Streams
The increased volume and flow of stormwater within a stream leads to erosion of beds and banks. Severe stream bank erosion also destroys riparian habitat.

Pathogens
Wet weather concentrations of the microbial pathogens *Cryptosporidium, E. coli, Giardia lamblia,* and fecal coliform bacteria are a significant water quality concern. Between 2004 and 2005, sampling for the WCWCCR measured fecal coliform bacteria at 11 locations within the Wissahickon Creek Watershed. During wet weather, samples taken from both Philadelphia and Montgomery County exceeded swimming season criteria for fecal coliform bacteria. Pathogens are often associated with human and animal waste from failing septic systems, and illicit sewage connections and waste water treatment plants.

Baseflow
Widespread urbanization, as present in the Wissahickon Creek Watershed, also magnifies flow modification by decreasing infiltration and groundwater recharge – establishing a hydrologic pattern of "feast or famine". Presently, baseflow accounts for only 38% of total mean annual flow at the mouth of

Wissahickon Creek, and only 32% of the flow at the Fort Washington USGS gage.

Flooding

Urbanization can lead to flooding. As an increase of impervious surfaces and development over time increases surface runoff; infrastructure in place may no longer have the capacity to handle the entire volume of stormwater runoff sent to it. Flooding has been identified as a significant problem in regions of the Montgomery County portion of the watershed.

Why the Philadelphia Water Department (PWD) led this initiative

PWD has been initiating inter-governmental, multi-jurisdictional watershed partnerships since 1999 in an effort to create and implement watershed-wide visions for ecological restoration and water quality improvement. PWD has sought to forge a link between the City and the surrounding suburbs, recognizing that development trends in upstream communities dramatically affect downstream waterways and natural resources. This vision is realized through PWD's Integrated Watershed Management Planning (IWMP) process. An IWMP is designed to be a long-term "roadmap" for implementation of a watershed-wide approach to achieve and maintain healthy natural resources. These plans incorporate municipal and conservation planning recommendations that strive to ensure that growth within the watershed occurs with particular care to the environment along with the goals and recommendations of a diversity of stakeholders, who live, work and recreate throughout the watershed.

PWD's integrated watershed management planning strategy was based on a carefully developed approach to meeting the challenges of watershed management in an "urban" setting. IWMPs are built upon solid, scientific foundations composed of water quality monitoring (wet and dry weather), macroinvertebrate and fish bioassessments, physical stream surveys (FGM) and computer simulated modeling programs for stormwater flows and pollutant loading. PWD initiated an IWMP planning process within the Wissahickon Creek Watershed in 2005. The "Wissahickon Basin Inventory" initiative presented the PWD an opportunity to partner with the upstream municipalities in a mutually beneficial data gathering process.

Funding:

Funding for this initiative was made possible through a grant from the United States Environmental Protection Agency (USEPA) 104b3 program, managed by the Pennsylvania Department of Environmental Protection (PA DEP).

Implementation Schedule:

This program was initiated in May of 2006 and completed by September of 2007.

INVENTORY DEVELOPMENT

Prior to initiating the data gathering process for development of a detention basin inventory, PWD contacted Wissahickon Watershed Partners to identify potential existing data sources that might help to populate such an inventory for this watershed. PWD additionally performed a review of in-house data for potential incorporation in this inventory – all with the goal of maximizing resources and avoiding duplication of efforts where possible.

Through this process the PWD Team learned that in 2004, the Montgomery County Conservation District (MCCD) had conducted an inventory of stormwater management facilities with a study area that partially overlapped the Wissahickon Creek Watershed – specifically the Pine Run Creek tributary of the Sandy Run Creek subshed. The MCCD shared all data produced through their initiative as well as examples of the data collection sheets utilized by their field staff to collect data on each basin so that we could attempt to mirror this process throughout the Wissahickon Creek Watershed. Basins identified through this initiative were entered into a Geographic Information Systems (GIS) “Basins” data layer.

Additionally, it was learned that PWD had existing data collected through a City-wide stormwater management structure inventory in 2001. The data collected through the City-wide inventory included all information that the team sought to collect as a part of the MCCD initiative, and then some. Within the City of Philadelphia there were only two dry-bottom basins – both of which drain to the Wissahickon Creek mainstem. All of data collection efforts for the creation of this inventory have been concentrated in the Montgomery County portion of the watershed. As a result of the level of detail available in this data set and its presumed up-to-date status, the Project Team decided that the City-wide inventory pre-empted any need to collect data or perform a field investigation within the Philadelphia portion of the watershed.

Other useful information identified through this assessment of existing data was that PWD had assembled the “start” of an inventory for the Montgomery County portion of the Wissahickon Watershed in 2004. This process was conducted using what they had called a “windshield assessment” where field staff used a GPS system to document basins as they drove through the watershed area. This assessment was conducted completely in the field and based on documentation of basins that could be seen from the roadway. Forty-three basins were identified though this inventory and locations were populated in a GIS data layer. This data was incorporated into the new watershed-wide inventory data layer, but all of these sites were cross-checked against new aerial photography and revisited in order to be documented with the new field data parameters.

Following the compilation of existing basin data from multiple sources into a single GIS data layer, further steps were developed for identifying additional basins within the Wissahickon Creek drainage area as well as populating the attribute table of the data layer with detailed information about each basin. The first step in this stage of the process involved an intensive desktop analysis of data in Geographic Information Systems (GIS); the second step included a field visit to each basin in order to collect additional basin specific data.

GIS analysis to identify basin location

The desktop analysis to identify potential basins within the Wissahickon Creek Watershed involved the input of multiple data layers with a visual inspection of the data to identify potential stormwater management facilities based on certain "tell-tale" characteristics that could be observed on aerial photos. The following data layers were utilized for the initial desktop analysis: 2004 color aerial photography, 2004 topography (contour lines at two-foot intervals), Wissahickon stream hydrology, watershed drainage delineation, municipal boundaries, and major roads.

The GIS scale was set to 1:2000, which allowed for the analyst to pan across the area at a resolution clear enough to visually identify the stormwater management structures. Orthophotographic tiles were used as organizing units, where 1 tile = 2500′ x 2500′, which was a 143.5 acre (0.22 sq. mi.) area – loaded and displayed in the GIS interface at usually 10 to 20 tiles at a time.

Techniques utilized to identify basins included: the evaluation of contour lines for locations with closed contours, especially those which looked unnaturally regular (often a series of concentric circular bands). These closed depressions would then be closely evaluated in the aerial photo for telltale indicators of stormwater management functionality. (Figure 3)

Figure 3: Zoomed image of aerial photography and topography illustrating the "tell tale" signs of a stormwater management basin

Many stormwater management basins were very obvious at the scale of 1:2000 and could be positively identified due to the presence of visible low-flow channels and inlet or outlet structures – combined with the telltale contour lines indicating steep embankments and a regular shape. Other "potential" basins required "zooming" in to look for further detail. Some sites and structures could not be positively identified as basins through the desktop analysis; these would instead be noted as "potential basins" and needed to be verified through the field investigation. Through the desktop analysis, the attribute table associated with the "Basins" data layer was then populated with additional information associated with each basin including individual basin area (as calculated through the delineation of closed contour lined in the topography data layer), municipal jurisdiction, receiving waters, stream order, soil type and ownership type (by category as determined through the parcel data layer on file with the Montgomery County Planning Commission (MCPC)).

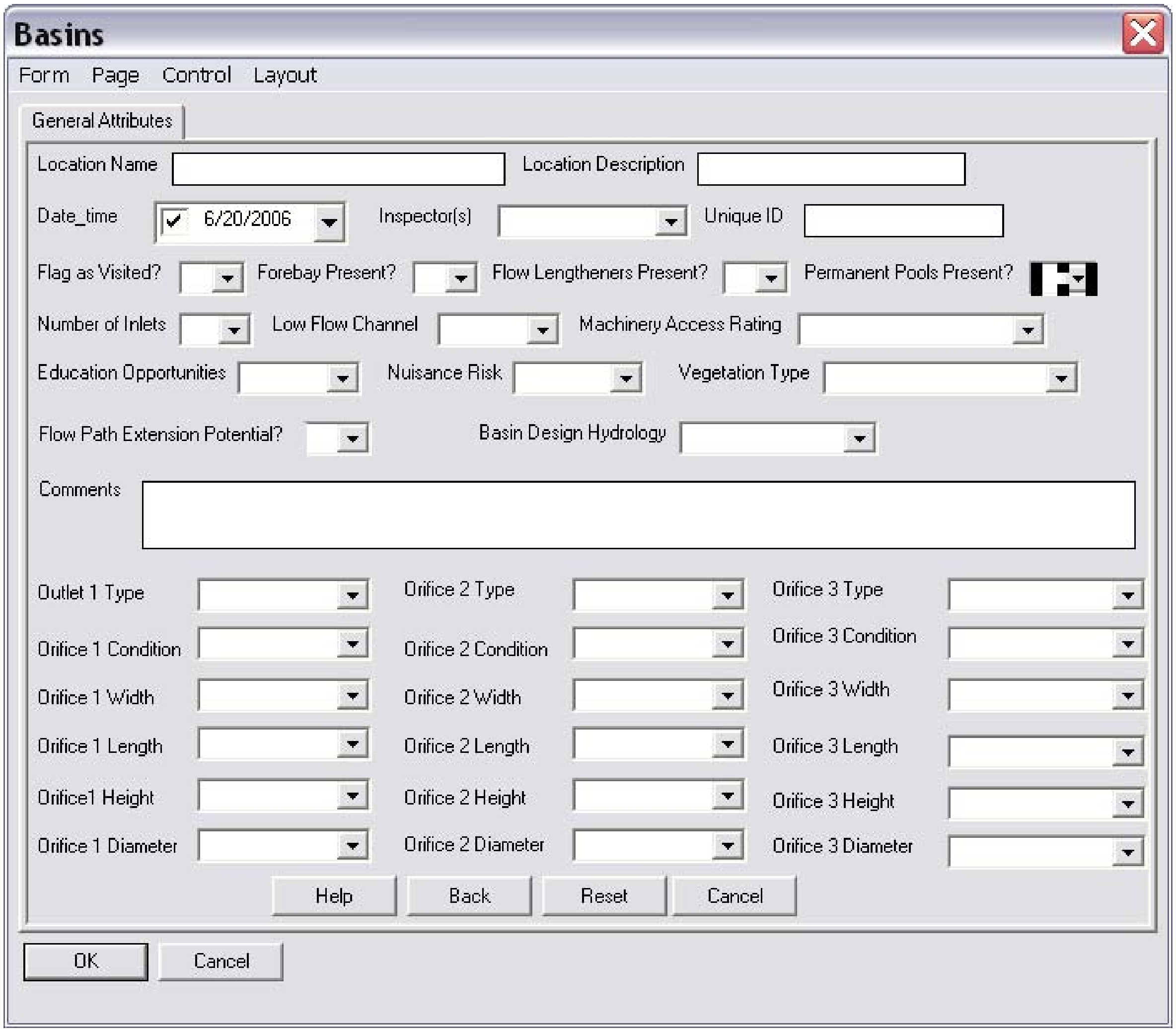
Field verification process

Once the desktop analysis was completed and a data layer had been created demarcating "potential basins", a protocol for field verification and data gathering was developed and executed by PWD field staff. The team was fortunate to be able to utilize a "ruggedized" tablet PC (field unit) equipped with GIS software and GPS tracking for the field investigation. The tablet PC was preloaded with aerial photography and topography layers, local roads layer and the newly created stormwater basin point file. At each basin location the information was collected and entered into the PC, instantly populating the "Basins" GIS data layer with this new information. (See Figure 4 for a screen capture of the field data sheet)

Field documentation included:

- Photos of site including outlet structure
- Condition and diameter of outlet structure
- Existence of concrete low-flow channels, berms, check-dams etc. – other flow controls to outlet structure
- Number of inlets
- Observations about site maintenance
- Accessibility for construction equipment to perform stream restoration
- Opportunities for public education (clear visibility from roadway, proximity to school, etc.)

Field visits were conducted over the two week period of June 13th through June 27th with a two person field crew at a rate of roughly 25 basins inventoried per day. Through this field investigation process – numerous "potential basins" as identified through the desktop evaluation were eliminated from the inventory as they were not actually stormwater management facilities. The number of basins within the inventory was cut from 215 to 178.



Basins

Form Page Control Layout

General Attributes

Location Name | Location Description

Date_time 6/20/2006 | Inspector(s) | Unique ID

Flag as Visited? | Forebay Present? | Flow Lengtheners Present? | Permanent Pools Present?

Number of Inlets | Low Flow Channel | Machinery Access Rating

Education Opportunities | Nuisance Risk | Vegetation Type

Flow Path Extension Potential? | Basin Design Hydrology

Comments

Outlet 1 Type	Orifice 2 Type	Orifice 3 Type
Orifice 1 Condition	Orifice 2 Condition	Orifice 3 Condition
Orifice 1 Width	Orifice 2 Width	Orifice 3 Width
Orifice 1 Length	Orifice 2 Length	Orifice 3 Length
Orifice1 Height	Orifice 2 Height	Orifice 3 Height
Orifice 1 Diameter	Orifice 2 Diameter	Orifice 3 Diameter

Help Back Reset Cancel

OK Cancel

Figure 4: Data Entry Form used by Project Team while Performing Field Survey

Additional Data Requests from Municipalities

It was determined that in order to make the basin prioritization more valuable to the "implementers" of the basin retrofits – that additional data needed to be collected from the municipalities regarding each basin. PWD initiated an additional "outreach driven" data gathering process through which each municipality with basins in the inventory was sent a packet with information about the initiative and description of data collection process to date along with a request for assistance with filling some newly identified data gaps.

Included in the packet was a series of maps illustrating locations of each basin identified within the Wissahickon Inventory, first zoomed to the whole municipal scale – illustrating the entire inventory of basins within an individual municipality, and then zoomed to the neighborhood level – with each basin numbered with a unique ID. Each municipality received multiple neighborhood level maps. (Figure 5) Municipalities were also sent a print-out of an HTML document that has been created to organize the multitude of photos taken of each basin during the field investigation process. The photo images sent in this mailing were small – in "thumbnail" size, but were intended to help municipal staff to recognize the basin in question. (HTMLs will be shared as Appendix A with municipalities in electronic form on the CD with associated project data.)

Municipalities were given a table listing each basin's "Unique ID" (illustrated on each map with the associated basin point location) along with the "Basin Name" (as named by our team) "Location" (based on on-the-ground closest street location), "Ownership Category" (based on Montgomery County Parcel Data), and "Receiving Waters" (the tributary that the basin drains to). The last three columns of the table were been left blank in hopes that municipalities might be able to fill in some of the missing information – including "Year Basin Constructed", whether the "Basin Municipally Maintained?", "Functionality" (whether the basin was functioning properly; whether there were known issues with basin function), and "Basin in Flood prone Area" (whether a basin was located in an area with known flooding issues as this was deemed critical to whether certain retrofits were appropriate).

Mailings were sent out via hard copy and e-mail to each municipality – specifically to the primary contact on file at the PA DEP for NPDES Phase II and MS4 related correspondence. Follow-up via e-mail and telephone was initiated immediately after the mailings were sent to municipalities. Of the 8 municipalities that the request for information was sent to, 6 returned completed data sets that were entered into the Basin Inventory data layer.

Figure 5a: Example Maps Created for Municipal Outreach – Zoom to entire municipal jurisdiction

Figure 5b: Example Maps Created for Municipal Outreach – Zoom to first cluster of basins (encased in red square in Figure 5a)

At the completion of the initial PWD Team initiated data gathering phase (prior to outreach to Wissahickon municipalities) there were 178 basins within the inventory. At the conclusion of the municipal outreach data gathering process, six basins identified by the PWD Project Team (illustrated in black) were eliminated by the municipal staff and six new basins were added to the inventory (illustrated in orange) by the municipal staff. (Figure 6)

Please note that new basins added to the inventory by municipalities were not able to be incorporated in the basin retrofit prioritization process because the data collected through field visits was not available for these basins. Additionally, data was collected for 16 basins that appear to drain to the mainstem of the Wissahickon Creek. This data was shared with municipalities and was incorporated in the inventory – but these basins were not included in the prioritization procedure (illustrated in gray).

A total of 153 basins were included in the prioritization procedure.

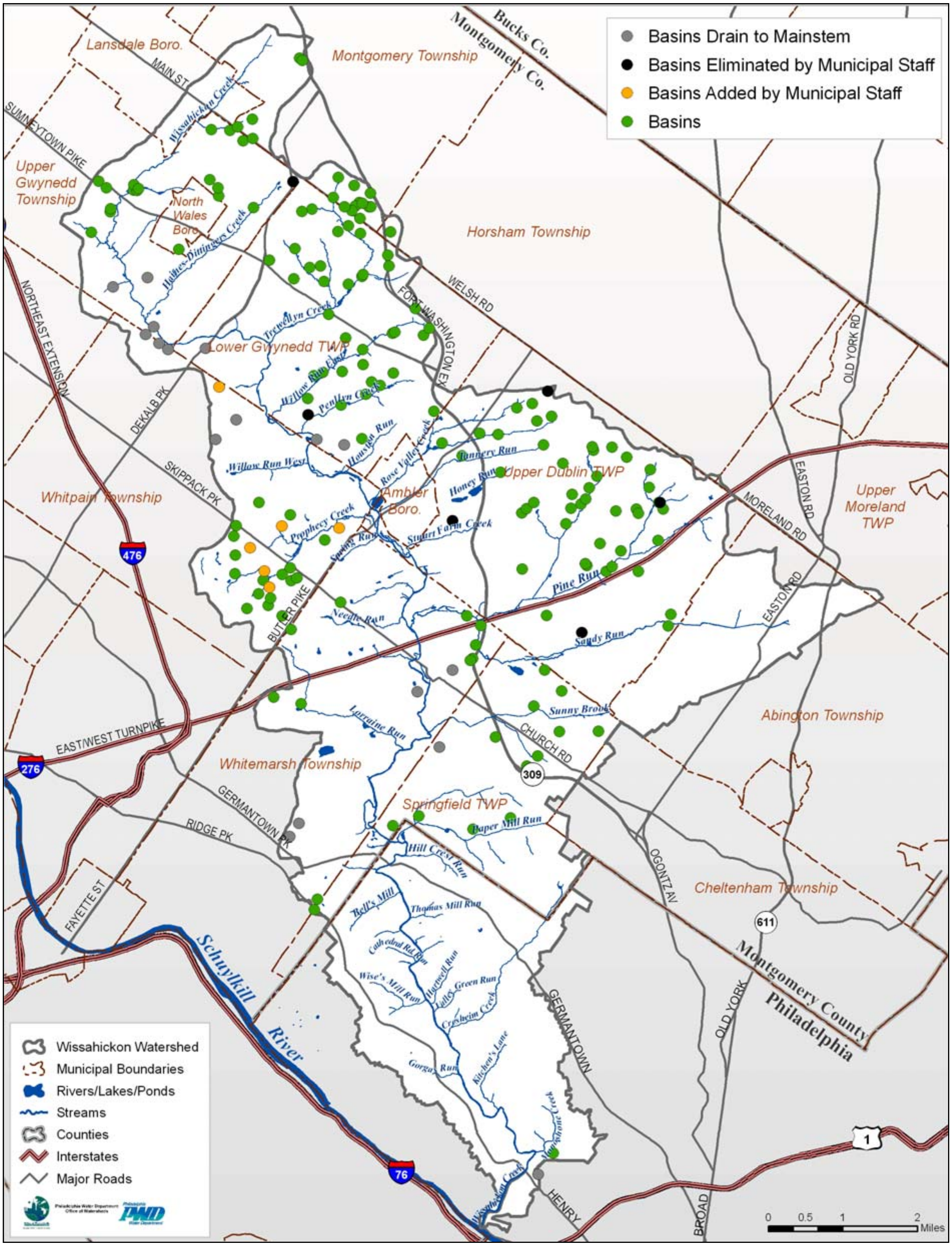


Figure 6: Locations of all basins identified in the Wissahickon Basin Inventory (including those added and eliminated by municipal staff as well as those within the Wissahickon Mainstem drainage that had been inadvertently added to the data layer)

General Findings amongst Basins in the Wissahickon:
Most of the stormwater management facilities in the study area appeared to be standard detention basins – designed to reduce the post development peak flow from a development site down to the existing conditions peak rate of runoff. As such, these basins did little to improve the quality of runoff exiting the basin. Most basins exhibited a primary outlet, which included a small diameter orifice in the outlet structure at the invert or bottom of the basin so they drain completely after a storm, leaving the basin with a dry grassed bottom between storms.

It appeared that maintenance of these standard dry-bottom detention basins typically consisted of mowing the grass bottom as well as some maintenance of the outlet structure to ensure that it did not become obstructed with debris. Most basins within the Wissahickon Inventory appeared to have been actively maintained – with manicured mown turf-grass bottoms. A few basins did not appear to have been actively maintained which had allowed dense vegetation to become established over time. These basins may already be *inadvertently* acting as water quality best management practices, aiding in groundwater recharge and filtering the pollutants proposed by implementation of recommendations of this report, but should each be further evaluated to be sure that they are functioning properly.

OVERVIEW OF PRIORITIZATION PROCEDURES

A prioritization procedure requires a clear method of ranking in order to produce stable valuable results. The most common approach involves the development of a two dimensional matrix consisting of the options to be evaluated (in this case, the basins) and a set of evaluation criteria. For every combination of basin and criterion, a score must be assigned. The evaluative criteria should be selected to cover the important considerations in selecting a basin for retrofit, and should represent information and data that are readily available, or can be collected with minimal expense and effort. The criteria must be clear and unambiguously defined, and can be set up as either quantitative criteria where the actual numeric value of the criterion was utilized (e.g. cost in dollars, basin volume), or qualitative criteria where the values are grouped into categories for the system to evaluate (e.g. high, medium, or low).

The choice of whether to define a criterion as quantitative or qualitative would depend on the feasibility of describing the impact with numbers, the availability of data to assign scores to each basin, and the reliability of the data. If gaining hard data within the time frame of the plan would be difficult, or the data would be unreliable, it may not be appropriate to assign a quantitative number to a particular option. The criteria then can be *downgraded* to a qualitative status, in which case criteria would simply be defined as "high", "medium", or "low".

If all the criteria are qualitative, with scores assigned to the "high", "medium" and "low" values – for example 1, 2, 3 etc., then a simple spreadsheet approach could be used to sum the scores to determine the highest ranked basins. If the proposed criteria are quantitative and represented in various units of measure, then the scores should be "normalized" to a similar scale of 1 to 100, or 0 to 1, so that the scores can be summed in the matrix. For example, if costs for basin retrofits vary between $10,000 and $20,000, the scores can be normalized by dividing each basin cost by the cost of the most expensive basin, thus creating scores that are 1.0 or less. If criteria consist of both quantitative and qualitative criteria, more sophisticated evaluation programs can be applied. There are several commercially available, multi-criteria evaluation programs available on the market that could be applied.

The ability to apply "weight" to criteria utilized in a prioritization procedure was deemed critical – as some of the criteria would be more critical to the prioritization than others. The selection of weights would be an inherently subjective process as there are no "correct" weights; they represent the importance associated with each criterion in making the decision. (For example, a municipality might attach great importance to cost —weighting the cost criteria heavily.) Once the matrix is populated and weights are assigned to each criterion, the calculation can be run and ranking of the basins produced.

For the Wissahickon Basin Inventory, both quantitative and qualitative criteria were defined through available data captured in the basin inventory. It was determined that weighting of the individual criterion would be necessary in the chosen prioritization procedure as in this prioritization scenario, some criteria would be more critical to the feasibility of retrofit implementation than others. As such, a commercially available multi-criteria evaluation program called EVAMIX was selected as the most appropriate evaluation tool for prioritizing the basins.

Please note: Though the EVAMIX program has not been made available to the Wissahickon Watershed Partners, if at the close of this project a potential implementer (such as a municipality) chooses to update the data or weightings used in this procedure, a simpler – spreadsheet based approach of the same ranking has been developed and is described under the heading "**RECOMMENDATIONS FOR A SPREADSHEET BASED PRIORITIZATION PROCEDURE".**

EVAMIX:

EVAMIX, a sophisticated, spreadsheet based multi-criteria evaluation program developed during the 1980s (Voogd, 1981, 1982, 1983, Maimone, 1985) was designed to handle both quantitative and qualitative data in a mathematically rigorous fashion. EVAMIX was a matrix based, multi-criteria evaluation program that made use of both quantitative and qualitative criteria within the same evaluation, regardless of the units of measure. The algorithm behind EVAMIX maintained the essential characteristics of quantitative and qualitative criteria, yet was designed to eventually combine the results in a single appraisal score. It was this unique feature that made its use in this project preferable to simpler approaches.

The completed matrix was processed by EVAMIX as follows. In the first step, the evaluation matrix was split into two sub-matrices, one with only quantitative criteria, and one with only qualitative criteria. Next, the priority of each criterion, as defined by the Project Team, was assigned to one of two vectors as well. Using the scores and weights, dominance scores "a" and "A", for qualitative and quantitative data respectively, were calculated. A dominance score was a number that represents the degree to which Basin A dominates Basins B. A dominance score was calculated for each potential pair of basins for each criterion. For the quantitative criteria, the difference in the values assigned to each alternative was preserved in the equations. Thus, the dominance score for Basin A over B would be much higher if A was significantly better than B, but would be small if the two scored almost equal for that criterion. The final output of EVAMIX was a ranking of basins, from highest to lowest priority, based on the scores and criteria weights assigned.

Identification of Evaluative Criteria for Matrix

In order to populate the EVAMIX matrix tool for prioritization of basins in the Wissahickon inventory, a "wish list" of all possible evaluative criteria by which basins would be appraised for retrofit priority was developed. This list included criteria that the Project Team believed would serve to produce a thoughtfully considered prioritization scheme for evaluating inventoried basins for retrofit potential. This "wish list" included criteria that the Team was able to utilize for the Wissahickon initiative as well as criteria that would be *ideal* for use in this initiative – for which data was unfortunately not available. Additionally, since this initiative was intended to serve as a model for potential replication in other Pennsylvania watersheds, several criteria have been added to the list that are not necessarily applicable to the Wissahickon Basin Inventory – but could be applicable to another watershed seeking to replicate the process.

Table 1: "Wish List" of Potential Criteria for use in the Evaluative Matrix

Proposed Criterion	Measure	Description	Data Needed	Source
Water Quality Benefit	Area of Basin (Sq. ft.)	Larger basins provide greater opportunity for various types retrofits that could be implemented within the existing footprint. Additionally, large basins are believed to correspond with a greater potential quantity of pollutant removal.	• Area of basin – calculated using 2-foot contours data; area of outermost closed contour approximated the outline of the basin	• PWD Topography data layer • Basins data layer
Infiltration Volume	Basin area x estimated saturated vertical infiltration rate	The area of the basin and the soil type provide important information about the benefits that a retrofit on the site could provide. A larger number here would correspond with a greater potential for infiltration capacity within the basin; as such basins with a larger number should be ranked higher.	• Area of basin • NRCS Soils data – based on Hydraulic Conductivity	• PWD generated GIS data layer • US Dept. of Ag, NRCS GIS data
Time to drain for smaller storms	Ratio of cross-sectional area of bottom-most orifice(in^2) to area of basin (in^2)	A high number here would indicate that the basin has been designed to drain quickly. Basins with this high ratio would be higher priority candidates for retrofit.	• Area of basin • Field data – dimensions of outlet structure	• PWD generated GIS data layer • PWD Field Reconnaissance
Distance from the Mouth	Distance (mi) from mouth of creek	Headwater streams located further upstream from the mouth of the creek would be higher priority candidates for retrofit.	• Stream hydrology GIS data layer	• PWD generated hydrology data layer
Opportunity to lengthen flow path within the basin	Qualitative, Low/High	Basins with opportunity to have the flow path between inlet and outlet lengthened will rank higher than those that do not. (based on visual assessment during field investigations) **High/Low:** Information entered into the dataset as a "yes/no" regarding whether basins had "short-circuited" flow paths. These "short-circuited" basins would be ranked high.	• Field data and photo documentation of site	• PWD Field Reconnaissance
Ownership of the basin	Qualitative, Low/Medium/ High	Priority based on ownership of basin; certain ownership categories make a basin a more likely candidate for implementation of retrofit recommendation. Ownership types were grouped together into categories as listed below: **Low:** residential, private ownership; **Medium:** commercial/ institutional / HOA ownership; **High:** municipal/ land trust/ educational institution ownership	• Parcel data files (GIS)	• Mont. Co. Planning Comm. • Phila. City Planning Comm.

Proposed Criterion	Measure	Description	Data Needed	Source
Accessibility for heavy equipment to gain entry to basin for construction of retrofit	Qualitative, Low/Medium/ High	This criterion was related to the ease or difficulty of getting large/heavy construction equipment into the basin area to implement retrofit recommendations. **Low:** not accessible by heavy machinery due to physical impediments. **Medium:** accessible, but requiring extra time or effort such as removing fence panels, crossing private property, or navigating very tight or steep areas. **High:** very accessible, roadway alongside or lots of open space around	• Qualitative information; based on subjective visual judgment.	• Gathered from field team, based on observations
Low-flow Path Material	Qualitative, Low/High	Low flow paths would be evaluated for retrofit based on the material utilized to create the channel (if channel present). **Low:** vegetated, rock, earthen, or no low flow channel; **High:** Presence of concrete low flow channel	• Field data and photo documentation of site	• PWD Field Reconnaissance
Type of Vegetation within basin	Qualitative, Low/High	**Low:** one or more established woody plants present in basin. **High:** mown turf grass present in basin.	• Field data and photo documentation of site	• PWD Field Reconnaissance
Age of Basin	Year the basin was constructed – entered into the EVAMIX as Low/Medium/ High groupings	Older basins would rank higher for retrofit as these might be in need of re-evaluation already. The project team split the age of basins into three categories as follows: **Low:** Basins most recently constructed – between 2003 and 2006 would be our lowest priority for retrofit **Medium:** Basins constructed between 1999 and 2002 would carry a medium priority. Additionally – basins for which no construction date data was available was assigned a medium priority. **High:** Basins constructed between 1978 and 1998 would be ranked highest for retrofit priority.	• Year construction of basin completed	• Each municipality would need to provide this information on their own basins
Basin Municipally Maintained?	Yes/No	Municipally maintained basins would rank higher because municipality was already assuming responsibility for maintaining structure and function of the basin. The PWD Project team believes that follow-through for implementation of retrofit recommendations might be more likely on these basins.	• Information from municipality	• Each municipality would need to provide this information on their own basins
Current Functionality	Qualitative, Low/Medium/ High	If a basin already has known issues with functionality, this would make it a high priority candidate for retrofit.	• Information from municipality	• Each municipality would need to provide this information on their own basins
Basin Located within Flood-prone area?	Yes/No	This would affect the types of retrofits that could be considered for this site; one would not want to exacerbate an existing issue. For the purposes of the Wissahickon Basin Inventory – basins identified by municipalities as being located within a flood-prone area were given a lower weight so that they would receive a lower priority for retrofit through this prioritization process.	• Information from municipality	• Each municipality would need to provide this information on their own basins

Proposed Criterion	Measure	Description	Data Needed	Source
Potential Nuisance or Public Perception issue associated with a retrofit	Qualitative, Low/Medium/ High	Potential for retrofit to be perceived as a nuisance by neighbors (fear of standing water, insects, vermin, etc.) **Low:** basins having low visibility and proximity to high-use residential and commercial areas. **Medium:** basins in residential or commercial areas but separated somewhat from high-use areas by distance and/or vegetative buffers. **High:** basins located in residential areas and having high visibility and proximity to houses.	• Qualitative assessment from field visits (Based on visibility and proximity to high-use areas)	• PWD Field Reconnaissance
Educational Opportunity presented by retrofit of a basin	Qualitative, Low/Medium/ High	Subjective judgment of potential for the basin to serve as a demonstration or educational resource once retrofitted with stormwater best management practices. **Low:** basins on private land and having minimal accessibility and/or visibility **Medium:** basins having intermediate visibility and accessibility (often situated on commercial or institutional land) **High:** very visible and publicly accessible basins on land owned by municipalities, land trusts, or some educational institutions.	• Qualitative assessment from field visits (Based on visibility and accessibility from roadway or location in a public space)	• PWD Field Reconnaissance
Cost of retrofit	Qualitative, Low/High	Recognizing that the cost of the retrofit might be the single most important limiting factor to the implementation of any recommendations – lower cost retrofits would be given higher priority	• Cost of retrofit	Data source for this information is unknown
Depth to bedrock	Depth to bedrock under basin	Those with a depth to bedrock of less than 2 feet would be eliminated from consideration	• Underlying Geology • Individual site assessments	• TBD
Depth to High Water Table	Depth to high water table under basin	Those with a depth to high water table of less than 2 feet would be eliminated from consideration	• Individual site assessments	• TBD
Maximum loading ratio	Ratio of drainage area that feeds an infiltration facility to the area (footprint) of that infiltration facility	PA DEP Suggested addition; data unavailable to perform analysis	• Area of basin • Drainage area to basin	• PWD assessment has produced a rough calculation of basin area • Area of drainage to each basin has not been delineated; perhaps municipalities will have this information from development plans.
Underlying Limestone (Karst) Geology	Yes/No	A basin with underlying limestone geology would present the project team with additional considerations regarding the types of retrofits that would be appropriate. Considerations must be made before recommendations for infiltration are made.	• Underlying Geology	• TBD
Existing Site Contamination	Yes/No	Was the basin located on or near a site with known contamination issues? If so, retrofits might not be an option. This would need to be thoroughly evaluated prior to considering retrofit of the basin.	• GIS data points illustrating known contamination sites	• TBD

Proposed Criterion	Measure	Description	Data Needed	Source
Proximity to Drinking Water Well	Yes/No	Was the basin located in close proximity to a drinking water well? If so, certain types of retrofits – especially those which involve infiltration – would need to be thoughtfully evaluated before a recommendation could be made.	• GIS data points illustrating locations of Drinking Water Wells	• TBD
Landslides	Yes/No	A basin in a region prone to landslides would present the project team with additional considerations regarding the types of retrofits that would be appropriate.	• TBD	• TBD
Subsurface Mining	Yes/No	Might not want to infiltrate; careful about type of retrofit considered	• TBD	• TBD
Condition downstream	Qualitative, high, medium, low	Existing streambank condition downstream of basin; more degraded streambank would receive higher weight (Not applicable to the Wissahickon as the entire waterway has been deemed impaired)	• Existing Stream conditions	• Watershed-wide physical stream assessment
Stream Designation	Qualitative, high, medium, low	This would be applicable in watershed systems with varying water quality designations; in such a case – Higher level stream designation (i.e. HQ/EV) would be weighted more heavily (Not applicable to the Wissahickon as the entire waterway has the same stream designation)	• Stream designation information	• PA DEP Stream Designation
Stream order	Qualitative, high, medium, low	The Wissahickon program was prioritized to first and second order streams only. For replication in other sheds, a procedure could be created to give a higher priority for retrofit of 1st and 2nd order streams, as the impact of the retrofit might be more pronounced	• Stream hydrology data layer	• TBD

Black Text: Indicates that this criterion was included in the Wissahickon Basin Inventory
Blue Text: Indicates that this criterion has been included in this "Wish List" as applicable to the Wissahickon, but due to the lack of available data the criterion was eliminated from the final list.
Red Text: Indicates that this criterion has been included in this "Wish List" for consideration in other watersheds where applicable

Populating the EVAMIX Spreadsheet

As previously described, the EVAMIX tool accepted both qualitative and quantitative data. In order to utilize the qualitative data criteria collected about each basin, the Project Team needed to "translate" some of the data inputs from its original raw data "text" entry format into numeric entries so that the matrix would be able to utilize the data.

Raw data in the database for criteria such as "Ownership", which detailed the ownership "type" for each basin – with data inputs including "private residential", "commercial", "institutional", "HOA" (Home Owners Association), "municipal", and "land trust" were grouped together into High, Medium and Low categories by the Project Team (Table 1). These High, Medium and Low categories then needed to be *translated* into numeric format that could be read by the EVAMIX tool. The Project Team needed "translate" the categories from High, Medium and Low "text" entries into the numeric entries – "1", "2" or "3" – with the number 3 being assigned to the "High" priority ownership types and the "1" assigned to the "Low" priority ownership types. This process was implemented for all raw data inputs that were broken into High, Medium and Low and "Yes"/"No" inputs. (In the case of Yes/No data, the assignment of the number "2" would be assigned to the entry more favored for retrofit potential.)

During this data *translation* process the Project Team developed a few "rules" for accounting for data gaps within the inventory – as the EVAMIX matrix would not be able to perform the prioritization if any fields were left blank. It was decided that for criteria where data was not available (either due to lack of a field visit or unfulfilled municipal request) the Team would enter the "Medium" level value of "2" for qualitative entries. In this way – the entry would not add or take away priority from this basin relative to others for this criterion. Utilizing this same philosophy, when data gaps existed for Yes/No categories, the Team entered the value "1" for fields lacking data, so as not to add the emphasis that the number "2" would bring. This again was done so that the entry would not add or take away priority from the basin relative to the others in the inventory.

Setting "weights" for individual criterion

Once the EVAMIX matrix was populated with all inventory data, the criteria were weighted prior to execution – as some criteria would be more critical to the feasibility of implementation of a retrofit than others. Weights are assigned to each of the fifteen evaluative criteria in the matrix, distributed as appropriate – all adding up to 100 percent.

The Project Team created an initial distribution of weights and ran EVAMIX and then began to adjust and re-run several times to see how the resulting prioritized lists were impacted by the adjustments to see if one criteria was too heavily weighted over the others. Finally, a set of weights was derived that appeared to produce a stable result. (Table 2)

Table 2: Updated Weights for Criteria in Matrix Tool

Criterion	Q or N +/-	Rationale for weighting scheme	Assigned Weight*
Water Quality Benefit	+N	**Basin Area** – The larger the basin was – the more benefit achieved for the money spent, so larger basins were given higher priority. Since this initiative will aim to achieve the most "bang for the buck", this criterion was heavily weighted in the matrix.	17
Infiltration Volume	+N	**Basin Area x Infiltration Rate** – the infiltration volume of the basin was deemed critical to the function of the basin and its retrofit opportunity. This criterion was weighted heavily because of the importance of this criterion.	13
Distance from Mouth	+N	The further upstream the retrofit was located, the more pronounced the water quality and infiltration benefit will be. This criterion was not critical to the ultimate feasibility of implementation so it was not weighted heavily.	3
Ownership	Q	Ownership was deemed critical to the ultimate implementation of the retrofit recommendation; as such this was weighted heavily.	11

Criterion	Q or N +/-	Rationale for weighting scheme	Assigned Weight*
Accessibility	Q	Basin retrofits could require the use of heavy equipment during construction as well as for follow-up maintenance; this factor was considered to be a fairly important criteria for retrofit prioritization and was weighted as such	8
Nuisance/ Public Perception	Q	This criterion could be critical to the implementation of a retrofit – especially in the case of retrofits that would significantly change the aesthetics of the basin; as such the weight was pronounced – but not heavy.	5
Educational Opportunity	Q	The opportunity to utilize the retrofit as a model or educational opportunity would increase the chance of the implementation of the recommended retrofit. Education opportunity presented by retrofitting a basin in was considered to be a fairly important criteria for retrofit prioritization and was weighted as such.	8
Vegetation Type	Q	The type of vegetation within the basin would be somewhat inconsequential to most of the retrofit types being considered. As such this was not be weighted heavily.	2
Time to drain for smaller storms	+N	The orifice type and area would be utilized to determine the type of retrofit that would be applicable to the basin. This information was relevant to a number of the retrofit types under consideration so the weight was pronounced – but not heavy.	6
Low-flow Path Material	Q	The presence of a concrete low flow channel within the basin would be somewhat inconsequential to most of the retrofit types being considered. As such this was not weighted heavily.	4
Opportunity to Lengthen Low Flow Path	Q	This information is relevant to a number of the retrofit types under consideration so the weight was pronounced – but not heavy.	5
Basin Municipally maintained?	Q	Retrofit recommendations on basins that are already municipally maintained would stand a better chance of being implementation and as such the criterion weight was pronounced – but not heavy.	6
Age of Basin	Q	Older basins would be ranked higher for retrofit priority as these were not created for the purpose of water quality or infiltration benefits. The age of the basin was considered to be a fairly important criterion for retrofit prioritization and was weighted as such.	7
Located within flood prone area?	Q	This information was only provided for a limited number of basins; as such it was not weighted heavily. This weight should be increased if this information was available for entry by municipalities in the future.	3
Current Functionality	Q	This information was only provided for a limited number of basins; as such it was not weighted heavily. This weight should be increased if this information is available for entry by municipalities in the future.	2

Note: Total weight allocated in each "retrofit type" column must add up too 100.

+N: These criterion are evaluated by the matrix as numeric criterion – so values entered are raw numbers – with a higher number being more favorable

Q: These qualitative criterion are evaluated in the matrix as "high", "medium", "low" (1, 2, 3 – with the "3" assigned to "high" or "low" based on which designation would be more favorable for retrofit.)

Execution and Results:
The matrix tool was executed both at the watershed-wide level to produce a watershed-wide prioritization and then again at the individual municipal level in order to produce a ranking for municipalities to evaluate as they put together their own implementation approach. (As noted "***Populating the EVAMIX Spreadsheet***" section, where data gaps existed in the Basin Inventory – the Project Team filled the gaps with provisional data in order to produce a watershed-wide prioritization utilizing all criteria.)

The prioritized output was sorted from 1 to 153 and categorized as "High", "Medium" and "Lower" priority candidate basins for retrofit potential. At the watershed-wide level, the basins ranked 1-20 were deemed "high priority" retrofit candidates, basins ranked 20-60 were ranked with a "medium priority" and the remaining basins were ranked with a "lower priority" for retrofit potential.

Please note – a lower ranking through this prioritization process did not mean that a basin should not be considered for retrofit, but rather that other basins are just deemed a higher priority in this first level of screening. If "implementers" of this initiative want to try for the "biggest bang for the buck" by clustering a number of retrofits within an individual tributary subshed, it would certainly make sense to implement retrofits on "lower priority" basins as a complement to retrofits on "medium" and "higher" priority basins.

Table 3: Watershed-wide EVAMIX Prioritization Output – "Top 20 Basin Candidates for Retrofit"

Rank	Basin ID #	Name	Location	Basin Area (ft^2)	Municipality	Receiving Waters
1	54	Jarrettown Elementary School		12086	Upper Dublin	Pine Run Trib A
2	41	Dublin Open Space	Jarrettown Rd	22839	Upper Dublin	Pine Run Trib C
3	9	Upper Dublin Lutheran Church	Butler Pike & Susquehanna	2919	Upper Dublin	Tannery Run
4	171	Lower Gwynedd Elementary School	Hoover & knight	21980	Lower Gwynedd	Houston Run
5	6	Saint Alphonsus school		15018	Upper Dublin	Rose Valley Creek
6	166	Meadowcreek estates	Meadowcreek Ln & Dager Ave	30319	Lower Gwynedd	Pennlyn Creek
7	210	Springfield Twp. Elementary School		27349	Springfield	Sunny Brook Creek Trib A
8	71	Heller way & Leah drive		20410	Upper Dublin	Pine Run
9	53	Dublin Woods 2	Catlin Way	1080	Upper Dublin	Pine Run Trib D

Rank	Basin ID #	Name	Location	Basin Area (ft^2)	Municipality	Receiving Waters
10	61	Dublin Hunt Open Space	Morningside Dr	6194	Upper Dublin	Pine Run
11	63	Vitae Pharmaceuticals	Ft. Washington office park	37676	Upper Dublin	Pine Run
12	33	Merck entrance 5		160100	Upper Gwynedd	Wissahickon Creek Upper Main Stem
13	24	Melrose enterprise ltd		7760	Upper Gwynedd	Wissahickon Creek Trib B
14	131	1305 Rohm & Haas Paint Quality inst		9207	Lower Gwynedd	Trewellyn Creek
15	55	Bantry drive		12972	Upper Dublin	Pine Run Trib A
16	154	412 Center St	@ Windsor way	8639	North Wales	Haines-Dittingers Run
17	149	Springhouse Estates		52890	Lower Gwynedd	Pennlyn Creek
18	85	Montgomery County Recycling Consortium		479	Upper Dublin	Sandy Run
19	39	UD01	Fort Washington entrance	15686	Upper Dublin	Tannery Run
20	56	Bantry drive		14879	Upper Dublin	Pine Run Trib A

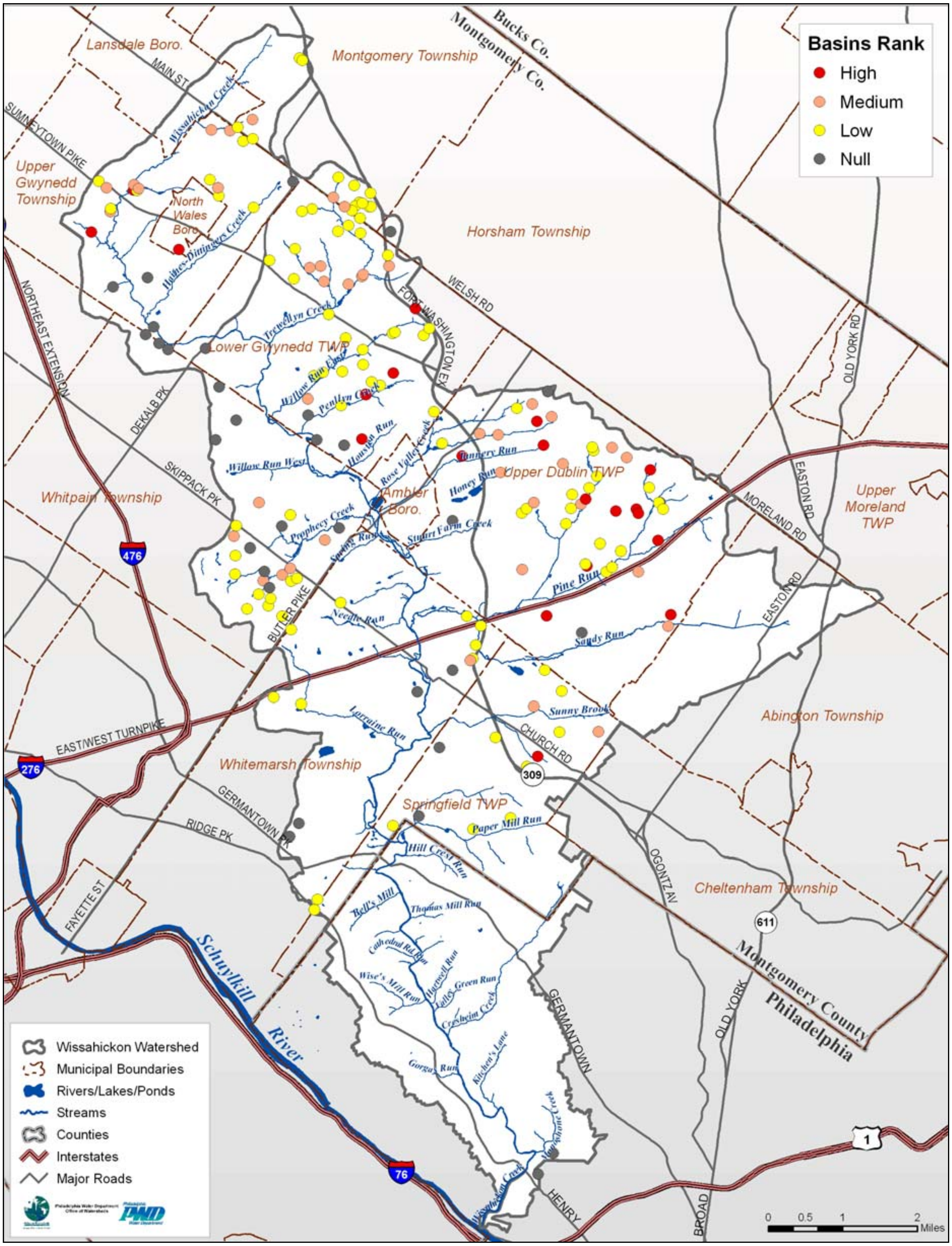


Figure 7: Retrofit Priority for Basins in Wissahickon Inventory
(This figure illustrates all data points in the inventory – including basins within the mainstem drainage area of the creek and basins that had been recommended for elimination by municipalities; all of these basins were eliminated from the prioritization and their retrofit priority has been designated as "null")

RECOMMENDATIONS FOR A SPREADSHEET BASED PRIORITIZATION PROCEDURE

The prioritization process utilized for this initiative was dependent on the commercially available EVAMIX software. In order to provide implementers of basin retrofits with the opportunity to update information in the dataset and/or tweak the weighting scheme used by the PWD Project team, a fairly user-friendly spreadsheet based approach was developed to somewhat mirror the process utilized by the EVAMIX software. Essentially the same evaluation process can performed with a few basic data transformation steps and a simple weighted summation approach. Appendix C: **"Exampleranking.xls"** included a spreadsheet based ranking tool that utilized a weighted summation approach – available for use by future "implementers" of this initiative.

Within Appendix C, the Microsoft Excel worksheet titled "Normalize" shows how the Wissahickon data was normalized – making it possible to be used in this weighted summation. Since most of the data in the Wissahickon dataset included qualitative scores (with scores ranging from 1 to 3) they were able to be used "as is" within the "Exampleranking" tool. Four of the criteria, however, are quantitative ("Basin Area", "Basin Area x Inf Rate", "Time to Drain", "Distance to Mouth"); as such these needed to be "normalized" by dividing each score by the maximum score for all basins for that criterion. This process produced scores that were all less than or equal to 1 – which were then multiplied by 3, to provide scores that were all less than or equal to 3, to match the qualitative scoring. If additional data are added by municipalities or partners – they would be entered into this same "normalize" tab and "normalized" using the procedure described above.

Once the data that has been "normalized", it is then copied from that tab within the spreadsheet and pasted into the "ranking" tab. The ranking method in this spreadsheet tool is simply a weighted summation. On the 6^{th} row of the "Ranking" tab – the weights developed by the PWD Project team for each prioritization criterion are listed. The user has the ability to adjust these assigned weights as desired in order to produce an updated ranking output. Current weight assignments have been developed to represent a criterion's relative importance.

The output "rank" was developed for a particular basin by simply multiplying the score (less than or equal to 3) of a criterion times its weight – summed across all criteria. A high "rank" was indicative of a high priority for retrofit of a basin and a low score was indicative of a lower priority for retrofit of basin. The results of the example ranking based on the weights assigned by the PWD Project Team are provided in the second Excel worksheet, titled "ranking".

RETROFIT TYPES EVALUATED

When developing the concept for this initiative, the Philadelphia Water Department focused specifically on identifying retrofit options deemed to be reasonably "*implementable*" recommendations. By *implementable*, we mean that these retrofit options have been thoughtfully considered for cost feasibility as well as potential for implementation by municipal staff (i.e. engineer, Public Works and/or other staff) and/or Watershed Partners under the existing conditions of the Wissahickon Creek Watershed.

The types of retrofits considered in this initiative include "Outlet Structure Modifications", "Basin Structure Modifications", and "Naturalization". For each of these retrofit types, our project team has derived an estimation of the projected benefits associated with implementation based on literature values extrapolated to the "model basin" size. The following includes a brief description of each of the retrofit types, estimated benefits associated with implementation of the retrofit, and finally, an estimated implementation costs.

Note:

It was assumed that the dry bottom basins within the Wissahickon Basin Inventory were designed so that water was retained and released (*i.e.* not infiltrated) and that soils beneath the basins have been compacted. Water quality benefits were assumed minimal as these basins were only designed for peak flow control.

Estimated benefits associated with reduction of runoff sediment and increased dry weather baseflow to the stream have been evaluated for each retrofit type. The runoff sediment reduction was represented in pounds per impervious acre served by the drainage basin (which was based on an average basin drainage size of 25 acres).

All recommendations made through this initiative will require a detailed site-specific feasibility study and engineering designs in order to proceed with implementation.

All work must be performed in accordance with existing state and local regulations and requirements (i.e. NPDES Permits, Act 167 ordinance, etc).

Costs and Benefits:

Cost and benefit calculations were derived based on "model sized basins" (which were based on the median size basin of roughly 15,000 ft^2 average depth of 3.5 feet) as described below. These costs can be extrapolated to account for the actual basin size. (See Appendix B – Basin Retrofitting Costs)

Benefits are expressed in terms of the parameters of interest for the WCIWMP (under development), including sediment and bacteria reductions and increase of baseflow at the mouth of the Wissahickon Creek. (Benefits associated with infiltration were calculated in in/year to represent the increase in dry weather baseflow at the mouth of the creek.)

Retrofit Option #1: Outlet Structure Modifications:
The water quality function of an existing stormwater basin could be improved if the outlet structure was modified to extend detention time within the existing basin footprint. A retrofit designed to delay the release of stormwater from 24 to 48 hours could increase the settling time for suspended particles, and depending on basin conditions could even potentially increase infiltration. These retrofits could also help to offset downstream flooding impacts (Chapter 6.6.3 of the PA BMP Manual). Examples of outlet controls are risers and low-flow orifices, underdrains, permeable weirs, positive overflows, floating basin skimmers, impervious liners, and simple obstruction of the orifice by a steel plate. In general, outlet structure modifications to create extended detention can be reasonably low-cost retrofits to existing stormwater infrastructure.

A simple modification that would utilize a steel plate to minimize the size of the lowest outlet orifice in a detention basin would be the lowest cost and least invasive retrofit type under consideration in this study. At the very minimum, this modification can extend the detention time in a basin where space for structural upgrades is limited. Impeding the lowest outlets will hold stormwater from small storms in the basin where it can slowly discharge into receiving waters. Design and implementation of this simple retrofit type could potentially be undertaken by municipal engineers and public works crews. This retrofit type has already been observed in several basins within the Wissahickon Study Area.

Figure 8: Retrofitted Basin with Metal Plate Minimizing Low Flow Orifice
Source: Photo by PWD Field Team; basin at Foxfield and Pennlyn in Lower Gwynedd Township

Other outlet structure modifications that could be considered for transitioning a basin from standard detention to extended detention include innovations such as permeable weirs, in which under low flow conditions, water ponds behind the permeable weir and slowly seeps through the weir. In high flow conditions water can flow both over and through the weir. Permeable weirs promote sediment reduction and reduce the velocity of stormwater exiting the basin. Figure 9 illustrates the profile of a stormwater basin retrofitted with permeable weirs.

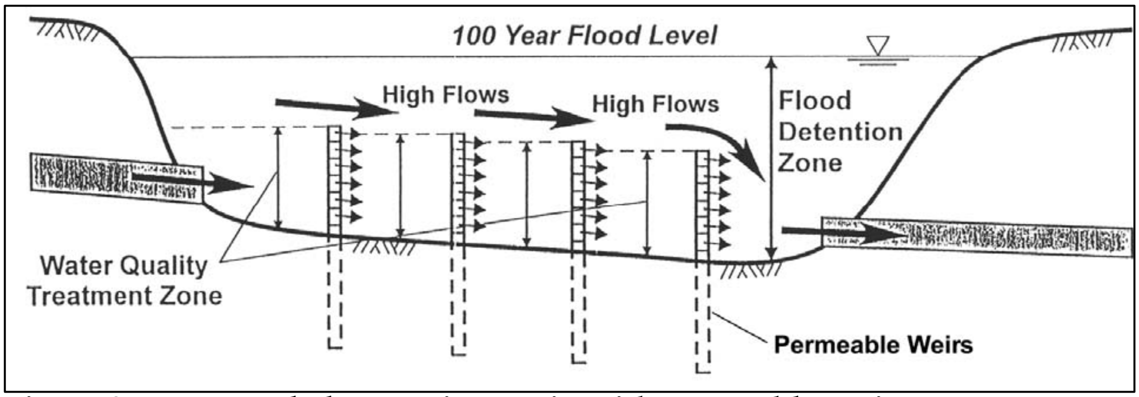


Figure 9 Dry Extended Detention Basin with Permeable Weirs
Source: Philadelphia Stormwater Guidance Manual Chapter 6.2.15

Outlet modifications could present an effective, low-cost, and easily implemented and could be used in conjunction with other stormwater BMPs to increase infiltration and improve water quality. One design, as outlined in Chapter 6.6.3 of the 2006 Pennsylvania State Best Management Practices (PA BMP) Manual and reproduced below incorporated infiltration, micropools, and vegetation into the "extended detention" basin design.

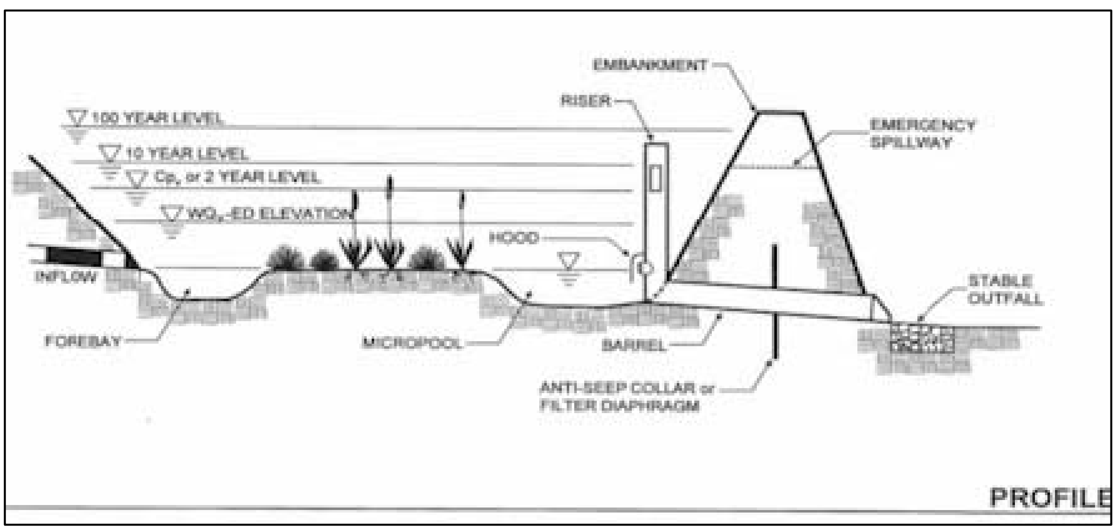


Figure 10: Dry Extended Detention Basin with the Addition of other Water Quality and Infiltration Practices
Source: PA BMP Manual Chapter 6.6.3

Estimated Cost: A 1-time implementation cost estimate has been derived for this retrofit type; the cost has been calculated to be up to roughly $14,000.00 with an estimated $1,100 annual maintenance cost – based on assumption that basin orifice will need to be maintained periodically to remove obstructions of natural and non-natural debris in order to allow for designed basin function. (Note: the 1-time implementation cost was based on a "simple" orifice modification retrofit; cost estimates have been overestimated to account for potential engineering time, field survey including topographic study and infiltration testing to assess the basin for feasibility. Annual maintenance cost does not account for assumed mowing costs already in effect in this basin.) Please see Appendix B – Basin Retrofitting Costs for cost assumptions and totals.

Associated Benefits: per acre of impervious served

Sediment Removal: Implementation of outlet structure modifications could result in a reduction of 2,900.00 lbs/yr of runoff sediment per impervious acre served.

Bacteria: Implementation of outlet structure modifications could result in a 0.0000074 oocyst decrease in Cryptosporidium concentration at the mouth of the Wissahickon per acre of impervious cover served. Additionally, implementation of outlet structure modifications could result in an increase in the percentage of samples meeting water quality standards in dry weather per acre of impervious cover served by a basin retrofit; this retrofit would increase the percentage by 0.014 %.

Increase in Baseflow at Mouth of Wissahickon: Unfortunately, based on the assumption that during basin construction the soils were compacted, it was assumed that a retrofit of this type would not increase infiltration within the basin.

Retrofit Option #2: Basin Structure Modifications:

This retrofit type has been developed to serve as a "potpourri" of sorts, including a variety of retrofit types that could be considered individually or in various combinations. Basin structure modifications are designed to increase the function of existing stormwater management infrastructure, increase the infiltration of stormwater into groundwater, improve water quality of stormwater discharged from the basin, dissipate velocity of discharged stormwater, and improve aesthetics of the stormwater management area. Structural modifications can be implemented singularly or in tandem to achieve the desired stormwater management goal.

Modifications such as constructing gravel beds, check dams, infiltration trenches, and excavating the detention basin to remove compacted soils help to drain stormwater from the basin into the groundwater. Soils in the bed of the basin become compacted during initial construction activities and form an impervious

barrier between the stormwater, surrounding soils and the water table. Infiltration can be achieved by removing portions of the compacted soils and replacing them with coarse substrate to increase storage of stormwater as well as increasing potential for infiltration to groundwater.
Gravel beds, infiltration trenches, and excavation can be used in both small and large scale stormwater management areas. Figure 11 illustrates both a small scale infiltration trench before completion and a completed, vegetated infiltration trench that collects stormwater from a nearby parking lot.

Figure 11: Infiltration Trench under Construction and Fully Constructed Infiltration Basin
Source: Philadelphia Stormwater Guidance Manual, 6.2.12 (under construction)
PA BMP Manual, 6.4 (constructed)

Construction intense basin modifications can be more costly than basin naturalization or extended detention modifications, however the improvements in water quality and groundwater infiltration can be considerably higher. The numerous retrofit make this option associated with this retrofit type were deemed flexible enough to be "*implementable*" on basins of any size and shape, a necessity in highly developed urban areas. Many of these options could potentially be designed and implemented by municipal staff.

Check dams (Figure 12) can be used to increase the storage capacity of existing basins and drainage trenches. The dams hold water in the basin and help to offset stormwater discharge peaks in nearby receiving water. Check dams used in conjunction with infiltration trenches will retain stormwater, allowing more time for infiltration.

Figure 12: Check Dams constructed along a Roadway
Source: Philadelphia Stormwater Guidance Manual, 6.2.3

Estimated Costs: Due to the high degree of variability for implementation of this retrofit type and the number of implementation options to be considered – deriving an overall cost estimate was difficult. Preliminarily, this retrofit type has been estimated to cost roughly $35,000.00. The placeholder cost was based on a retrofit that assumes grading for a low-flow channel, installation of micropools, and also adding berms. Annual maintenance cost associated with this retrofit was estimated at ~$1,100.00. Please see Appendix B – Basin Retrofitting Costs for cost assumptions and totals.

Associated Benefits:

Sediment Removal: Implementation of basin structure modifications as outlined above could result in a reduction of >2,700 lbs/yr of runoff sediment per impervious acre served.

Bacteria: Implementation of basin structure modifications as outlined above could result in a 0.0000074 oocyst decrease in Cryptosporidium concentration at the mouth of the Wissahickon per acre of impervious cover served. Additionally, implementation of basin structure modifications could result in an increase in the percentage of samples meeting water quality standards in dry weather per acre of impervious cover served by a basin retrofit; this retrofit would increase the percentage by 0.017 %.

Increase in Baseflow at Mouth of Wissahickon: Additionally, a retrofit of this type could be associated with an increase in baseflow at the mouth of the Wissahickon of 0.0002 in/year.

Retrofit Option #3: Naturalization:

Basin naturalization can improve the function of existing stormwater management basins through increased infiltration and water quality improvements. Over time, as the grasses are removed from basin surfaces and replaced with herbaceous and woody vegetation, root systems can grow and loosen up compacted soils. Replacing mown turf grass basins with mixed native vegetated basins was a low cost retrofit that not only improves the performance of the infrastructure, but can also improve the aesthetic appeal of the stormwater basin. Basin naturalization can occur in both dry and wet basins. The amount and duration of standing water in the basin will dictate the variety of plants selected for this retrofit.

Basin naturalization, sometimes called bio-retention, was deemed appropriate for urban areas that require increased infiltration but do not have available space for expanding beyond the existing basin size. Additional benefits to urban areas resulting from incorporation of bio-retention and naturalization into existing stormwater basins would be that they can help to offset the urban heat island effect and improve local air and water quality (Philadelphia Stormwater Guidance Manual 6.2.5).

Figure 13: Image of a vegetated stormwater detention area
Source: (Philadelphia Stormwater Guidance Manual 6.2.9)

This fairly low cost retrofit could additionally result in an annual maintenance cost savings for the municipality – as the basin would only need to be mown once or twice a year. (Additional maintenance would include inspection and monitoring to keep trash from clogging the orifice structure.) Design and implementation of this retrofit type could potentially be undertaken by municipal staff.

Estimated Cost: The 1-time implementation cost could be roughly $29,000.00 with an estimated $2,500.00 annual maintenance cost. Please see Appendix B – Basin Retrofitting Costs for cost assumptions and totals.

Associated Benefits:

Sediment Removal: Implementation of basin naturalization could result in a reduction of 2,100 lbs/yr of runoff sediment per impervious acre served.

Bacteria: Implementation of basin naturalization could result in a 0.0000054 oocyst decrease in Cryptosporidium concentration at the mouth of the Wissahickon per acre of impervious cover served. Additionally, implementation of basin naturalization could result in an increase in the percentage of samples meeting water quality standards in dry weather per acre of impervious cover served by a basin retrofit; this retrofit would increase the percentage by 0.011 %.

Increase in Baseflow at Mouth of Wissahickon: Additionally, a retrofit of this type could be associated with an increase in baseflow at the mouth of the Wissahickon of 0.00017 in/year.

"REAL WORLD" EXAMPLE BASIN RETROFIT:
The PWD Project Team thought that users of this report would find value in seeing costs and sketch designs associated with a similar project that has now been vetted through the process from design to bid to construction.

In August 2004, a conceptual stormwater management plan was completed for a Norristown Area School District (NASD) site through a technical assistance grant from DEP. This plan included proposed concepts for structural and non-structural "better" management practices (BMPs) at Norristown Area High School, Whitehall Elementary School, and the Norristown Area School District Administration building, which would mitigate the quality and quantity of stormwater runoff from the sites to Stony Creek, a tributary to the Schuylkill River. After the plan was completed, funding from the USEPA was secured through the Schuylkill Watershed Initiative Grant for design and implementation of several of the highest priority projects outlined in the plan. The prioritization was developed by project partners based on perceived stormwater impact and cost of the identified projects. Within this list of high priority projects, the detention basin retrofits were selected as the projects for full design and construction. Since the water was already concentrated into the basins, the retrofits provided the opportunity for the greatest stormwater benefit within the project budget.

The two detention basins discharge directly to Stony Creek and were originally designed only to control the peak flow from large storms. Both basins were covered with mown turf, and one had a concrete low flow channel that connected the inflow pipe to the outflow pipe. Although the basins appeared to be well maintained and were probably functioning as designed, they provided little water quality benefit or attenuation of the small storms that account for the majority of the annual rainfall volume. The goal of the retrofit projects was to provide management of these small storms and improve the quality of the discharge to Stony Creek. The retrofit design was completed in 2006-2007 and bid in July 2007. A contractor was selected in August 2007 and construction was completed in September-October 2007.
The retrofit plan for Basin B included removal of low flow channel, re-grading of basin to lengthen flow path, soil amendment, planting, and modification of outlet control structure.

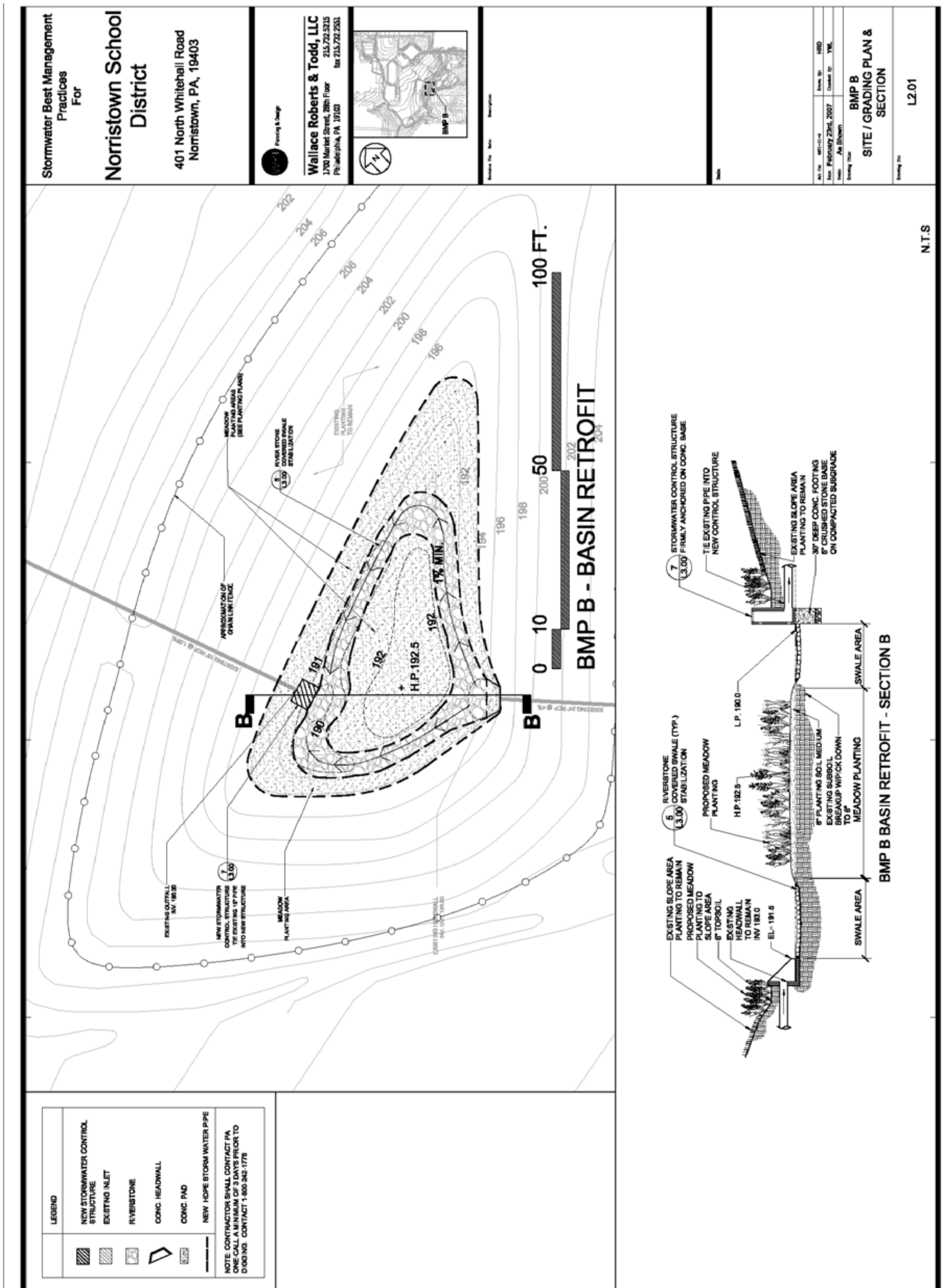


Figure 14: Retrofit Design for Basin B, Norristown High School

The retrofit plan for Basin C included soil amendment, planting, and modification of outlet control structure.

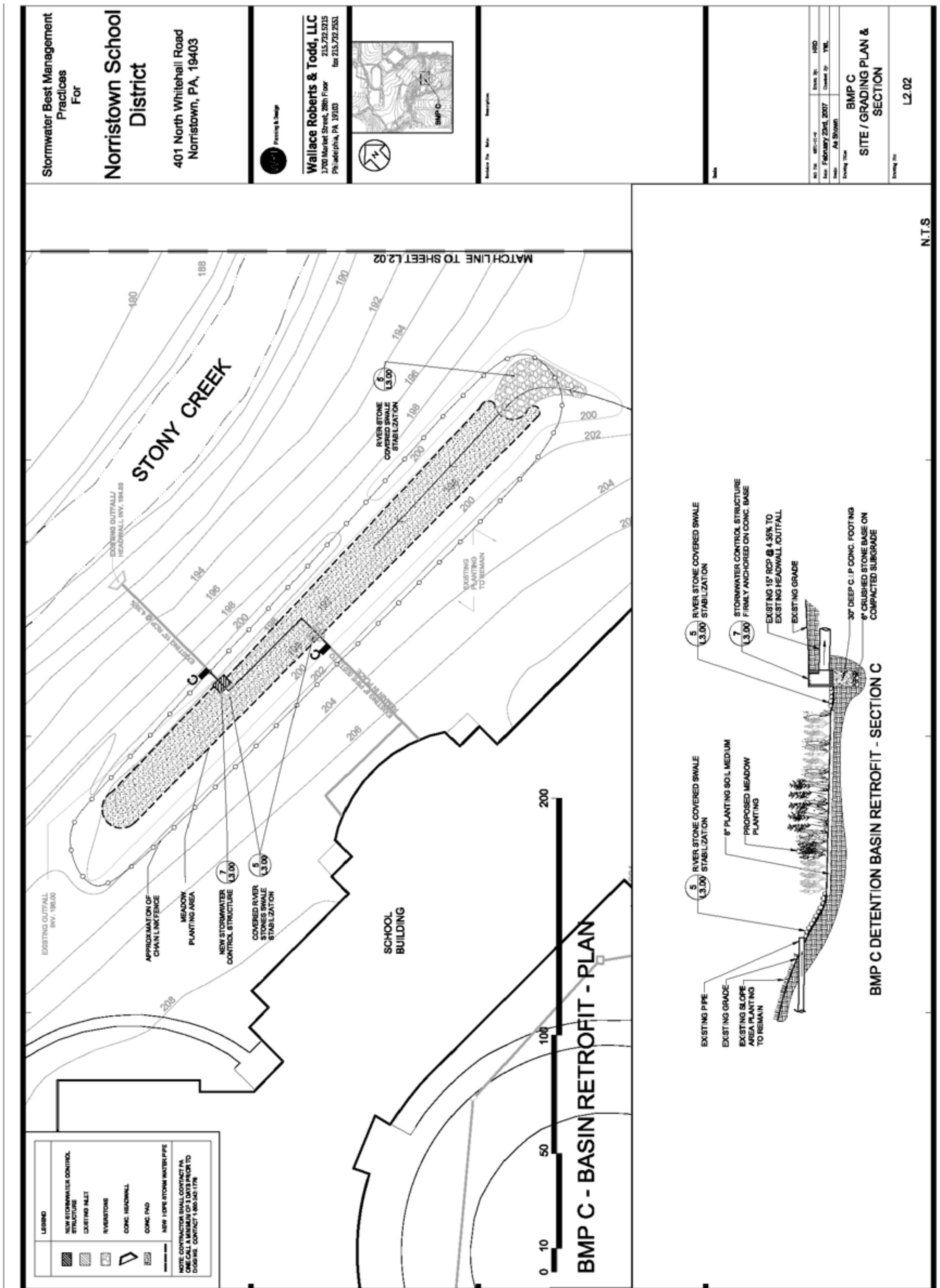


Figure 15: Retrofit Design for Basin C, Norristown High School

Costs:
The total cost of construction for retrofit of both basins totaled $63,082.50.

Next Steps:
As f fall 2007, the retrofits have been constructed and the next step will be to continue watering and monitoring of vegetation to ensure establishment. Additionally, maintenance and inspection of detention basin inlet locations will be necessary in order to ensure that erosion was not occurring before vegetation was established. If erosion was observed – corrections must be designed and implemented as needed. There are plans for visual monitoring of detention basin outfalls to Stony Creek as well as performing of visual assessments of stream characteristics upstream and downstream of detention basin outfalls. Lastly, benthic surveys will be conducted in the fall of 2008 assess the potential habitat benefits associated with these and other retrofits proposed for this watershed area.

For more information about this project, please visit www.schuylkillactionnetwork.org.

DESCRIPTION OF DATA OUTPUTS:
All data produced through this initiative was made available to US EPA, PA DEP and Wissahickon Watershed municipalities. In order share this data in such a way that it will provide the most value and universal applicability to PWD partners – the PWD Project Team has packaged all of the GIS data layers produced through this process in both ArcGIS data layer format as well as in KML format which will be usable by any computer with internet access. Users will need to download the free "Google Earth" software from the following link: http://earth.google.com/ in order to utilize the KML files.

KML was a file format used to display geographic data in an "Earth browser", such as Google Earth or Google Maps. KML files used a tag-based structure with nested elements and attributes and were based on the XML standard – meaning that data was exported into this format while retaining the critical attribute data associated with the data layer. Once in KML format, the file will overlay itself in the "Google Earth" window – allowing the user to pan across the area and zoom in and out to view the details of the basin and the region.

Data layers the PWD Project Team has exported into KML format for Wissahickon municipalities include:

- **Watershed Boundary:** Wissahickon boundary delineated by PWD Staff for the Wissahickon Integrated Watershed Management Plan (WCIWMP)
- **Wissahickon Stream Hydrology:** PWD Staff updated stream hydrology including tributaries
- **Municipal Jurisdiction:** Boundaries for all municipalities within the Wissahickon Creek Watershed
- **Wissahickon Basin Inventory:** Includes all attribute data in the Wissahickon Dry-Bottom Detention Basin Inventory established through this initiative.
- **Wissahickon Infrastructure Survey Data:** Includes bridges, culverts, outfalls, constrictions, etc. within the Wissahickon Creek and tributaries as identified by the PWD Field Staff in 2005 – gathered for the WCIWMP under development.

Microsoft excel spreadsheet exports of the Basin Inventory data in its tabular format was packaged along with the KML files to share with municipal partners so that data can be sorted and queried as necessary. Photos taken during PWD's field visits were compiled into HTML files and have been shared with municipal partners in both raw image format as well as the packaged HTML format.

Additionally, a spreadsheet ranking tool described in the section entitled **"RECOMMENDATIONS FOR A SPREADSHEET BASED PRIORITIZATION PROCEDURE"**was packaged and shared with partners in order to give users of this data the opportunity to continue to add data to the evaluative matrix and prioritize basins for retrofit potential.

CONCLUSIONS

The data that has been produced through this initiative should serve as a tool to empower the project "implementers" within the Wissahickon Creek Watershed. These implementers should work together to continue to fill data gaps that will further enhance the prioritization scheme in order to identify basins for implementation of various water quality improving or infiltration enhancement based retrofits.

As stated on page 3 under the heading "**WHAT THIS PROJECT IS – AND WHAT IT IS NOT**", this initiative did not produce a listing of basins *recommended* for retrofit, but rather a tool for use by the municipalities and stakeholders of the Wissahickon Creek Watershed to identify their own implementation strategies for achieving the biggest water quality and infiltration benefits with the resources they have available.

At the completion of this initiative, the data has been turned over to all municipalities of the watershed and has been posted online (available via link from http://www.phillyriverinfo.org/Watersheds/Wissahickon.aspx). The Wissahickon Watershed Partnership (established 2005) will be working on identifying next steps via its Public Education and Outreach Committee.

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