2024

Elm Avenue Storm Drain Outfall Surge Control

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Abstract

I designed a control structure just past the storm drain outfall at the end of Elm Avenue near Swarthmore College's North entrance. This structure will allow the large, fast-moving flow from the outfall to be discharged in a more controlled manner after rain events, preventing erosion and damage to the Crum Woods downstream of the outfall. To create my design, I consulted with experienced professionals and created a model of the contributing drainage area to determine the site needs and characteristics to decide an appropriate design. For the design itself, I used CAD and GIS software to model the size, shape, and location of the physical structures to be designed. I will pass on the design to the College so they can decide whether they actually want it constructed, but any further steps lie outside the scope of this project.

Introduction

The storm drain and adjacent outfall at the end of Elm Avenue near Swarthmore College's North entrance has been a perennial problem for the Crum Woods, into which the outfall faces. Due to local topography and infrastructure design, the stormwater which passes through this drain system is unusually high in both volume and velocity. These high energy flows have been causing erosion downstream of the outfall in the woods, and this erosion will continue to worsen without intervention. My design to address these problems is a system to temporarily capture and store this flow, so that it can be discharged in a more controlled manner to avoid further erosion.

Procedure

The design happened in stages. First, I consulted with an expert in the field of stormwater management, combining their expertise with my own current knowledge and future research to determine an appropriate type of design for the particular site conditions faced.

Based on that, I then model the site conditions by using data of the site topography to determine the contributing drainage area. Once all these steps are completed, I could move to the actual design. I used CAD software to model my design, and use that to create a set of engineering drawings that will constitute the design itself.or the site conditions at all stages.

Methods

The major issue at hand is the volume and velocity of flow passing through the storm drain outfall during peak events. This flow is dependent on many factors, including but not limited to:

- Amount of rainfall
- Contributing drainage area
- Soil types and infiltration rates
- Impervious surface coverage and land use
- Slope

These factors all influence the design of stormwater management facilities. According to PennDOT, “The design criteria for storage facilities should include:

• Release rate.

• Storage volume.

• Grading and depth requirements.

• Outlet works and location.

• Freeboard above the maximum water surface elevation.

• Time to dewater.

• Provisions for maintenance (such as slope limitations and access ramps).” (1)

Release rate is regulated by Pennsylvania’s Storm Water Management Act (Act 167), which sets targets for various Pennsylvania watersheds. Storage volume is based on the site characteristics that impact flow, with a design storm (i.e. a particular amount of rainfall in a 24 hour period) to be chosen from project needs. Other requirements are also subject to Act 167 regulations, to ensure that hydrographic changes caused by new structures do not have an adverse effect on the larger watershed.

Design Goals

Additional regulation comes from Swarthmore Borough. Design criteria are determined by the Act 167 SWM Plan for the Crum Creek Watershed (3). According to this plan, the site is made of of Type B (Moderate infiltration) soils and has residential land cover with lot sizes ⅓ to 1 acre (3). The site falls within a region designated subarea 73, in the B management district. This means that peak rate controls are required to reduce runoff rates from design storms as such:

Table 1: Runoff Reduction Requirements for Crum Creek Watershed Management District B

Before	After
2 year	1 year
5 year	2 year
10 year	5 year
25 year	10 year
50 year	25 year
100 year	100 year

According to the NOAA, the predicted amount of precipitation at the site for each of these storms in a 24 hour period is as follows (4):

Table 2: PDS-based precipitation frequency estimates with 90% confidence intervals (in inches) for Swarthmore Borough

Storm frequency	1	2	5	10	25	50	100

(yr)							
Precipitation (in)	**2.69**(2.48-2.94)	**3.25**(2.99-3.55)	**4.10**(3.77-4.48)	**4.82**(4.41-5.25)	**5.86**(5.34-6.38)	**6.75**(6.11-7.33)	**7.72**(6.94-8.36

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Via TR-55, the runoff depth can be calculated as a function of rainfall depth and site characteristics with the SCS runoff curve number method. This method calculates the runoff with the following formula:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$$

where Q is the runoff depth, P is the rainfall depth, and S is the potential maximum retention after runoff

begins. S is related to the curve number CN with the following equation:

$$S = \frac{1000}{CN} - 10$$

With the site characteristics described earlier, i.e. type B soils in a residential district with ½ acre lots on average, the site can be determined to have

CN = 70.

Using this value, the rainfall amounts for design storms, and the drainage area of the site (as calculated below), peak runoff volume can be calculated for storms of various frequencies. The goal of the design will be to temporarily capture a sufficient portion of the runoff to reduce the runoff rates from storms of each frequency by the amounts described in Table 1.

Storage Depth

With the values described above, the necessary depth of rain to be stored could be determined. The runoff reduction requirements give the storage requirements in terms of the difference between storms of varying frequency, and thus intensity. The formula for runoff depth was calculated for each storm frequency, and the difference between them gave the necessary depth of rainfall to be stored, as described in table 3 below:

Table 3: Rainfall Storage Requirements for Detention Facility

Design Storm	Acceptable Flow Release Storm Equivalent	Initial Runoff Depth (in)	Target Release Depth (in)	Storage Depth Requirement (in)
2 year	1 year	0.549	0.214	0.335
5 year	2 year	0.857	0.549	0.308
10 year	5 year	1.397	0.857	0.539
25 year	10 year	1.904	1.397	0.507
50 year	25 year	2.695	1.904	0.791

For design purposes, the maximum value of 0.791 in. was used to determine the storage volume requirements. No safety factor was applied to this value because the runoff formula implicitly accounts for the necessary safety factor (5). Once the drainage area for the storm drain was determined, the drainage area could be multiplied by the necessary storage depth to obtain the necessary storage volume.

Drainage Area

The drainage area of the storm drain was determined via hydrologic analysis of the surrounding area, as shown in Figure 1 below:

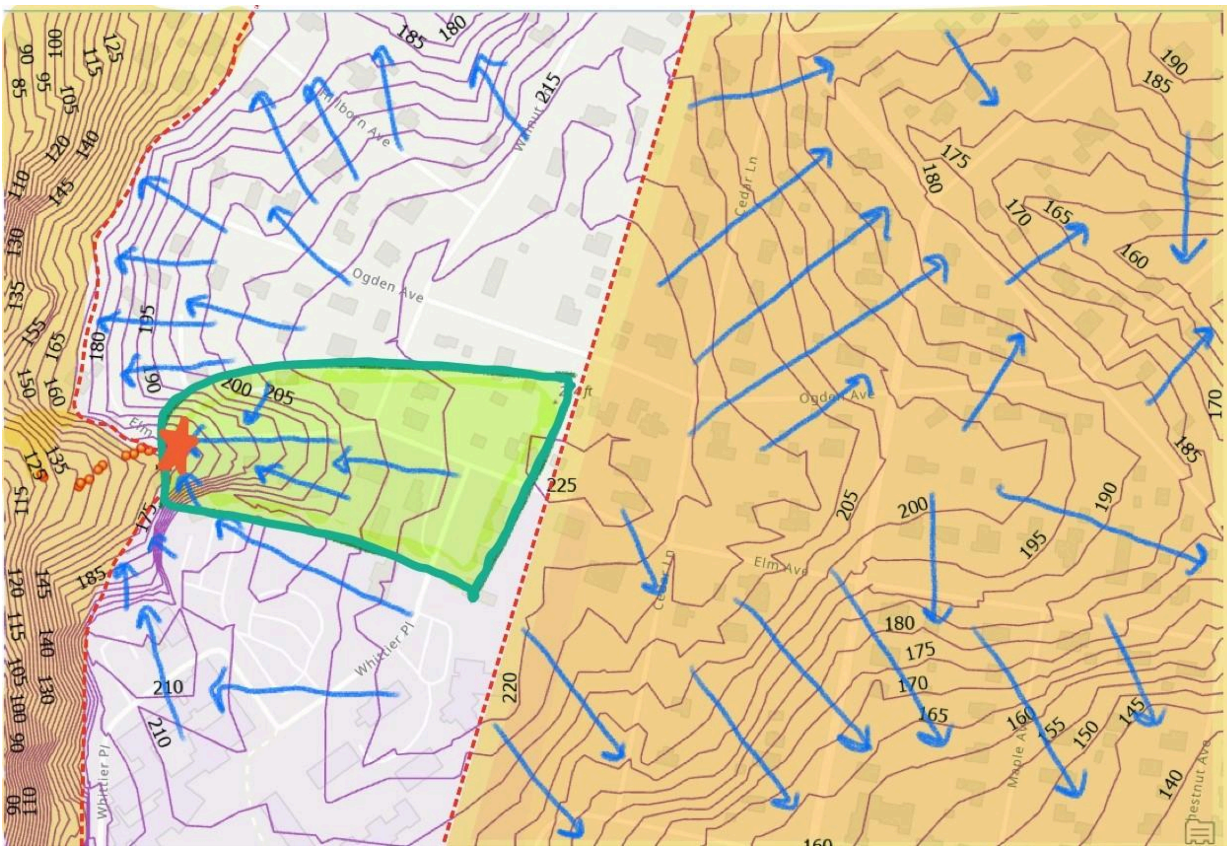

Fig. 1: Contributing Drainage Area for Elm Avenue Storm Drain Outfall

The drainage area, shown in green, represents the area from which stormwater runoff is likely to reach the storm drain outfall, marked with a red star, in its flow path. The purple lines, labeled in black, represent contours of elevation above sea level. Principles of hydrology demonstrate that flow paths of water across Earth's surface are perpendicular to contours of elevation. This principle is visually represented by blue arrows in Figure 1, showing probable flow paths at different points near the storm drain outfall.

Analysis of this drainage area using ArcGIS Pro software revealed the area to be approximately 82,000 m^2, or about 20 acres. With this value in hand, the necessary storage volume could be determined.

Storage Volume

A depth of 0.0659 ft. over an area of 883,000 ft^2 gave a required storage volume of 58,200 ft^3. With this value in hand, the site topography could be analyzed to determine the necessary dimensions of the detention facility.

Facility Dimensions

Pennsylvania DOT regulations provide several options for determining the shape and dimensions of facilities. Due to the existing channel conveying flow, a trapezoidal basin was determined to be most appropriate for the site conditions (5). According to these regulations, “The prismoidal formula for trapezoidal basins is expressed as:

V = LWD + (L + W) ZD2 + 4/3 Z2 D3

where: V = volume of trapezoidal basin, m3 (ft3)

L = length of basin bottom, m (ft)

W = width of basin bottom, m (ft)

D = depth of basin, m (ft)

Z = side slope factor, ratio of horizontal to vertical” (5)

On site, the left slope was measured to be 36°, and the right slope was measured to be 18°. Since the design calls for symmetrical side slopes, it was decided that the design include soil fill on the left slope to make both sides symmetrical. Additionally, the reduction in grade would contribute to the design goal of erosion prevention.

The width of the existing channel was measured to be about 12’ 8”. Due to the slope of the channel, the length L was able to be estimated as a linear function of the depth D. The channel slope was measured to be 16.7°, almost precisely a 3:1 slope. A depth of 5 ft was determined to be ideal. This depth would maximize both safety of the design and storage volume. The following values were therefore determined for the basin:

Table 4: Basin Dimensions

Side slope factor	3.08
Depth of basin (ft)	5
Length of basin bottom (ft)	4.08
Length of basin (ft)	15
Volume (ft^3)	2236

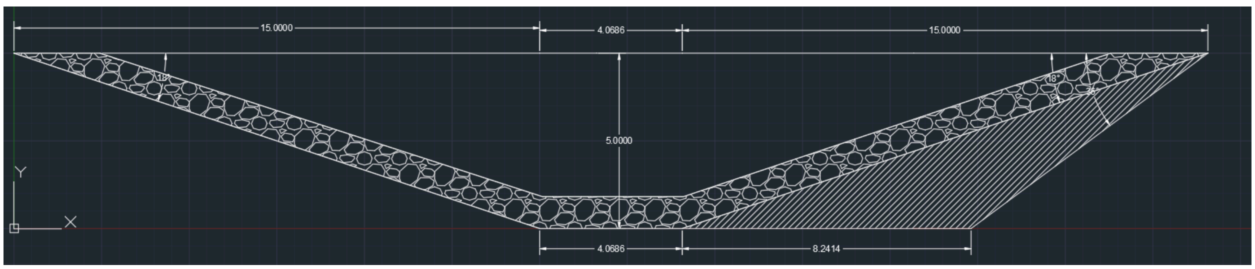

Fig. 2: Storage Basin Front Profile

As shown in figure 2, the basin would have a base width of about 4 ft, and a total width of 34 ft. The basin would be lined with rock, with soil fill (shown by shaded area) to make the facility symmetrical.

This design would necessitate a removal of soil from the upper end of the facility to make the bottom of the facility flat, increasing cost and complexity. However, this design has two major advantages. First, the increase in depth allows for a smaller footprint of the design, and less impact on the surrounding environment and nearby homeowners. Second, removal of earth directly adjacent to the outfall creates a physical drop for the flow, which will assist in dissipation of flow velocity, a major source of the scouring issues that were the impetus for this project. This change in grade can be seen in the side profile view of the facility design, as shown in figure 3 below:

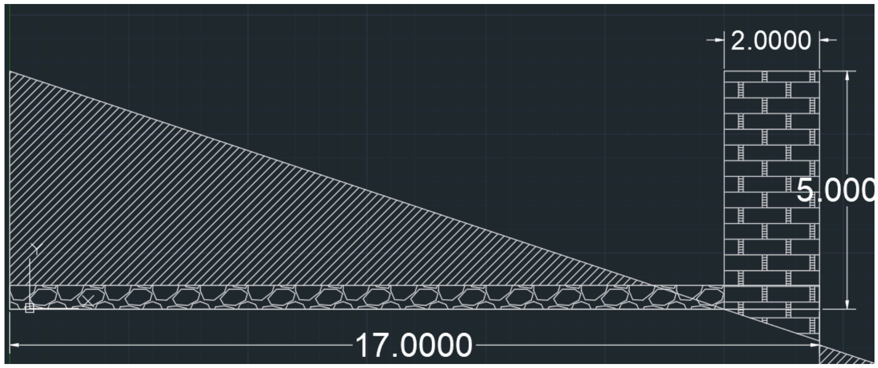

Fig. 3: Storage Basin Side Profile

The shaded area represents earth to be removed from the facility. The rock dam, with a height of 5 ft and a thickness of 2 ft, forms the lower end of the facility.

Basin Series

As shown in table 4, the design volume of the basin shown does not meet the design goal of 58,200 ft^3. To meet the design goal, 26 of these basins are needed. To fit the existing channel, these basins are to be placed in series, as shown in figure 4 below:

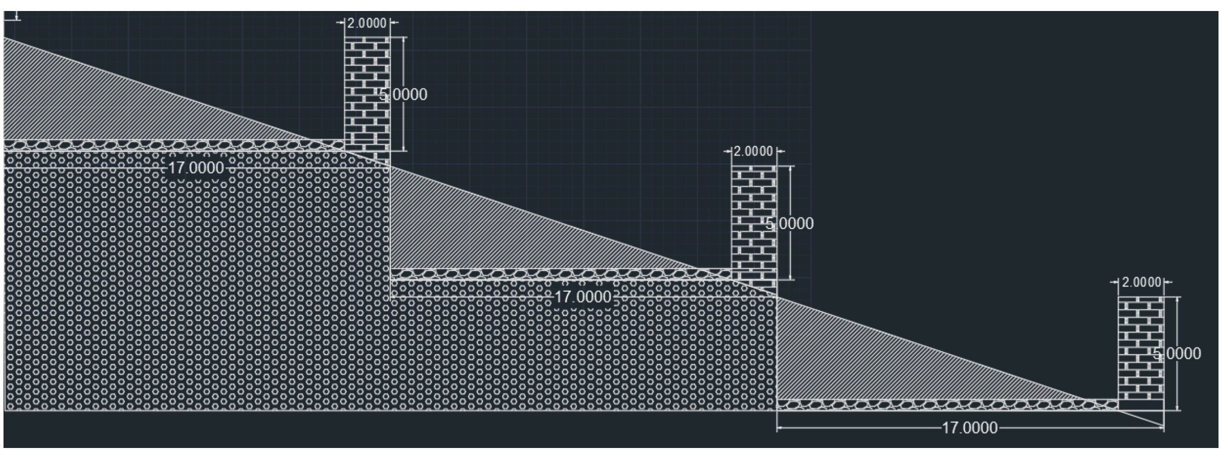

Fig. 4: Basin Series Side Profile View

To follow the channel, each successive basin would be placed at an angle to match the existing channel's direction. The path of the channel is shown in figure 5 below:

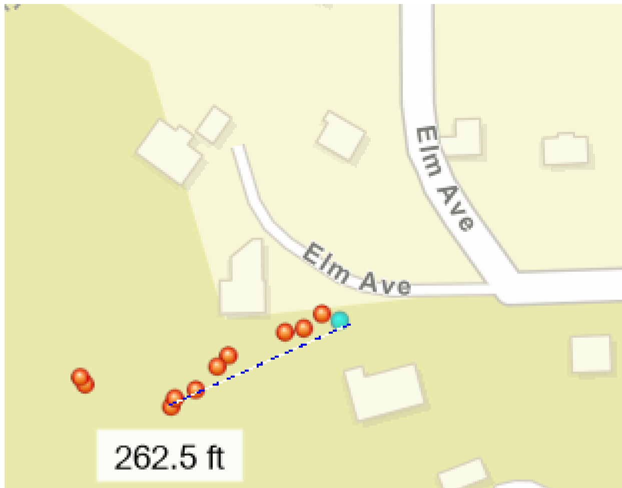

Fig. 5: Channel Path (marked in red)

As Figure 5 shows, the channel is roughly straight (within the margin of error for GPS measurements of about 30 ft) for a distance that would accommodate 15 basins in a simple linear series. The remaining 11 would need to be offset at an angle matching the channel's turns.

Sources

(1) https://www.dot.state.pa.us/public/bureaus/design/PUB584/PDMChapter14.pdf

[2] https://www.swarthmorepa.org/DocumentCenter/View/537/Stormwater-Management-Regulations?bidId=

[3] https://www.delcopa.gov/planning/pubs/CrumCreekWatershed167_Vols_I_II.pdf

(4)https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=pa

(5)https://www.dot.state.pa.us/public/bureaus/design/PUB584/PDMChapter07.pdf

(6)https://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section02-jan-rev.pdf