

# Study of stormwater runoff reduction by greening vacant lots in north Philadelphia

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## Abstract

The feasibility of using urban vacant lots to retain stormwater after they were cleared and planted with vegetation was studied in five vacant lots in north Philadelphia. The stormwater credit allowed by Pennsylvania Department of Environmental Protection was calculated. The stormwater management model (SWMM, version 5.0) was used to simulate the long-term stormwater runoff on those sites. The cost of stormwater detention using greening approach was calculated and compared to costs of other conventional BMPs. The result shows that about 11,404 cubic feet of stormwater credit can be claimed for restored vacant lots. The unit cost of stormwater detention was between \$2.54 and \$8.76 per cubic feet. From June 2005 to May 2006, the total runoff on those lots was reduced by 30% in average and the average peak runoff reduction was about 24%. The greening of vacant lots has the potential to become an effective way of reducing the stormwater runoff in dense urban situation if the cost can be lowered. Recommendations were given on how to improve the benefits/costs ratio of the greening approach.

## Introduction

Urban vacant lot, also known as urban vacant land or urban void, has become a serious problem in many American cities, especially in formal industry centers, such as Detroit and Philadelphia. This problem was created by the decline of the manufactory industry, the exodus of the high- income families to suburb, and deteriorated economic and social conditions in the urban centers (Goldstein et al. 2001). Urban vacant lot is not only visually unappealing, it also can create many social and environmental problems. Lopez and Hynes (2006) found that urban vacant lots attract criminal activities. Studies also showed that urban vacant lots lead to the decline of the property value in the surrounding neighborhoods (Goldstein et al. 2001). Urban vacant lots also pose many environmental problems. They often become the illegal dumping sites, which raise serious health concerns for people living nearby. Urban vacant lots are also the source for pollutants. They are sources of dust (Goldstein et al. 2001). They are also identified as the non-point source for water pollution (Pitt and Bozeman 1980).

To tackle the problem of urban vacant lots, different approaches have been adopted in cities across the country. Including in those approaches are financial means to discourage people to abandon their properties and encourage people to develop vacant lots; laws and regulation to control illegal dumping. Beside these indirect approaches, many municipal governments also start programs to restore or redevelop vacant lots (Accordino and

Johnson 2000). A quick survey of plans and reports produced from these programs showed that most programs addressed the problem of vacant lots from social and economic aspects, while a few projects had explicitly targeted the environmental aspect of vacant lots.

A project conducted in 2004 by the Pennsylvania Horticulture Society (PHS) and the Philadelphia Water Department (PWD) aimed to restore vacant lots in Philadelphia to detain stormwater runoff. Urban vacant lots are widespread in Philadelphia. It is estimated that there are around 30,000-40,000 vacant lots in the city. In some part of the city, the vacant lots accounts for about 40% of the total land use. The city with its ancient combined sewer systems faces serious challenges in controlling the flooding problem and managing the quality of runoff. It is expected that the pressure on the combined sewer systems will be reduced if the stormwater runoff from vacant lots and neighboring rooftops can be detained on vacant lots. Also, even though the total area of vacant lots is only 7% of the land area of Philadelphia, their proximity to the major rivers means that the runoff from the vacant lots can have great impacts on the water quality of those rivers (Fig. 1). This study was conducted to analyze the effectiveness of the project. There are two objectives: 1) estimate the impact of the greening measure on stormwater runoff volume, and 2) evaluate the cost and benefit of the greening measure.

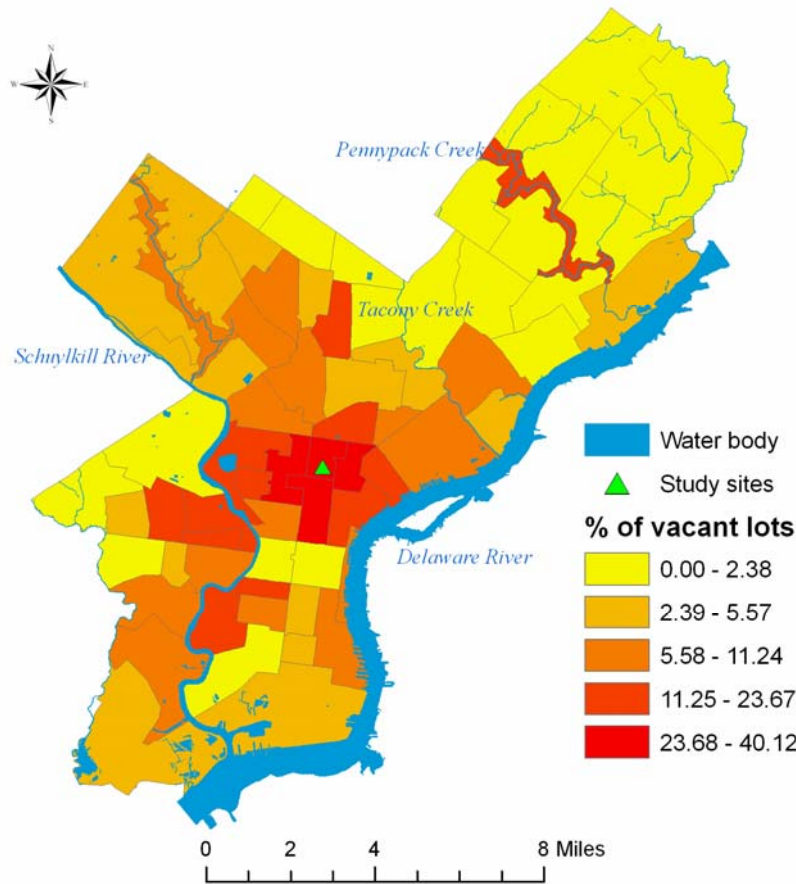


Figure 1. The distribution of vacant lots in Philadelphia. The map was drawn using 2005 vacant property data from the Neighborhood Information System Database (NIS) hosted by the University of Pennsylvania.

## Study site and methods

### *Study sites*

Five vacant lots were chosen as study sites. They are located in a residential area in north Philadelphia, including site at 3<sup>rd</sup> Street and N. Bordine Street., site at 3<sup>rd</sup> Street and W. Norris Street., site at 8<sup>th</sup> Street and N. Berks Street, site at 8<sup>th</sup> Street and W. Norris Street., and site at 9<sup>th</sup> Street and W. Norris Street. Prior to the treatment, about 50-70% of the surface area of these lots was covered with weeds, such as Common chickweed (*Stellaria media*), Kochia (*Kochia scoparia*), Mugwort (*Artemisia vulgaris*), and small trees like Tree-of-heaven (*Ailanthus altissima*). The rest part of lots was covered with garbage and concrete rubbles. At all sites, the garbage was first cleared. Remnant concrete was broken and removed. Except for the site at 3<sup>rd</sup> Street and N. Bordine Street, all sites were graded to create a slight slope of 2%. Soil berms were constructed to hold water in designed retention zones on those lots. The retention zones were located at least 25 feet away from existing structures and tilled to a depth of six inches, four inches of topsoil (amended with leaf compost) was added to the retention basin. In other parts of the lots, surface soil was tilled to a depth between three and four inches, and about three inches of amended topsoil was added to the surface. A different grading approach was used for the site at 3<sup>rd</sup> Street and N. Bordine Street. Approximately two thirds of the site was graded to create a “slope and valley” like landscape. The rest of the site was graded flat and designated as retention zone. After the construction, all sites were replanted with trees and annual grasses. By the time this study was conducted, average vegetation cover on those sites is about 90%. The main herbaceous plants growing on sites include Dandelion (*Taraxacum officinale*), White clover (*Trifolium repens*), Red clover (*Trifolium pratense*), Buckhorn plantain (*Plantago lanceolata*), Broadleaf plantain (*Plantago major*), Quackgrass (*Elytrigia repens*), Hard fescue (*Festuca longifolia*), and Creeping red fescue (*Festuca rubra*). Major tree and shrub species planted include Red maple (*Acer rubrum* ‘Franksred’), Shawnee Brave baldcypress (*Taxodium distichum* ‘Shawnee Brave’), Chokecherry (*Prunus virginiana*), Black gum (*Nyssa sylvatica*), American basswood (*Tilia americana*), and Yellowwood (*Cladrastis kentukea* ‘Sweetshade’). According to the PHS, the initial observation showed the system is working and stormwater drain down quickly after each rain event (Lawrence, personal conversation).

### *Methods*

The compaction of soil was first investigated because soil compaction is thought to be highly correlated to the infiltration rate of water. A penetrometer (Field scout 900, Spectrum Inc.) was used to measure the compaction of soil. A systematic sampling scheme was used to lay the sampling points on ground. Each lot was divided into 30 feet x 30 feet grids. The center of each grid was measured with the penetrometer. At each point, the cone was pushed into the soil and the soil compaction every one-inch was measured until the cone hit an impenetrable target or layer. An inverse distance weighted (IDW) interpolator was used to interpolate the compaction profile for the entire lot from the data measured at each grid. Areas with relatively homogeneous compactness at different depth were identified from the map. Software package ArcView 3.2 (ESRI) was used for this task. The maximum reading of the penetrometer is 1000 psi. If the soil at certain depth was not penetrable, it was assigned the value of 1000 psi. According to

Pitt et al. (1999), if the compaction reached 300 psi, the soil was classified as compacted soil.

Infiltration rates were measured by using Turf-ric double ring infiltration meters. The equipment is accepted by Pennsylvania Department of Environmental Protection (PDEP) to measure infiltration rates on sites of best management practice (BMP). In each lot, three infiltration meters were used. The locations for infiltration tests were determined from soil compaction profiles. Each site was divided into three areas with similar soil compactness at the depth of six inches. For each area, an infiltration test was conducted following the procedure listed in the Pennsylvania Stormwater Best Management Practice Manual (PDEP 2007). This sampling set-up was done to accommodate as much spatial variability of infiltration rates in one lot as resources allowed. The area weighted average infiltration rate was then calculated from the three measurements to represent the infiltration rate on each site.

At each lot where an infiltration test was conducted, a soil sample was collected following the ATMS code D1587-00. Soil samples were analyzed for water content and texture following the ATMS code D 2216-05 and D6913-04. The soil porosity and dry bulk density were calculated using methods from Dingman (2002).

The method described in the Pennsylvania Stormwater Best Management Practice Manual was used to calculate the stormwater credit. The greening work conducted on those plots included following BMP practices: (1) the garbage and remnant concrete were removed; (2) top soil was tilled and amended with organic mater and sand; (3) sites were planted with grass, shrubs and trees. These treatments reduced impervious surface area and credit can be claimed for the reduced runoff. A stormwater credit of six cubic feet is allowed for every native tree planted. Besides these BMP practices, shallow depressions were also created on four lots to contain stormwater. They were also included in the calculation of stromwater credit.

The real volume of water detention storage capacity by each lot was calculated by assume the water balance in each lot as:

$$P_T = L + E + I + D_s + R \quad (1)$$

where

$P_T$  = the total rainfall depth in inches for one storm event,

$L$  = interception in inches,

$E$  = evapotranspiration in inches

$I$  = infiltration in inches

$D_s$  = depression storage in inches

$R$  = run off in inches

$L$  is the rainwater intercepted by trees and shrubs. Here the interception by herbaceous plants was neglected because the value is small.  $L$  was calculated using the equation developed by Aron (1992, cited in Akan and Houghtalen 2003).

$$L = cP_T^m \quad (2)$$

where  $c$  and  $m$  are fitting parameters for different tree species. Values of  $c$  and  $m$  are obtained from Kibler et al. (1996, cited in Akan and Houghtalen 2003). If  $c$  and  $m$  values are not listed for one specific species, the values for one listed species which has similar canopy structure and leaf characteristics as the targeted species will be used. For example,  $c$  and  $m$  values for Chokecherry are not available, so the values for apple were assigned to Chokecherry. Interception storage was only calculated for areas covered by tree canopy.

$E$  is the evapotranspiration. Here it was assumed to be zero during the storm event.  $I$  is the infiltration. In this study,  $I$  was assumed to be the maximum water storage capacity by topsoil because the existing of a hard layer under the topsoil. The original grading for construction created that hard layer. The topsoil will soon saturate during a storm event and excess water will become surface runoff as well as subsurface flow and leave the lot. So the water contained in the saturated topsoil was considered as the maximum water that can infiltrate downward.  $I$  was calculated as the product of the volumetric water content multiplied by the thickness of the topsoil (Dingman 2002).  $D_s$  is the depression storage. It includes both large depressions intentionally created by grading and small depressions and puddles on the ground surface. The volume of large depressions at each site was calculated based on the measurement of dimensions of the depressions from the site plan. The small depressions storage was assumed to be 0.3 inch per unit area for lawn grass according to Akan and Houghtalen (2003)

The volume of water detention was then calculated as the sum of  $L$ ,  $I$ , and  $D_s$ . The cost of per cubic meter detained on site was obtained by dividing the real volume of water storage with the total cost. The value was compared to the cost of other BMPs listed by the Office of Water, EPA (1999). The values given by EPA were adjusted for the inflation and geographic locations according to the methods listed in Office of Water, EPA(1999).

The stormwater management model (SWMM, version 5.0) developed by EPA was used to simulate the long-term stormwater runoff on those sites. It was assumed that all lots received same precipitation due to their close distances. And runoff from those lots would directly flow into the sewer system. Two scenarios were simulated. They are stormwater runoff before the greening activity and stormwater runoff after greening. The different land cover information and infiltration rates measured before and after the greening activity were entered into the model. The precipitation and other climatic data beginning from June 1<sup>st</sup>, 2005 to May 31<sup>st</sup>, 2006 from the weather station at the Philadelphia International Airport were obtained from the National Climatic Data Center to run the model.

## Results

Results of the soil sampling and infiltration test for the five lots are shown in Table 1.

Table 1 Soil types, dry bulk density, average depth of top soil, soil porosity, water content, and infiltration rate on study sites

Site	Soil type	Bulk density (g/cm <sup>3</sup> )	Average depth of top soil* (in)	Soil porosity (%)	Water content (%)	Area weighted Average infiltration rate before/after treatment (in/hr)
3 <sup>rd</sup> & N. Bordine	Sandy loam	1.28	6.67	47.12	15.86	2.42/6.83
3 <sup>rd</sup> & W. Norris	Sandy loam	0.93	5.33	62.49	14.13	3.78/8.53
8 <sup>th</sup> & N. Berks	Sandy loam	0.98	5.54	62.62	13.01	2.75/5.84
8 <sup>th</sup> & W. Norris	Sandy loam	1.20	6.39	50.96	15.86	2.21/3.73
9 <sup>th</sup> & W. Norris	Sandy loam	1.22	6.29	54.33	15.27	2.19/3.85

\* the average depth of top soil is the thickness of soil layer above an highly compacted hard surface

Based on the Pennsylvania Stormwater Best Management Practice Manual, the following amount of stormwater credits can be claimed from these sites.

Table 2 Stormwater credits claimed based on the manual

Site	Runoff reduction (cf)	Soil amendment (cf)	Tree planting (cf)	Depression (cf)	Total (cf)
3 <sup>rd</sup> & N. Bordine	1,804.09	911.67	48	0	2,763.75
3 <sup>rd</sup> & W. Norris	540.01	663.54	126	113.9	1,443.45
8 <sup>th</sup> & N. Berks	390.81	480.21	30	919.5	1,820.52
8 <sup>th</sup> & W. Norris	867.75	1,066.25	60	1,533.88	3,529.88
9 <sup>th</sup> & W. Norris	746.45	891.38	84	425.5	2,147.33
Total:					11,404.93

The amount of stormwater that these five sites can detain during a rain event and the unit cost of the detention are shown below (Table 3).

Table 3 Detention storage of stormwater on study sites

Site	Estimation of detention storage (cf)	Installation and maintenance cost (\$)	Unit cost of stormwater detention (\$/cf)
3 <sup>rd</sup> & N. Bordine	5,667.56	49,690	8.76
3 <sup>rd</sup> & W. Norris	4,390.40	11,185	2.54
8 <sup>th</sup> & N. Berks	3,308.16	12,652	3.82
8 <sup>th</sup> & W. Norris	6,865.53	28,205	4.11
9 <sup>th</sup> & W. Norris	5,649.70	21,817	3.86

Unit costs of stormwater on those lots are compared to unit costs of stormwater detention storage of other BMPs listed in EPA document (Table 4).

Table 4 Unit costs of stormwater detention by different BMPs

Retention & detention basins (\$/cf)	Sand filter (\$/cf)	Infiltration trench (\$/cf)	Grass swale (\$/cf)	Infiltration Basin (\$/cf)	Bioretention (\$/cf)
0.58-1.16	5.35-6.99	4.66	0.58	1.51	6.17

Obviously the high installation cost of site at 3<sup>rd</sup> Street and N. Bordine Street raised the overall average cost significantly. If only unit costs from other four lots were averaged, the cost falls into the range between 2.36-4.11 (\$/cf)

Stormwater runoff simulation for the time period between June 2005 to May 2006 are shown below (Table 5)

Table 5 Results of stormwater runoff simulation using SWMM

Site	Total Precipitation (in)	Total Evapotranspiration (in)	Total Infiltration (in)	Total Runoff (in)	Peak runoff (CFS*)
Before greening					
3 <sup>rd</sup> & N. Bordine	37.2	2.35	28.24	6.13	0.49
3 <sup>rd</sup> & W Norris	37.2	1.98	32.92	2.03	0.27
8 <sup>th</sup> & N. Berks	37.2	2.03	32.94	2.04	0.19
8 <sup>th</sup> & W. Norris	37.2	1.82	32.98	2.00	0.41
9 <sup>th</sup> & W Norris	37.2	1.89	32.92	2.03	0.36
After greening					
3 <sup>rd</sup> & N. Bordine	37.2	1.78	33.57	1.56	0.29
3 <sup>rd</sup> & W Norris	37.2	1.88	33.69	1.41	0.21
8 <sup>th</sup> & N. Berks	37.2	1.94	33.69	1.42	0.15
8 <sup>th</sup> & W. Norris	37.2	1.79	33.72	1.39	0.3
9 <sup>th</sup> & W Norris	37.2	1.82	33.69	1.41	0.27

\* CFS is cubic feet per second

The simulation results showed that the greening approach reduced the annual total runoff and peak discharge from those sites. The average annual runoff reduction from all sites except site at 3<sup>rd</sup> Street and N. Bordine Street was about 30% and the average peak runoff reduction was about 24%. For site at 3<sup>rd</sup> Street and N. Bordine Street, those numbers were 75% and 41%, respectively. This high reduction was due to the removal of an impervious surface which is 25% of the total area on that site. The values of runoff of other four lots were similar because the same restoration measure used while the site at 3<sup>rd</sup> Street and N. Bordine Street was slightly higher than others. The possible reason for this difference is the steeper slope on this site contributes to shorter concentration time (Tc) and the runoff will form earlier than on other sites. A calculation showed that the Tc for site at 3<sup>rd</sup> Street and N. Bordine Street was 0.08 hr for a 2 year storm while Tc value for other sites were all over 0.1 hr.

## **Discussion**

The findings show that stormwater runoff reduction was achieved by using greening approach. The unit cost associated with this approach is higher than that of conventional BMPs, such as detention basin and grass swale but is parallel to infiltration trench (Office of Water, EPA 1999). However, conventional approaches may not be feasible, or practical in dense urban situations. For example, retention basins have the lowest cost but are not acceptable due to the health/safety concern associated with free-standing water. Nevertheless, the benefits/costs ratio of the greening approach can be improved with the following measures:

(1) Keep the topographic change and grading work to a minimum. The cost of this part of work accounts for 85%-97% of the total cost. The study indicates that the site with the most dramatic grading approach (at 3<sup>rd</sup> St. and N. Bordine St) did not have a significantly higher stormwater detention capacity. On the contrary, the runoff was even slightly higher than on other sites.

(2) Increase tree and shrub cover where possible. The current tree canopy cover rates on those sites are only between 2.33% and 4.07%. Trees can intercept as much as 36% of the rainfall in summer as shown by a study in Sacramento, CA (Xiao et al. 1998). To improve the stormwater reduction efficiency, the tree densities can be increased on those sites. Increasing shrub cover can also improve the stormwater detention capacity. However, according to PHS, shrub is expensive to maintain on those sites so it is not an option here.

(3) Add more social/recreational functions to stormwater detention sites. During the field survey, the neighborhood residents frequently interacted with us and requested adding play or recreation facilities. Neighborhoods can be more involved in maintaining sites if they can use the sites for recreational activities, such as, sitting, gardening or play. Some uses can be integrated without sacrificing stormwater benefits. The relatively high cost of installation can be better justified if the sites also provide other important civic functions.

The limitations of this study should be kept in mind. The stormwater benefits were estimated by using the best available knowledge and models, such as SWMM. However, there are uncertainties imbedded in the results which could be better addressed if data from on-site monitoring were available for calibration and verification purposes. On-site monitoring work was not part of this study due to budget and time restrictions. It is highly recommended that PHS incorporate an on-site monitoring component in future programs. Such monitoring will improve the accuracy of the results and will contribute significantly to general understanding of urban hydrology.

## Reference

- Akan, O. A., and Houghtalen, R. J. (2003) *Urban hydrology, hydraulics, and stormwater quality-Engineering applications and computer modeling*. John Wiley & Sons, Inc. Hoboken, New Jersey.
- Accordino, J., and Johnson, G.T.(2000) “Addressing the vacant and abandoned property problem.” *J. urban Aff.* 22(3), 301-315.
- Dingman, S. L. (2002) *Physical hydrology, second edition*. Prentice Hall, Upper Saddle River, New Jersey.
- Goldstein, J., Jensen, M., and Reiskin, E. (2001) “Urban vacant land redevelopment: Challenges and progress.” Working paper, Lincoln Institute of Land Policy. <http://66.223.94.76/pubs/PubDetail.aspx?pubid=91>. (August 21, 2007).
- Lopez, R. R., and Hynes, H. P. (2006) “Obesity, physical activity, and the urban environment: public health research needs”. *Environ Health Global Access Sci Source*. 5(25) <http://www.ehjournal.net/content/5/1/25>. (August 21, 2007)
- Pitt, R., and Bozeman, M. (1980) “Water Quality and Biological Degradation in an Urban Creek.” *Urban Stormwater and Combined Sewer Overflow Impact on Receiving Water Bodies*, Proceedings of the National Conference, Orlando, Florida November 26-28, 1979, Environmental Protection Agency Report EPA 600/9-80-056, December, 1980. pp 371-405
- Pitt, R., Lantrip, J., Harrison, R., Henry, C.L., and Xue, D.S. (1999) *Infiltration through disturbed urban soils and compost-amended soil effects on runoff quality and quantity*. EPA/600/R-00/016. <http://www.epa.gov/ednrmrml/publications/reports/epa600r00016/beginningsection.pdf>. (August 12, 2007)
- Pennsylvania Department of Environmental Protection. (2007) *Pennsylvania Stormwater Best Management Practice Manual*. <http://www.dep.state.pa.us/dep/subject/advcoun/Stormwater/stormwatercomm.htm>. (August 20, 2007)
- Office of Water, Environmental Protection Agency. (1999) *Preliminary Data Summary of Urban Stormwater Best Management Practices*. EPA-821-R-99-012 [http://www.epa.gov/waterscience/guide/stormwater/files/usw\\_a.pdf](http://www.epa.gov/waterscience/guide/stormwater/files/usw_a.pdf). (August 20, 2007)
- Xiao, Q. F., McPherson, E. G., Simpson, J. R., and Ustin, S. L. (1998) “Rainfall interception by Sacramento’s urban forest”. *J. Arboricult.* 24 (4), 235-244.