A High-Density, Low Impact Development with Infiltration in a Limestone Area: The Village at Springbrook Farms

Andrew Potts, P.E., M. ASCE; Michele Adams, P.E., M. ASCE; Thomas Cahill, P.E.

Abstract

This paper describes the site evaluation, design, permitting, and construction of a Low Impact Development stormwater management system for a 259-unit residential development on 23.9 hectares (59 acres) in Lebanon County, PA.

Stormwater management is achieved by the use of 124 storage/infiltration elements distributed throughout the site. These elements are integrated into the built landscape and include vegetated infiltration beds, pervious concrete sidewalks, vegetated infiltration swales, rain gardens, infiltration beneath standard driveway parking areas, porous asphalt pathways, and similar landscape/stormwater elements. These elements are designed to reduce runoff volume and maintain the natural hydrologic balance. The system is designed such that there is no increase in the volume of runoff after development for the 2-year frequency, 24-hour duration storm event, and no increase in peak flow rates for the 1-year through 100-year storms.

One benefit of LID is that projects often incorporate many distributed BMPs to manage stormwater “close to the source.” The challenges of developing calculations with traditional engineering methodologies for a site that includes many volume-control BMPs will also be discussed.

Introduction

When completed, the 23.9-hectare (59-acre) site in Campbelltown, PA will include 146 townhouses, 96 quad units, 17 single-family homes, a community center, public and private roads, public bicycle paths, and related amenities. As shown in Figure 1, the stormwater management system for this dense residential development will consist
Figure 1. Conceptual plan showing distributed stormwater system

of 124 stormwater Better Management Practices (BMPs) distributed throughout
the site.

Interesting components of this project include its location in a karst topography
that is marked by large "closed depressions" (Figure 2) and underlain by limestone that
has experienced sinkhole activity prior to development. Since much of the site had no
off-site drainage prior to development, meeting the regulatory peak rate control criteria
was especially challenging. Specifically, this paper will cover the project from design and
site investigation through construction of Phases 1, 2, 3 and 7 from 2004 to 2006,
including:

- Geotechnical investigation and sinkhole remediation
- Infiltration and soils investigation
- Critical coordination among design team
- Detailed BMP design
- Considerations for BMP design (overflow, distance to sinkholes, maintenance,
etc.)
- Calculations for volume control
- Calculations for peak rate control, including detailed routing analysis for one sub-
area
• Construction coordination and other issues
• Municipal considerations

Figure 2. Existing site with closed depression drainage before development

**Site Description**

Prior to development, the site was under active cultivation for row crops (soybeans and corn) and was characterized by a gently rolling topography marked by closed depressions and some sinkholes. According to the Lebanon County Soil Survey, the soils at the site are primarily Duffield silt loam (Hydrologic Soil Group “B”) with some Hagerstown silt loam (HSG “C”) and a small amount of Clarkesburg silt loam (HSG “C”). Of the 23.9 total hectares (59 acres), approximately 21.2 hectares (52.3 acres) are “B” soils with the remaining 2.7 hectares (6.7 acres) being “C.”

Based on Pennsylvania geologic mapping reports and maps (Figure 3), the site is underlain entirely by limestone formations, primarily the Buffalo Springs formation with some Snitz Creek formation. The Stonehenge formation also lies just to the north of the site. All of these formations are susceptible to subsidence and sinkhole formation. Approximately 45% of the site (10.8 hectares), mostly on the northern side, drains internally to closed depressions during normal storm events. The southern side of the site generally drains to surface channels along the southeast and southwest borders of the site.

**Geotechnical investigation and sinkhole remediation**

Designing an effective stormwater management system in a limestone area
Figure 3. Geologic formations in the site area

requires careful consideration of the existing conditions and the risk of subsidence/sinkholes. Stormwater infiltration can and should be maintained in many settings but cannot be over-concentrated in one location. Stormwater should infiltrate into a soil mantle of suitable depth to remove pollutants and control the rate of infiltration. Areas of sinkholes and potential sinkholes must be avoided.

To understand the conditions at the Springbrook site, a detailed site investigation was conducted including:

1. A desktop review of geologic and hydrogeologic maps and publications; as well as aerial photographs.
2. Discussions with the previous owner concerning the history of sinkhole formation on the site.
3. A field survey to locate existing sinkholes and closed depressions.
4. A field investigation of soil probes to determine the depth of soil mantle and depth to rock across the site. 178 rock probes were dug in a grid pattern across the proposed development area: 56 to a depth of 7.3 meters (24 ft) and 122 to a depth of 4 meters (13 ft).
5. A series of test pits were investigated across the site to visually inspect and
understand the subsurface conditions. These deep holes were excavated to a depth of approximately 7-8 feet to visually observe conditions. Twenty-seven soil test pits w/ 53 percolation tests (discussed later) were performed.

Additionally, a geotechnical engineer was consulted and performed additional testing near existing sinkholes and closed depressions and provided recommended sinkhole repair procedures.

**Infiltration and Soils Investigation**

The existing site soils are well drained, and the silt loam provides significant cation exchange capacity for pollutant removal, with the ability to remove most surface pollutants that may infiltrate (notable exceptions may be nitrate and chloride which are very soluble and tend to migrate through the soil). To verify existing infiltration capacity, Cahill Associates analyzed the soil in April 2003 by examining 27 test pits (2 m average depth) and performing percolation tests at two depths in each test pit (Figure 4). No bedrock or indications of seasonally high water table were encountered and the measured in-situ infiltration rates were good in the subsoil, up to 25 cm/hr (9.8 in/hr), with an average in the deeper soil of 6.4 cm/hr (2.5 in/hr). Due to the potential for subsidence, the infiltration bed bottoms have been kept as close to the existing surface elevations as possible (i.e., excavation and grading are kept to a minimum, except for the removal of topsoil). For the purposes of the stormwater calculations a safety factor of two was applied to the average percolation rate in the deeper soil, resulting in an applied rate of 3.2 cm/hr (1.25 in/hr).

![Figure 4. Detailed soil and subsurface investigations were conducted prior to design](image)
Calculations for Stormwater Volume and Peak Rate Control

The existing site drainage conditions presented an unusual situation for the stormwater management design and analysis. Much of the site drained to the closed depression areas, with no apparent surface runoff occurring. Runoff infiltrated within each small catchment, sometimes forming shallow ponds which slowly infiltrated. Direct surface runoff, however, did not occur beyond the closed depressions for much of the site under normal conditions.

This presented several stormwater management challenges. For portions of the site, the “Before” or “Pre-Developed” runoff condition was essentially zero for both the rate of discharge and the volume of runoff. Because of this topography, conventional stormwater collection and conveyance systems would require excessive grading and excavation which is costly and an undesirable construction approach in soils over limestone formations.

Based on discussions with the local reviewing agencies, the site was analyzed as though runoff could occur from the closed depressions during extreme events, and the following stormwater management strategy was applied:

- For volume control, the various BMPs were designed so that there would be no increase in the volume of runoff after development for the 2-year, 24-hour storm event of 7.6 cm (3.0 inches).
- For peak rate control and to prevent localized flooding, the various stormwater BMPs were interconnected with a shallow piping system capable of conveying the 2-year through 100-year flow rates without overtopping the BMPs or creating damaging flooding.

This strategy was achieved by the use of 124 storage/infiltration elements distributed throughout the site. These elements are integrated into the built landscape and include vegetated infiltration beds, pervious concrete sidewalks, vegetated infiltration swales, rain gardens, infiltration beneath standard driveway parking areas, porous asphalt pathways, and similar landscape/stormwater elements (Figures 5 to 10).

Figure 5. Porous concrete sidewalks
Figure 6. Construction of vegetated infiltration swale and overflow structure with weir

Figure 7. Porous Asphalt Bicycle Path
Figure 8. Rain garden in common quad unit area

Figure 9. Decorated single-family residential rain garden
Each BMP was located and sized based on the drainage area to that BMP, with consideration of both the storage volume and the surface area required to “spread the water out” and avoid over-concentrating infiltration. The design attempted to keep the loading ratio (the ratio of impervious area draining to the BMP to the BMP area itself) at or below 3 for many of the BMPs, with a maximum ratio of approximately five.

During the design process, detailed routing of one sub-area was performed by carefully routing each BMP based on its stage-storage-discharge characteristics to confirm that control of volume and travel time would reduce peak flow rates in large storms.

**Considerations for BMP Design**

The proposed plan includes over 90 infiltration systems in the townhouse and quad unit areas and an additional 34 among the single-family homes. Table 1 summarizes the total storage available in the various BMP types and Table 2 shows detailed properties of the surface infiltration beds as an example. The BMPs cover 3.03 hectares (7.49 acres) of the site and are capable of permanently retaining and infiltrating at least $5,430 \text{ m}^3$ (4.40 ac-ft) of runoff, as well as temporarily detaining an additional $1,150 \text{ m}^3$ (0.93 ac-ft), while infiltrating considerably more during large storm events ($3,610 \text{ m}^3$ or 2.93 ac-ft over approximately 4 hours).
Table 1. Total available storage by BMP type

<table>
<thead>
<tr>
<th>Facility</th>
<th>Storage Volume (CF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain Gardens</td>
<td>6,509</td>
</tr>
<tr>
<td>Surface Infiltration Beds</td>
<td>70,670</td>
</tr>
<tr>
<td>Infiltration Beds</td>
<td>41,543</td>
</tr>
<tr>
<td>Porous Pavement Beds</td>
<td>2,506</td>
</tr>
<tr>
<td>Porous Asphalt Pathway</td>
<td>13,847</td>
</tr>
<tr>
<td>Trench Beds</td>
<td>46,852</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>182,125</strong></td>
</tr>
</tbody>
</table>

**4.18 ac ft.**

Table 2. Detailed properties of Surface Infiltration Basins

<table>
<thead>
<tr>
<th>No.</th>
<th>BB Area (SF)</th>
<th>Surface Area (SF)</th>
<th>Overflow Area (SF)</th>
<th>Average Surface Area (SF)</th>
<th>Volume to Overflow (CF)</th>
<th>Add'l Vol to Berm (CF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,900</td>
<td>4,500</td>
<td>5,560</td>
<td>5030</td>
<td>6,055</td>
<td>2,515</td>
</tr>
<tr>
<td>2</td>
<td>3,500</td>
<td>1,500</td>
<td>2,170</td>
<td>1835</td>
<td>3,018</td>
<td>918</td>
</tr>
<tr>
<td>3</td>
<td>3,870</td>
<td>780</td>
<td>1,520</td>
<td>1150</td>
<td>2,897</td>
<td>748</td>
</tr>
<tr>
<td>4</td>
<td>2,570</td>
<td>1,300</td>
<td>1,730</td>
<td>1515</td>
<td>2,300</td>
<td>1,515</td>
</tr>
<tr>
<td>5</td>
<td>2,650</td>
<td>2,200</td>
<td>2,700</td>
<td>2450</td>
<td>2,815</td>
<td>3,063</td>
</tr>
<tr>
<td>6</td>
<td>4,780</td>
<td>1,420</td>
<td>1,770</td>
<td>1595</td>
<td>3,666</td>
<td>2,393</td>
</tr>
<tr>
<td>7</td>
<td>6,330</td>
<td>6,200</td>
<td>8,200</td>
<td>6200</td>
<td>6,898</td>
<td>1,860</td>
</tr>
<tr>
<td>8</td>
<td>3,100</td>
<td>2,020</td>
<td>2,020</td>
<td>2020</td>
<td>2,870</td>
<td>1,111</td>
</tr>
<tr>
<td>9</td>
<td>7,700</td>
<td>7,260</td>
<td>8,110</td>
<td>7685</td>
<td>8,463</td>
<td>3,074</td>
</tr>
<tr>
<td>10</td>
<td>8,270</td>
<td>11,940</td>
<td>12,720</td>
<td>12330</td>
<td>11,127</td>
<td>4,932</td>
</tr>
<tr>
<td>11</td>
<td>10,400</td>
<td>12,830</td>
<td>14,190</td>
<td>13510</td>
<td>12,995</td>
<td>9,457</td>
</tr>
<tr>
<td>12</td>
<td>6,600</td>
<td>7,080</td>
<td>8,150</td>
<td>7615</td>
<td>7,768</td>
<td>6,092</td>
</tr>
<tr>
<td>13</td>
<td>65,670</td>
<td>59,030</td>
<td>66,840</td>
<td>62935</td>
<td>70,870</td>
<td>37,676</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>65,670</strong></td>
<td><strong>59,030</strong></td>
<td><strong>66,840</strong></td>
<td><strong>62935</strong></td>
<td><strong>70,870</strong></td>
<td><strong>37,676</strong></td>
</tr>
</tbody>
</table>

**Construction Issues**

Issues that arose during construction include:

- The need to continuously maintain rigorous erosion and sediment control measures.
- The presence of limestone pinnacles. When this occurred, stormwater BMPs were adjusted in the field to avoid excavation of limestone or the placement of infiltration directly on limestone.
- The need to coordinate overall site construction with stormwater BMP construction, in terms of phasing, site protection, and materials (Figure 11).

As of late 2006, construction of Phases 1 and 7 are nearing completion and that of Phases 2 and 3 are underway. One of the final elements will be the installation of signs and identifying markers for long-term location and maintenance of the BMPs.
Acknowledgements

RGS Associates served as the Landscape Architect for the project and played a critical role in the design and integration of these stormwater landscape elements. Careful grading and limited excavation were a design goal and were carefully developed by RGS Associates. The developer, Brownstone Real Estate Co., made this project possible through their flexibility, open mindedness, and foresight. The site contractor, Abel Construction, has also been a critical partner in the project: from participation in planning and design meetings to the actual site construction.