# Senior Design Spring 2017 Report

May 4th, 2017


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# Introduction

### Mission Statement

The mission of Cowboy Stormwater Management is to design and implement sustainable storm and surface water systems that control erosion damage from stormwater runoff, improve urban development, and enhance quality of life in Stillwater, OK.

### Project Summary

Park View Estates in Stillwater, OK is experiencing erosion and flooding in certain locations due to a high volume of stormwater and a poorly designed water management structures. To address this problem, Cowboy Stormwater Management (CSM) is tasked to develop solutions at several different "problem sites". These sites will each have a design that will function to ultimately improve the control of stormwater in the neighborhood. Several design options of varying costs were presented to the Park View Estates Homeowner's Association (HOA) in December 2016. In January 2017, a preferred cost option was chosen. During the months of January to April 2017, a final design was constructed.

### Project Parameters

*Client Requirements*

- Eliminate ponding in streets and yards
- Reduce erosion in public area
- Reduce streambank erosion
- Provide three cost-based solution options

*Project Constraints*

- Solutions must have a feasible cost/benefit ratio
- Solutions must be safe after implementation
- Solutions must have a natural appearance
- Solutions must have a long life span

**Deliverables**

Cowboy Stormwater Management will deliver solutions to the Park View Estates Homeowner's Association that will reduce the stormwater runoff damage they are experiencing on their property. CSM will provide a document containing a preliminary plan that will detail high cost, medium cost and low cost solutions for the HOA to review. These solutions will include approximate time spans for which the solutions can be implemented by the homeowner's association. This document will be given to the HOA by December 9th, 2016. It will be the responsibility of Park View Estates HOA to review the document and decide upon which option they prefer by January 17th, 2017. Cowboy Stormwater Management will then focus on the chosen plan for the remainder of the project.

Cowboy Stormwater Management will provide a document containing a finalized plan to the Park View Estates HOA. This document will detail the final draft of the solution plan that the HOA decided upon in December/January. This draft will contain a thorough cost analysis, time spans, and means of implementation. The document will be provided to Park View Estates HOA no later than April 21st, 2017.

| Item | Media | Due Date |
|---|---|---|
| Preliminary cost-based solutions | Document | December 9th, 2016 |
| Final Draft of chosen solution | Document | May 4th, 2017 |

**Project Scope**

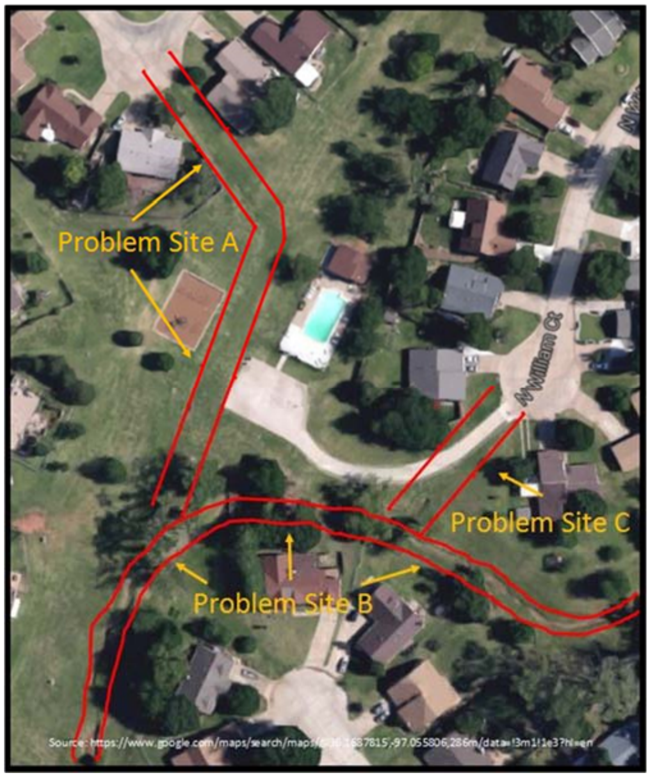


Figure 1. Problem Site Locations

*Problem Site A*

Problem Site A encompasses the natural water way starting at 304 E. Marie Drive and ending at the swale outlet at the stream (Figure 1). Due to runoff from impermeable surfaces and an undersized drain, the cul-de-sac at 304 E. Marie Drive is experiencing flooding and ponding during storm events, as seen in Figure 2. The impermeable streets and driveways are not allowing for any infiltration. This creates a high volume of runoff directed to a drain that is under designed for the drainage area. The undersized drain results in overflow, causing ponding and erosion down the slope toward the stream. The grass swale that leads to the greenbelt area is poorly angled at about 1.8%. This poor grading has caused water to back up into the cul-de-sac and not flow downward toward the stream. Solutions to this site should focus on properly grading the grass swale.

The greenbelt area, for this problem site, is defined as the grassed area between the cul-de-sac drainage areas and the stream. There are several small, but severe, erosion sites in the greenbelt area. The outlet for the drain from 304 E. Marie has caused erosion resulting in a large hole. Also, in Figure 3 below, the area around a stump has been heavily eroded causing a large hole that is potentially hazardous.

Figure 2. Ponding at Cul-de-sac

Figure 3. Erosion around Stump

*Problem Site B*

Problem Site B is the entire stream that flows through the neighborhood. It has a total length of 1700ft. This stream is non-perennial as it only flows after rainfall events. With the large amount of runoff mentioned above, all of the water is being guided directly to the stream leading to erosion along the stream banks, as seen in Figure 4 and Figure 5 below. The erosion is responsible for several problems, such as large pools in the stream and sediment deposits, as well as sediment transport to Boomer Lake (Appendix D).

Figure 4. Erosion at Site B

Figure 5. Erosion near Walking Bridge

*Problem Site C*

Problem Site C is the area at the N. Williams Ct. cul-de-sac. This site is experiencing mild erosion along the pool driveway and at the storm drain outlet. The cul-de-sac has a drain that is potentially sized correctly, but the outlet riprap is undersized, leading to heavy erosion around the pipe and riprap washout, as seen in Figure 6. While the effects of this problem site are not detrimental to the management of the stormwater, it does negatively affect the aesthetic appearance of this location, especially since the pool driveway is a commonly used route to the public pool area. It was determined that this problem site would not have any immediate changes to it. The cost option that was selected by the HOA included that this site be left as it is. Future improvements can be implemented if desired by the HOA.

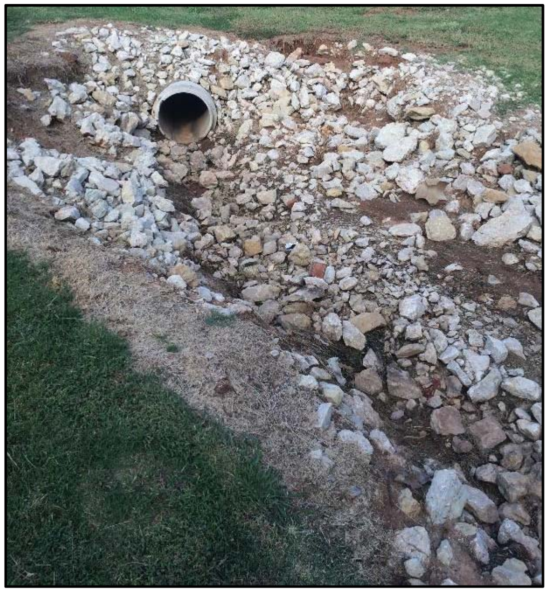

Figure 6. Erosion at Outlet at Problem Site C

**Task List**

- Determine client requirements
- Conduct research
  - Construct technical analysis
  - Conduct on-site surveying
  - Test soil types
  - Delineate watershed
    - Ground proof boundaries
    - Determine impervious area
- Investigate possible solutions
  - Understand technical feasibility
  - Attain customer acceptance
- Determine final solutions for each problem site
  - Develop three cost-based solutions
  - Analyze cost
  - Suggests individual homeowner applications
  - Attain customer acceptance/approval

- Design Problem Site A
    - Determine watershed
    - Determine peak flow
    - Determine channel characteristics
        - Slope
        - Shape
        - Inlet/outlet
- Design Problem Site B
    - Determine peak flow
    - Determine shape of grading
    - Include high and medium priority sites
    - Determine no-mow zone parameters
- Deliverables
    - Fall report
    - Spring final report

# Background Research

A technical analysis was constructed in order to provide information necessary on our preliminary designs. It covers any possible designs or solutions that the team might implement. This analysis can be found in Appendix B.

*Low Impact Development*

CSM wished to determine the feasibility of Low Impact Development (LID) practices at our problem sites. LID practices aim to reduce stormwater runoff by increasing water infiltration in the soil and using retention devices. Several LID solutions can be seen in Appendix B. The team investigated the soil types in the area to determine if stormwater would easily infiltrate or if the soil would need to be replaced for water to infiltrate quickly. We conducted a soil-by-feel test at several five different sites. The test sites were located at areas that could potentially have an enhanced bioswale or bioretention cell. The soil type from every test site was mostly clay. Significant infiltration could only be achieved by replacing the existing soil with a soil with higher porosity. We concluded that water infiltration would not be feasible for a low cost solution in any problem site.

*Watershed*

To delineate our watershed, we used the StreamStats website. This site uses topographic information from the USGS to determine watershed boundaries of a known stream. We chose a point at the end of the neighborhood stream to observe how much area was contributing to our stream (Figure 7). To confirm the results that StreamStats provided, several team members went to the watershed boundaries to check if the geographic conditions were consistent with the website. After ground proofing, we determined several small changes to our watershed boundary which were then edited on the StreamStats website.

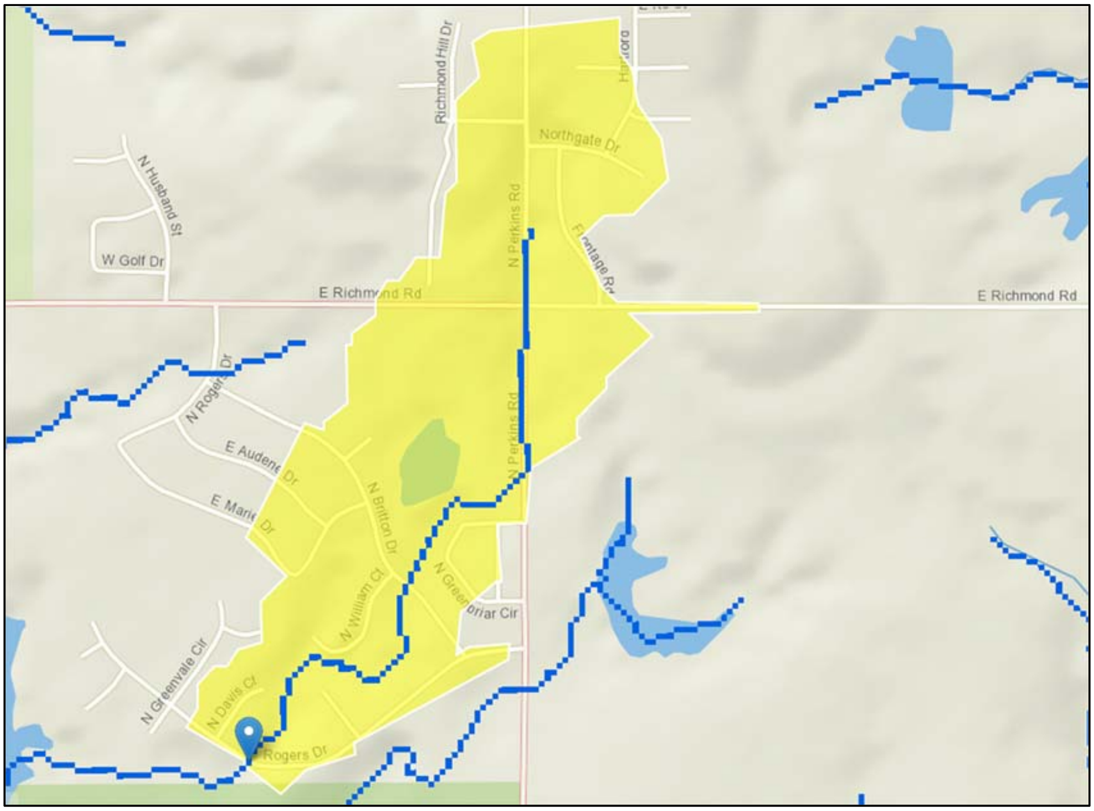


Figure 7. Watershed Boundary

*Sub-reaches*

The neighborhood was further separated into sub-reaches or sub-watersheds. We wished to determine which streets, roofs, and driveways contributed to our problem sites. To do this, topographic maps were utilized to see where the high points and changes in slope were. After this, we ground proofed the streets and separated the neighborhood according to separate water outlets (Figure 8 & Figure 9). This assisted us in determining stormwater parameters and flow calculations at Problem Site A.


Figure 8. Direction of Flow in Streets

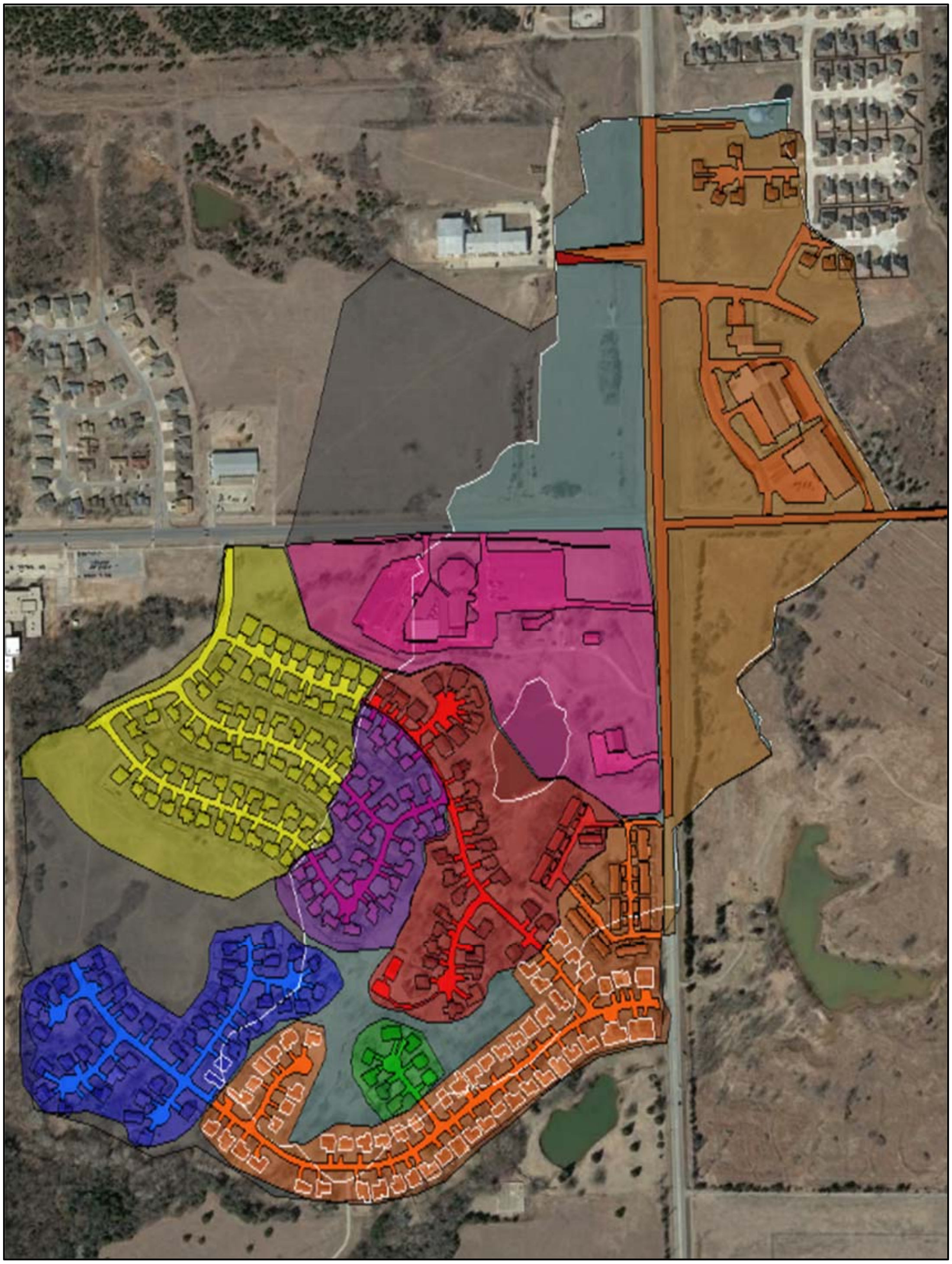

Figure 9. Entire Watershed and Sub-reaches

# Final Design

A finalized design was developed after the Park View Estates HOA chose a preferred solution in January, 2017. The “Methods” section details the engineering specifications that are should be considered in the construction and implementation process of the solution chosen by the HOA. The “Future Expansion” section details the suggested specifications on any additions to the final design. The “Costs” section details the rough costs for the design. The “Equations and Variables” section outlines the various equations that were used in the final design.

**Methods**

*Problem Site A*

The main issue in this area is ponding in the cul-de-sac after storm events are over. The water is supposed to flow towards the greenbelt area but is not able to do so due to the poor slope of the grass swale outlet. The current slope is at 1.8%. CSM suggests to regrade the grass swale to a more appropriate slope that will allow the water to leave the cul-de-sac without ponding. The current swale, up to about 120ft, is shaped parabolically. The houses on either side are raised in order to protect them from floods.

The design for this area is to partially regrade the middle of the swale. We want to have a 4% slope with for a 12ft wide channel that is parabolic in shape. This channel will continue until it reaches the hill in the greenbelt area. The total channel length will be approximately 150ft with a 30ft length hill as the outlet. Figure 10 shows the comparison of slopes between the original swale and the final design.

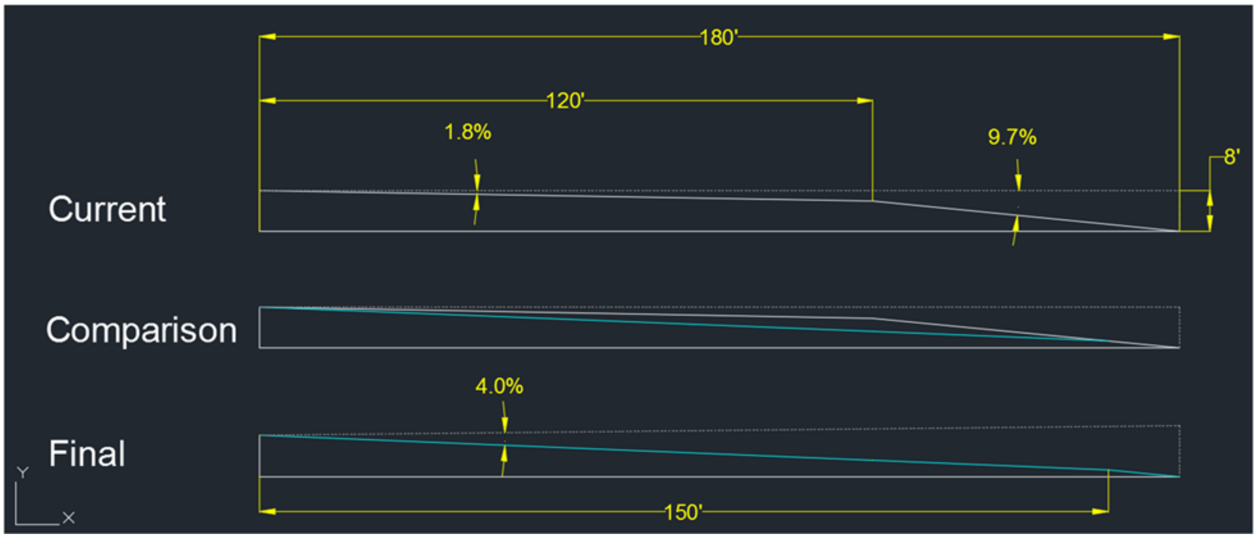


Figure 10. Site A Slope Comparison

The channel will be covered with sod to introduce grass that will stabilize the soil. The grass type should be bermuda, the same as the surrounding grass type. The rest of the swale will be unchanged. This will give the new swale a step shape for the first 120ft. The step shape is advantageous because it provides an area for larger amounts of water to go if the channel should flood. In this case, the water will have less concentrated energy due to the larger wetted area.

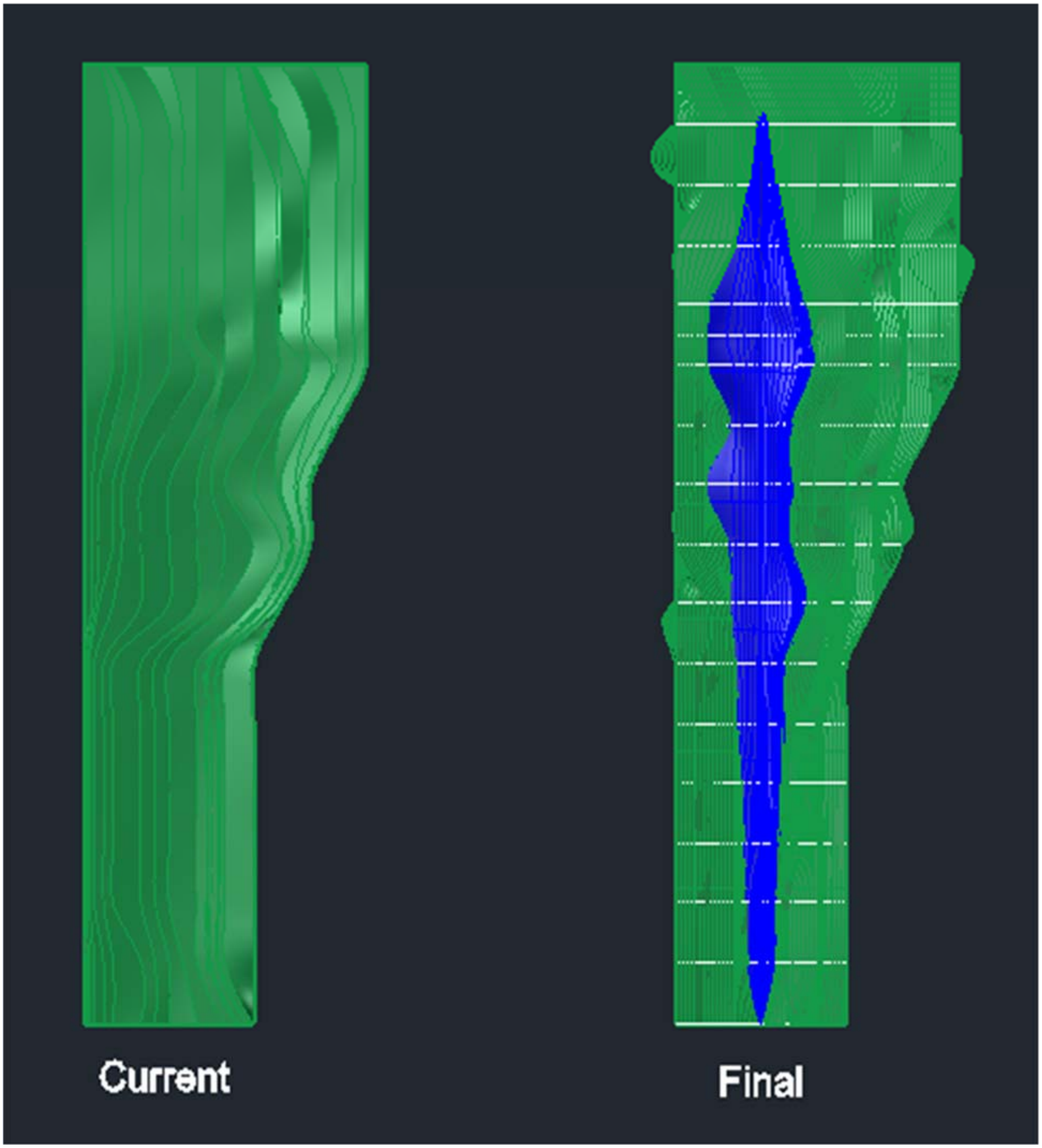


Figure 11. Top View of Site A Design

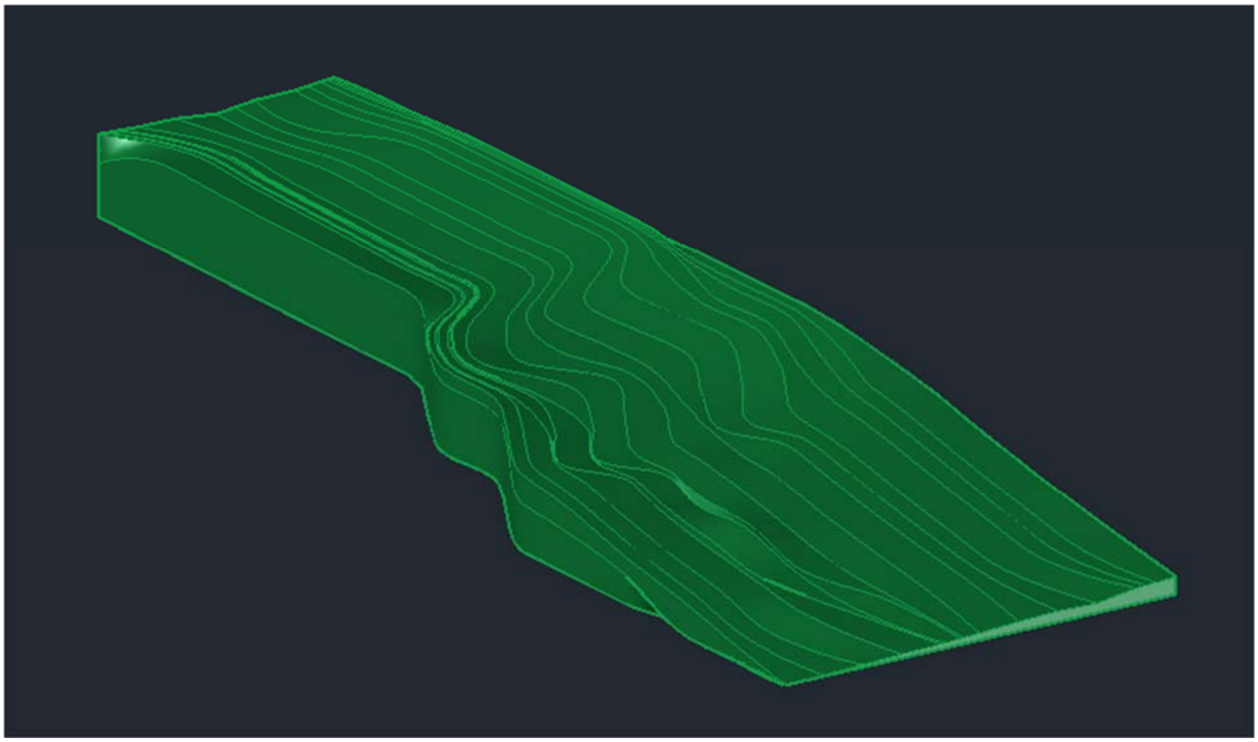

Figure 12. Isometric Site A Current

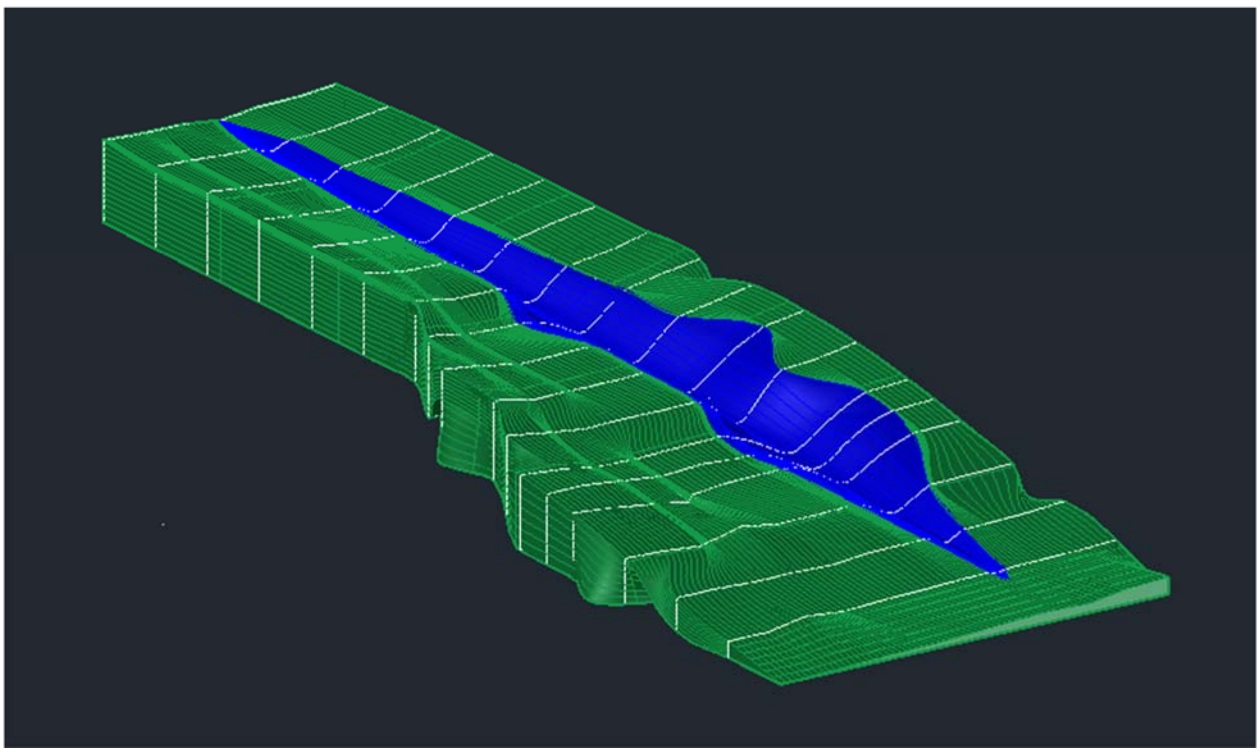

Figure 13. Isometric Site A Final

The inlet and outlet areas of the channel should be expanded. The current PVC pipe located at this site should be removed when dirt excavation is being done. The concrete inlet should be expanded to a 12ft width that flows directly into the start of the parabolic channel. The soil height at the inlet should be lowered by 3-4in to allow for the water to flow directly into the channel. The inlet should be heavily vegetated with grass. This will ensure stability of the soil and will ideally eliminate any chance for erosion. Mid-sized rocks can be placed here if vegetation is sparse. The outlet of the channel should be tapered and shaped to the surrounding hill. The outlet should be smoothed as much as possible and stabilized with sod. The inlet and outlet are the most vulnerable places for erosion to occur so vegetative growth in those areas is crucial.

With this design, the maximum flow that the channel can handle is about 23.8 cubic feet per second (cfs). This will be sufficient for 5-year storms or less. The entire drainage area is capable of handling up to 42.7 cfs of flow. The peak flow for a 100-year, 24 hour storm is roughly 34.6 cfs. We are confident that the drainage area will be able to handle a 100-year, 24 hour storm, given that healthy vegetation is present.

There are also some areas in the greenbelt that will need to be rehabilitated due to severe erosion. One of these spots, seen in Figure 14, must have the stump and rocks removed. Soil removed for the construction of the channel can be used to fill in this area. It must also be graded to the shape of the current waterway. After this, it must be covered with bermuda sod. The same solution applies for the other eroded spots in the greenbelt area.

Figure 14. Greenbelt Erosion

*Problem Site B*

Extreme soil erosion has affected some areas along the ephemeral stream that runs through Park View Estates. Large holes and banks with steep slopes have formed due to the amount of stormwater runoff passing through the stream. The erosion at Site B has been addressed using gully wall reshaping techniques that change the slopes of the stream banks at the affected areas, creating a more stable and healthy system.

A bank slope of 45% is suggested for the reshaping design at the affected areas. The method used is from a field guide on gully prevention and control that is based on the depth of the stream at the erosion site. A distance of ⅔ the depth of the stream will be reshaped along the stream bank to the suggested slope (Desta, 2012). The average depths of the affected areas along the stream range between 3-4ft. However, in more extreme cases the stream may have depths of more than 6ft in some locations, with steep banks. A diagram of the reshaping method can be seen in Figures 15, 16, & 17.

The entirety of the stream should incorporate a “no-mow” zone that extends to 5ft from either bank. This will allow grass to stabilize the soil around the stream. Erosion will significantly reduce once a healthy vegetative zone is established.

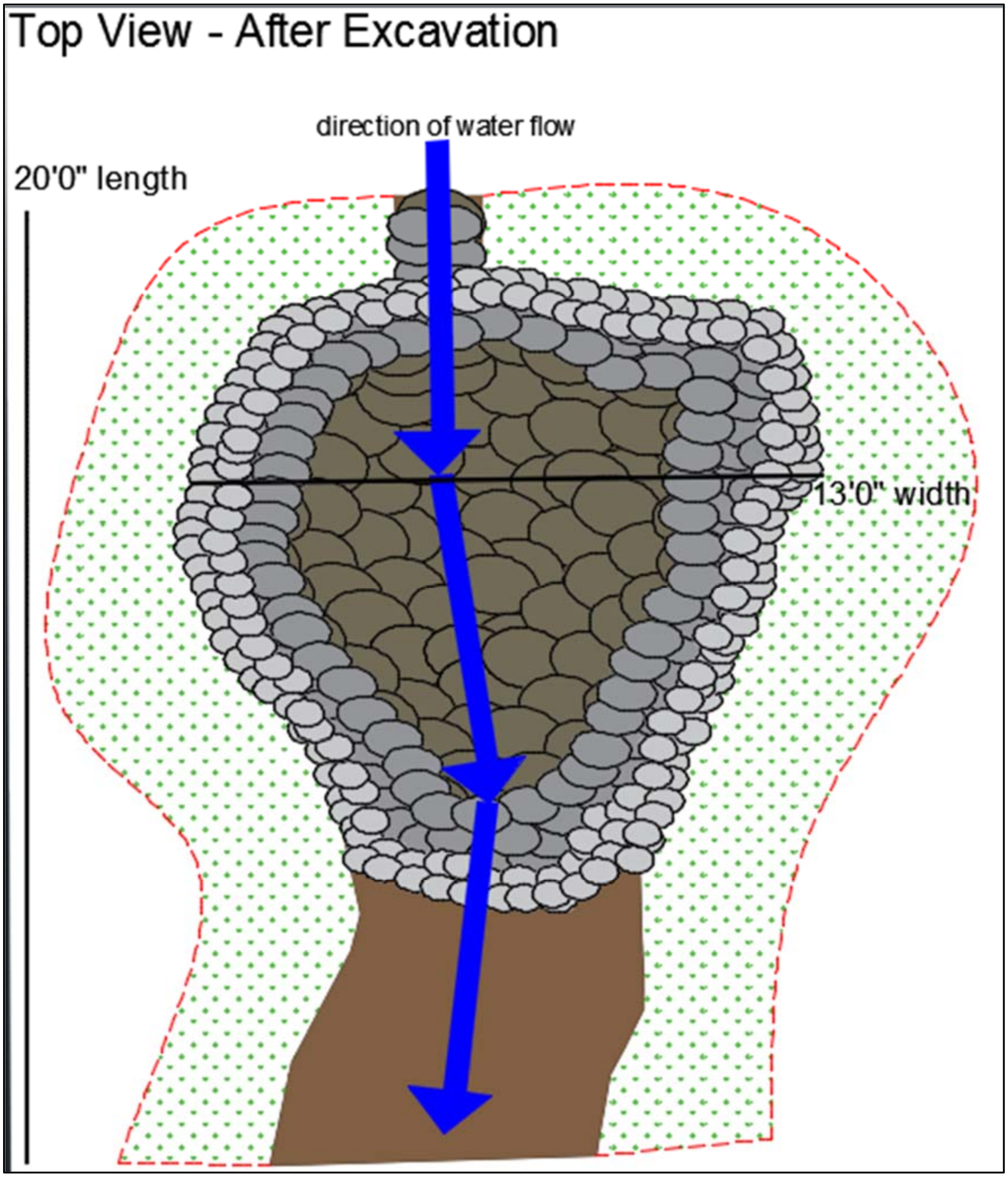


Figure 15. Top View of Hole Redesign

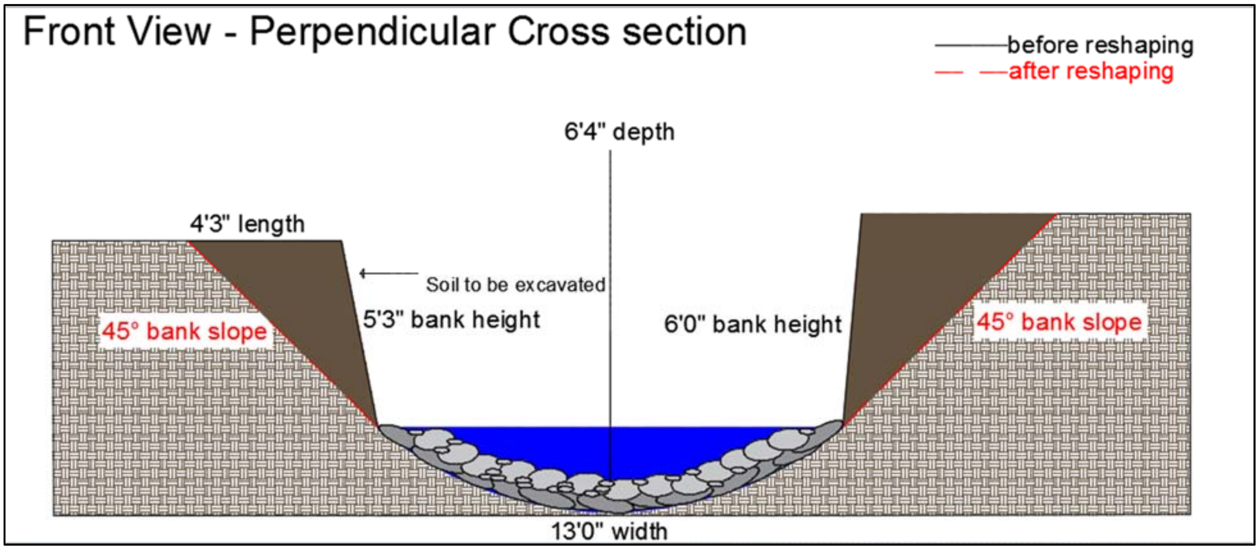


Figure 16. Front View of Hole Redesign

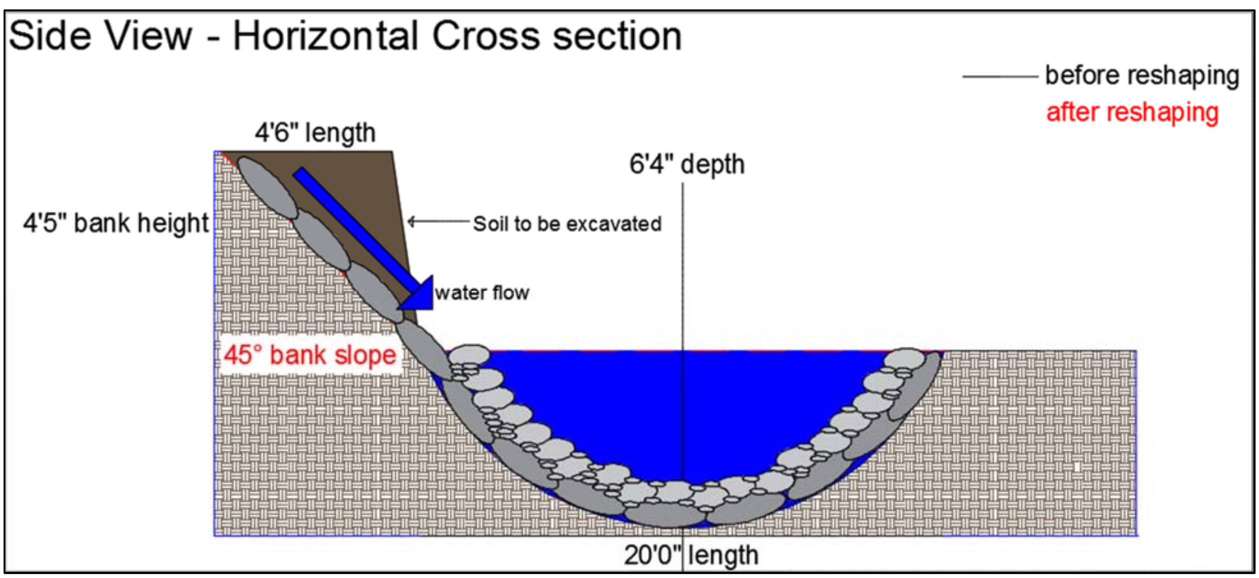


Figure 17. Side View of Hole Redesign

**Specifications**

*Problem Site A*

- Remove broken PVC pipe and drain inlet
- Concrete inlet at cul-de-sac should be expanded to 12ft width
- Soil height at 12ft inlet should be lowered by 3-4in
- Channel to be graded must be at a 4% longitudinal slope minimum
- Channel shape should be parabolic with a 12ft width
- Channel dimensions can be taken from AutoCad file
- Top layer will be replaced with sod (bermuda)
- Channel will continue for 165ft at a 4% slope (until it exits at the hill)
- Channel vegetation should be not be mowed/weed-eated any lower than 6in
- Must remove stump and debris from eroded spots
- Regrade spots to shape of surrounding waterway
- Cover spots with bermuda sod
- Dirt excavation: 5,000-6,000 $ft^3$
- Addition of sod: 300-350 $ft^2$

*Problem Site B*

- Bank slopes to be graded and reshaped to 45 degrees
- ⅔ of stream depth at location to be graded horizontally
- Reshaped stream banks will be covered with sod (bermuda)
- A "No-Mow" zone along the stream must extend out 5ft from the channel to the upper bank
- Streambank should be graded to a maximum slope of 2:1 (Horizontal:Vertical)

## Costs

A quote for Site A and Site B was being conducted, but the contractor chose to not proceed with the job. Because of this, an accurate quote from a company was not acquired by CSM. It will be the responsibility of Park View Estates to attain an accurate quote. The cost estimates below are from landscaping cost estimate websites. The work that is required for both problem sites does not need a large scale company. A local landscaping company will be able to provide the work to bring this project to fruition. They should be provided with this report.

Estimates for Site A and Site B

Skid steer operator = $600 per week (Assume one week of work)

Turf installation for 450 $ft^2$ = $1,000

Riprap for 150 $ft^2$ = $500

Labor = $4,400 - $5,000

*Project Total = $6,500 - $7,100*

## Equations and Variables

Hand written calculations can be found in Appendix H.

Rational Method

$$Q_p = I * A * C$$

Where,

$Q_p$ = Peak flow [$ft^3$/s]

I = Intensity [in/hr]

A = Watershed area [acres]

C = Runoff coefficient [unitless]

Kirpich Equation

$$t_c = 0.019 * \frac{L^{0.77}}{S_0^{0.385}}$$

Where,

$t_c$ = Time of concentration [min]

L = Furthest length to watershed outlet [m]

$S_0$ = Slope of watershed [decimal form]

Manning's Equation

This equation was used in the math from Figure 46.

$$Q = \frac{1.486}{n} A{R_h}^{2/3} S^{1/2}$$

Where,

Q = Flow rate [$ft^3$/sec]

n = Manning's Roughness Coefficient [unitless]

A = Cross-sectional area [$ft^2$]

$R_h$ = Hydraulic radius [ft]

S = Slope [decimal form]

**Future Expansions**

The specifications listed below are to be taken as general suggestions & information that the HOA can use to determine additions to their neighborhood in the future. This information is listed categorically and is not separated into individual problem sites.

*One-Rock Dam*

One-rock dams are typically used with channelized waterways or other flow paths where water has the ability to generate speed. This structures success is dependent rock depth in stream.

Figure 18. One-Rock Dam

- Perpendicular to the water flow
- Single stacked rock line
- 6in diameter rocks minimum in front line
- Rock diameter should gradually increase with each consecutive row.
- Consist of 4 to 6 rows

*Log and Fabric Step Falls*

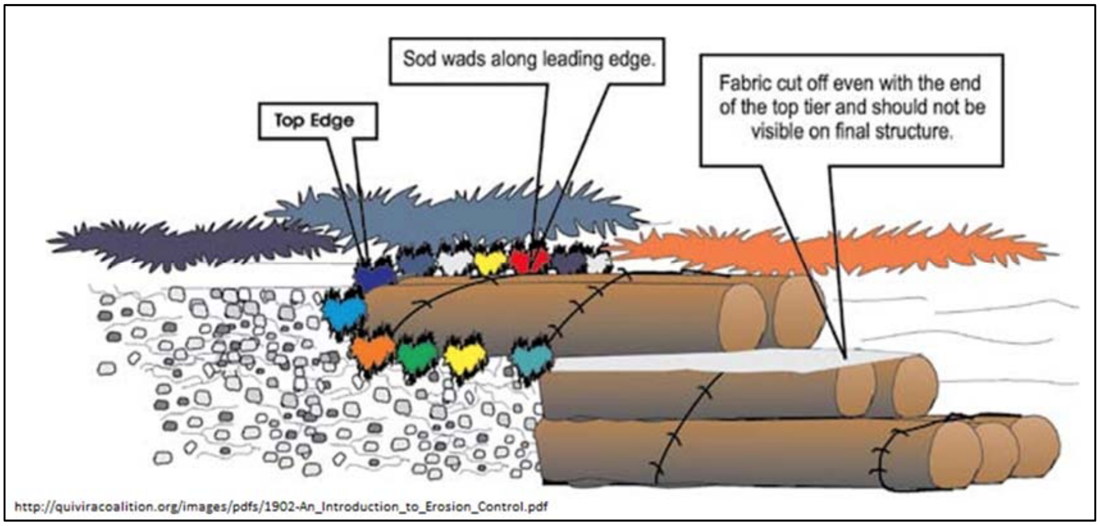


Figure 19. Log and Fabric Step Fall

- Steps should be cut upstream into gully.
- steps to make 45 degree average slope
- Steps are to be ½ the length of the logs and the same height, until reaching the surface.
- Lay fabric down first and wrap around logs once they are placed..
- Surround log layers with sediment and sod clumps

*Rock Bowl*

Rock bowls can be used to heal head cuts of less than 2ft. Soccer to Basketball sized rocks. Early detection is key for this structure to be successful.

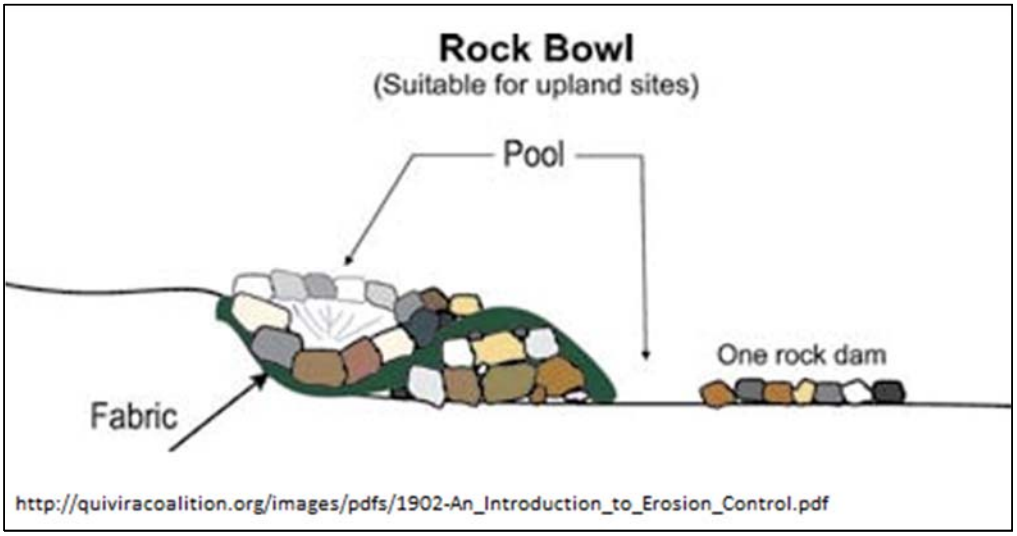


Figure 20. Rock Bowl

- 2-4 wheel-barrow load of rocks
- Rocks need to be "basketball" size
- Upstream - Fabric is beneath rocks near head cut
- Downstream - Fabric is laid on top of rocks
- This forms an S shape with the fabric

*Streambank Erosion Control*

These are materials and methods that should be used if further stream rehabilitation is done (Appendix B).

- Coconut matting should be 3ft to 5ft in width from the lower bank to the upper bank.
- Live stakes should be placed 3ft to 6ft apart and spaced triangularly (Ernst Seed, 2014).
- Live stakes should extend out by 5ft from the lower bank to the upper bank.
- A riparian zone along the stream must extend out 5ft from the channel to the upper bank.
- Riprap should be placed from the toe of the stream to the lower bank.

- Individual rocks used in riprap used must not exceed 220lb.
- Streambank should be graded to a maximum slope of 2:1

*Permeable Pavement*

This material can be used to assist with infiltration. It be used for sideways/walkways, water dissipation devices, or cul-de-sacs (Appendix B).

- Three types of permeable pavement
  - Asphalt
  - Concrete
  - Interlocking pavers
- Variable size
  - Can customize area to specific needs
- Requires various layers for support and infiltration
- Must have type A or type B soil underneath

*Bioretention Cells*

These can be placed in areas where water flows towards the stream. The greenbelt area would be an ideal place for this (Appendix B).

- Optional underdrain pipe
- Underdrain pipe diameter will be 4-5in
- Multiple layers
  - Top soil
  - Sand
  - Gravel
  - Native soil
- Design parameters vary

*Enhanced Bioswales*

These are grass waterways that have a underlying soil layer that is design to enhance infiltration (Appendix B). The greenbelt area would be an ideal location for this in the future.

- Longitudinal slope should be between 1-6%
- Horizontal slope should be between a 7:1 and 3:1 (horizontal:vertical)
- Should be designed to handle at least a 10 year, 24 hour storm
- Trough width should be at least 2ft wide
- Depth should be at least 6in deeper than the maximum design flow depth
- Length should be designed to have a water residence time of at least 5 minutes
- Water velocity should not exceed 5ft/s
- Water infiltration should extend to at least 12in below the topsoil of the swale

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# Appendix A

## Project Schedule & Travel

### Travel

Parkview Estates is in close proximity to CSM. Many site visits were conducted throughout the fall and spring semesters. An OSU vehicle was used one time to transport the team to Park View Estates. The cost of this was covered by the Biosystems and Agricultural Engineering department. All other site visits used personal vehicles.

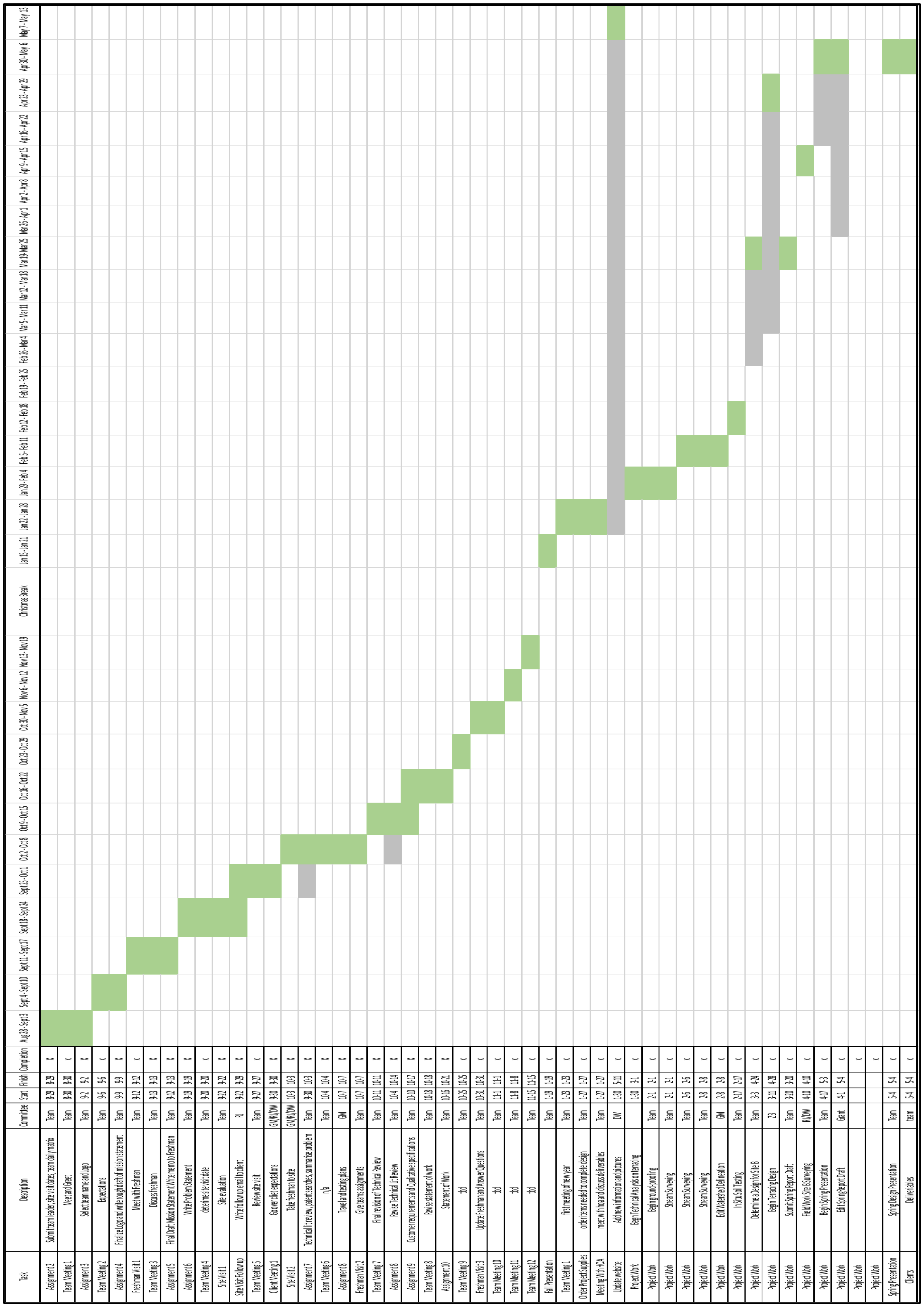



Figure 21. Gantt Chart

# Appendix B

## Technical Analysis

### Streambank Stabilization Techniques

*Vegetation*

A lack of vegetation surrounding the stream bank at Parkview Estates is contributing to the bank erosion. There are several techniques that utilize vegetation as a stabilizer for stream banks. Those within the constraints of our problem include live stakes, joint planting, and coconut fiber mats. These biological applications help stabilize loose soil while maintaining a natural look. Furthermore, these techniques are inexpensive and biodegradable, which eliminates the need for their removal at the end of the project. Maintenance for these applications is also minimal.

Live stakes are woody, slender parts of a plant species that can be strategically placed in the toe of the bank to assist in soil development (Ernst Seeds, 2014). They are stored dormant but once they are transferred to the bank, they begin growing roots (Figure 22). These roots act like rebar in the soil and bind soil particles together, reducing erosion.

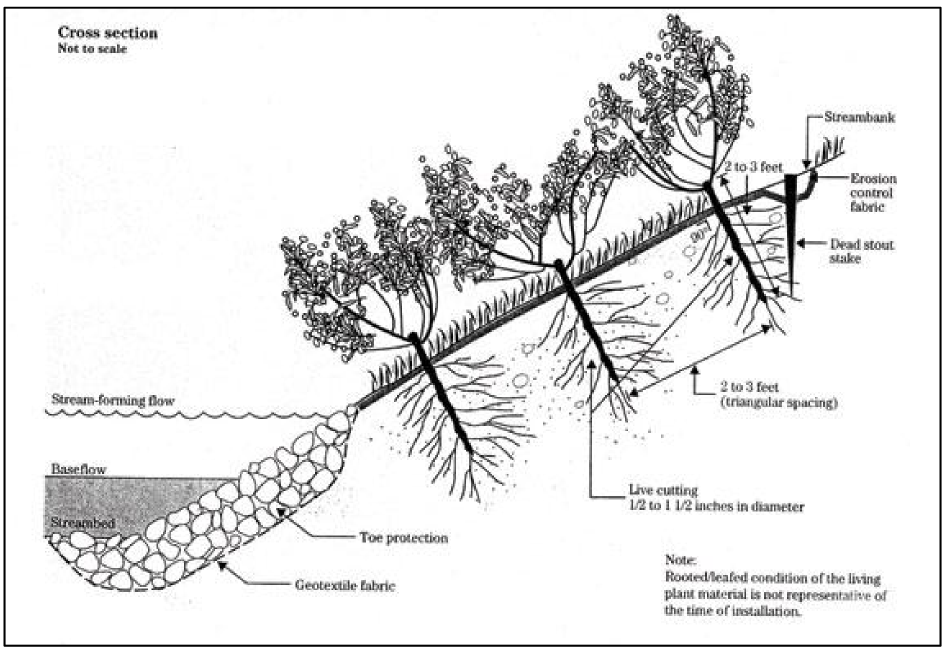



Figure 22: Cross Section of Live Stake Placement

A combination of these techniques is more realistic for this project. For example, using coconut fiber sheets and live stakes together will be more effective in stabilizing the soil near the stream than using them apart (Figure 23). The coconut fiber mats stabilize the topsoil, while the live stakes develop the soil below. This would be a great application for the main stream that flows throughout Parkview Estates. There are currently tri-lock blocks along a problem area that will be available for improving the soil stability. Planting seeds in between these blocks could be an inexpensive and effective way to reduce erosion at that particular site.


Figure 23. Combination of Live Stakes & Coconut Matting

These solutions could fail if they are not properly implemented. They require the use of suitable plant species, adequate soil conditions, and proper grading along the stream bank (Li, 2002). A large volume of water could destroy the biological components if they are not well established in the soil.

Other possible solutions include using concrete trenches to direct the water flow, or using dead trees strategically placed along the bank. These solutions will not be considered because they do not meet the criteria of low cost and safety. Concrete is expensive and does not have a natural appearance. Dead trees are not an aesthetic solution.

*Riprap*

Using large, angular rocks placed along the stream bank will also stabilize the soil. The rocks act as barriers that reduce the velocity of the water flow and increase the bulk density of the soil. The reduced velocity of the stream will increase water infiltration and protect the bank from erosion (Iowa Department of Natural Resources, 2006). See Figure 24 for a cross sectional view of a typical riprap layout.

Graded riprap uses different sized rocks and is more suitable for this project than uniform riprap. Uniform riprap uses the same size for every rock. This can be disadvantageous because it is more expensive and the gaps in between the uniform rocks will have allow for slight erosion if there is nothing solid to fill the gaps (Massachusetts Department of Environmental Protection, 1997). The wide range of rock sizes in graded riprap will help the bank self-heal when the stones are moved by the stream, provided proper grading along the streambank. Having a self-healing application for this project makes it a beneficial long-term solution. Riprap can also be used in combination with biological techniques. A riparian zone could be integrated around the rocks to further increase stabilization and environmental quality. Considering aesthetics, riprap has a natural look to it and contributes to the environmental appearance of the stream.

Riprap is more expensive than planting vegetation along the bank. It requires grading the bank of the stream to, at most, a 1:2 ratio (Iowa Department of Natural Resources, 2006). Figure 24 illustrates this slope. Due to the weight of the stones, use of high grade geotextile fabric is required. This fabric acts as an erosion control blanket underneath the riprap. Use of gravel or crushed stone between the geotextile fabric and the riprap is a beneficial option, but may not be necessary in this project. Using equipment to grade the streambank to the proper slope and purchasing geotextile fabric will significantly increase the cost of this project. Overall, using riprap to stabilize the streambank will be an effective, long term, and natural looking technique, but also an expensive one.

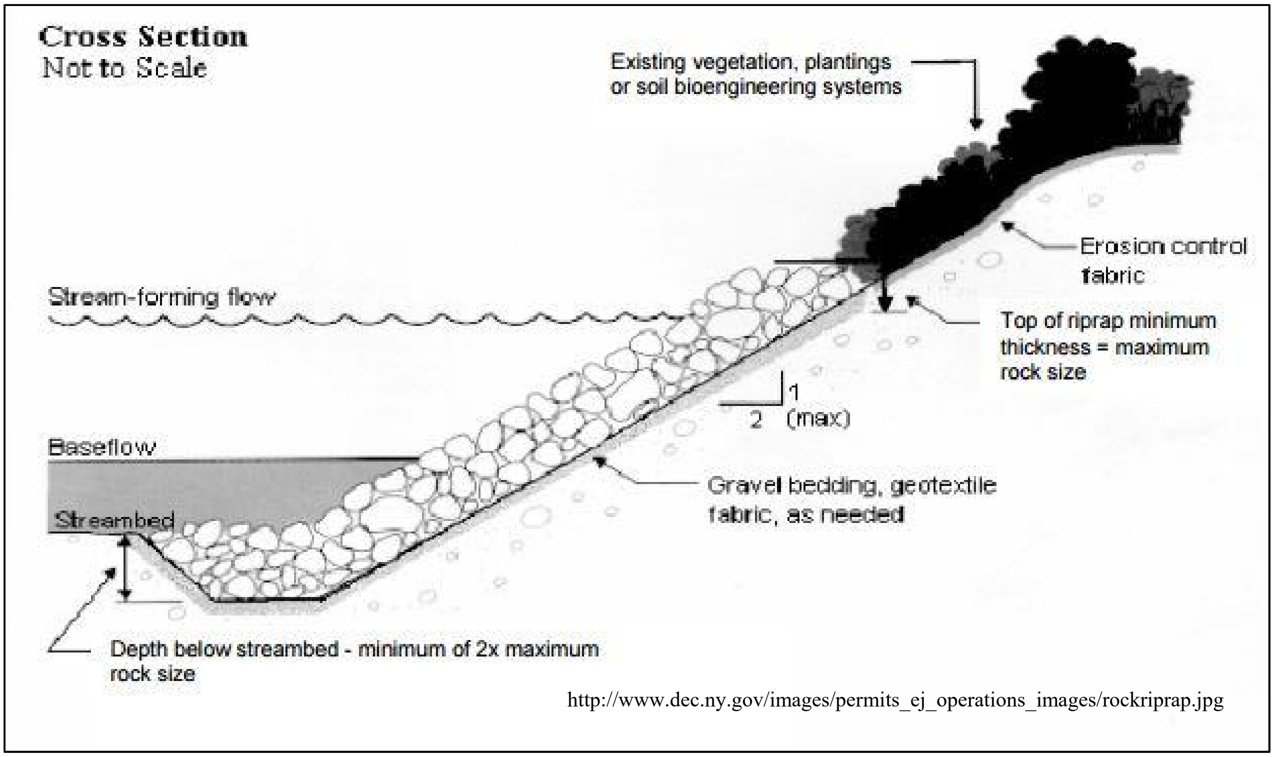



Figure 24. Cross Section of Riprap

**Low Impact Development practices**

One of many possible solutions to this problem would be the implementation of LID practices. LID practices have successfully been used to manage stormwater runoff, improve water quality, and protect the environment. LID allows for greater development potential with less environmental impacts through the use of smarter designs and advanced technologies that achieve a better balance between conservation, growth, ecosystem protection, and public health / quality of life (Urban Design Tools Low Impact Development, 2016). Examples of LID practices include rain gardens, permeable pavement, rain barrels, and soil amendments. However, in the case of Parkview Estates only bioretention and permeable pavement practices will be discussed.

*Bioretention Cells*

Bioretention cells are very effective at removing pollutants found in runoff through soil and plant based filtration (Figure 25). They also have highly aesthetic qualities due to the indigenous vegetation incorporated in the bioretention area, making the practice frequently used. Some disadvantages of implementing a bioretention area would be cost and upkeep. Installing the cell requires design, excavation, and purchasing all of the material such as plants, soil, gravel or sand, and pipes for draining. An average cost for installing a bioretention cell complete with an underdrain is around \$10 - \$40 per $ft^2$ (Bioretention, 2007).

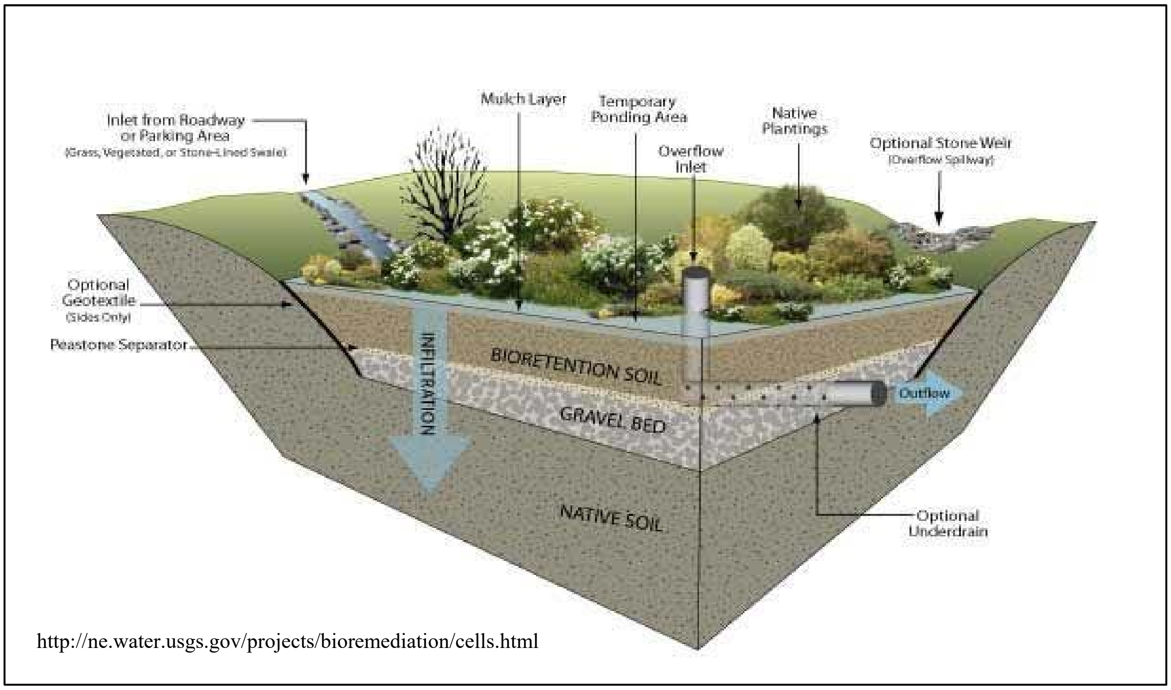



Figure 25. Bioretention Cell Diagram

*Enhanced Bioswales*

Similar to bioretention cells, enhanced bioswales utilize vegetation in a sloped area to reduce water velocity and increase water infiltration and filtration. While bioretention cells only cover a small area, bioswales are structured more like a channel that directs water flow instead of retaining it (Figure 26). They have an average life span of 30 years and can cost from \$5.00 to \$24.00 per square foot (Green Values, n.d.). They should be sized to handle a minimum of a 10-year storm (NRCS, 2005).

Bioswales have four standard cross-sectional designs: rectangular, triangular, trapezoidal, and parabolic. Rectangular cross sections area easy to design, but difficult to maintain over time. The steep slope makes it difficult for vegetation to grow and stabilize the bank. It also can be a safety liability. Triangular cross sections can be used if the slope is about 10:1 (horizontal: vertical) or shallower. Trapezoidal cross sections are the most common because they are simple to design, easy to construct, and facilitate healthy hydraulic performance. Parabolic cross sections behave similarly to trapezoidal ones, but are slightly more difficult to construct.

A 5:1 slope is considered the steepest that allows for mowing in any cross section. The ideal longitudinal slope is roughly 1-2% and should allow for at least five minutes of runoff residence time. Check dams may be required to slow the water velocity in order to ensure adequate residence time. Longitudinal slopes should not exceed 6%. The bottom width of bioswales should be between 2ft-8ft.

Some bioswales incorporate plants for the purpose of phytoextraction, and others are simply used to reduce water velocity and stabilize the top layer of the subsoil. Plants can also add to the aesthetic appeal to the bioswale. Turf bioswales are an option in areas that do not require the treatment of heavy metals in water runoff.  Turf bioswales have the advantage of easy maintenance, lower cost, and accessibility.

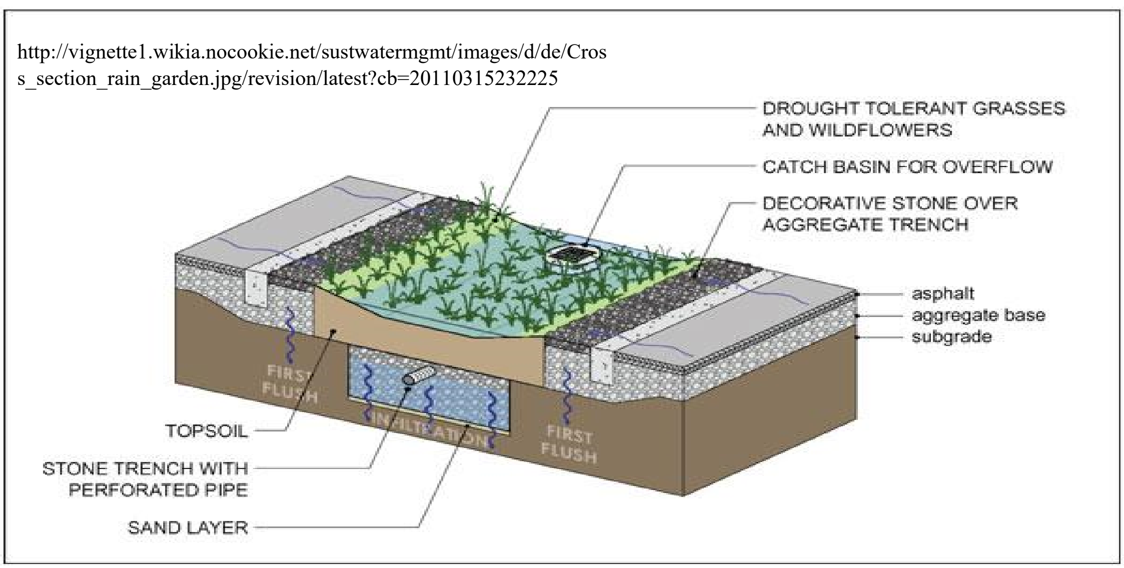



Figure 26: Components of Enhanced Bioswale

*Terraces*

Terracing is an LID practice that involves reshaping a slope into step like or channel like structures in an attempt to disrupt straight-line flow. Breaking up the flow into steps can greatly reduce erosion, especially on the downstream side of the slope. The water spreads out and slows down instead of gaining speed and energy down a consistent slope. The terrace steps themselves are generally designed in one of three ways, outward sloping, inward sloping, and level sloped terracing, as seen in Figure 27. Decisions on sloping depend upon intended use of the terrace. An inward terrace would be great for infiltration and decreasing runoff while an outward sloping terrace would be more helpful at moving the water towards an outlet. According to the Ohio Department of Natural Resources (ODNR), terraces can improve water quality by promoting settling of sediments out of runoff as well as infiltration into the soil, especially if designed with the optional shoulder bund or check dam and an inward facing slope. Terracing can also be used in conjunction with other LID practices due to the versatility of its outlet or lack thereof depending on the specific design. According to the Terracing Standard created by the NRCS, terraces are relatively low maintenance, involving seasonal mowing or brush control, sediment removal if buildup occurs, maintaining the size and shape of individual terraces, and periodic inspections.

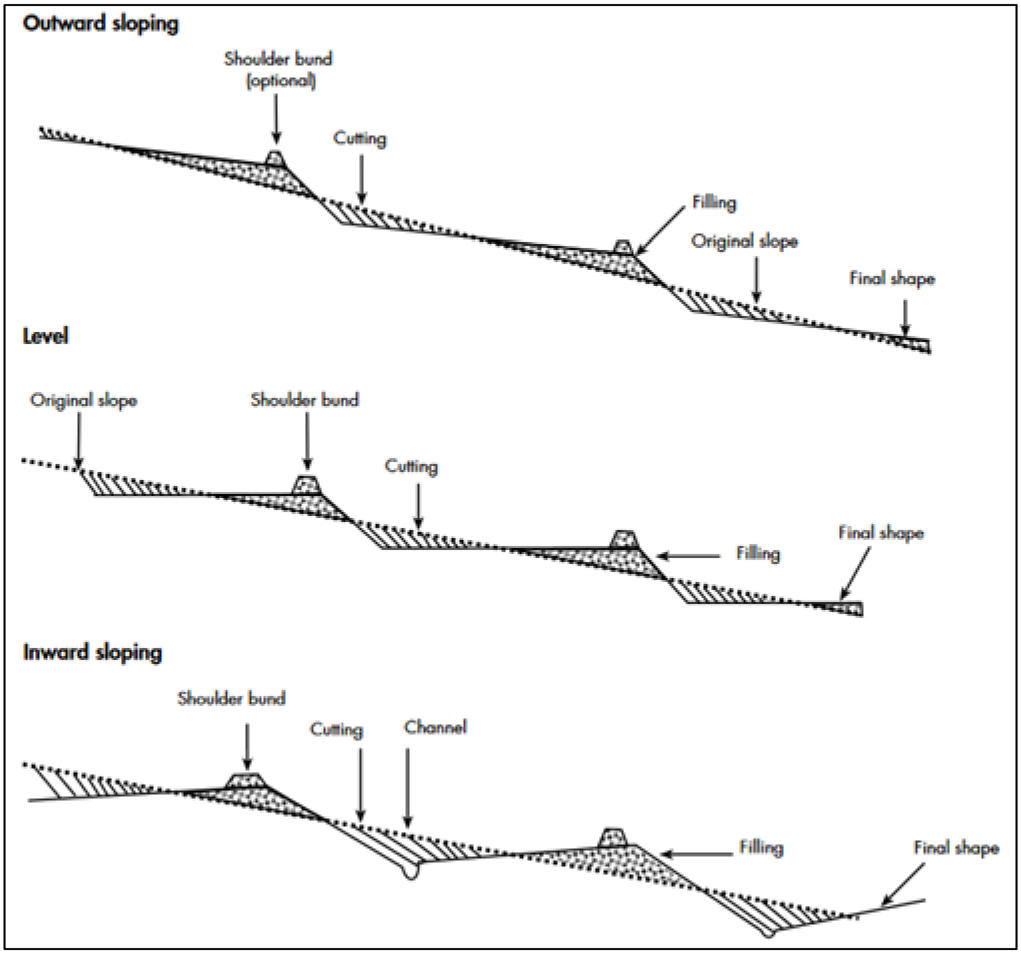



Figure 27. Types of Terracing

*Permeable Pavement*

Permeable paving is an LID practice that involves paving developed areas with pavement or bricks that are made to be porous, which allows storm water runoff to infiltrate the pavement and reach the soil beneath it. Durability and maintenance are some of the problem factors in this practice. The pavement will need regular cleaning due to sediment clogging the small holes in the pavement which the water passes through. Since permeable pavement is not as strong as regular pavement, durability becomes an issue when the paved area is heavily used. Different types of permeable pavement include asphalt, concrete, and bricks or pavers (Figure 28). The costs of permeable material vary. Asphalt is about \$0.50 -\$1.00 per $ft^2$, concrete is about \$2.00 -

$6.50 ft$^{2,}$ and interlocking bricks or pavers cost around $5.00 - $10.00 ft$^2$ (Permeable Paver, 2007). Multiple layers of substrate are required in permeable pavement design for run-off filtration, and to provide solid support for the pavement. A detailed example of a permeable paver design can be seen in Figure 29

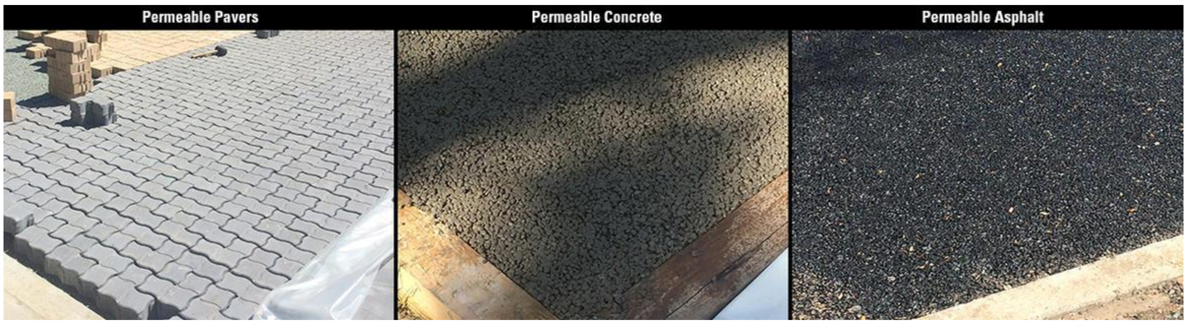



Figure 28. Different Types of Permeable Pavement

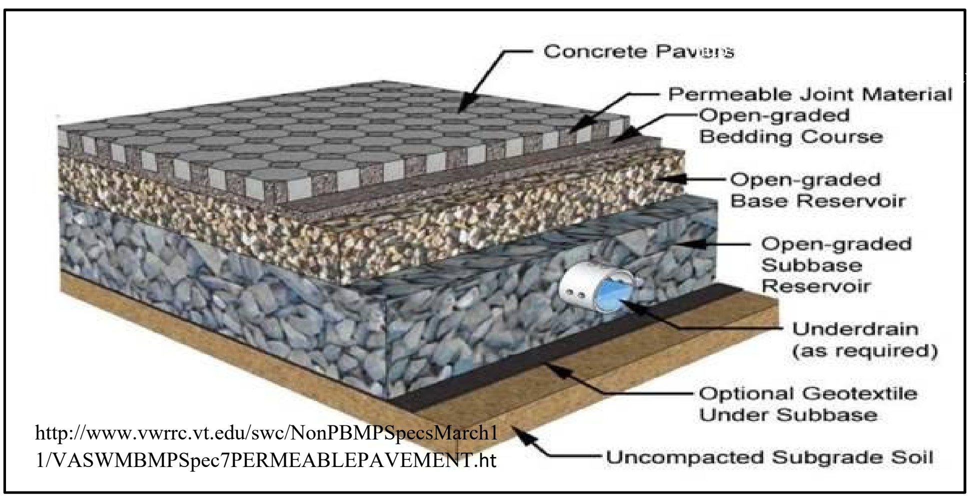



Figure 29. Permeable Pavement Diagram

## Modeling Urban Rainfall Runoff

### *Types of Models*

Hydrologic models are used to estimate rainfall runoff volume, peak discharge, and the temporal distribution of stormwater runoff at a specific location resulting from a given rainfall data (MPCC, 2016). In other words, these types of models are used to predict how factors such as site topography, soil characteristics, and land use will cause runoff either to flow relatively unhindered through the stream to the outlet, or to be delayed or retained somewhere upstream. Hydrographs are often generated from hydrologic models to route runoff across multiple sub-areas within a watershed, or to combine several watersheds. Such characteristics make this type of modeling essential to urban stormwater management practices.

*Potential Models*

WinTR-55 is a hydrologic model developed by the NRCS in 1975 to determine rainfall excess parameters in small urban watersheds such as storm runoff volume and peak discharge (MPCC, 2016). Hydrographs are generated from the determined rainfall excess parameters and are used to map flood routing. Due to the size and shape of Parkview Estates, there are multiple inlets where runoff enters Parkview Creek. The ability of WinTR-55 to break a watershed into sub-areas enables the user to assess the amount of runoff being contributed by each individual sub-area. This in turn, allows the user to determine particular areas to implement LID practices.

The EPA Stormwater Calculator is a hydrologic model developed by the EPA that assists with implementing stormwater management practices. Using soil, land use, and rainfall data, the EPA Stormwater Calculator estimates the amount of runoff that the predicted LID techniques will reduce (EPA, 2016). By transferring the data generated by the EPA Stormwater Calculator into excel, a concise plan of action can be established by using the Solver function in Excel to optimize the design.

The City of Stillwater has expressed concern about sediment loading into the Northeast end of Boomer Lake. This loading is coming from the outlet of Parkview Creek. Soil and Water Assessment Tool (SWAT) is an agricultural based model often used to quantify herbicide/pesticide and sediment pollution being transported from farmland into a fluvial body. Since this model is typically used for farms, the validity of using this model needs to be further assessed.

**Slope Gradation**

Slope gradation is a practice used to control and direct water flow across or down a slope. Water will naturally flow to the lowest point in a landscape and grading allows for the land to be reformed and the drainage patterns controlled (Matusik and Deible, 1996). Controlling the drainage is important for the preservation of structures as well as landscape. Allowing the water to drain too quickly can result in erosion. Conversely, draining too slowly causes ponding, which can also be destructive in a landscape, as seen at Parkview Estates in Figure 30 (Mihalic, 2014).

Figure 30. Ponding Observed at Park View Estates

*Large Scale vs Small Scale*

One unique quality about slope gradation as a storm water runoff management technique is the vast scale it can be practiced on, from excavators regrading entire cities to a homeowner with a shovel and landscape rake in their own backyard. Regrading, regardless of scale, involves surveying the slopes, calculating the desired slope (generally around 2%), removing vegetation, moving the soil, and replanting vegetation to control erosion. Surveying can be done with equipment such as laser levels and rods or simply using bubble levels and a tape measure, depending on how much ground needs surveyed. Vegetation can be removed with anything from a shovel or landscape rake, to a till machine, to heavy machinery such as an excavator or backhoe. The soil then can be pushed around to set the desired slope to match the design or plans. This is a point in the process where swales or drains can be added to aid in drainage. A swale, in its most simple form, is a crease in a slope where water can gather to drain to lower ground, as seen in Figure 31. Swales do not have to be simple, however. They can be expressed in many functional, and aesthetically pleasing, ways according to Mihalic, such as filling them with plants, stones, making them curvy to mimic creeks and river beds, or any combination of the three.

Cost can be the biggest constraint on how much slope gradation is done in an area. A shovel, a landscape rake, and a tape measure are relatively inexpensive to a homeowner, especially when most design is done with slope gradation in mind. The biggest cost for a small scale project would be rolls of sod for erosion control and revegetation. For a personal installation, sod costs between 8-30 cents per square foot depending on species and grade of sod, and 14-60 cents per square foot to have it professionally installed (HA 2016). For a big project, needing the use of heavy equipment can drive the price up quickly. Simply for grading the cost is roughly $2500-$5000, depending on location and site condition (BA 2016). Home advisor estimates sod costing $1800-$4000 per 2000 square feet, adding to the bill (HA 2016).

*Parkview Application*

Slope grading will be a very useful technique to use in the issues in Parkview Estates, more specifically in the area beside 304 Marie Drive house leading into the creek area behind all the houses. With the undersized drain, as seen in Figure 32, and slope down to the creek, the water is not being directed correctly and causing erosion problems as well as ponding issues. Grading the hillsides of the property into a natural swale to direct the water seamlessly down to the creek bed will cut down on ponding and provide a natural looking solution. It will also cut down on the erosion issues such as the pipe blowout in Figure 33.

Figure 31. Simple Grass Swale

Figure 32. Undersized Drain

Figure 33. Erosion Caused by Broken Pipe

# Appendix C

## Freshman Involvement

Freshman students from the Biosystems and Agricultural Engineering Department at Oklahoma State University were assigned to help research management practices for the erosion problems occurring at Park View Estates. The students were placed in two teams. The first team focused on researching possible solutions in the area of LID practices. The second team researched streambank restoration and erosion prevention techniques that Cowboy Stormwater Management could possibly implement in the project. The LID practices the first team researched were permeable pavement, bioretention cells, and bioswales. They researched each of the practices and provided a short summary. They then performed a cost analysis for each installation. Permeable pavement cost between $5.50 and $11.60 per square foot, while a retention pond or swale would cost between $5.50 and $24 per square foot. Both solutions had a similar maintenance fee, but the largest difference was the labor costs of installation. Permeable pavement requires removing the existing pavement and replacing it with permeable surface, driving the price up quickly. The team concluded that a bioswale should be the recommended solution due to lower labor costs and practicality in the project area. The stream restoration team looked specifically into the practices CSM was interested in; riprap, coconut fiber matting, and live stake planting. They evaluated the restoration on two premises, a “realistic,” or low cost, solution and an “idealistic,” or high cost, solution. The team used the constraints given to CSM by the HOA, naturally aesthetic, cost effective, safety, and longevity. Their cost analysis concluded the realistic solution would cost roughly $11.50 per 10 square feet and the ideal solution would cost roughly $74.50 per 10 square feet. They recommended the “realistic” package as the solution for the stream bank, based upon the HOA criteria of cost effectiveness and safety.

# Appendix D

## Environmental Impacts

The final design that will be implemented at Park View Estates has potential to not only benefit the neighborhood, but Boomer Lake as well. If bioretention cells and/or bioswales are implemented, the water that infiltrates these biological systems will be filtered, reducing stormwater pollution in the water. This will positively impact the water quality of Boomer Lake, where current water quality is approaching violations. If a considerable impact is to be expected, solutions that filter stormwater must intake water from all or most impervious surfaces at Park View Estates. The requirement that this project must be cost effective for the HOA means that it is unlikely to see biological filtration systems that covers the entire neighborhood. Currently, only a portion of the neighborhood is expected to be impacted by bioretention cells or bioswales. The amount of water that is expected to be filtered will not have a significant impact of the quality of water that flows to Boomer Lake. If the HOA had a much higher budget, multiple bioretention cells at major water outlets of the neighborhood would be more feasible to have a greater, positive environmental impact.

# Appendix E

## Preliminary Design Concepts

CSM developed three different preliminary solutions for each problem site. These solutions were presented to the Park View Estates HOA in December 2016 in order to determine which cost options was most feasible to them. Each problem site had a corresponding low cost solution, as well as more expensive solutions that could possibly be implemented in the future. The low cost solution would incorporate designs that will solve the specific issues at the respective problem site with the least amount of required cost (estimated). This type of solution is considered the "bare minimum" that must be implemented if the customer requirements are to be met. The higher cost solutions would use the low cost solution as a foundation to add upon. They incorporate the low cost solution designs with further additions that improve quality and aesthetics. These solutions were developed with these cost options so that the Park View Estates HOA can decide on a custom solution that meets their requirements and financial needs.

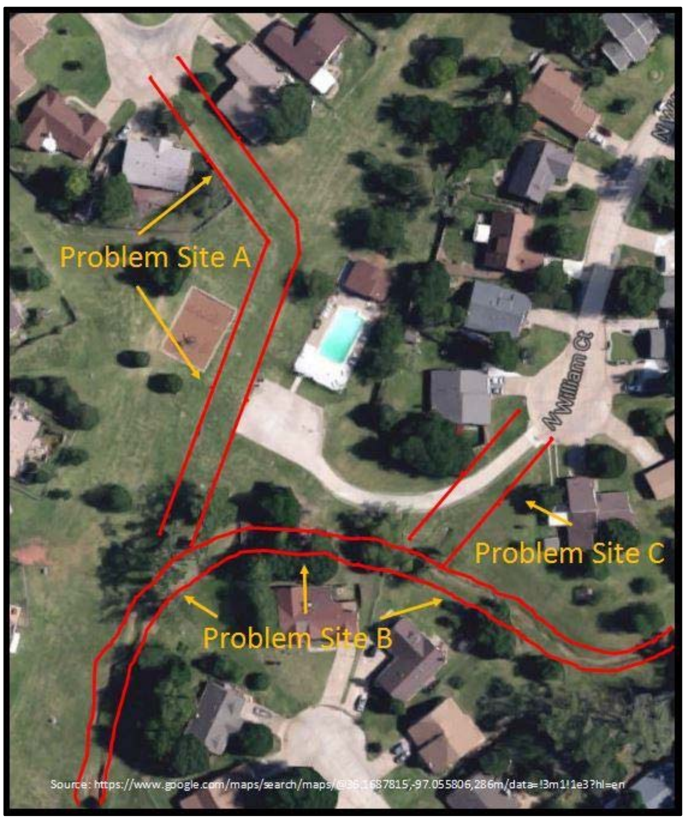



Figure 34. Problem Site Locations

**Site A - Low Cost Solution**

*Marie Drive Cul-de-sac*

The low cost solution for this site is to remove the undersized drain (Figure 35), along with the drainage pipe (Figure 36), and then re-grade the grass swale to a more optimal downhill slope for draining the stormwater. Sod would then be implemented onto the top of the regraded area. Some survey work of the grass swale has been conducted but more work is necessary. With complete data, CSM can create a model of the cross sections and slope of the swale and hill to begin the re-design.

Figure 35. Undersized Storm Drain at Site A

Figure 36. Drainage Pipe Located at Site A

*Greenbelt Area*

The greenbelt area contains several places where high velocity stormwater has cut deep holes in the waterway (Figure 36). The low cost solution requires that these individual sites be excavated, regraded, and covered with turf. Other areas along the greenbelt space may also require regrading. Ideally, stormwater runoff volume and velocity would be reduced, however, regrading key areas instead of implementing LID practices will reduce cost and still meet customer requirements.

### Site A - Medium Cost Solution

*Marie Drive Cul-de-sac*

The medium cost solution for the cul-de-sac area includes everything that the low cost solution did with some extra features. In addition to regrading the area where the water enters the greenbelt space, permeable pavers would be incorporated as a walkway to the public area. The size of the walkway depends of the budget of the HOA. The permeable pavers would help in two ways. It would improve the aesthetics of that area as well as increase water infiltration. The water that infiltrates between the bricks would mean less water that enters the stream. This could potentially improve Problem Site B as well as Problem Site A.

*Greenbelt Area*

In addition to removing the eroded sites, a bioswale would be implemented along the greenbelt area (Figure 37). The bioswale would be graded to at least a 7:1 (horizontal:vertical) slope that is suitable for easy access and maintenance such as mowing. The top layer of the swale would incorporate grass/sod as a vegetative buffer that would slow water velocity, thereby increasing infiltration. The bioswale would be a natural looking solution that guides stormwater to the stream and reduces stormwater runoff.

Incorporating permeable pavers and a large bioswale is an expensive solution. Depending on the budget of the HOA, the area covered by both a bioswale and permeable pavers could be customized to meet their needs.

Figure 37. Potential Location of Enhanced Bioswale at Site A

LID practices are also being considered for implementation. LID practices such as bioretention cells, bioswales, and permeable pavement reduce stormwater runoff by allowing stormwater to better infiltrate into the soil, or collect stormwater for retention. Possible locations at Site A for bioretention cells or bioswales can be seen in Figure 38.

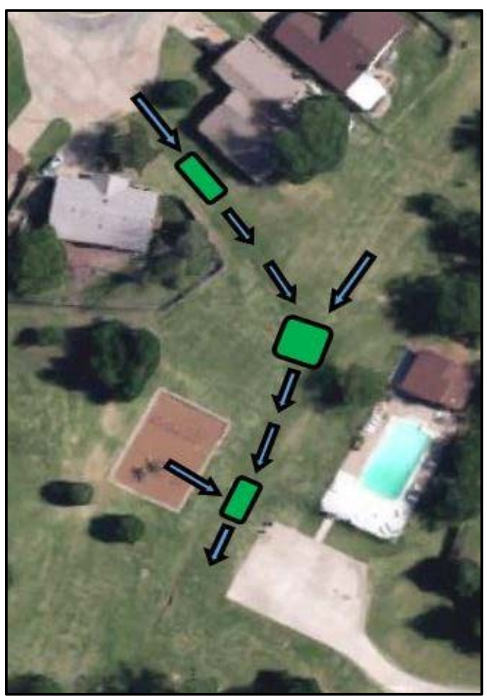


Figure 38. Possible Location of Bioretention Cells or Bioswales at Site A

**Site B - Low Cost Solution**

The low cost solution will reduce stream erosion at Site B by implementing a riparian buffer zone (Figure 39), or “no-mow” zone, which will allow vegetation to grow along the top and sides of the bank. The riparian zone is essential for stream stability. The roots from the vegetation provide an anchor for streambank soil. This adds no cost to the solution.

The stream was surveyed to determine high and medium priority sites that require regrading. These areas can be seen in Figure 40. Regrading is required for the high priority sites in order to ensure that sediment detachment is significantly reduced and safety and aesthesis improves. The areas would be regraded to a 2:1 or 3:1 ratio. Sod would be applied along the top of the slope and coir matting would be used as an erosion control fabric along the bank.

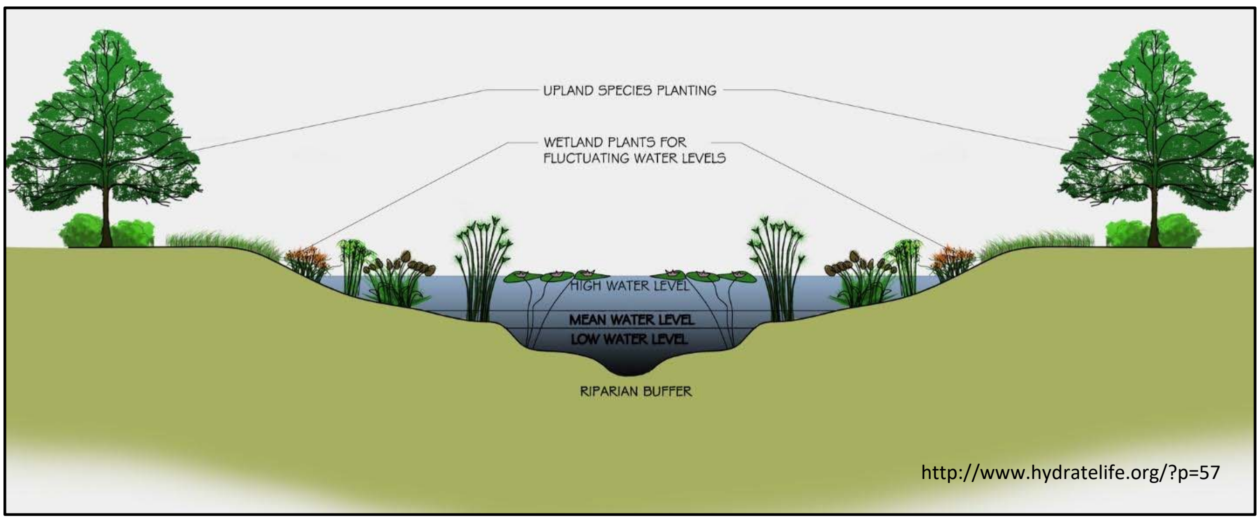



Figure 39. Riparian Buffer Zone Diagram

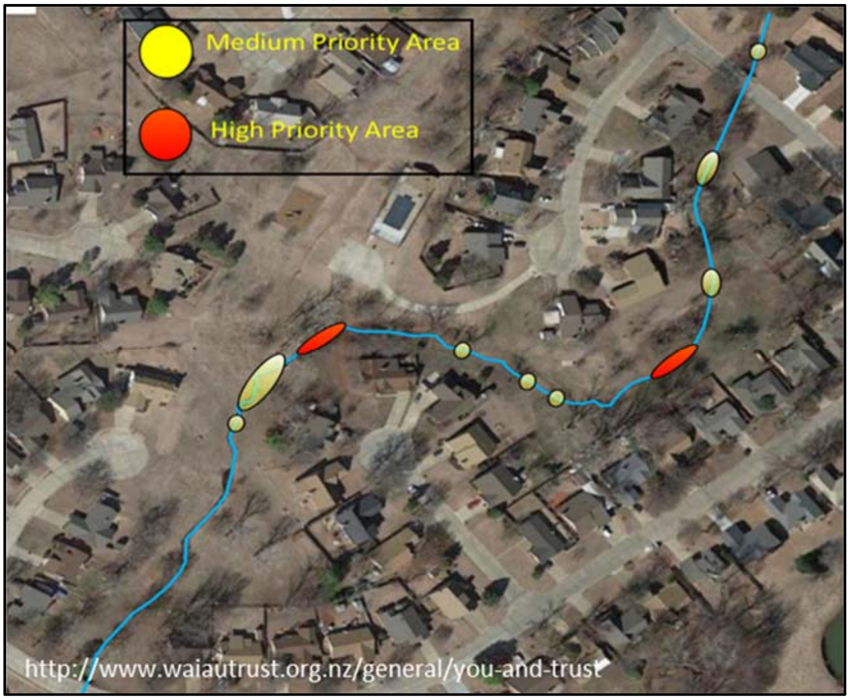



Figure 40. Priority Sites along Problem Site B

**Site B - Medium Cost Solution**

This solution includes regrading the high priority sites and medium priority sites. The slope and vegetative cover would be the same as designed for the low cost solution. Live stakes may be added in places that vegetative growth is bare. Riprap may also be added in key places to reduce stream velocity.

**Site B - High Cost Solution**

The high cost solution includes stabilizing every priority site along the stream and incorporating a multitude of soil stabilization practices. This includes sod, live stakes, riprap, coir matting, and geo-fabric material.

Our long term solution would be to survey and re-design the entire stream by excavating the soil and making the streambanks into slopes that promote stream stability and reduces erosion. This solution is much more expensive and time consuming, but ultimately more effective.

**Site C - Low Cost Solution**

This site has the least severe erosion issues relative to the rest of the project area. None of the erosion in this area is immediately detrimental to the site or greenbelt area as a whole. Because this erosion is the least impactful, the low cost solution in this problem site is to do nothing.

**Site C - Medium Cost Solution**

The medium cost solution for the erosion occurring at the pool driveway entrance is implementing more soil and vegetation along the edge of the driveway (Figure 41). Current "tri-lock" erosion management practices will be left there. The erosion at the storm culvert outlet will be addressed by surveying the outlet, excavating the soil, and re-designing the outlet to create stable slopes and a flood plain for the water to spread out and slow down.

**Site C - High Cost Solution**

The high cost solution builds off the medium solution. CSM would replace the railroad ties that had been previously implemented and still introduce vegetation up to the edge of the ties. The outlet will be re-graded as mentioned above and larger riprap will be implemented at the outlet so the velocity of water flowing into the stream at Site B will be reduced

Figure 41. Soil Erosion along Pool Driveway Entrance at Site C

# Appendix F

## Failure Mode Effects Analysis

| Rating of Importance to Customer | | 6 | 7 | 7 | 10 | 10 | 9 | | |
|---|---|---|---|---|---|---|---|---|---|
| # | KPIV | Aesthetics | Ponding in Streets | Erosion Control | Functionality | Design Life Span | Cost | Total | % Rank |
| 1 | Regrading | 8 | 10 | 10 | 10 | 10 | 8 | 460 | 14% |
| 3 | LID Implementataion | 10 | 7 | 10 | 10 | 10 | 9 | 460 | 14% |
| 2 | Swales | 10 | 10 | 7 | 10 | 10 | 8 | 451 | 14% |
| 8 | Restoration to Stream | 10 | 1 | 10 | 10 | 10 | 8 | 409 | 13% |
| 4 | Stormwater Modeling | 2 | 10 | 10 | 10 | 10 | 2 | 370 | 11% |
| 7 | Individual Prevention | 4 | 9 | 9 | 9 | 8 | 2 | 338 | 10% |
| 5 | Grass Type | 8 | 1 | 8 | 8 | 7 | 5 | 306 | 9% |
| 9 | Construction / Implementation Time | 5 | 4 | 7 | 7 | 4 | 7 | 280 | 9% |
| 6 | Contractor | 7 | 1 | 1 | 1 | 1 | 9 | 157 | 5% |
| | Total | 64 | 53 | 72 | 75 | 70 | 58 | 3231 | |

Figure 42. Cause and Effect Matrix

# Failure Modes Effects Analysis

| | | | |
|---|---|---|---|
| Process or Product Name: | Park View Estates Stormwater Management | Prepared by: | Grant Moore |
| Process Owner: | Cowboy Stormwater Management | FMEA Date (Orig): | 4/26/2017 |

Page: of

Rev.

| Key Process Step or Input | Potential Failure Mode | Potential Failure Effects | SEV | Potential Causes | OCC | Current Controls | DET | RPN | Actions Recommended | Resp. | Actions Taken | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| What is the Process Step or Input? | In what ways can the Process Step or Input fail? | What is the impact on the Key Output Variables once it fails (customer or internal requirements)? | How **Severe** is the effect to the customer? | What causes the Key Input to go wrong? | How **often** does cause or FM **occur**? | What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode? | How well can you **detect** the Cause or the Failure Mode? | | What are the actions for reducing the occurrence of the cause, or improving detection? | Who is Responsible for the recommended action? | Note the actions taken. Include dates of completion. | | | | |
| Regrading | Loose soil. Unhealthy sod. Underground pipe damage. | Erosion. Loss of aestetics. | 5 | Not packing soil. No vegetative growth. | 3 | Observation. | 2 | 30 | Correct impelentation. Mending vegetation. | Contractor. HOA. | New sod. | 5 | 3 | 2 | 30 |
| LID Implementation | Ponding upstream. Redirect water flow. | Loss of aestetics. Possible erosion. | 4 | Incorrect design. Bad location. | 3 | Observation. | 2 | 24 | Improve design. | Engineers. | Redesign. | 4 | 3 | 2 | 24 |
| Swale | Unhealthy sod. Steep slopes. High water velocity. | Possible erosion. Loss of aestetics. | 4 | Not packing soil. No vegetative growth. Incorrect design. | 2 | Observation. Erosion. | 2 | 16 | Correct impelentation. Mending vegetation. | Contractor. HOA. Engineers. | New sod. | 4 | 2 | 2 | 16 |
| Stream Restoration | Loose banks. | Erosion. Loss of aestetics. | 6 | Intense storm systems. Incorrect implementation. No vegetative growth. | 4 | Observation. | 1 | 24 | Correct impelentation. Mending vegetation. | Contractor. | Bank stabilization practices. | 6 | 4 | 1 | 24 |
| Stormwater Modeling | Incorrect inputs. | Disfunctional design. | 6 | User error | 1 | Team members | 3 | 18 | Check work with team. | Engineers. | Redo model. | 6 | 1 | 3 | 18 |
| Individual Prevention | incorrect implementation. | Problems for other properties. Flooding. Erosion. | 5 | User error | 2 | Observation. | 2 | 20 | Cooperation with neighbors. | Homeowners. | Communicate with HOA. | 5 | 2 | 2 | 20 |
| Grass Type | Too short. Not healthy. | Loss of aestetics. Possible erosion. | 5 | Climate/water conditions. | 2 | Withering grass. Erosion. | 1 | 10 | Not mowing low. Mending. Watering well. | HOA. | New sod. | 5 | 2 | 1 | 10 |
| Construction/Implentation on Time | High storm season. | Erosion. | 4 | Choice of construction time. | 2 | Observation. | 1 | 8 | Choosing non storm season to construct. | Engineers. HOA. | Construct during dry seasons. | 4 | 2 | 1 | 8 |
| Contractor | Rushes work. Not complete. | Loss of aestetics. Possible erosion. | 4 | Business/poor work ethic. | 1 | Observation. | 1 | 4 | Communication with contractor and client. | Contractor. | New contractor. | 4 | 1 | 1 | 4 |

Figure 43. FMEA

# Appendix G

## Preliminary Cost Estimates

These cost estimates should be considered to be a representation of a general cost range that is expected for each solution at each problem site. These costs do not represent accurate expectations for real solution costs. They simply display the order of magnitude that is realistic for the types of solutions CSM has considered.

### Site A

**Table 1. Problem Site A - Low Cost Solution**

| Problem Site A - Low Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | \$ 13.00 | \$ 29.50 |
| Regrading ($ft^2$) | 5100 | \$ 0.50 | \$ 0.68 |
| Turf ($ft^2$) | 5100 | \$ 0.01 | \$ 1.09 |
| Rough Cost Range | - | \$ 2,600 | \$ 9,000 |

**Table 2. Problem Site A - Medium Cost Solution (Option 1)**

| Problem Site A - Med Cost Solution (Option 1 - Large Bioswale) | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | \$ 13.00 | \$ 29.50 |
| Regrading ($ft^2$) | 800 | \$ 0.50 | \$ 0.68 |
| Turf ($ft^2$) | 800 | \$ 0.01 | \$ 1.09 |
| Permeable Pavers ($ft^2$) | 500 | \$ 7.10 | \$ 12.00 |
| Bioswale | 4200 | \$ 5.50 | \$ 24.00 |
| Calculated Costs | - | \$ 27,000 | \$ 109,000 |

**Table 3. Problem Site A - Med Cost Solution (Option 2)**

| Problem Site A - Med Cost Solution (Option 2 Small Bioswale) | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$) | 800 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 800 | $ 0.01 | $ 1.09 |
| Permeable Pavers ($ft^2$) | 0 | $ 7.10 | $ 12.00 |
| Bioswale | 2775 | $ 5.50 | $ 24.00 |
| Calculated Costs | - | $ 16,000 | $ 68,000 |

The high cost solution for Problem Site A is expected to be greater than $110,000.

## Site B

**Table 4. Problem Site B - Low Cost Solution**

| Problem Site B - Low Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 3600 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 3600 | $ 0.01 | $ 1.09 |
| Coir Matting (Roll) | 2 | $ 90.00 | $ 100.00 |
| Calculated Costs | - | $ 2,000 | $ 6,500 |

**Table 5. Problem Site B - Medium Cost Solution**

| Problem Site B - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 14800 | $ 0.50 | $ 0.68 |
| Turf ($ft^{2)}$ | 14800 | $ 0.01 | $ 1.09 |
| Coir Matting (Roll) | 15 | $ 90.00 | $ 100.00 |
| Calculated Costs | - | $ 9,000 | $ 12,000 |

**Table 6. Problem Site B - High Cost Solution**

| Problem Site B - High Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Coir Matting (Roll) | 15 | $ 90.00 | $ 100.00 |
| Regrading ($ft^2$) | 14800 | $ 0.50 | $ 0.68 |
| Riprap ($ft^2$) | 7500 | $ 2.77 | $ 2.77 |
| Native Vegetation (Linear ft.) | 3400 | $ 0.02 | $ 0.15 |
| Calculated Costs | - | $ 30,000 | $ 33,000 |

## Site C

The low cost solution for Problem Site C is to leave the site as it is. It was determined that doing nothing at this site would still meet the customer requirements. Improving this site is recommended for improving aesthetics, but not required.

**Table 7. Problem Site C – Medium Cost Solution**

| Problem Site C - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 1250 | $ 0.50 | $ 0.68 |
| Vegetation, walkway (linear ft.) | 125 | $ 0.41 | $ 1.44 |
| Vegetation, outlet ($ft^2$) | 1250 | $ 0.31 | $ 1.08 |
| Calculated Costs | - | $ 650 | $ 1,000 |

**Table 8. Problem Site C - High Cost Solution**

| Problem Site C - High Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 1250 | $ 0.50 | $ 0.68 |
| Vegetation, outlet ($ft^2$) | 125 | $ 0.31 | $ 1.08 |
| Railroad Ties | 31 | $ 15.00 | $ 15.00 |
| Riprap | 1250 | $ 2.77 | $ 2.77 |
| Calculated Costs | - | $ 4,600 | $ 5,000 |

**Solution Cost Outline**

Problem Site A

*Low Cost Solution* -------------------------------------- Rough Solution Cost Range: $2,600 - $9,000

- Remove current drain & pipe (Marie Drive Cul-de-sac)
- Regrade water way to optimal slope (Marie Drive Cul-de-sac)
- Apply sod over regraded area (Marie Drive Cul-de-sac)
- Restore highly eroded sites (Greenbelt Area)

*Medium Cost Solution* ----------------------------- Rough Solution Cost Range: $16,000 - $109,000

- Remove current drain & pipe (Marie Drive Cul-de-sac)
- Regrade water way to optimal slope (Marie Drive Cul-de-sac)
- Apply sod over regraded area (Marie Drive Cul-de-sac)
- Optional permeable pavers (Marie Drive Cul-de-sac)
- Restore highly eroded sites (Greenbelt Area)
- Install grass bioswale (Greenbelt Area)

*High Cost Solution* ------------------------------------- Rough Solution Cost: Greater than $110,000

- Remove current drain & pipe (Marie Drive Cul-de-sac)
- Regrade water way to optimal slope (Marie Drive Cul-de-sac)
- Apply sod over regraded area (Marie Drive Cul-de-sac)
- Optional permeable pavers (Marie Drive Cul-de-sac & Greenbelt Area)
- Restore highly eroded sites (Greenbelt Area)
- Install grass bioswale (Greenbelt Area)
- Add aesthetic vegetation to bioswale (Greenbelt Area)
- Install bioretention cells (Greenbelt Area)

Problem Site B

*Low Cost Solution* -------------------------------------- Rough Solution Cost Range: $2,000 - $6,500

- Incorporate "No Mow" zone along bank
- Regrade high priority sites
- Apply sod
- Apply erosion control matting

*Medium Cost Solution* -------------------------------- Rough Solution Cost Range: $9,000 - $12,000

- Incorporate "No Mow" zone along bank
- Regrade high priority sites
- Regrade medium priority sites
- Apply sod
- Apply erosion control matting
- Apply live stakes
- Apply riprap

*High Cost Solution* ---------------------------------- Rough Solution Cost Range: $30,000 - $33,000

- Incorporate "No Mow" zone along bank
- Regrade high priority sites
- Regrade medium priority sites
- Regrade low priority sites
- Apply sod
- Apply erosion control matting
- Apply live stakes
- Apply riprap

Problem Site C

*Low Cost Solution* ------------------------------------------------------------- Rough Solution Cost: $0

- Do nothing

*Medium Cost Solution* ----------------------------------- Rough Solution Cost Range: $650 - $1,000

- Apply grass in-between tri-locks
- Regrade pipe outlet
- Apply erosion control matting

*High Cost Solution* ------------------------------------- Rough Solution Cost Range: $4,600 - $5,000

- Apply grass in-between tri-lock
- Replace railroad ties
- Regrade pipe outlet
- Apply erosion control matting
- Add appropriately sized riprap

# Appendix H

## Hydrology Calculations

**Time of Concentration: Problem Site A**

Kirpich Equation: $t_c = 0.019 \frac{L^{0.77}}{S_o^{0.385}}$

Where $t_c$ = time of concentration (min)

$L$ = length of watershed to outlet (m)

$S_o$ = Slope (decimal)

Assumptions

1. The longest path for water flow is the longest street path
2. There is no significant water retention
3. Slope used is slope of streets.

$t_{c\,total} = [t_{c_1} + t_{c_2}]\,0.4$ (0.4 indicates asphalt as surface)

$t_{c_1}$

$L_1 = 151\,m = 497\,ft$

$S_{o1} = \frac{970 - 956\,ft}{497\,ft} = 0.0282$ → Britton st.

$t_{c_1} = 0.019 \left[\frac{151^{0.77}}{0.0282^{0.385}}\right] = 3.57\,min$

$t_{c_2}$

$L_2 = 195\,m = 639.8\,ft$

$S_{o2} = \frac{956 - 950\,ft}{640\,ft} = 0.00934$ → Marie st.

$t_{c_2} = 0.019 \left[\frac{195^{.77}}{0.00934^{.385}}\right] = 6.66\,min$

$t_{c\,tot} = [3.57\,min + 6.66\,min]\,0.4 = \underline{4.09\,min}$

Figure 44. Site A Time of Concentration Calculation

Peak Flow : Problem Site A (100yr, 24 hr Storm)

Rational Method: $Q_p = I A C$

where,

$Q_p$ = Peak flow ($ft^3/s$)

I = intensity (in/hr)

A = Watershed Area (acres)

C = Runoff coefficent

From ODOT Roadway Drainage Manual, Figure 7.6-K

using a $T_c = 5$ min, 100yr 24 hr storm

$I = 10.5$ in/hr

Using Google Earth Pro, Watershed Area = 8.24 acres

From Table 7.6-A (ODOT Manual), $C = 0.4$ → assumed higher value due to clay soil & impervious area cover.

$Q_p = (10.5\ in/hr)(8.24\ acres)(0.4) = 34.61\ ft^3/s$ = Peak flow

Figure 45. Site A Peak Flow Calculations

| Channel Only | | | | | | |
|---|---|---|---|---|---|---|
| Cross Section | Width (ft) | Depth (ft) | Wetted Perimeter (ft) | Cross-sectional Area (ft^2) | Hydraulic Radius (ft) | Flow (cfs) |
| 1 | 12 | 0.54 | 12.065 | 4.32 | 0.358 | 1.579 |
| 2 | 12 | 0.76 | 12.128 | 6.08 | 0.501 | 2.781 |
| 3 | 12 | 0.99 | 12.218 | 7.92 | 0.648 | 4.300 |
| 4 | 12 | 1.49 | 12.493 | 11.92 | 0.954 | 8.374 |
| 5 | 12 | 1.91 | 12.811 | 15.28 | 1.193 | 12.457 |
| 6 | 12 | 2.77 | 13.705 | 22.16 | 1.617 | 22.129 |
| 7 | 12 | 3.15 | 14.205 | 25.2 | 1.774 | 26.769 |
| 8 | 12 | 3.47 | 14.676 | 27.76 | 1.892 | 30.777 |
| 9 | 12 | 4.06 | 15.663 | 32.48 | 2.074 | 38.286 |
| 10 | 12 | 4.24 | 15.995 | 33.92 | 2.121 | 40.585 |
| 11 | 12 | 4.138 | 15.805 | 33.104 | 2.095 | 39.283 |
| 12 | 12 | 4.193 | 15.907 | 33.544 | 2.109 | 39.985 |
| 13 | 12 | 3.857 | 15.306 | 30.856 | 2.016 | 35.694 |
| 14 | 12 | 3.46 | 14.660 | 27.68 | 1.888 | 30.651 |
| | | | | | Average Flow = 23.83 | |
| Mannings Roughness (n) = 0.41 | | | Bermuda Grass | | | |

| Area Surrounding Channel | | | | | | |
|---|---|---|---|---|---|---|
| Cross Section | Width (ft) | Depth (ft) | Wetted Perimeter (ft) | Cross-sectional Area (ft^2) | Hydraulic Radius (ft) | Flow (cfs) |
| 1 | 30 | 0.29 | 30.007 | 5.800 | 0.193 | 0.943 |
| 2 | 30 | 1.06 | 30.100 | 21.200 | 0.704 | 8.161 |
| 3 | 30 | 1.37 | 30.167 | 27.400 | 0.908 | 12.496 |
| 4 | 30 | 1.41 | 30.177 | 28.200 | 0.934 | 13.107 |
| 5 | 30 | 1.33 | 30.157 | 26.600 | 0.882 | 11.896 |
| 6 | 30 | 1.41 | 30.177 | 28.200 | 0.934 | 13.107 |
| 7 | 30 | 1.59 | 30.225 | 31.800 | 1.052 | 15.996 |
| 8 | 35 | 1.81 | 35.250 | 42.233 | 1.198 | 23.167 |
| 9 | 40 | 2.32 | 40.359 | 61.867 | 1.533 | 39.995 |
| 10 | 40 | 2.3 | 40.353 | 61.333 | 1.520 | 39.426 |
| 11 | 45 | 2.3 | 45.313 | 69.000 | 1.523 | 44.409 |
| 12 | 50 | 1.4 | 50.105 | 46.667 | 0.931 | 21.642 |
| 13 | 50 | 1.09 | 50.063 | 36.333 | 0.726 | 14.268 |
| 14 | 50 | 0.64 | 50.022 | 21.333 | 0.426 | 5.878 |
| | | | | | Average Flow = 18.89 | |

Figure 46. Site A Channel Flow Calculations

# Appendix I

## Acknowledgements

Cowboy Stormwater Management would like to acknowledge several professors and OSU staff members for their contributions to this projects. First of all, to Dr. Paul Weckler for his guidance and direction for two semesters. Secondly, to Dr. Jason Vogel for his shared knowledge in water resource management and hydrology. He was able to provide key information that assisted us in our design process. Thirdly, to Dr. Daniel Thomas for his valuable perspective in our numerical results. Fourthly, to Dr. Hasan Atiyeh for his advice in the modeling stage of the design for Site A.

CSM would also like to thank the Park View Estates Homeowners Association for their continual support and communication with us. We sincerely appreciated the opportunity to develop our engineering experience and skills on your neighborhood. Finally, CSM would like to thank Sharla Lovern with the City of Stillwater for her expertise in the initial understanding of the problem at Park View Estates, as well has her willingness to work with the homeowners association in solving their stormwater problems.

# Stormwater Management at
# Park View Estates

COWBOY STORMWATER MANAGEMENT

Zach Bradley | Riley Jones | Grant Moore | Derek West

November 18, 2016

Biosystems & Agricultural Engineering
Oklahoma State University

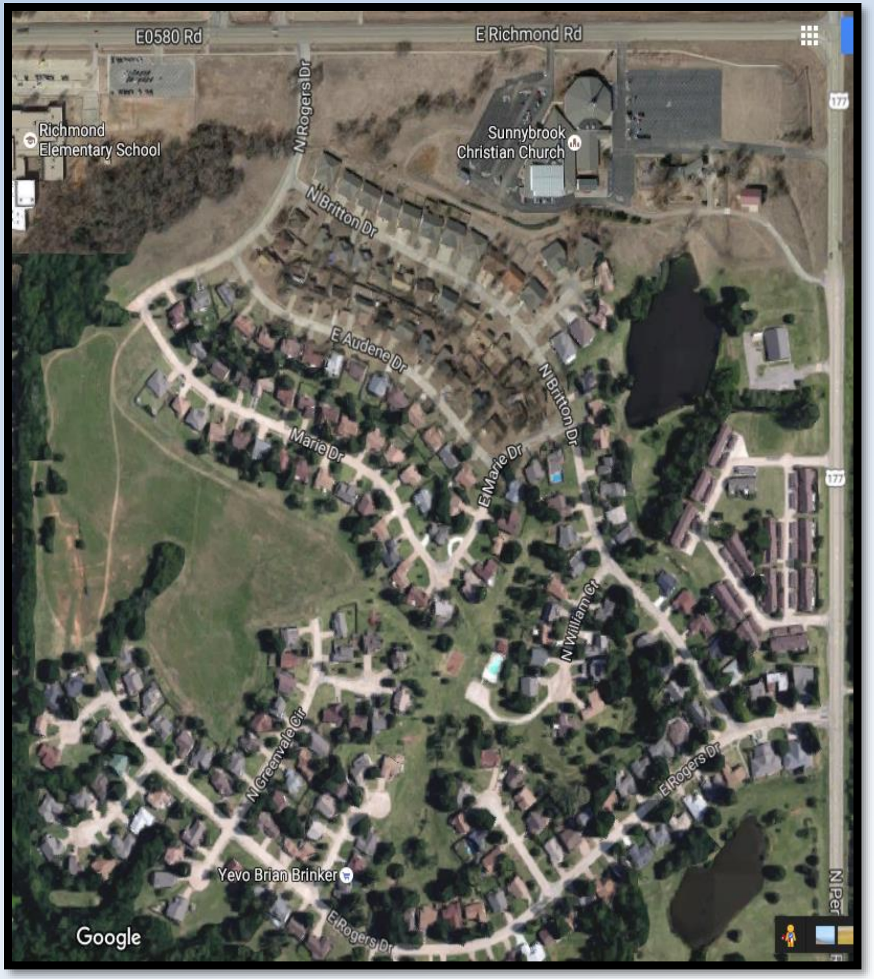
# *Mission Statement*

The mission of the Cowboy Stormwater Management team is to design and implement sustainable storm and surface water systems that control erosion damage from stormwater runoff, improve urban development, and enhance quality of life in Stillwater, OK.

COWBOY STORMWATER MANAGEMENT

# Statement of Work

- Period of Performance: Aug 15, 2016 – May 12, 2017
- Client: Park View Estates Homeowners Association
- Location: Stillwater, Oklahoma



# Client Information

- Park View Estates Home Owners Association
  - Incorporated in 1976
  - J.C and Evelyn Rogers, from dairy to community
  - Preside over 230 lots

# Project Parameters

**Client Requirements**

- Eliminate ponding in streets and yards (top priority)
- Reduce erosion in public space
- Stabilize stream bank erosion of creek
- Provide three cost options

**Client Constraints**

- Cost/Benefit
- Safe for residents
- Natural looking

# Project Approach

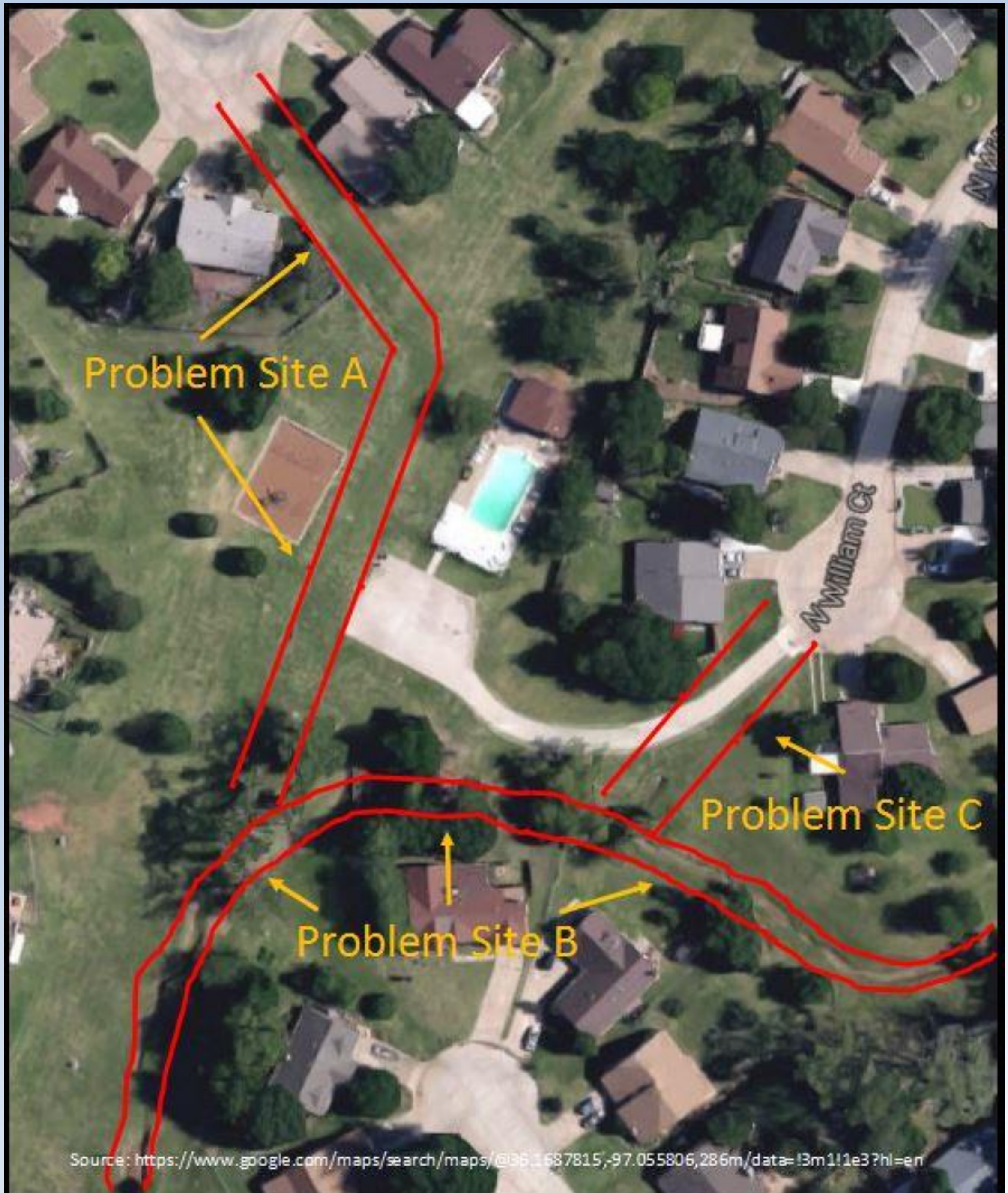
## 2 Schools of Thought

**Low Impact Development (LID)**

Using natural methods to reduce stormwater runoff, increase water infiltration into soil, and eventually direct water into streams, rivers, and lakes

**Traditional**

Moving the water towards streams, rivers, and lakes, generally using impermeable surfaces such as concrete


Problem Site A
N William Ct
Problem Site C
Problem Site B
Source: https://www.google.com/maps/search/maps/@36.1687815,-97.055806,286m/data=!3m1!1e3?hl=en

# Problem Sites at a Glance

<u>Site A</u>

- Ponded water in cul-de-sac 48 hours after storm event
- Under designed drain pipe
- Erosion at drainpipe outlet & at tree stump

# Problem Sites at a Glance

<u>Site B</u>

- Massive holes forming throughout stream
- Streambank erosion
- Sediment transport
- Sediment deposition

# Problem Sites at a Glance

Site C

- Erosion along left side of pool driveway
- Washout of riprap at culvert outlet
- Excessive energy at culvert outlet

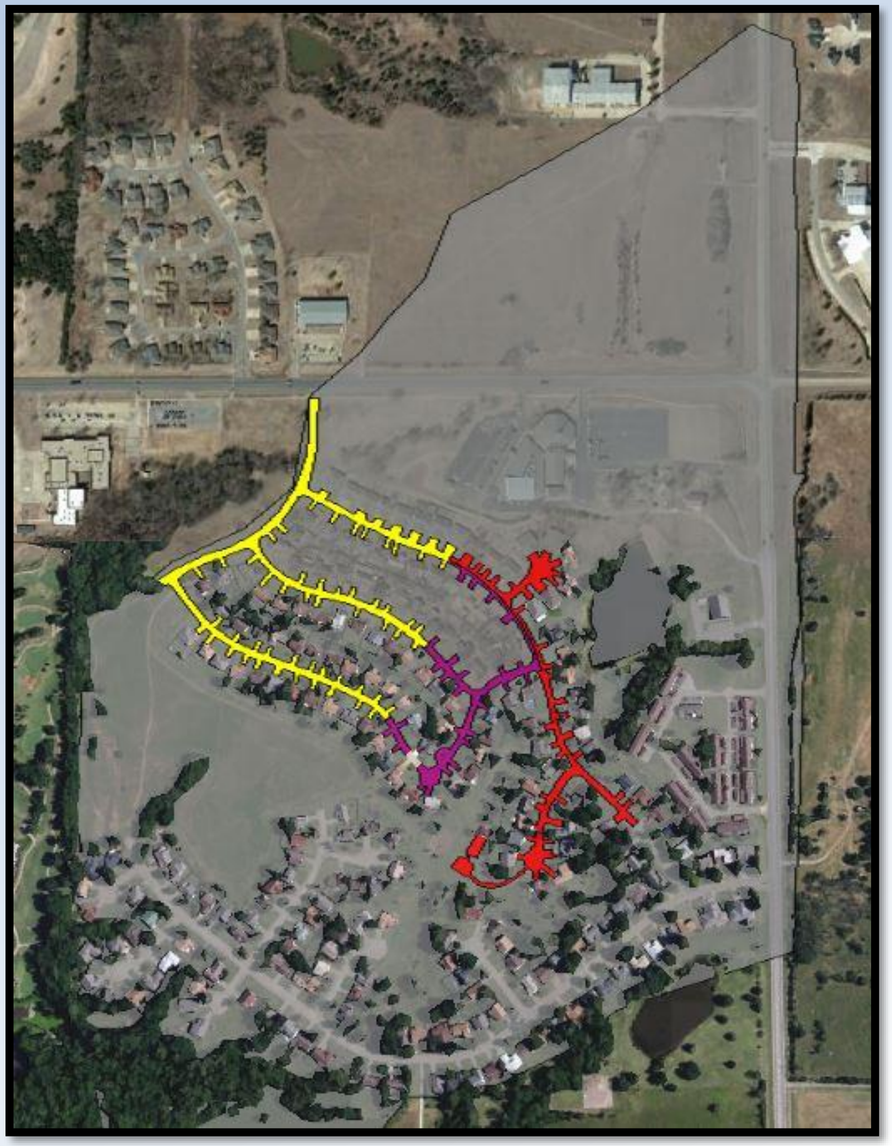
# Data Collection

**Surveying**

- Cross sections at A, B, and C
- Watershed delineation
- For use in hydrologic and hydraulic modeling

**Model Parameters**

- $t_c$, time of concentration
- Q, flowrate
- P, precipitation
- S, Slope



# Development of the Model

- Rainfall Data
  - Stillwater, OK IDF curve

    P = $R_{24}^{25}$ = 6.8in

- Estimating Runoff
  - SCS Curve Number Method

    Q = $\frac{(P-I_a)^n}{(P-I_a)+S}$ , where

    Q = runoff (in)
    P = rainfall (in)
    S = potential retention after runoff (in)
    $I_a$ = initial abstraction (in)

# Development the Model

- Time of Concentration
  - Kirpich Equation

$$t_c = \frac{L^{0.77}}{{S_0}^{0.385}},$$ where

L = distance from boundary to outlet (m)

$t_c$ = mins

$S_0$ = slope (decimal)

- Slope
  - Slope Equation

$$\frac{h_1 - h_2}{\Delta L},$$ where

$h_1$ = elevation 1

$h_2$ = elevation 2

$\Delta L$ = change is distance

# Risk Analysis

- Flood Frequency Analysis

$$f(P_T, n) = 1 - \left(1 - \frac{1}{T}\right)^n, \quad \text{where}$$

$P_T$ = Exceedance Probability

T $=$ Recurrance Interval

n $=$ # years storm event

  - High Cost

$$0.15 = 1 - \left(1 - \frac{1}{T}\right)^{25}, T_{hc} = 154\text{-yr}$$

  - Medium Cost

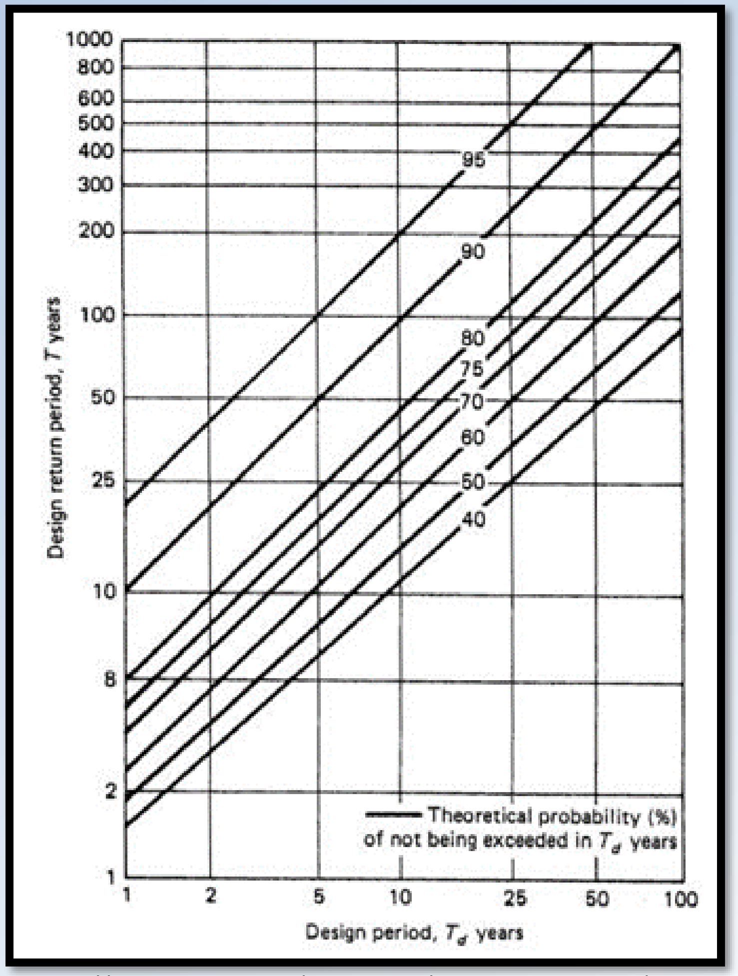
$$0.50 = 1 - \left(1 - \frac{1}{T}\right)^{25}, T_{mc} = 37\text{-yr}$$

  - Low Cost

$$0.80 = 1 - \left(1 - \frac{1}{T}\right)^{25}, T_{lc} = 16\text{-yr}$$

# Risk Analysis

- Design Life Span
  - High Cost
    @ $T_{hc}$ , $T_D$ = Y1 year
  - Medium Cost
    @ $T_{mc}$ , $T_D$ = Y2 year
  - Low Cost
    @ $T_{lc}$ , $T_D$ = Y3 year




http://rpitt.eng.ua.edu/Workshop/WSErorionControl/Module4/Module4.htm

# Problem Site A

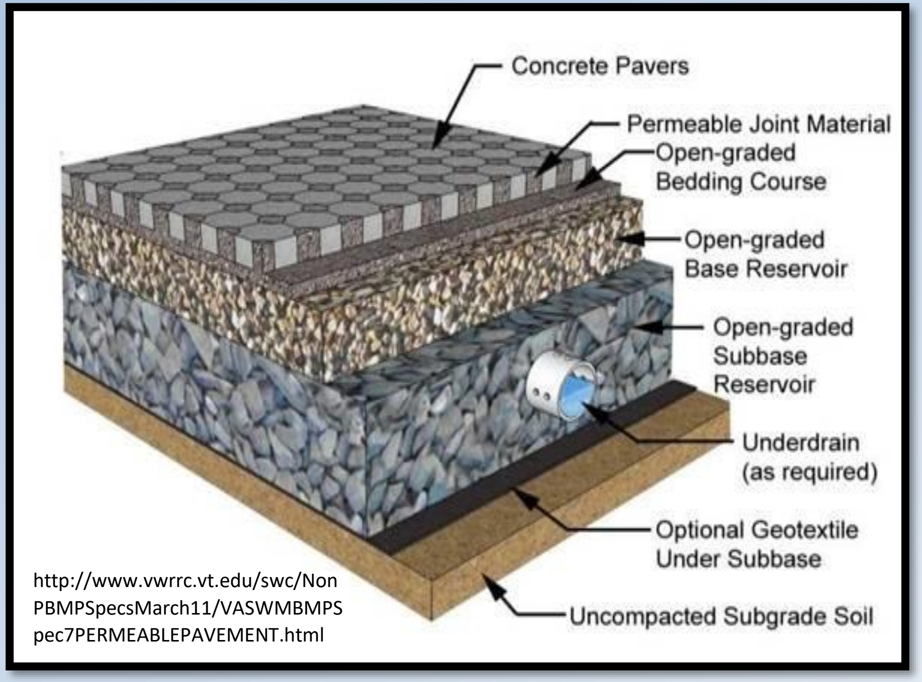

# Possible Solutions

- Regrading Slope
- Permeable Pavement
- Multiple Bioretention Cells
- Enhanced Bioswale

# Permeable Pavement

**Pros**

- Fast water infiltration
- Long life
- Aesthetic
- Walkway to Greenbelt



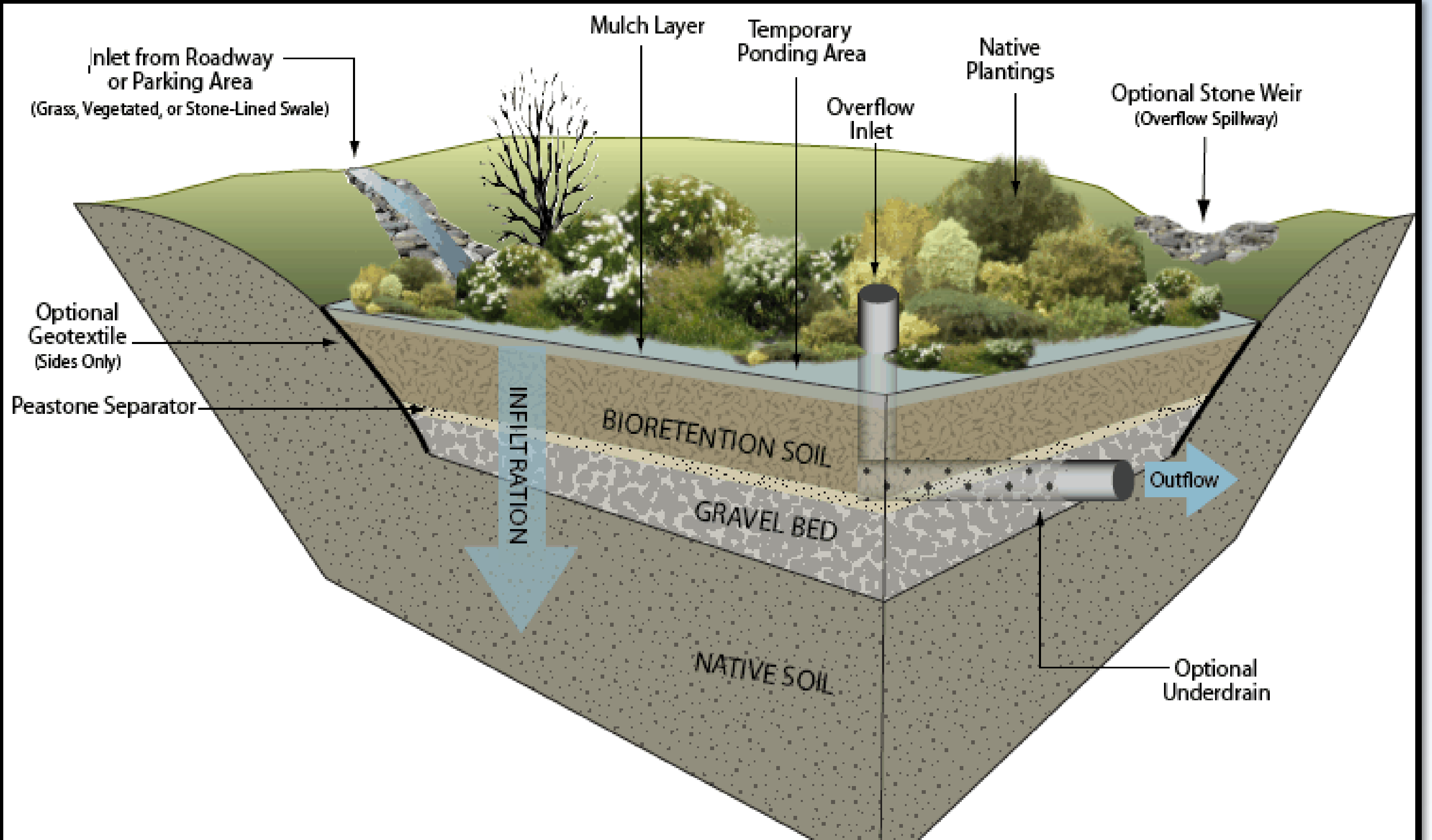

**Cons**

- High cost
- High maintenance
- Low strength

*Cost Range: $5.30 - $7.10 / sq. ft*

*Average Life: 25 years*

# Bioretention Cells




http://ne.water.usgs.gov/projects/bioremediation/cells.html

# Bioretention Cells

**<u>Pros</u>**

- Aesthetic
- Reduces water to stream
- Cleans water contaminants

**<u>Cons</u>**

- High cost
- Some maintenance
- Small area

*Cost Range: $5.50 - $ 24.00 / sq. ft*

*Average Life: 30 years*

# Bioswale

**Pros**

- Aesthetic
- Guides water flow
- High infiltration
- Filters stormwater
- Covers large area

**Cons**

- High cost
- Some maintenance

https://www.columbus.gov/uploadedImages/Public_Utilities/Water_Protection/Watershed/Bioswale%20Illustration%201(1).jpg

*Cost Range: $5.50 - $ 24.00 / sq. ft*

*Average Life: 30 years*

# Advantages of Turf Bioswales

- Directs water
- Easily maintained
- Decreases water velocity
- Less expensive

http://chesapeakestormwater.net/wp-content/uploads/2009/11/dry-swale.gif

# Regrading Slope

- The poor slope is the main cause of flooding in cul-de-sac
- Regrading will eliminate future flooding
- Average cost of grading: $0.59 / sq. ft

# Site A - Low Cost Solution

- Curb and Pathway
  - Regrade slope
  - Seal or remove pipe
  - Widen curb inlet

- Greenbelt Area
  - Remove eroded sites
  - Regrade existing swale
  - Keep existing soil

# Site A - Low Cost Solution

| Problem Site A - Low Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$) | 5100 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 5100 | $ 0.01 | $ 1.09 |
| Calculated Costs | - | $ 2,666.00 | $ 9,174.50 |
| Average Cost | $ 5,920.25 | | |

# Site A - Medium Cost Solution

- Curb and Pathway
  - Redo slope grading
  - Remove broken pipe
  - Implement permeable walkway
- Greenbelt Area
  - Construct complete bioswale
  - Replace subsoil with sand


http://docplayer.net/docs-images/14/42740/images/34-1.jpg

# Site A - Medium Cost Solution

- Small bioswale
- No permeable pavers

| Problem Site A - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$) | 800 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 800 | $ 0.01 | $ 1.09 |
| Permeable Pavers ($ft^2$) | 0 | $ 7.10 | $ 12.00 |
| Bioswale | 2775 | $ 5.50 | $ 24.00 |
| Calculated Costs | - | $ 15,735.50 | $ 68,163.50 |
| Average Cost | $ 41,949.50 | | |

# Site A - Medium Cost Solution

- Large bioswale
- Including permeable pavers

| Problem Site A - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$ ) | 800 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 800 | $ 0.01 | $ 1.09 |
| Permeable Pavers ($ft^2$ ) | 500 | $ 7.10 | $ 12.00 |
| Bioswale | 4200 | $ 5.50 | $ 24.00 |
| Calculated Costs | - | $ 27,123.00 | $ 108,363.50 |
| Average Cost | $ 67,743.25 | | |

# Site A - High Cost Solution

- Curb and Pathway
  – Redo slope grading
  – Remove pipe
  – Implement permeable walkway
  – Install multiple small bioretention cells
- Greenbelt Area
  – Construct complete bioswale
  – Add check dams
  – Input aesthetic vegetation along swale


**Example of High Cost Residential Bioswale**

# Site A - Cost Analysis

- Low Cost solution
  - Cost range: $2615.00 – $3615.50
- Medium Cost solution
  - Small swale cost range: $15,727.50 – $67,291.50
  - Large swale cost range: $27,115.00 – $107,491.50
- High Cost solution
  - Cost > $110,000

Sources:

- http://www.homewyse.com/services/cost_to_grade_landscaping.html
- http://greenvalues.cnt.org/national/cost_detail.php

# Problem Site B - Stream

- Streambank erosion
- Vertical banks
- Large pooling
- Sediment build up

# Possible Solutions

- Riparian buffer zone
- Riprap
- Streambank slope restoration
- Implement native vegetation

# Riparian Zone


- Roots from vegetation provide an anchor for the stream bank soil
- Provides an ecosystem for small animals and insects that help stream stability
- Inexpensive way to help prevent stream bank erosion

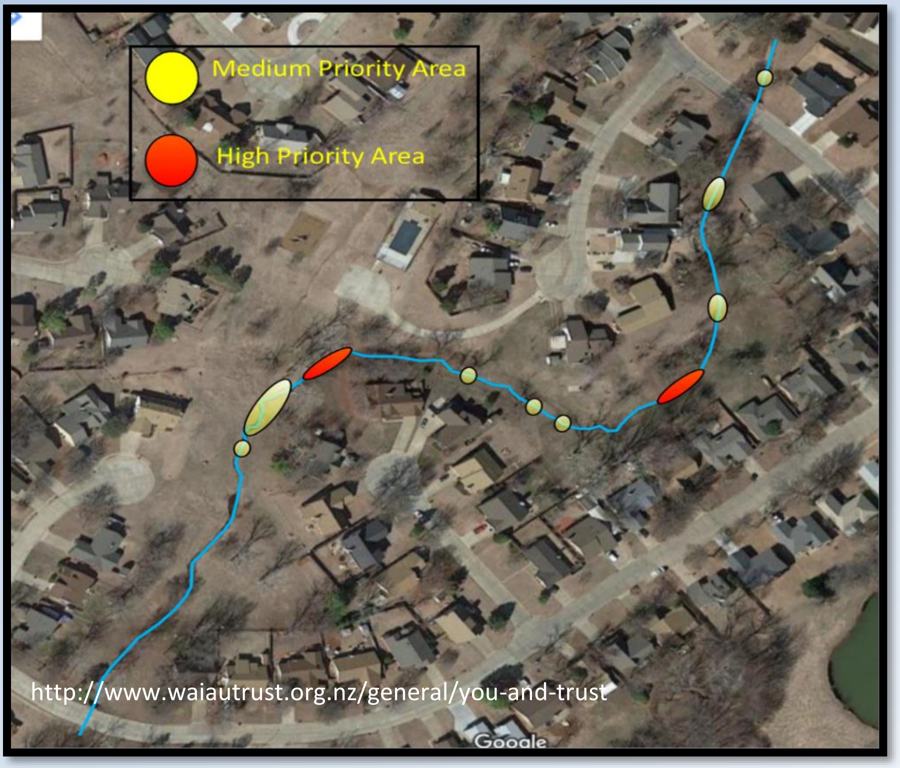
# Riprap


- Riprap prevents erosion by providing armor for the streambank soil
- Vegetation can grow in between the stones, benefiting the riparian zone
- Natural appearance

# Native Vegetation


- "Live stakes" are small woody cuttings of indigenous trees or shrubs that can easily be replanted into the stream bank
- Implementing vegetation that is indigenous to the area provides stability, biofiltration, and natural aesthetics

# Site B - Low Cost Solutions




- Implement "No Mow" riparian buffer zone
- Regrade high priority sites
- After regrading apply turf and coir matting

# Site B – Medium Cost Solution


- Build on low cost solutions
- Regrade the medium priority sites along with the high priority sites
- After regrading, apply turf and coir matting

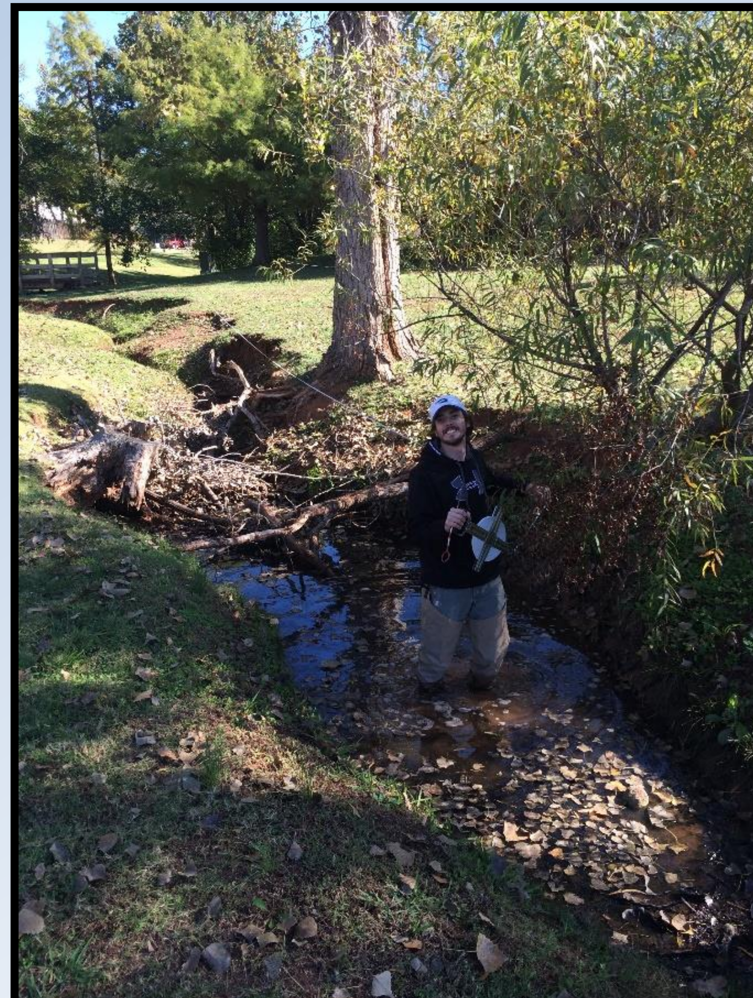
# Site B Long Term – High Cost


ttps://www.dubois-king.com/projects/oak-hill-stream-channel-restoration/


http://www.biohabitats.com/newsletters/ecological-construction-planting-and-management/

- Build on low and medium cost solutions
- Plant live stakes and other native vegetation
- Incorporate all possible solutions into one total stream reconstruction design

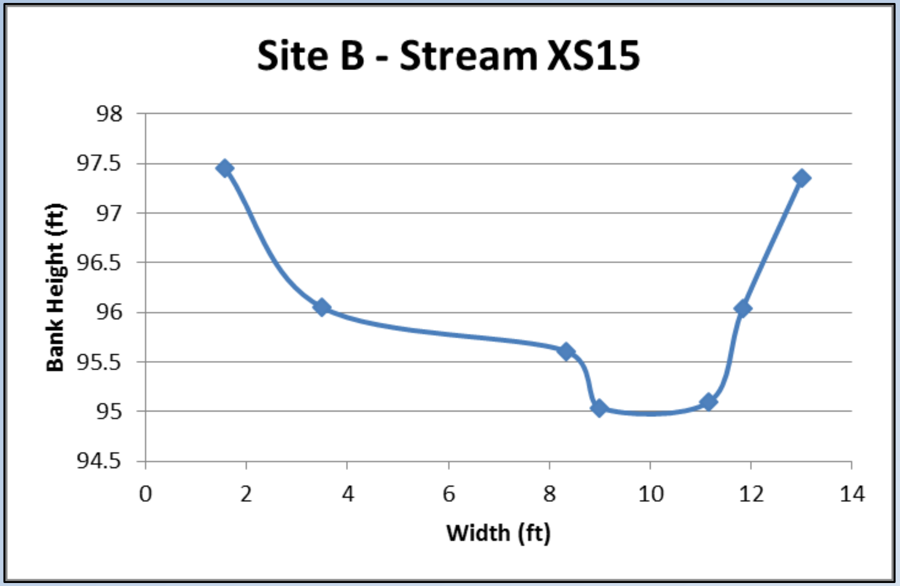
# Surveying

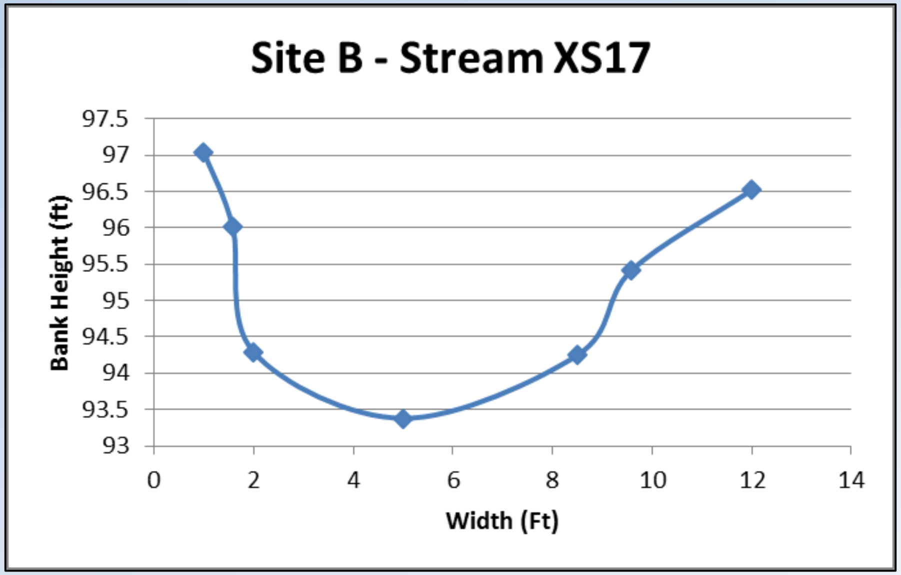


- Cross section surveys were conducted
- Survey data will allow us to determine priority sites, stream profiles, and bank slopes ratios
- These parameters will be used to assess stream bank erosion and the best restoration practice to be applied

# Surveying

## Example of surveyed stream cross sections




- This data will be utilized in future work to create a model of the stream using river and stream morphology software

# Site B Cost Analysis

- **1,500 lb Skid Steer Loader from Kinnunen rental**
  - $30.25/hr $165.00/day $495.00/week
  - $50.00-$85.00/hr for operator
  - http://ksrsales.com/excavation/66-1500-lb-skid-steer-loader
- **Rip Rap**
  - $110.75/ton
  - 40 sq. ft / ton
  - http://minickmaterials.com/pricelist/#crushedlimestonerock
- **Live Stakes**
  - 2 ft stakes for $0.70 each
  - http://www.ernstseed.com/files/documents/2017-wholesale-pricelist.pdf
- **Coir Matting**
  - 8ft x 113 ft (around 100 sq. yrds) $100/roll
  - http://www.amleo.com/coconut-erosion-control-blanket-8ft-x-113ft-roll/p/C4000/
  - http://greenvalues.cnt.org/national/cost_detail.php

# Site B Low Cost Solution

- Regrade stream banks only at high priority sites
- Implement turf and coir matting after regrading

| Problem Site B - Low Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 3600 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 3600 | $ 0.01 | $ 1.09 |
| Coir Matting (Roll) | 2 | $ 90.00 | $ 100.00 |
| Calculated Costs | - | $ 2,016.00 | $ 6,572.00 |
| Average Cost | $ 4,294.00 | | |

# Site B Medium Cost Solution

- Regrade stream banks at all priority sites, both medium and high
- Implement turf and coir matting after regrading

| Problem Site B - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 14800 | $ 0.50 | $ 0.68 |
| Turf ($ft^{2)}$ | 14800 | $ 0.01 | $ 1.09 |
| Coir Matting (Roll) | 15 | $ 90.00 | $ 100.00 |
| Calculated Costs | - | $ 8,750.00 | $ 11,564.00 |
| Average Cost | $ 10,157.00 | | |

# Site B High Cost Solution

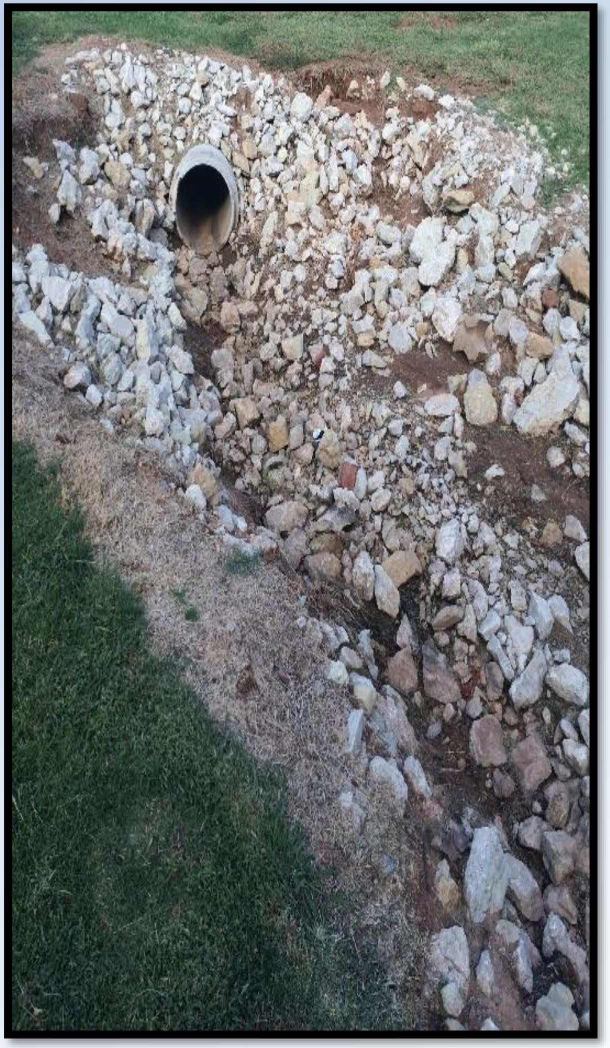
- Regrade stream banks at all priority sites
- Apply turf and coir matting
- Implement riprap at certain locations
- Plant native vegetation along the regraded stream banks

| Problem Site B - High Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Coir Matting (Roll) | 15 | $ 90.00 | $ 100.00 |
| Regrading ($ft^2$) | 14800 | $ 0.50 | $ 0.68 |
| Riprap ($ft^2$) | 7500 | $ 2.77 | $ 2.77 |
| Native Vegetation (Linear ft.) | 3400 | $ 0.02 | $ 0.15 |
| Calculated Costs | - | $ 29,593.00 | $ 32,849.00 |
| Average Cost | $ 31,221.00 | | |

# Problem Site C Overview

Erosion along walkway from cul-de-sac to pool area

Erosion and undersized riprap at outlet pipe from cul-de-sac drain



# Site C-Possible Solutions

- Riprap, appropriately sized
- Regrading
- Vegetation introduction

# Riprap

- Pros
  - Breakup of runoff energy
  - Armoring for soil
- Cons
  - Expensive
  - Can cause potential downcutting and scouring

http://www.ecolandscaping.org/05/erosion-control/streambank-stabilization-after-the-2009-atlanta-floods-a-case-study/

# Regrade and Vegetation

- Pros
  - Better slope
  - More secure soil
- Cons
  - Initial maintenance

# Site C Long Term – Low Cost

## Doing Nothing

# Site C Long Term – Medium Cost

- Regrading slope into floodplain at outlet with grass
- Adding grass and plants over tri-locks

| Problem Site C - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 1250 | $ 0.50 | $ 0.68 |
| Vegetation, walkway (linear ft.) | 125 | $ 0.41 | $ 1.44 |
| Vegetation, outlet ($ft^2$) | 1250 | $ 0.31 | $ 1.08 |
| Calculated Costs | - | $ 676.25 | $ 1,030.00 |
| Average Cost | $ 853.13 | | |

# Site C Long Term – High Cost

- Replacing tri-locks with railroad ties
- Bigger, BETTER riprap
- Regrading and resizing outlet

| Problem Site C - High Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 1250 | $ 0.50 | $ 0.68 |
| Vegetation, outlet ($ft^2$) | 125 | $ 0.31 | $ 1.08 |
| Railroad Ties | 31 | $ 15.00 | $ 15.00 |
| Riprap | 1250 | $ 2.77 | $ 2.77 |
| Calculated Costs | - | $ 4,591.25 | $ 4,912.50 |
| Average Cost | $ 4,751.88 | | |

# Cost Analysis

- Riprap
  - $110.75/ton
  - 40 sq. ft. / ton
- Grading
  - $0.64 to $0.87 per square yard
- Railroad Tie
  - $15 at Lowe’s per tie
  - $945 for 63 ties
- Sod
  - $.41-$1.44 per linear ft. or $.31-$1.08 per sq. ft.

Sources:

- http://www.homewyse.com/services/cost_to_grade_landscaping.html
- http://greenvalues.cnt.org/national/cost_detail.php
- http://sod.promatcher.com/cost/oklahoma-city-ok-sod-costs-prices.aspx

# Looking Ahead

- Construct document for HOA to review
  - Each solution organized by cost/benefit
  - Review dates: December 9th, 2016 – January 17th, 2017
- Complete delineation of watershed
  - Utilize EPA Stormwater Calculator
- Spend spring 2017 refining preferred solution
  - Utilize LID optimization worksheets on Excel

COWBOY STORMWATER MANAGEMENT

# **<u>Senior Design Fall 2016 Report</u>**

December 2nd, 2016


Zachary Bradley

Riley Jones

Grant Moore

Derek West

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## List of Figures

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# Introduction

## Mission Statement

The mission of the Cowboy Stormwater Management team is to design and implement sustainable storm and surface water systems that control erosion damage from stormwater runoff, improve urban development, and enhance quality of life in Stillwater, OK.

## Project Summary

Park View Estates in Stillwater, OK is experiencing erosion and flooding due to a high volume of storm water. To address this problem, Cowboy Stormwater Management (CSM) is tasked to deliver several options of erosion control, low impact development (LID), and slope gradation to the Park View Estates Home Owners Association (HOA). Possible solutions will be designed during fall of 2016, and then delivered to the HOA Spring of 2017.

## Project Parameters

*Client Requirements*

- Eliminate ponding in streets and yards
- Reduce erosion in public area
- Reduce streambank erosion
- Provide three cost-based solution options

*Project Constraints*

- Solutions must have a feasible cost/benefit ratio
- Solutions must be safe after implementation
- Solutions must have a natural appearance
- Solutions must have a long life span

# Statement of Work

## Objective

Reduce erosion problems caused by stormwater runoff located at Park View Estates by developing high cost, medium cost, and low cost solutions.

## Project Scope

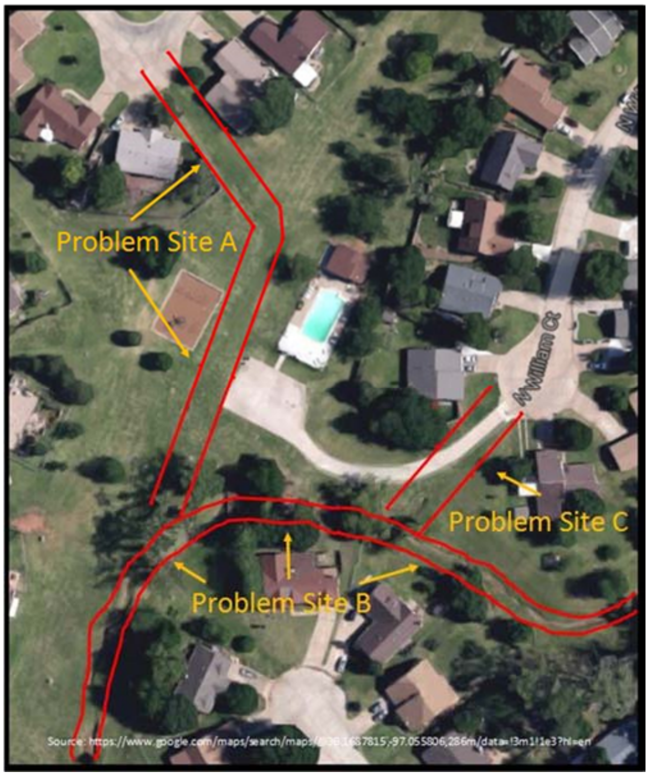



Figure 1: Problem Site Locations

*Problem Site A*

Due to runoff from impermeable surfaces and an undersized drain, the area near 304 E Marie drive is experiencing flooding and ponding during storm events, as seen in Figure 2. The impermeable streets and driveways are not allowing for any infiltration. This creates a high volume of runoff directed to a drain that is under designed for the drainage area. The undersized drain results in overflow, causing ponding and erosion down the slope toward the stream.

The greenbelt area for this job site is defined as the area between the cul-de-sac drainage areas and the stream. There are several small, but severe, problem sites in the greenbelt. The outlet for the drain from 304 E Marie has experienced erosion causing a large hole. Also, in Figure 3 below, the area around the stump has been heavily eroded causing a large hole that has potential safety hazards for residents.

Figure 2. Flooding and Ponding During Storm Event

Figure 3. Example of Erosion in Greenbelt Area

*Problem Site B-Stream Bank Erosion*

With the large amount of runoff mentioned above, all of the water is being guided directly to the stream leading to erosion along the stream banks, as seen in Figure 4 below. The erosion is responsible for several problems, such as large pools in the stream and sediment deposits, as well as sediment transport to Boomer Lake

Figure 4. Erosion near Walking Bridge

*Problem Site C*

The area at N Williams cul-de-sac is experiencing mild erosion along the pool driveway and at the storm drain outlet. The cul-de-sac has a drain that is potentially sized correctly, but the outlet riprap is undersized, leading to heavy erosion around the pipe and riprap washout, as seen in Figure 5. While the effects of this problem site are not detrimental to the management of the stormwater, it does negatively affect the aesthetic appearance of this location, especially since the pool driveway is a commonly used route to the public pool area.

Figure 5. Erosion at Outlet in Problem Site C.

# Task List

- Determine client requirements
- Conduct research
    - Technical analysis
    - On-site surveying
- Investigate possible solutions
    - Cost/benefit
    - Technical feasibility
    - Customer acceptance
- Determine final solutions
    - Three cost-based solutions
    - Cost breakdown
    - Customer acceptance/approval
- Deliverables
    - Final report
    - Document detailing feasible solutions

# Modeling, Test Plans, & Travel

## Modeling

Computers models will be required for this project. Based on our research, Win TR-55 will be the most appropriate model to utilize. This hydrologic model will allow us to measure storm runoff volume, observe peak rate of discharge at various locations, and generate hydrographs. It can be applied to our designs of bioretention cells, riparian buffer zones, and permeable structures in the problem areas.

## Test Plans

Test plans are dependent upon the desired solution of the Park View Estates HOA. If bioretention cells are involved in the chosen solution, percolation and infiltration tests will be conducted at every potential location at Park View Estates. These tests will be done for the existing soil and for the chosen subsoil mixture that will be implemented. If enhanced bioswales are chosen in the final solution, only infiltration testing will be necessary. If permeable pavement is chosen, lab testing will be done with a small scale design to determine infiltration rates.

## Travel

Parkview Estates is in close proximity to the Cowboy Stormwater Management (CSM) team. There are no travel expenses. A preliminary site visit was conducted with a professional engineer to determine locations where improvement is required. This visit identified the problem areas. A second site visit was conducted on Sunday, Oct. 9th. This visit was for the freshman team that assisted in the project. The freshmen observed the problem areas to further their understanding of the project so that they can provide alternative solutions. Other site visits have been done to conduct surveying along the stream, the public streets, and in the greenbelt area.

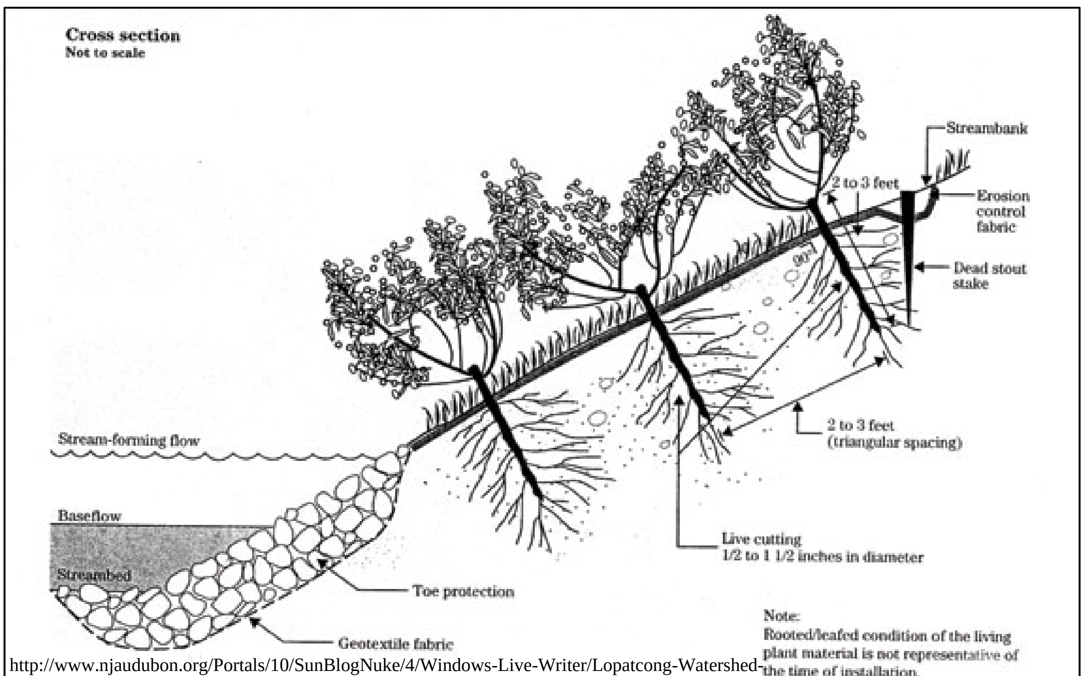
# Technical Analysis

## Streambank Stabilization Techniques

*Vegetation*

A lack of vegetation surrounding the stream bank at Parkview Estates is contributing to the bank erosion. There are several techniques that utilize vegetation as a stabilizer for stream banks. Those within the constraints of our problem include live stakes, joint planting, and coconut fiber mats. These biological applications help stabilize loose soil while maintaining a natural look. Furthermore, these techniques are inexpensive and biodegradable, which eliminates the need for their removal at the end of the project. Maintenance for these applications is also minimal.

Live stakes are woody, slender parts of a plant species that can be strategically placed in the toe of the bank to assist in soil development (Ernst Seeds, 2014). They are stored dormant but once they are transferred to the bank, they begin growing roots (Figure 6). These roots act like rebar in the soil and bind soil particles together, reducing erosion.



http://www.njaudubon.org/Portals/10/SunBlogNuke/4/Windows-Live-Writer/Lopatcong-Watershed-Enhanced-Through-Tea_EFD1/0008_live-stake-cross-section-diagram-lg_2.jpg

Figure 6: Cross Section of Live Stake Placement

A combination of these techniques is more realistic for this project. For example, using coconut fiber sheets and live stakes together will be more effective in stabilizing the soil near the stream than using them apart (Figure 7). The coconut fiber mats stabilize the top soil, while the live stakes develop the soil below. This would be a great application for the main stream that flows throughout Parkview Estates. There are currently tri-lock blocks along a problem area that will be available for improving the soil stability. Planting seeds in between these blocks could be an inexpensive and effective way to reduce erosion at that particular site.


Figure 7. Combination of Live Stakes & Coconut Matting

These solutions could fail if they are not properly implemented. They require the use of suitable plant species, adequate soil conditions, and proper grading along the stream bank (Li, 2002). A large volume of water could destroy the biological components if they are not well established in the soil.

Other possible solutions include using concrete trenches to direct the water flow, or using dead trees strategically placed along the bank. These solutions will not be considered because they do not meet the criteria of low cost and safety. Concrete is expensive and does not have a natural appearance. Dead trees are not an aesthetic solution.

*Riprap*

Using large, angular rocks placed along the stream bank will also stabilize the soil. The rocks act as barriers that reduce the velocity of the water flow and increase the bulk density of the soil. The reduced velocity of the stream will increase water infiltration and protect the bank from erosion (Iowa Department of Natural Resources, 2006). See Figure 8 for a cross sectional view of a typical riprap layout.

Graded riprap uses different sized rocks and is more suitable for this project than uniform riprap. Uniform riprap uses the same size for every rock. This can be disadvantageous because it is more expensive and the gaps in between the uniform rocks will have allow for slight erosion if there is nothing solid to fill the gaps (Massachusetts Department of Environmental Protection, 1997). The wide range of rock sizes in graded riprap will help the bank self-heal when the stones are moved by the stream, provided proper grading along the streambank. Having a self-healing application for this project makes it a beneficial long-term solution. Riprap can also be used in combination with biological techniques. A riparian zone could be integrated around the rocks to further increase stabilization and environmental quality. Considering aesthetics, riprap has a natural look to it and contributes to the environmental appearance of the stream.

Riprap is more expensive than planting vegetation along the bank. It requires grading the bank of the stream to, at most, a 1:2 ratio (Iowa Department of Natural Resources, 2006). Figure 8 illustrates this slope. Due to the weight of the stones, use of high grade geotextile fabric is required. This fabric acts as an erosion control blanket underneath the riprap. Use of gravel or crushed stone between the geotextile fabric and the riprap is a beneficial option, but may not be necessary in this project. Using equipment to grade the streambank to the proper slope and purchasing geotextile fabric will significantly increase the cost of this project. Overall, using riprap to stabilize the streambank will be an effective, long term, and natural looking technique, but also an expensive one.

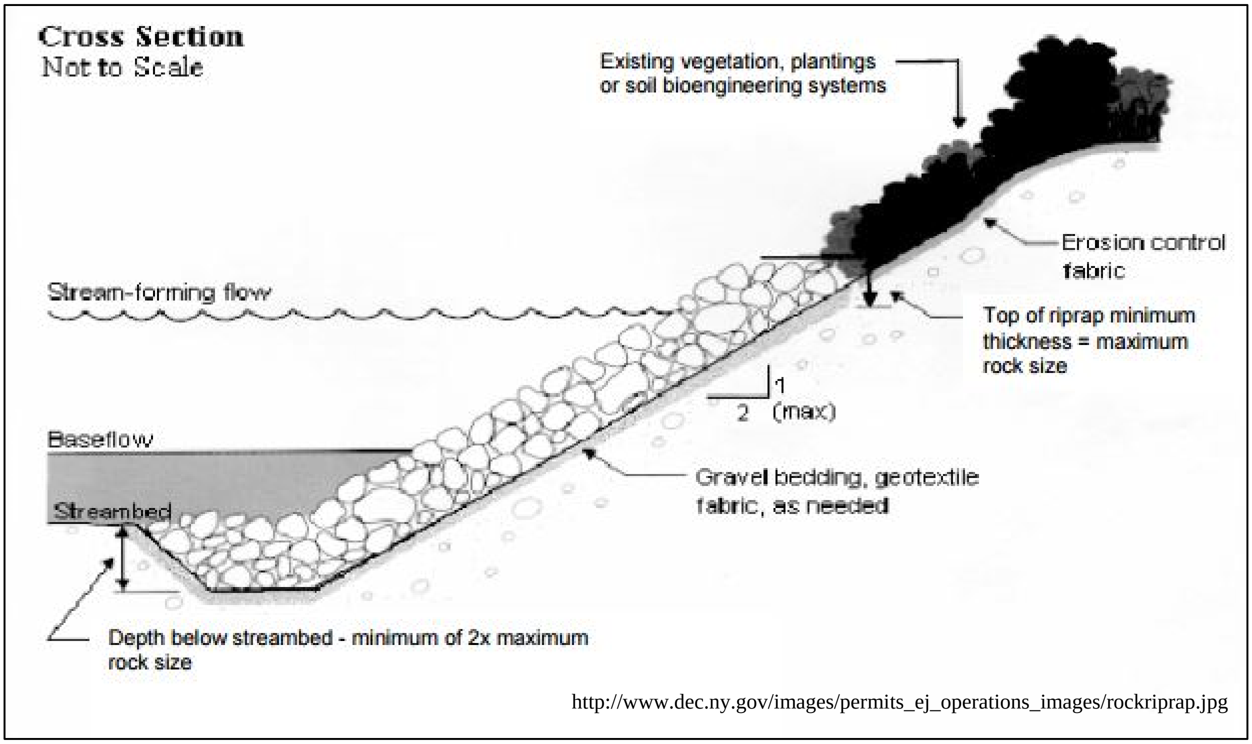



Figure 8. Cross Section of Riprap

### Low Impact Development practices

One of many possible solutions to this problem would be the implementation of LID practices. LID practices have successfully been used to manage stormwater runoff, improve water quality, and protect the environment. LID allows for greater development potential with less environmental impacts through the use of smarter designs and advanced technologies that achieve a better balance between conservation, growth, ecosystem protection, and public health / quality of life (Urban Design Tools Low Impact Development, 2016). Examples of LID practices include rain gardens, permeable pavement, rain barrels, and soil amendments. However, in the case of Parkview Estates only bioretention and permeable pavement practices will be discussed.

*Bioretention Cells*

Bioretention cells are very effective at removing pollutants found in run-off through soil and plant based filtration (Figure 9). They also have highly aesthetic qualities due to the indigenous vegetation incorporated in the bioretention area, making the practice frequently used. Some disadvantages of implementing a bioretention area would be cost and upkeep. Installing the cell requires design, excavation, and purchasing all of the material such as plants, soil, gravel or sand, and pipes for draining. An average cost for installing a bioretention cell complete with an underdrain is around \$10 - \$40 per $ft^2$ (Bioretention, 2007).

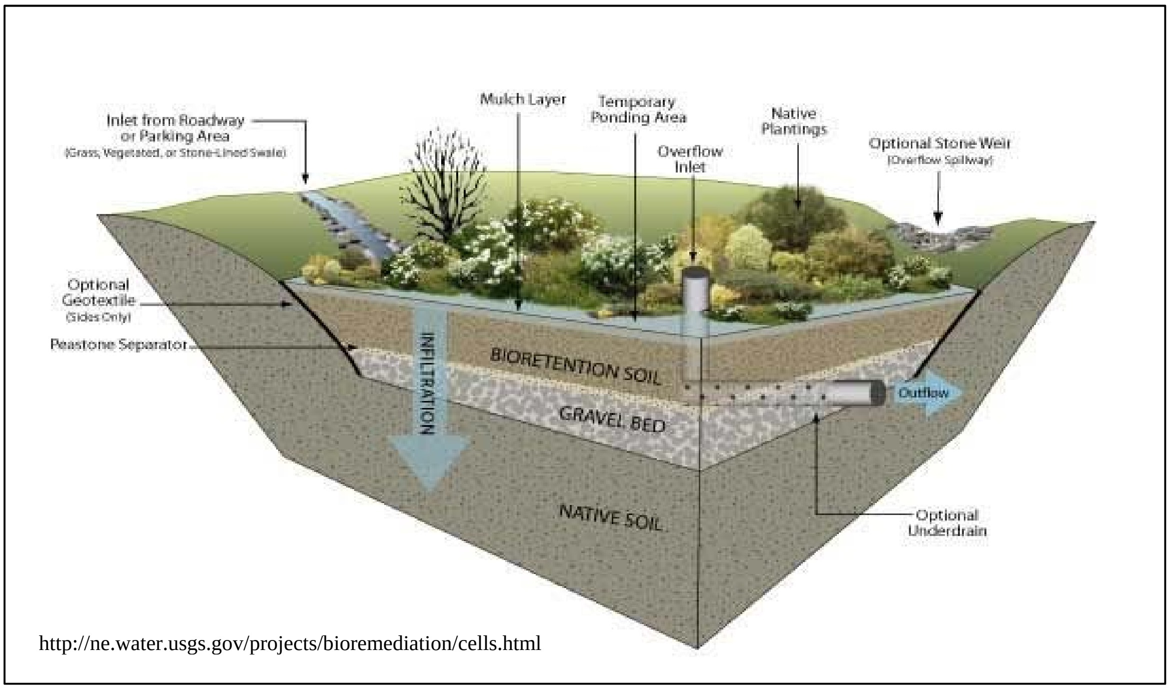



Figure 9. Bioretention Cell Diagram

*Enhanced Bioswales*

Similar to bioretention cells, enhanced bioswales utilize vegetation in a sloped area to reduce water velocity and increase water infiltration and filtration. While bioretention cells only cover a small area, bioswales are structured more like a channel that directs water flow instead of retaining it (Figure 10). They have an average life span of 30 years and can cost from \$5.00 to \$24.00 per square foot (Green Values, n.d.). They should be sized to handle a minimum of a 10-year storm (NRCS, 2005).

Bioswales have four standard cross-sectional designs: rectangular, triangular, trapezoidal, and parabolic. Rectangular cross sections area easy to design, but difficult to maintain over time. The steep slope makes it difficult for vegetation to grow and stabilize the bank. It also can be a safety liability. Triangular cross sections can be used if the slope is about 10:1 (horizontal: vertical) or shallower. Trapezoidal cross sections are the most common because they are simple to design, easy to construct, and facilitate healthy hydraulic performance. Parabolic cross sections behave similarly to trapezoidal ones, but are slightly more difficult to construct.

A 5:1 slope is considered the steepest that allows for mowing in any cross section. The ideal longitudinal slope is roughly 1-2% and should allow for at least five minutes of runoff residence time. Check dams may be required to slow the water velocity in order to ensure adequate residence time. Longitudinal slopes should not exceed 6%. The bottom width of bioswales should be between 2ft-8ft.

Some bioswales incorporate plants for the purpose of phytoextraction, and others are simply used to reduce water velocity and stabilize the top layer of the subsoil. Plants can also add to the aesthetic appeal to the bioswale. Turf bioswales are an option in areas that do not require the treatment of heavy metals in water runoff.  Turf bioswales have the advantage of easy maintenance, lower cost, and accessibility.

http://vignette1.wikia.nocookie.net/sustwatermgmt/images/d/de/Cross_section_rain_garden.jpg/revision/latest?cb=20110315232225

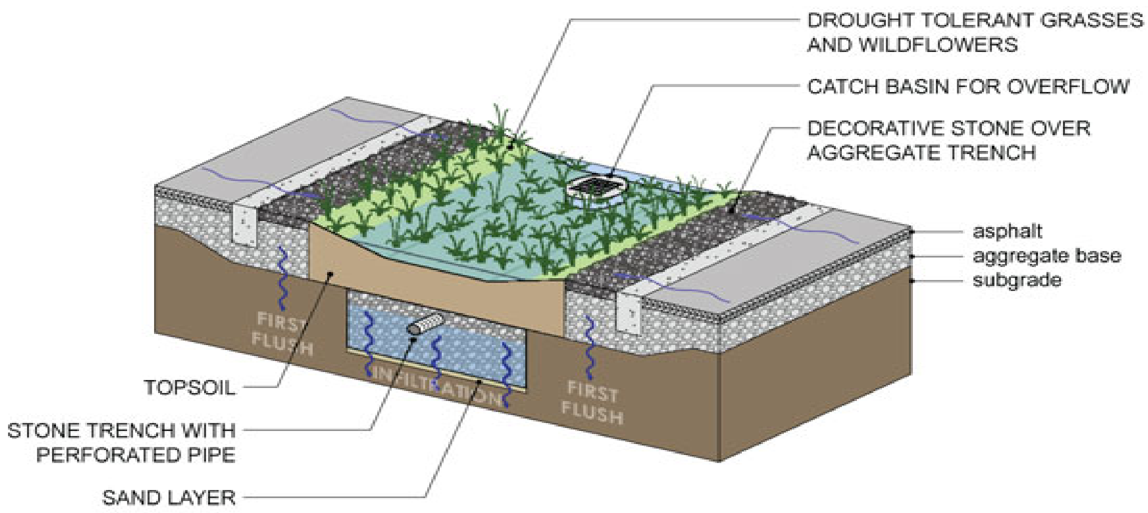



Figure 10: Components of Enhanced Bioswale

*Permeable Pavement*

Permeable paving is an LID practice that involves paving developed areas with pavement or bricks that are made to be porous, which allows storm water run-off to infiltrate the pavement and reach the soil beneath it. Durability and maintenance are some of the problem factors in this practice. The pavement will need regular cleaning due to sediment clogging the small holes in the pavement which the water passes through. Since permeable pavement is not as strong as regular pavement, durability becomes an issue when the paved area is heavily used. Different types of permeable pavement include asphalt, concrete, and bricks or pavers (Figure 11). The costs of permeable material vary. Asphalt is about \$0.50 -\$1.00 per $ft^2$, concrete is about \$2.00 - \$6.50 $ft^{2,}$ and interlocking bricks or pavers cost around \$5.00 - \$10.00 $ft^2$ (Permeable Paver, 2007). Multiple layers of substrate are required in permeable pavement design for run-off filtration, and to provide solid support for the pavement. A detailed example of a permeable paver design can be seen in Figure 12

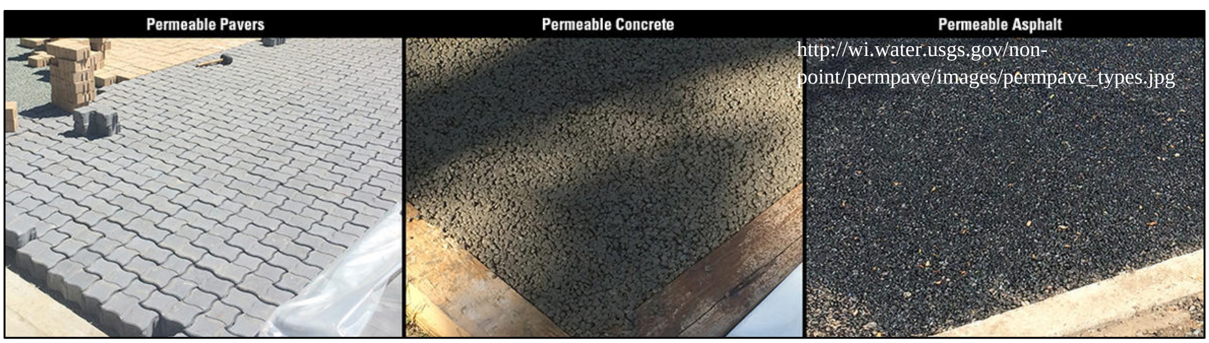



Figure 11. Different Types of Permeable Pavement

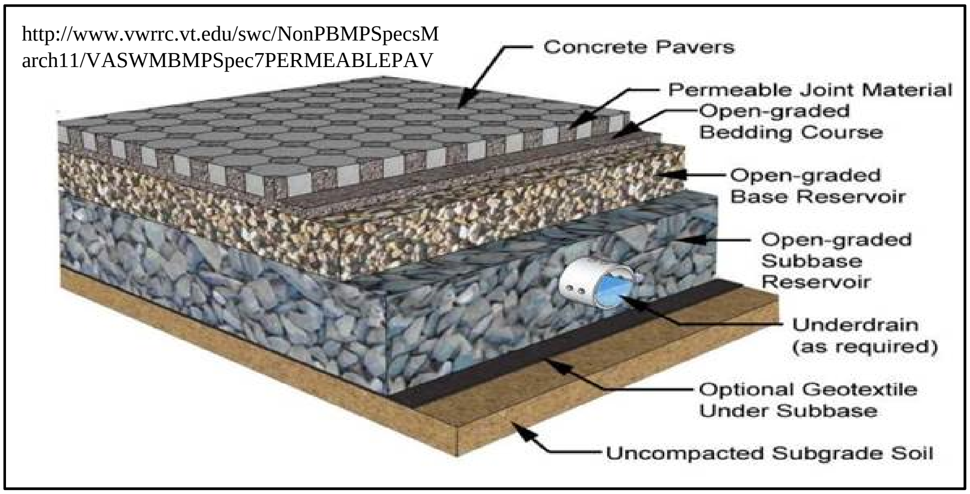



Figure 12. Permeable Pavement Diagram

## **Modeling Urban Rainfall Runoff**

### *Types of Models*

Hydrologic models are used to estimate rainfall runoff volume, peak discharge, and the temporal distribution of stormwater runoff at a specific location resulting from a given rainfall data (MPCC, 2016). In other words, these types of models are used to predict how factors such as site topography, soil characteristics, and land use will cause runoff either to flow relatively unhindered through the stream to the outlet, or to be delayed or retained somewhere upstream. Hydrographs are often generated from hydrologic modes to route runoff across multiple sub-areas within a watershed, or to combine several watersheds. Such characteristics make this type of modeling essential to urban stormwater management practices.

### *Models Used*

WinTR-55 is a hydrologic model developed by the NRCS in 1975 to determine rainfall excess parameters in small urban watersheds such as storm runoff volume and peak discharge (MPCC, 2016). Hydrographs are generated from the determined rainfall excess parameters and are used to map flood routing. Due to the size and shape of Parkview Estates, there are multiple inlets where runoff enters Parkview Creek. The ability of WinTR-55 to break a watershed in to sub-areas enables the user to assess the amount of runoff being contributed by each individual sub-area. This in turn, allows the user to determine particular areas to implement LID practices.

The EPA Stormwater Calculator is a hydrologic model developed by the EPA that assists with implementing stormwater management practices. Using soil, land use, and rainfall data, the EPA Stormwater Calculator estimates the amount of runoff that the predicted LID techniques will reduce (EPA, 2016). By transferring the data generated by the EPA Stormwater Calculator into excel, a concise plan on action can be established by using the Solver function in Excel to optimize the design.

### *Models for Possible Use*

The City of Stillwater has expressed concern about sediment loading into the Northeast end of Boomer Lake. This loading is coming from the outlet of Parkview Creek. Soil and Water Assessment Tool (SWAT) is an agriculture use based model often used to quantify herbicide/pesticide and sediment pollution being transported from farm land into a fluvial body. Since this model is typically used for farms, the validity of using this model needs to be further assessed.

## Slope Gradation

Slope gradation is a practice used to control and direct water flow across or down a slope. Water will naturally flow to the lowest point in a landscape and grading allows for the land to be reformed and the drainage patterns controlled (Matusik and Deible, 1996). Controlling the drainage is important for the preservation of structures as well as landscape. Allowing the water to drain too quickly can result in erosion. Conversely, draining too slowly causes ponding, which can also be destructive in a landscape, as seen at Parkview Estates in Figure 13 (Mihalic, 2014).

Figure 13. Ponding Observed at Park View Estates

### *Large Scale vs Small Scale*

One unique quality about slope gradation as a storm water runoff management technique is the vast scale it can be practiced on, from excavators regrading entire cities to a homeowner with a shovel and landscape rake in their own backyard. Regrading, regardless of scale, involves surveying the slopes, calculating the desired slope (generally around 2%), removing vegetation, moving the soil, and replanting vegetation to control erosion. Surveying can be done with equipment such as laser levels and rods or simply using bubble levels and a tape measure, depending on how much ground needs surveyed. Vegetation can be removed with anything from a shovel or landscape rake, to a till machine, to heavy machinery such as an excavator or backhoe. The soil then can be pushed around to set the desired slope to match the design or plans. This is a point in the process where swales or drains can be added to aid in drainage. A swale, in its most simple form, is a crease in a slope where water can gather to drain to lower ground, as seen in Figure 14. Swales do not have to be simple, however. They can be expressed in many functional, and aesthetically pleasing, ways according to Mihalic, such as filling them with plants, stones, making them curvy to mimic creeks and river beds, or any combination of the three.

Cost can be the biggest constraint on how much slope gradation is done in an area. A shovel, a landscape rake, and a tape measure are relatively in expensive to a homeowner, especially when most design is done with slope gradation in mind. The biggest cost for a small scale project would be rolls of sod for erosion control and revegetation. For a personal installation, sod costs between 8-30 cents per square foot depending on species and grade of sod, and 14-60 cents per square foot to have it professionally installed (HA 2016). For a big project, needing the use of heavy equipment can drive the price up quickly. Simply for grading the cost is roughly $2500-$5000, depending on location and site condition (BA 2016). Home advisor estimates sod costing $1800-$4000 per 2000 square feet, adding to the bill (HA 2016).

*Parkview Application*

Slope grading will be a very useful technique to use in the issues in Parkview Estates, more specifically in the area beside 304 Marie Drive house leading into the creek area behind all the houses. With the undersized drain, as seen in Figure 15, and slope down to the creek, the water is not being directed correctly and causing erosion problems as well as ponding issues. Grading the hillsides of the property into a natural swale to direct the water seamlessly down to the creek bed will cut down on ponding and provide a natural looking solution. It will also cut down on the erosion issues such as the pipe blowout in Figure 16.

Figure 14. Simple Grass Swale

Figure 15. Undersized Drain at Park View Estates

Figure 16. Erosion Caused by Pipe Blowout

# Freshman Group Involvement

Freshman students from the Biosystems and Agricultural Engineering Department at Oklahoma State University were assigned to help research management practices for the erosion problems occurring at Park View Estates. The students were placed in two teams. The first team focused on researching possible solutions in the area of LID practices. The second team researched streambank restoration and erosion prevention techniques that Cowboy Stormwater Management could possibly implement in the project. The LID practices the first team researched were permeable pavement, bioretention cells, and bioswales. They researched each of the practices and provided a short summary. They then performed a cost analysis for each installation. Permeable pavement cost between $5.50 and $11.60 per square foot, while a retention pond or swale would cost between $5.50 and $24 per square foot. Both solutions had a similar maintenance fee, but the largest difference was the labor costs of installation. Permeable pavement requires removing the existing pavement and replacing it with permeable surface, driving the price up quickly. The team concluded that a bioswale should be the recommended solution due to lower labor costs and practicality in the project area. The stream restoration team looked specifically into the practices CSM was interested in; riprap, coconut fiber matting, and live stake planting. They evaluated the restoration on two premises, a “realistic,” or low cost, solution and an “idealistic,” or high cost, solution. The team used the constraints given to CSM by the HOA, naturally aesthetic, cost effective, safety, and longevity. Their cost analysis concluded the realistic solution would cost roughly $11.50 per 10 square feet and the ideal solution would cost roughly $74.50 per 10 square feet. They recommended the “realistic” package as the solution for the stream bank, based upon the HOA criteria of cost effectiveness and safety.

# Preliminary Design Concepts

CSM has developed three different solutions for each problem site. These problem sites can be distinguished into their respective areas as seen in Figure 17. Each problem site will have a low cost solution, a medium cost solution, and a high cost solution. The low cost solution incorporates designs that will solve the specific issues at the respective problem site with the least amount of required cost (estimated). This type of solution is considered the “bare minimum” that must be implemented if the customer requirements are to be met. The medium and high cost solutions will use the low cost solution as a foundation to add upon. They incorporate the low cost solution designs with further additions that improve quality and aesthetics. These solutions have been developed with these cost options so that the Park View Estates HOA can decide on a custom solution that meets their requirements and financial needs.

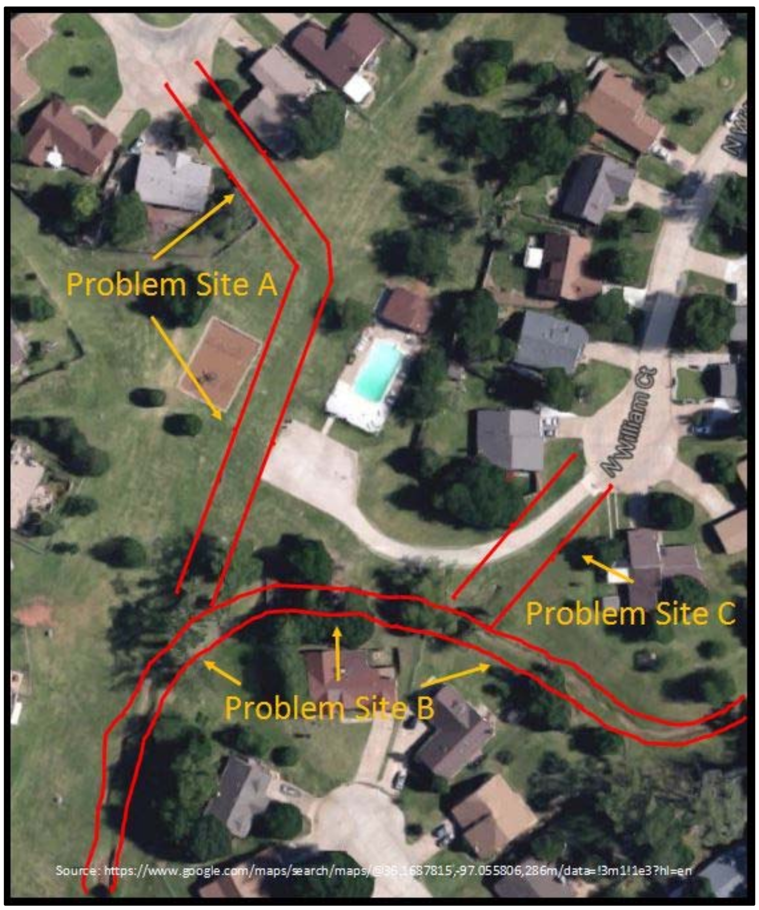



Figure 17. Problem site locations

## **Problem Site A**

As seen in Figure 17, Problem Site A encompasses the drainage area from the cul-de-sac located on Marie Drive at Park View Estates. This area is a grass swale, or water way, that is supposed to allow water to drain from the Marie Drive cul-de-sac at Site A to the stream located at Site B. Poor design of the drainage system and sloping of the swale has resulted in flooding from the Marie Drive cul-de-sac to the end of the swale (Figure 18).

Figure 18. Flooding at Site A

### Low cost solution

*Marie Drive Cul-de-sac*

The low cost solution for this site is to remove the undersized drain (Figure 19), along with the drainage pipe (Figure 20), and then re-grade the grass swale to a more optimal downhill slope for draining the stormwater. Sod would then be implemented onto the top of the regraded area. Some survey work of the grass swale has been conducted but more work is necessary. With complete data, CSM can create a model of the cross sections and slope of the swale and hill to begin the re-design.

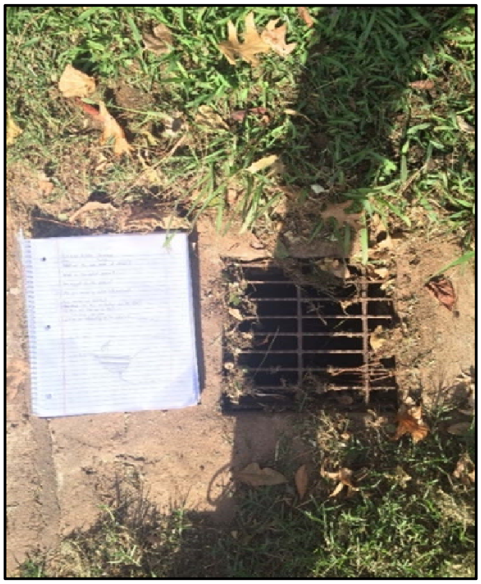


Figure 19. Undersized storm drain located at Site A

Figure 20. Drainage pipe located at Site A

*Greenbelt Area*

The greenbelt area contains several places where high velocity stormwater has cut deep holes in the waterway (Figure 3). The low cost solution requires that these individual sites be excavated, regraded, and covered with turf. Other areas along the greenbelt space may also require regrading. Ideally, stormwater runoff volume and velocity would be reduced, however, regrading key areas instead of implementing LID practices will reduce cost and still meet customer requirements.

**Medium Cost Solution**

*Marie Drive Cul-de-sac*

The medium cost solution for the cul-de-sac area includes everything that the low cost solution did with some extra features. In addition to regrading the area where the water enters the greenbelt space, permeable pavers would be incorpated as a walkway to the pubilc area. The size of the walkway depends of the budget of the HOA. The permeable pavers would help in two ways. It would improve the aesthetics of that area as well as increase water infiltration. The water that infiltrates between the bricks would mean less water that enters the stream. This could potentially improve Problem Site B as well as Problem Site A.

*Greenbelt Area*

In addition to removing the eroded sites, a bioswale would be implemented along the greenbelt area (Figure 21). The bioswale would be graded to at least a 7:1 (horizontal:vertical) slope that is suitable for easy access and maintanence such as mowing. The top layer of the swale would incorpate grass/sod as a vegetative buffer that would slow water velocity, thereby increasing infiltration. The bioswale would be a natural looking solution that guides stormwater to the stream and reduces stormwater runoff.

Incorporating permeable pavers and a large bioswale is an expensive solution. Depending on the budget of the HOA, the area covered by both a bioswale and permeable pavers could be customized to meet their needs.

Figure 21. Location of Bioswale and Permeable Pavement at Problem Site A

LID practices are also being considered for implementation. LID practices such as bioretention cells, bioswales, and permeable pavement reduce stormwater run-off by allowing stormwater to better infiltrate into the soil, or collect stormwater for retention. Possible locations at Site A for bioretention cells or bioswales can be seen in Figure 22.

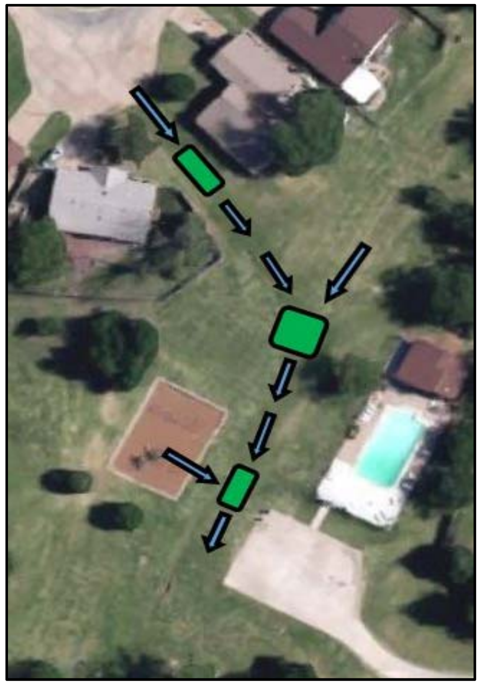


Figure 22. Possible Location of Bioretention Cells or Bioswales at Site A

**Problem Site B**

Streambank erosion is occurring along the entirety of the stream located at Site B. This erosion is caused by the high volume and velocity of the stormwater flowing through the stream. The erosion has caused large pools and sediment barges to form, which are detrimental to the overall stability, flow, and aesthetic functions of the stream. An example of the stream erosion can be seen in Figure 23.

Figure 23. Example of Erosion Occurring at Site B

**Low cost solution**

The low cost solution will reduce stream erosion at Site B by implementing a riparian buffer zone (Figure 24), or “no-mow” zone, which will allow vegetation to grow along the top and sides of the bank. The riparian zone is essential for stream stability. The roots from the vegetation provide an anchor for streambank soil. This adds no cost to the solution.

The stream was surveyed to determine high and medium priority sites that require regrading. These areas can be seen in Figure 25. Regrading is required for the high priority sites in order to ensure that sediment detachment is significantly reduced and safety and aesthesis improves. An example of one of the high priority sites can be seen in Figure 23. The areas would be regraded to a 2:1 or 3:1 ratio. Sod would be applied along the top of the slope and coir matting would be used as an erosion control fabric along the bank.

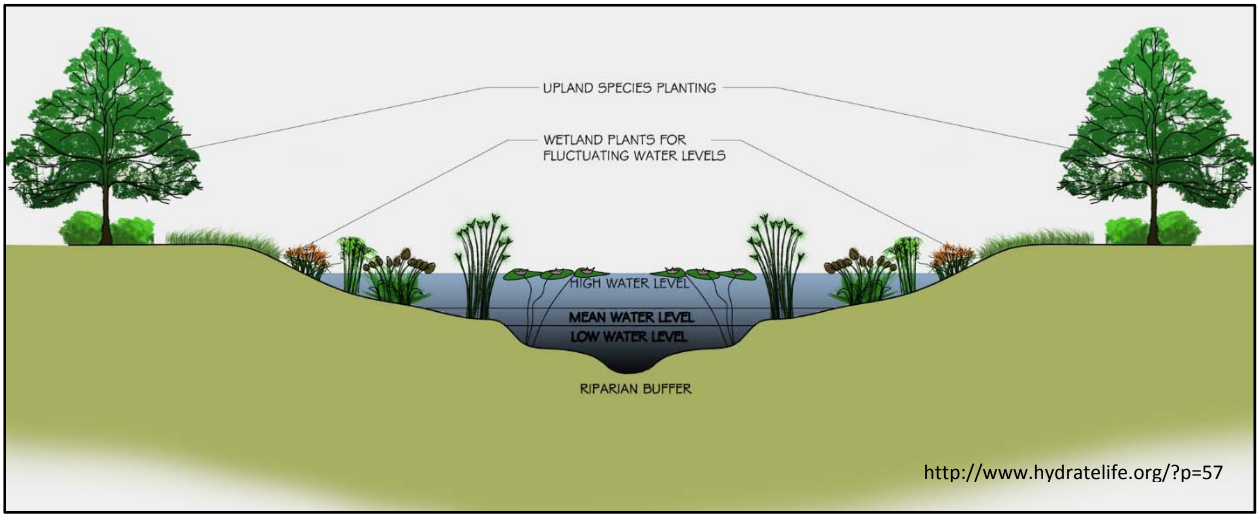



Figure 24. Riparian Buffer Zone Diagram

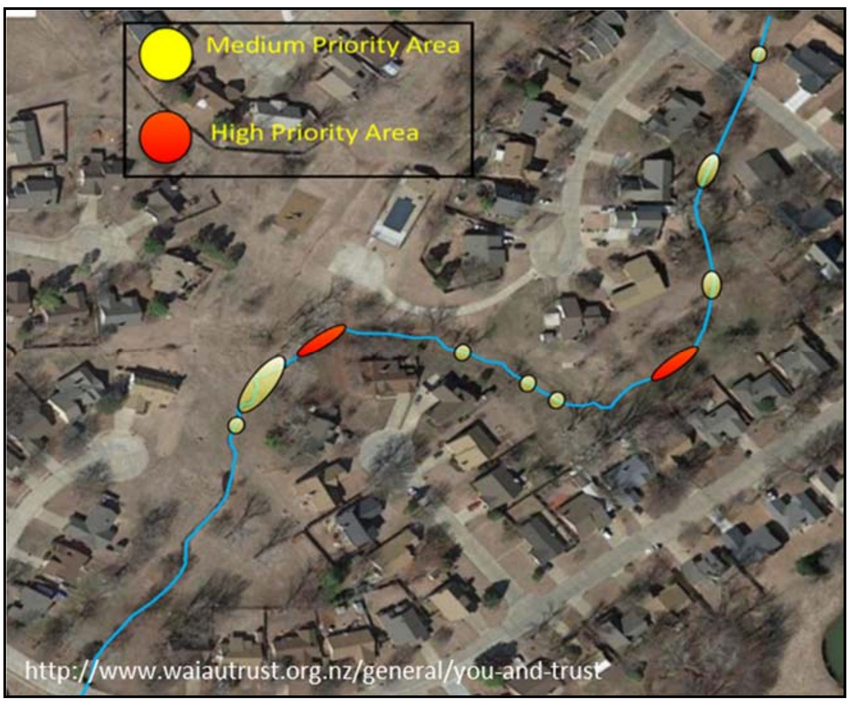



Figure 25. Priority Sites Along Problem Site B

### Medium Cost Solution

This solution includes regrading the high priority sites and medium priority sites. The slope and vegetative cover would be the same as designed for the low cost solution. Live stakes may be added in places that vegetative growth is bare. Riprap may also be added in key places to reduce stream velocity.

### High Cost Solution

The high cost solution includes stabilizing every priority site along the stream and incorporating a multitude of soil stabilization practices. This includes sod, live stakes, riprap, coir matting, and geo-fabric material.

Our long term solution would be to survey and re-design the entire stream by excavating the soil and making the streambanks into slopes that promote stream stability and reduces erosion. This solution is much more expensive and time consuming, but ultimately more effective.

## Problem Site C

Soil erosion is occurring along the pool driveway entrance, and also at the storm culvert outlet located at Site C (Figure 26). This erosion is caused by excessive stormwater runoff from the North Williams Drive cul-de-sac.

Figure 26. Erosion Occurring at Storm Culvert Outlet Located at Site C

### Low Cost Solution

This site has the least severe erosion issues relative to the rest of the project area. None of the erosion in this area is immediately detrimental to the site or greenbelt area as a whole.

Because this erosion is the least impactful, the low cost solution in this problem site is to do nothing.

**Medium Cost Solution**

The medium cost solution for the erosion occurring at the pool driveway entrance is implementing more soil and vegetation along the edge of the driveway (Figure 27). Current “tri-lock” erosion management practices will be left there. The erosion at the storm culvert outlet will be addressed by surveying the outlet, excavating the soil, and re-designing the outlet to create stable slopes and a flood plain for the water to spread out and slow down.

**High Cost Solution**

The high cost solution builds off the medium solution. CSM would replace the railroad ties that had been previously implemented and still introduce vegetation up to the edge of the ties. The outlet will be re-graded as mentioned above and larger riprap will be implemented at the outlet so the velocity of water flowing into the stream at Site B will be reduced.

Figure 27. Soil Erosion along Pool Driveway Entrance at Site C

# Quantitative Engineering Specifications

A finalized design will be developed after the Park View Estates HOA chooses a preferred solution before January 17th. The specifications below describe general requirements for the various solutions. They are organized based on the type of solution, and are not separated into the three problem sites.

*Streambank Erosion Control*

- Coconut matting should be 3ft to 5ft in width from the lower bank to the upper bank.
- Under a high budget solution, matting would be implemented along the entire stream.
- Under a low budget solution, matting would be placing in strategic areas where erosion is severe.
- Live stakes should be placed 3ft to 6ft apart and spaced triangularly (Ernst Seed, 2014).
- Live stakes should extend out by 5ft from the lower bank to the upper bank.
- A riparian zone along the stream must extend out 5ft from the channel to the upper bank.
- Individual rocks used in riprap used must not exceed 220lbs.
- Riprap should be placed from the toe of the stream to the lower bank.
- Streambank should be graded to a maximum slope of 2:1

*Permeable Pavement*

- Three types of permeable pavement
  - Asphalt
  - Concrete
  - Interlocking pavers
- Variable size
    - Can customize area to specific needs
- Requires various layers for support and infiltration

*Bioretention Cells*

- Optional underdrain pipe

- Underdrain pipe diameter will be 4in – 5in
- Multiple layers
    - Top soil
    - Sand
    - Gravel
    - Native soil
- Design parameters vary

*Grading*

- Waterways to be graded must be at a 2% slope minimum
- Top layer will be replaced with sod

*Enhanced Bioswales*

- Longitudinal slope should be between 1% - 6%
- Horizontal slope should be between a 7:1 and 3:1 (horizontal: vertical)
- Should be designed to handle at least a 10 year, 24 hour storm
- Trough width should be at least 2 feet wide
- Depth should be at least 6 inches deeper than the maximum design flow depth
- Length should be designed to have a water residence time of at least 5 minutes
- Water velocity should not exceed 5 feet per second
- Water infiltration should extend to at least 12 inches below the top soil of the swale

## **Environmental Impacts**

The final design that will be implemented at Park View Estates has potential to not only benefit the neighborhood, but Boomer Lake as well. If bioretention cells and/or bioswales are implemented, the water that infiltrates these biological systems will be filtered, reducing stormwater pollution in the water. This will positively impact the water quality of Boomer Lake, where current water quality is approaching violations. If a considerable impact is to be expected, solutions that filter stormwater must intake water from all or most impervious surfaces at Park View Estates. The requirement that this project must be cost effective for the HOA means that it is unlikely to see biological filtration systems that covers the entire neighborhood. Currently, only a portion of the neighborhood is expected to be impacted by bioretention cells or bioswales. The amount of water that is expected to be filtered will not have a significant impact of the quality of water that flows to Boomer Lake. If the HOA had a much higher budget, multiple bioretention cells at major water outlets of the neighborhood would be more feasible to have a greater, positive environmental impact.

# Preliminary Cost Estimates

These cost estimates should be considered to be a representation of a general cost range that is expected for each solution at each problem site. These costs do not represent accurate expectations for real solution costs. They simply display the order of magnitude that is realistic for the types of solutions CSM has considered.

## Site A

**Table 1. Problem Site A - Low Cost Solution**

| Problem Site A - Low Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$) | 5100 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 5100 | $ 0.01 | $ 1.09 |
| Rough Cost Range | - | $ 2,600 | $ 9,000 |

**Table 2. Problem Site A - Med Cost Solution (Option 1)**

| Problem Site A - Med Cost Solution (Option 1 - Large Bioswale) | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$) | 800 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 800 | $ 0.01 | $ 1.09 |
| Permeable Pavers ($ft^2$) | 500 | $ 7.10 | $ 12.00 |
| Bioswale | 4200 | $ 5.50 | $ 24.00 |
| Calculated Costs | - | $ 27,000 | $ 109,000 |

**Table 3. Problem Site A - Med Cost Solution (Option 2)**

| Problem Site A - Med Cost Solution (Option 2 Small Bioswale) | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Curb Inlet (ft) | 5 | $ 13.00 | $ 29.50 |
| Regrading ($ft^2$) | 800 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 800 | $ 0.01 | $ 1.09 |
| Permeable Pavers ($ft^2$) | 0 | $ 7.10 | $ 12.00 |
| Bioswale | 2775 | $ 5.50 | $ 24.00 |
| Calculated Costs | - | $ 16,000 | $ 68,000 |

The high cost solution for Problem Site A is expected to be greater than $110,000.

## Site B

**Table 4. Problem Site B - Low Cost Solution**

| Problem Site B - Low Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 3600 | $ 0.50 | $ 0.68 |
| Turf ($ft^2$) | 3600 | $ 0.01 | $ 1.09 |
| Coir Matting (Roll) | 2 | $ 90.00 | $ 100.00 |
| Calculated Costs | - | $ 2,000 | $ 6,500 |

**Table 5. Problem Site B - Med Cost Solution**

| Problem Site B - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 14800 | $ 0.50 | $ 0.68 |
| Turf ($ft^{2)}$ | 14800 | $ 0.01 | $ 1.09 |
| Coir Matting (Roll) | 15 | $ 90.00 | $ 100.00 |
| Calculated Costs | - | $ 9,000 | $ 12,000 |

**Table 6. Problem Site B - High Cost Solution**

| Problem Site B - High Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Coir Matting (Roll) | 15 | $ 90.00 | $ 100.00 |
| Regrading ($ft^2$) | 14800 | $ 0.50 | $ 0.68 |
| Riprap ($ft^2$) | 7500 | $ 2.77 | $ 2.77 |
| Native Vegetation (Linear ft.) | 3400 | $ 0.02 | $ 0.15 |
| Calculated Costs | - | $ 30,000 | $ 33,000 |

## Site C

The low cost solution for Problem Site C is to leave the site as it is. It was determined that doing nothing at this site would still meet the customer requirements. Improving this site is recommended for improving aesthetics, but not required.

**Table 7. Problem Site C – Med Cost Solution**

| Problem Site C - Med Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 1250 | $ 0.50 | $ 0.68 |
| Vegetation, walkway (linear ft.) | 125 | $ 0.41 | $ 1.44 |
| Vegetation, outlet ($ft^2$) | 1250 | $ 0.31 | $ 1.08 |
| Calculated Costs | - | $ 650 | $ 1,000 |

**Table 8. Problem Site C - High Cost Solution**

| Problem Site C - High Cost Solution | | | |
|---|---|---|---|
| | Unit | Low Rate (per unit) | High Rate (per unit) |
| Regrading ($ft^2$) | 1250 | $ 0.50 | $ 0.68 |
| Vegetation, outlet ($ft^2$) | 125 | $ 0.31 | $ 1.08 |
| Railroad Ties | 31 | $ 15.00 | $ 15.00 |
| Riprap | 1250 | $ 2.77 | $ 2.77 |
| Calculated Costs | - | $ 4,600 | $ 5,000 |

# Deliverables

Cowboy Stormwater Management will deliver solutions to the Park View Estates Homeowner's Association that will reduce the stormwater runoff damage they are experiencing on their property. CSM will provide a document containing a preliminary plan that will detail high cost, medium cost and low cost solutions for the HOA to review. These solutions will include approximate time spans for which the solutions can be implemented by the homeowner's association. This document will be given to the HOA by December 9th, 2016. It will be the responsibility of Park View Estates HOA to review the document and decide upon which option they prefer by January 17th, 2017. Cowboy Stormwater Management will then focus on the chosen plan for the remainder of the project.

Cowboy Stormwater Management will provide a document containing a finalized plan to the Park View Estates HOA. This document will detail the final draft of the solution plan that the HOA decided upon in December/January. This draft will contain a thorough cost analysis, time spans, and means of implementation. The document will be provided to Park View Estates HOA no later than April 21st, 2017.

| Item | Media | Due Date |
|---|---|---|
| Preliminary cost-based solutions | Document | December 9th, 2016 |
| Final Draft of chosen solution | Document | April 21st, 2017 |

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