Ridgedale Mall Storm Water Management

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Executive Summary

An expansion on the Ridgedale Mall has created a need for a new storm water management system. A previous landscape architecture study was analyzed to consider what options might be feasible for this site. It was determined that pervious pavement, rain gardens, tree trenches, rainwater harvesting and green roofs were feasible options for reducing and treating runoff from the Ridgedale Mall site.

Infiltration is the most cost effective way to treat storm water if feasible. To determine if the site was suitable to implement infiltration, research on the depth of the water table and the soil composition was studied. The water table is greater than 6.5 feet away from the surface for 68.9% of the site area. The main soil types are B and C soils. Both of these parameters were determined to be suitable for infiltration.

A working model in HydroCAD was created in order to determine dimensions needed in order to fulfill storm water standards using these design options. Based on areas that had both a relatively low water table and suitable soils, optimal placements of infiltration options were determined. This model was then analyzed based on cost in order to determine the cost effective options for the site. Based on the Removal Efficiency Analysis, rain gardens and tree trenches are the most cost effective options. Green Roofs were very expensive to implement and not necessary in order to handle the water.

Project Description

The Ridgedale Shopping Center is being renovated and the City of Minnetonka requires that a new stormwater management system is implemented to deal with the post-development runoff and treatment. The city would like environmentally friendly options to be considered in order promote sustainability. Previously, a landscape architecture study was completed that analyzed the site and presented numerous options to deal with the runoff. Our group is to analyze the options presented by this study and report their feasibility. Additional feasible options will also be considered.

Parameters

Limited Space

The current site is now dedicated to the building and parking lot with limited green space. The two separate Macy's stores will consolidate to 1 expanded location. The addition will be 84,000 square feet. A Nordstrom store will also be added that will occupy 138,000 square feet. Due to the addition, the shopping center will lose numerous parking spots. Large retailer stores have to approve all reductions in parking lot size, so in order to avoid requiring a consensus; the City of Minnetonka has asked that this study evaluate BMPs that result in no loss of parking.

Water Table

Prior to the construction of the Ridgedale Shopping Center, the site was once swamp land. The water table below the mall is still close to the surface, making infiltration difficult. To determine whether infiltration is possible on the Ridgedale site, a map was generated that showed the depths to water table using the Web Soil Survey from the National Resources Conservation Service. This table is shown in figure 1 below.

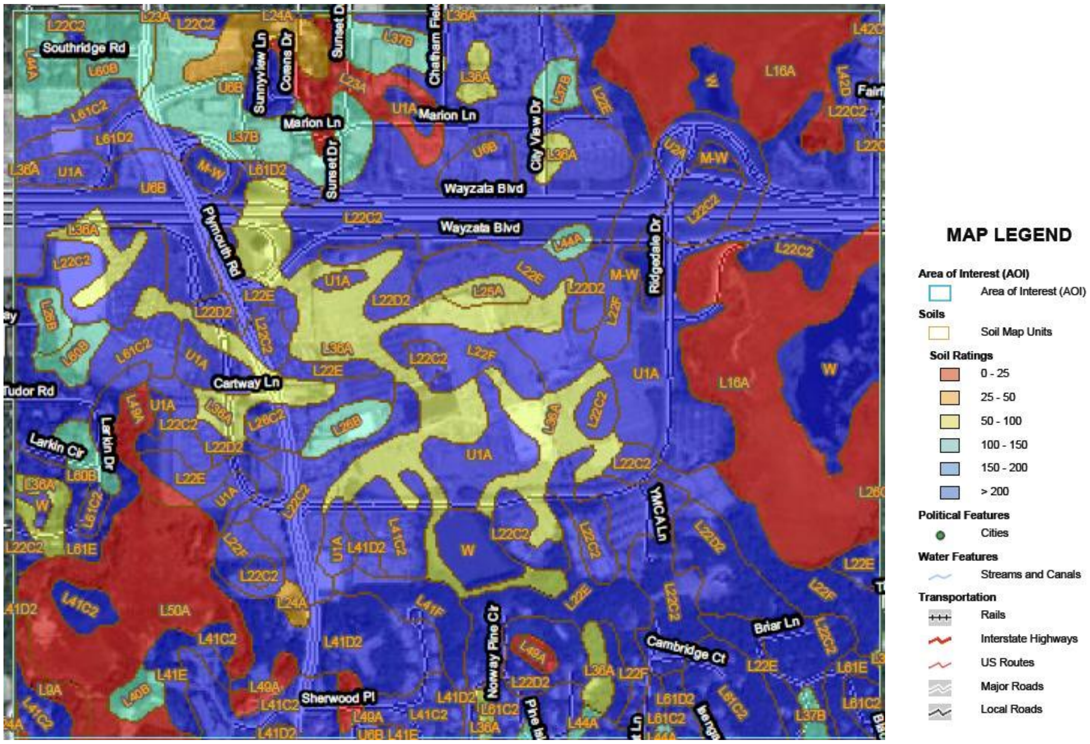

Figure 1: Water table map in and around Ridgedale Mall area (NRCS)

The legend for Figure 1 is shown in Table 1 below.

Table 1: Water Table Legend

Color	Depth to Water Table (ft)	Percent of Area (%)
Blue	6.51	68.9
Yellow	2.47-1.46	28.1
Red	0	3.0

According to the Minnesota Stormwater Manual, three feet of soil is required between the water table and the BMP in order to allow for infiltration. For 68.9% of the site infiltration will be possible. Due to these restrictions the infiltration structure can be 3.5 feet below the ground surface. In order to get an exact idea of the water table, more precise field measurements will have to be obtained. These measurements may allow for deeper infiltration structures.

Soils

In order to infiltrate water effectively, the soils should be composed of A and B type soils. To determine whether infiltration is an effective option on the Ridgedale site, a soils map was generated using the Web Soil Survey from the National Resources Conservation Service. This figure is shown in Figure 2 below.

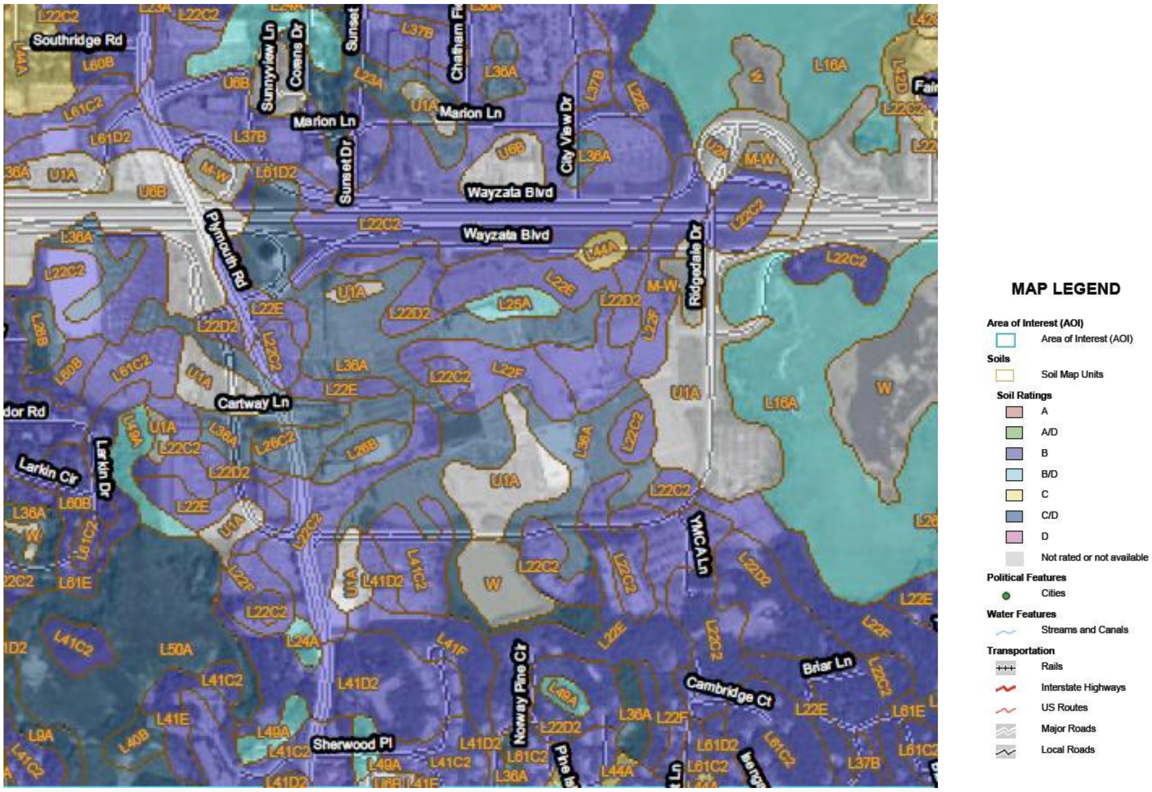

Figure 2: Soil type map in and around Ridgedale Mall area (NRCS)

Figure 2 shows mostly A and B soils depicted by blue and green areas. This shows that the soils on the Ridgedale site would support infiltration in a number of areas.

Water Quality Requirements

Stormwater treatment must meet the following criteria (City of Minnetonka):

- Runoff Rate Control: Limit the peak runoff flow rates to that from existing conditions for the 2-, 10-, and 100-year storm events for all points where stormwater leaves the parcel.

- Runoff Volume Control: Provide on-site retention of 1-inch of runoff from all impervious surfaces. The City of Minnetonka prefers that the 1-inch of runoff be retained through the implementation of infiltration practices. However, if site conditions preclude infiltration, volume control can be achieved through alternative reduction methods.

- Water Quality Treatment: Provide for all runoff to be treated to at least 60 percent annual removal efficiency for total phosphorus and 90 percent total annual removal efficiency for total suspended solids. Pollutant removal efficiencies can be achieved through onsite or offsite detention/retention designed to treat the 2.5-inch storm event (NURP criteria) or through use of alternative practices providing equivalent or better treatment.

- Nondegradation: For some redevelopment scenarios, nondegradation (no increase in total phosphorus load) is required. See Figure AppA-1 for more information.

This information was taken directly from the City of Minnetonka Water Resources Management Plan (City of Minnetonka).

Preliminary Feasibility Analysis

Previous studies on options for water management/sustainability for the site yielded a variety of options. Based on the parameters of the site a preliminary analysis was performed on these options to determine if they were feasible to implement. Table 2 below shows the analysis of the various options. Sections shaded in green show feasible options while red shows non-feasible options and highlights possible difficulties.

Table 2: Preliminary Feasibility Analysis

Method	Description	Cost Estimate ($-$$$$$)	Environmental Impact	Public Perception	Required Maintanance/Upkeep	Space Required	Complications	Benefits	Is it Feasable?
Stormwater Detention Vault	Underground Storage of water in tanks or pipes	$$$$	Vaults alone do not treat water although filters or infiltration may be used in addition	People will not be able to see them, so none	None	May be built under parking lots or even under structures	Requires digging and ripping up pavement and does not treat the water alone	Would effectively handle storm-water run-off without taking up any space. Could be used for water reuse	Yes, but could not infiltrate runoff due to high water table
Native Planting	Using indigenous plants for landscaping benefits the environment	$	Provide nectar pollen and seeds to wildlife. Protect soil with their deep root systems, prevent erosion. Decrease Runoff.	People will enjoy access green space and native landscapes	Once established, native plants need little maintenance.	Whereever space for gardens or other greenspace is permitted, native plants are the best option	May not have enough green space, to be very effective.	Great for the environment and decrease runoff compared to alternatives.	Yes, whereever green space is available.
Bioswale	landscape structures to remove silt and pollution	$$	Occupies space, but help trapping pollutants and silt	May be pleasing if designed properly	Occasional cleaning and fixing	May require relatively large space	Spacing and design difficulties	Help reduce pollution in runoff	No, spacing seems to be a critical element
Water Squares	Artistically Designed concrete landscape that temporarily holds water	$	Reduce runoff volume and some settling	Aesthetically pleasing and educational	Regular maintenace and cleaning, removal of settled particles	Depends on size of design	Requires space not available in urban areas. May be damaged by foot traffic or sand/salt	Reduces runoff volume and can be interactive and pleasing to look at	No, not enough room on property to implement. Could only be used off-site
Green Roofs	A roof of a building covered with soils and vegetation used to absorb rainwater	$$$	creates wildlife habitat, provides building insultaion, lower urban air temperature, reduces impervious surface	Aesthetically pleasing, could be used as rooftop park, very environmentally friendly	Extensive Gardening required	Utilizes space available on building roof	Can only be used on flat surfaces, requires extra structural design, so can not ussually be used on existing structures, requires frequent maintanance	Very Environmentally Friendly, Requires no extra Space, Aesthetically Pleasing and publically admired	Yes, but most likely only on new structures. Potted plants could be added to existing rooftops
Pervious Pavers	A surface pavement that allows stormwater to drain through, made of permeable materials	$$	Help runoff infiltration as well as pollutant control, also may help plant growth	Mostly human friendly, some may have disadvantages for pedestrians	Requries frequent maintenance because the pores may be blocked often	Possibly needs to rebuild some of the parking spaces	Can cause maintenance problem if traffic volume is large, also cold weather may be a challenge for their life	Can be a part of runoff infiltration, doe not need extra space, provides various surface view	Yes but only in low traffic areas also high water table may be a problem.
Pervious Concrete	A surface pavement that allows stormwater to drain through, made of permeable materials	$$	Help runoff infiltration as well as pollutant control, also may help plant growth	Mostly human friendly, some may have disadvantages for pedestrians	Requries frequent maintenance because the pores may be blocked often	Possibly needs to rebuild some of the parking spaces	Can cause maintenance problem if traffic volume is large, also cold weather may be a challenge for	Can be a part of runoff infiltration, doe not need extra space, provides various surface view	Yes but only in low traffic areas also high water table may be a problem.

Method	Description	Cost Estimate ($-$$$$$)	Environmental Impact	Public Perception	Required Maintanance/Upkeep	Space Required	Complications	Benefits	Is it Feasable?
Grass Pavers	Gridlike concrete structure with Grass Between, that allows rainwater to pass through	$	Infiltrates Rainfall, Reduces Runoff, adds Green Space	Added Green Space	None, except may need to be replaced	Would replace low traffic concrete or asphalt	Could only be placed stategically in low traffic areas, such as overflow parking on maybe a fire lane	reduces runoff volume and is more attractive then asphalt or concrete	Yes but only in low traffic areas also high water table may be a problem.
Rainwater Harvesting	Collection and treatment of rainwater to be reused on site	$$	Decreases runoff and recycles water	They won't be able to see it, but if publically noted people will be very fond of it.	Cleaning of filters	Could be collected underground, possibly by stormwater detention vault	May be difficult to reuse large quantities of water.	May be used for toilet flushing, boilers, cleaning, gardens, general cleaning	Yes, but not for all of the rainfall
Tree Pits and Trenches	Fully Integrated System of trenches that treat runoff by evapotranspira tion,	$$$	Handles and treats stormwater, filters air	Provides shade and added green space	Treatment of tree pests and fertilizer may be required. Trees need to be water during drought	Can be integrated within parking lots and sidewalks	Requires digging up of parking lots and regrading. Shortens length of parking spot,	Evapotranspirati on fully treats water and provides no site runoff in low rainfall cases	Yes
Low-Flow Fixtures	Plumbing fixtures that reduce consumption of water. Reducing water use is pertinant to future development	$	Reduces water consumption	People will love eco friendly fixtures.	No more than regular fixtures	Same space as normal fixtures	More expensive start up cost	Reduce water usage by 30%	Yes
Living Machines	Water reuse garden that treats building wastewater for reuse	More Information Needed	Water Reuse is very eco friendly.	More Information Needed	More Information Needed	More Information Needed	More Information Needed	More Information Needed	More Information Needed
Rain Garden	Native planting garden planted in a small depression that holds and infiltrates runoff	$$	Handles and effectively treats rainwater by evapotranspiratio n and infiltration	People will enjoy access green space and native landscapes	Once established, native plants need little maintenance.	May require more space then is allowed. New layout of parking lot may allow to fit rain gardens in	May require regrading and water table is an issue when infiltration	Evapotranspirati on fully treats water and provides no site runoff in low rainfall cases	Yes
Dredging of current pond	Pond in NE corner was built when the mall was built in 1974. Has never been maintenanced. Handles much of the current runoff	More information Needed	More information Needed	More information Needed	More information Needed	More information Needed	More information Needed	More information Needed	More information Needed

Design Options

Feasible storm-water management options determined from our preliminary analysis were studied further. These options included pervious pavement, rainwater harvesting, tree trenches, rain gardens and green roofs.

Pervious Pavement

General Information

Pervious pavement construction is an efficient way to capture and infiltrate the stormwater, perform some pretreatment on the stormwater, as well as save some space. In addition, it can also create an aesthetically pleasing environment. If properly constructed and operated, pervious pavement can reduce the number of other infiltration basins/structures. Thus, a fair amount of space and budget may be saved. Pervious concrete is a common type of pervious pavement.

"The use of pervious concrete is among the Best Management Practices (BMPs) recommended by EPA – and by other agencies and geotechnical engineers across the country – for the management of stormwater runoff on a regional and local basis." (perviouspavement.org, 2012)

The composition of a pervious pavement material is carefully experimented and designed. The purpose is to not only have a sufficient hardness and thickness on the ground surface but also have an appropriate porous percentage to allow fast permeable process. The flow rates of stormwater infiltrate through the pervious pavement are on average about 0.35 cm/s. (perviouspavement.org, 2012)

Figure 3: Porous pavers, Harrison Park Parking Lot, Bloomington, MN (City of Bloomington)

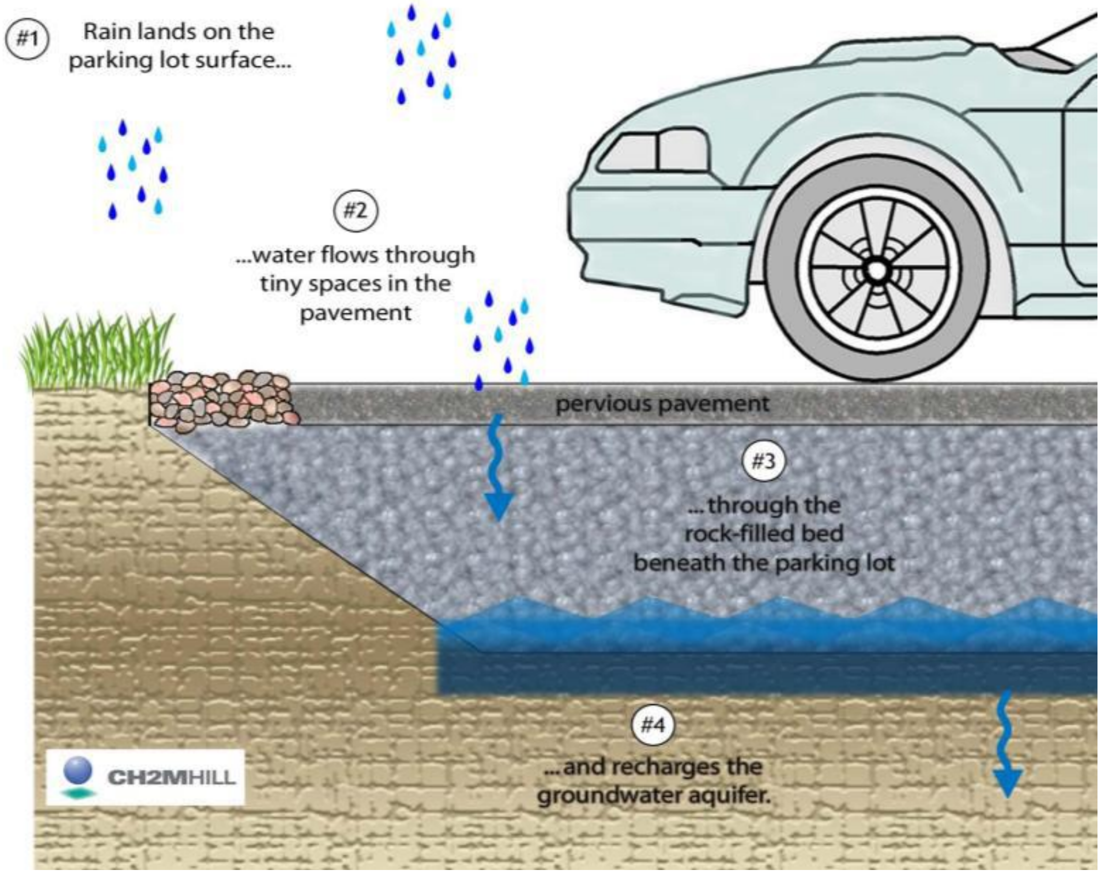

Figure 4: Conceptual diagram of pervious pavement (CH2M HILL)

Figure 1 gives an example of pervious pavement application. City of Bloomington considered design features include "soil boring, sand (S) down to 11", sized for 2" runoff from contributing area (1.75 ac), 5% grade benched sub-grade at 1' contours." (City of Bloomington, 2012) They also built two rain gardens and some wet plant species. Schematics of a pervious pavement are shown in figure 2, some of the key designing features include infiltration testing, soil types, surface permeability and pretreatment.

Possible Application at Ridgedale Mall

According to Pennsylvania Department of Conservation and Natural Resources, the site factor has a minimum requirement of 2-ft water table, A&B type of soil preferred, low feasibility on steeper slopes. According to the water table distribution map from "Web Soil Survey" website, aside from some central part of the mall area, it is possible to build some pervious pavement or pervious concrete at the surface. In addition, a significant part of the soil are A&B type, also the slopes are all relatively flat. As the developer suggested, parking space is for the best not to be compromised. The functions for pervious pavement satisfy not only infiltration but also allow sufficient surface parking space. The main purpose of the pervious pavement should be constructed for parking space along with other infiltration practices including tree trenches, rain gardens and etc.

Of course, disadvantages shall not be ignored. Some types of the pavement surface may be difficult for pedestrians to walk on. It requires constant maintenance as the pores will be clogged after a certain length of usage. In general, pervious pavement is an efficient and matured development technique. It is recommended to be used in the Ridgedale Mall renovation.

The method to plan the construction of pervious pavement in Ridgedale Mall is generally replacing the current pavement for parking space. Along with other infiltration practices, some or most of the parking surface is possible to be replaced by pervious pavement.

Rainwater Harvesting

Rainwater harvesting is a means of collecting rainwater, which would otherwise become runoff, and use it as piped water. Uses for piped water include irrigation, pressure washing, toilet flush water, and drinking water if treated adequately. A rainwater reclamation system could be added to Ridgedale Shopping Center to capture and treat rainwater, reducing the site's runoff volume and its dependency on potable water.

Collection

In a storm event, water flows from the rooftop to scuppers, which direct water to downspouts. Water then flows through the downspouts to pipes leading to rainwater storage tanks.

Storage

Rainwater can be stored either above ground or below ground. Surface storage is much less expensive and easier to install than underground storage. However, surface storage has liabilities. These liabilities include negative effects of extreme weather on water quality and storage tank life, loss of land area, and difficulties with plumbing and pre-filtration due to numerous downspouts.

In comparison, water stored underground is not affected by weather extremes as it is kept in a dark, cool environment. Underground storage tanks do not occupy land space and therefore will not impact the aesthetics of the mall. Also, it is much easier to organize an underground pipe system which will carry water from roof downspouts through pre-filtration and into a storage tank. The largest concern with an underground storage tank for the Ridgedale Shopping Center site besides the escalated installation costs is the high water table. Installing an underground storage tank requires a significant amount of excavation.

Rainwater storage tanks or cisterns are made in a variety of sizes and materials. They range from holding anywhere from 50 gallons to a million gallons. Storage tanks are manufactured in fiber glass, concrete, metal, polypropylene, wood, etc.

Treatment Process

Rainwater is generally a fairly clean water source. However, it picks up debris as it travels from the rooftop to the storage tank. These solids will settle to the bottom of storage tank reducing the storage tank's capacity as well as clog the pipes, pumps, and valves of a rainwater reclamation system. In response, filtration practices are used to remove these unwanted solids. Practical types of rainwater filtration for the Ridgedale Shopping Center site include filtration through filters or a planting bed. According to the Minnesota Storm Water Manual, if rainwater is drained to a vegetated pervious area prior to flowing into a storage tank, then a hundred percent of total suspended solids, phosphorus, nitrogen, metals, pathogens, and toxins can be removed.

Rainwater harvesting can also help reduce the spread of pollutants. According to the United States Environmental Protection Agency (EPA), non-point source pollution is a big water quality issue. Non-point source pollution is caused by runoff moving over and through the ground picking up pollutants and depositing them into larger bodies of water. By collecting rainwater, runoff will be reduced therefore reducing non-point source pollution.

Distribution

Water will be directed through pipes to an irrigation system. If the water level within the storage tank becomes low, the system will switch over to its current water supply by direct backup. Direct backup is where “both the backup source and rainwater supply connect to the plumbing system through a motorized three-port valve” (conservation technology).

Tank Sizing

A basic monthly water balance equation was used to calculate and adequately sized storage tank for the Ridgedale Shopping Center.

$$Water\ Available\ [gal] = V_0 + V_c - V_u$$

Where

$$V_0 = inital\ volume\ in\ storage\ [gal]$$

$$V_c = \ captured\ volume\ [gal]$$

$$V_u = used\ volume\ [gal]$$

The captured volume was computed with the assumptions that the system had a collection efficiency of 85% and that 0.62 gallons of rainwater can be collected per square foot of roof area per inch of rain.

$$W = 0.85 \times 0.62 \times R \times A$$

Where

$$W = collectable\ rainwater\ [gal]$$

$$R = rainfall\ [in]$$

$$A = catchment\ area\ [ft^2]$$

The Ridgedale Shopping Center site is required to be 20 percent pervious. With the assumption that pervious area will be watered during the months of May through October with about 400,000 gallons of water per month, the water use volume for irrigation was estimated. From these calculations, it can be determined that, more than more than enough rainwater can be collected from the roof of the Ridgedale Shopping Center. Therefore, the size of the storage tank will be dependent on the irrigation demand for water. It is suggested that the Ridgedale Shopping Center store 500,000 gallons of water to be self-sustaining.

Operation and Maintenance

Once installed, a rainwater reclamation system requires very little maintenance. The most maintenance necessary is for the filter used to filter rainwater before it enters the storage tank. The moving components such as the water pump and float switch have relatively long operational lives.

Advantages:

- University of Minnesota landscape architecture study will have many ideas on how to create aesthetically pleasing entryways to the mall using the rainwater that is being routed from the roofs to the underground storage tank.
- Reduce building's dependency on potable water
- Low maintenance. Generally self-sustaining

Disadvantages:

- Costly
- Surface storage competes with parking space
- Underground storage requires large amounts of excavation which could be problematic with the site's high water table

Tree Trenches

General Information

Tree trenches are a low impact development practice that manages stormwater through bioretention. They provide infiltration, storage, evapotranspiration, and increased air quality. Infiltration applied with a special medium, such as soil containing iron, increases water quality by removing phosphates. Additional pollutants such as heavy metals, nitrogen, and oil are retained by the system. Tree trenches also provide tree canopy and can contribute shade in exposed areas such as parking lots. The Maplewood Mall in Ramsey County, MN recently underwent a stormwater infiltration retrofit in which they added tree trenches into their parking lots. Their design used angular, load bearing rock with a soil mix washed into the void space after the rock had been compacted. This design, pictured below, is ideal for parking lots because the rock can support heavy traffic loads (Anderson Wenz, 2012).

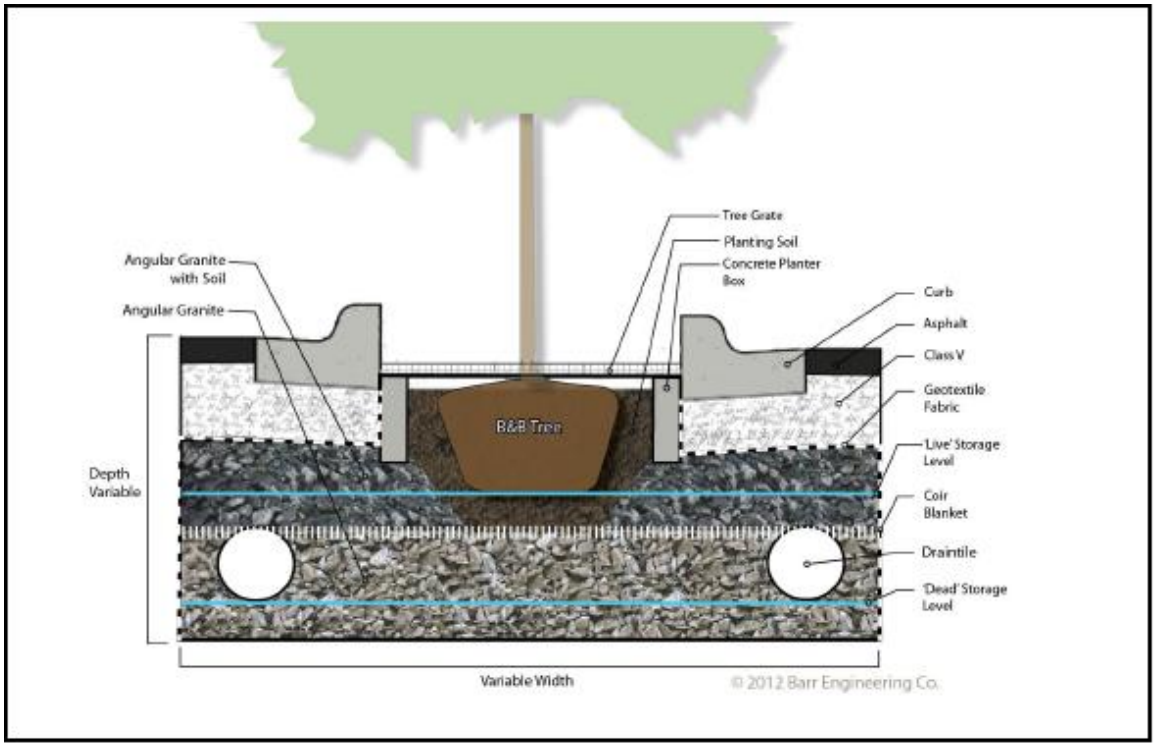

Figure 5: Maplewood Mall Tree Trench Design

Drain tiles can be used to connect tree trenches together with rain gardens to create a treatment train. Excess water from tree trenches flows through the system of drain tiles connecting the tree trenches, with any untreated water eventually flowing into the rain gardens. The amount of storage provided by the tree trenches is determined by a downstream weir and orifice. These levels are adjustable for future modifications to the treatment train system (Anderson Wenz, 2012).

Possible Application of Tree Trenches at Ridgedale Mall

Existing conditions limit the tree trench design. The width of the tree trenches must be small enough so that the number of parking spaces in the Ridgedale Mall parking lot is reserved. A design similar to the Maplewood Mall tree trench is recommended. This design includes rock that can support automobile weight, therefore allowing the tree trench to exist partially below the parking space. The narrowed spaces next to tree trenches are ideal for compact parking, and while space is a concern, tree trenches can provide separation and traffic control in a parking lot. The depth of the tree trench is limited as well. The existing water table is approximately 5 to 10 feet below grade, with some regions being less than 5 feet. A tree trench requires a minimum depth of 3 feet. If the water table is within 3 feet, then infiltration will not be able to occur. Adequate root space must also be provided for the trees and the high water table should be factored into the type of tree chosen on location. Supplementary conflicts may arise from utility or electrical lines.

Green Roofs

A green roof is a roof composed of full or partial vegetation growth over a sheet drainage system, and lined with a waterproof membrane. Not only is a green roof more aesthetically pleasing to the eye than a conventional roof, it also has many environmental benefits and can increase the lifespan of the roof. According to AD Greenroof LLC, green roof benefits include reduced storm-run off, extended roof life, energy savings, reduced carbon footprint and increased biodiversity (adgreenroofs.com, 2013). Also, when implemented in a public setting, a green roof can provide an area for enjoyment of rest and recreation.

There are two different types of green roofs, varying in size and vegetation composition, categorized as extensive and intensive. An extensive green roof is the simpler version, only a few inches thick and is generally designed to be more self-sustaining with minimal maintenance. An intensive green roof, on the other hand, is considerably deeper as it is able to sustain shrubs and small trees.

A simpler extensive green roof may be most desirable for the Ridgedale reconstruction project, at it can retain 1-inch of runoff, per the City of Minnetonka Requirements.

Structural Support

A green roof is typically composed of eight different layers. The lowest later is the substrate, or structural support. According to Angie Durhman, a green roof expert with AD Greenroof LLC, "the typical weight of a light-weight and simple (extensive) green roof is about 17-25 pounds/square foot, compared to gravel ballast, which is typically 12-15 lbs/sf." This added weight needs to be incorporated in the new building construction, or accounted for in roof replacement for a retrofit project. This load must be considered and designed for by a structural engineer.

Waterproofing Membrane

Next is the waterproofing layer, a membrane designed to keep water out of the building. This is protected by a root barrier and insulation. The root barrier keeps plants roots from penetrating into the waterproofing layer, while the insulation controls the buildings heat loss and gain. Because of these layers, a roof is protected from high temperatures, freeze-thaw cycles and UV-radiation, therefore increasing its life. "A well-installed green roof can last 35-50 years, or even longer" (mngreenroofs.org, 2013). This adds to the green roof's long term benefits.

Drainage System

Above the insulation, a drainage and retention layer is installed, covered by a filter fabric. This drainage system is generally a prefabricated, specialized product. Often this will consist of a perforated and "dimpled' layer of plastic, designed to store water in the dimples for plant use, and drain excess water into the void space below (mngreenroffs.org, 2013). One corporation that specializes in drainage solutions offers a product called the "AMERIGREEN prefabricated drain". According to their website, "AMERIGREEN green roof products consist of a formed and perforated core covered with a soil filter layer and a fabric protection layer. By design, AMERIGREEN products offer intensive and extensive solutions that incorporate drainage, water storage, aeration and membrane protection in an easy to install, lightweight, long-lasting and cost effective design" (americanwick.com/products, 2013).

Growing Medium and Plants

The top two layers consist of a growing medium and the plants. The growing medium, not to be confused with regular soil, is "a highly-engineered, lightweight mix with relatively low organic content", which will deter weeds and clogging, and prevents overloading of the structure (mngreenroofs.org, 2013). This can also be combined with an erosion control blanket to help keep the growing medium in place. In selecting plants, "hardy, shallow-rooted and drought-tolerant" plants are preferred, such as sedums and succulents. Also, green roofs in Minnesota often use native species that are adapted to bedrock bluff prairies because "they're used to living in shallow soils over rock ledges, with lots of sun and wind exposure" (mngreenroofs.org, 2013).

Minnesota Green Roof Success

Green roofs have been successfully implemented many places in Minnesota. Condominiums, such as the Edgewater Condominium in Minneapolis near Lake Calhoun, provide a living environment for residents to enjoy, while reducing stormwater runoff. The Edgewater Condominium green roof is 3,800 square feet and diverts 70,000 gallons of water every year. The largest green roof presently in Minnesota, located over the Target Center in Minneapolis is 2.5 acres in area, and "will retain up to 0.9 inches of rainfall without runoff", and has a return on investment of 7.6 years (mngreenroofs.org, 2013).

Rain Gardens

A rain garden is a depression or small ponding area that will receive runoff from nearby impervious surfaces. Rain gardens are capable of handling runoff by storage, infiltration and evapotranspiration. Rain Gardens are usually designed with multiple layers. The top layer is the pooling zone that is filled with plants. This top layer provides storage, evapotranspiration and aesthetically pleasing greenery. The next layer down is the filtration zone. This layer usually contains sand or some other filtration material and removes pollutants from stormwater. The bottom layer is filled with a high void stone material that allows for access storage. Some rain gardens are solely used for infiltration while others may include an under pipe that reroute the treated water (Committee). These layers are shown in the image below.

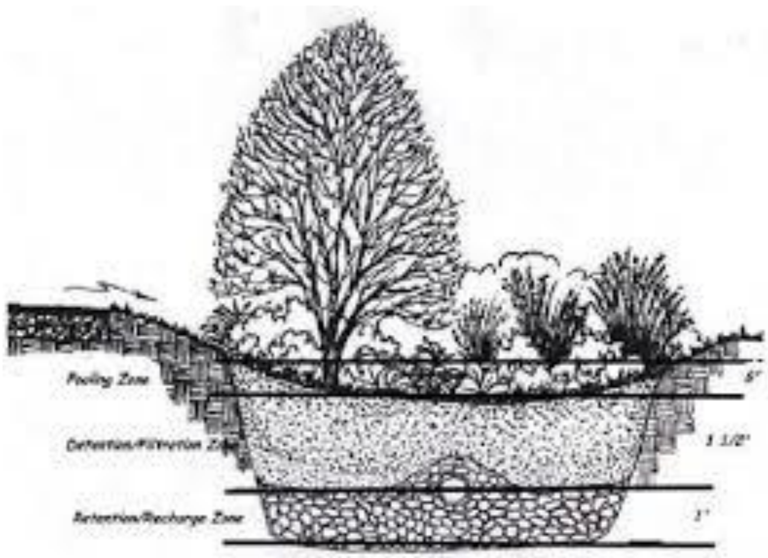

Figure 6: Rain Garden (Moines)

Removal Efficiency

Native planting improves dissolved phosphorous and nitrogen detention through plant intake (Lucas). While a sand filter is efficient in removing suspended solids, dissolved solids may not be removed to fulfill the design criteria. Additional nutrients can be removed using a combination of compost and iron fillings. Using 3-5% compost in the filter material cheaply and effectively reduce metal concentrations (Morgan). Using 5% Iron Filings in the filter material had a removal efficiency of over 80% for nearly 35 years of service (Erickson). Using a combination of these filter materials would be very effective in treating stormwater for not only infiltration, but filtration as well.

Feasibility

Not only would rain gardens be feasible for the Ridgedale Mall, but they are highly recommended. There is plenty of underutilized green space within and surrounding the site that would be suitable for a rain garden. Not only will the rain gardens effectively treat the storm water, but they provide green space that is often needed in an urban landscape.

Cost Estimates

Pervious Pavement

According to multiply sources and papers, the cost of pervious pavement is listed as below (lakesuperiorstreams.org, 2012):

Cost of laying pervious pavement exceeds that of traditional pavement, historically:

- Pervious asphalt is 20-25% higher than regular asphalt
- Pervious concrete is approximately 35% greater than regular concrete
- Correct site preparation may also increase the costs. Costs that are site specific such as proximity and cost of gravel supplies and site permeability must be factored into estimates

However higher instillation costs can be off-set by elimination of the need for curbs, gutters, storm drains and large retention ponds. Many communities will reduce stormwater fees in recognition of these practices." According to DCNR of PA, on average, the price of pervious pavement is $7-15 per square foot, including underground infiltration bed.

The maintenance work include clean surface and pores, vacuum every year, maintain surrounding plants, need-based replacement of blocks. The maintenance cost is "approximately $400-500 per year for vacuum sweeping of a half-acre parking lot." (Department of Conservation and Natural Resources, PA, 2012)

Although initially expensive and may require higher maintenance care, but it is a good option that the city should consider for treatment. First, pervious pavement could save some budget for reducing other infiltration practices like underground storage. Second, it can help pollution control which can also save some budget. At last, it plays an aesthetically pleasing decoration role in a place like shopping mall, as the environment of a mall is a key factor to attract more customers. Among pervious concrete and pervious asphalt, the material suggested is pervious asphalt, since it has a lighter weight and relatively cheaper initial cost.

Rainwater Harvesting

The most expensive piece of rainwater reclamation systems are the storage tanks. Cost is dependent on tank size and material. It is suggested to store 500,000 gallons of water for the Ridgedale Shopping Center site. According to the Texas Water Development Board, the cost of storing this much water will depend on the material of the tank, and how many tanks the water would be split between for storage. Table 2 shows the approximate costs of each storage tank material type.

Since rainwater contains low amounts of phosphorus upon falling on ground surface, low amounts of phosphorous need to be removed by vegetated pervious areas. Therefore, rainwater has a high cost per pound of phosphorus removed. Rainwater harvesting is ultimately more a runoff volume minimization method over treatment method.

Table 3: Storage Tank Cost Estimates

Table 6-1. Storage Tank

	Cost	Size	Comments
Fiberglass	$0.50–2.00/gallon	500–20,000 gallons	Can last for decades w/out deterioration; easily repaired; can be painted
Concrete	$0.30–1.25/gallon	Usually 10,000 gallons or more	Risks of cracks and leaks but these are easily repaired; immobile; smell and taste of water sometimes affected but the tank can be retrofitted with a plastic liner
Metal	$0.50–1.50/gallon	150–2,500 gallons	Lightweight and easily transported; rusting and leaching of zinc can pose a problem but this can be mitigated with a potable-approved liner
Polypropylene	$0.35–1.00/gallon	300–10,000 gallons	Durable and lightweight; black tanks result in warmer water if tank is exposed to sunlight; clear/translucent tanks foster algae growth
Wood	$2.00/gallon	700–50,000 gallons	Esthetically pleasing, sometimes preferable in public areas and residential neighborhoods
Polyethylene	$0.74–1.67/gallon	300–5,000 gallons	
Welded Steel	$0.80–$4.00/gallon	30,000–1 million gallons	
Rain Barrel	$100	55–100 gallons	Avoid barrels that contain toxic materials; add screens for mosquitoes

Tree Trenches

Native planting that can handle both dry periods and periods of excess moisture if used within the tree trenches. Maintenance for the trees and vegetation includes watering, applying mulch, treating diseased trees, and removing debris. Inspections should be made annually for erosion or sediment buildup. Biannual inspections should be performed to clear inlets and outlets. Total maintenance cost varies from $100 to $500 per year per prefabricated tree trench. A typical tree in a tree pit costs $850 dollars. Vegetation costs range $10 to $15 per square foot and seeding is recommended over using sod. Purchasing a prefabricated tree pit with some maintenance costs included ranges from $8,000 to $10,000 with an additional installation cost of $1,500 to $6,000 (City of Lancaster Green Infrastructure Plan, 2011).

Green Roofs

The construction cost of a simple green roof is $10-15 per square foot. In a retrofit project, reroofing is most likely required, therefore adding an additional $8-12 per square foot. Designing a green roof usually costs 10% of the project cost. Maintenance, such as weeding and watering (for the first couple of years) and routine inspections, add about $1-2 per square foot (Durhman, 2013).

Table 4: Green roof cost estimates

	Cost/sqft	Cost for 222,000 sqft addition
Simple Green Roof	$ 15.00	$ 3,330,000.00
Design	$ 1.50	$ 333,000.00
Maintenance (total life)	$ 1.00	$ 222,000.00
Total	$ 17.50	$ 3,885,000.00

Rain Gardens

The cost of the proposed rain gardens was determined by the use of the following equation:

$$Cost = 178.967V^{0.69}$$ (Field, Lai and Fan)

Where V = volume of the basin [m^3]

Then assuming that we are to construct roughly 210,000 ft^2 of 4 foot deep rain gardens(depth from surface to bottom of gravel layer), the total volume of the structures will be 23786 m^3, making the cost of the rain gardens $187255.

Proposed Design

Our proposed design will incorporate a variety of management options. This design will not only fulfill Minnesota stormwater standards, but will provide an increased amount of green space that is necessary for a sustainable development. Using the stormwater modeling software HydroCAD, iterations were performed in order to find a suitable management system to treat the water quality volume of the Ridgedale Mall site.

Water from the large parking lot areas will first be collected in Tree trenches. These tree trenches will be incorporated into the parking lot, so that no extra parking spots need to be sacrificed for storm water management. These tree trenches will treat the water through exfiltration and infiltration as well as store about 31,250 square feet of water. Overflow from these trenches will then be routed to the rain gardens.

Surrounding the site is a large amount of under-utilized green space that could easily handle the excess runoff from the roof and parking lots. Implementing about 210,000 square feet of 4 feet deep rain gardens in these areas will provide ample treatment of the remaining water. It is recommended that field measurements of the water table be taken to ensure the best placement of rain gardens. If the water table will not allow for infiltration anywhere on the site, it is recommended that iron fillings and compost be incorporated into the fill material within the rain gardens. This way the fill material would be able treat the water and then send it of the site through the piping system.

Next, a green roof was incorporated into the proposed design. The green roof would provide extra impervious areas on the site and also increase much needed greenery. We have proposed from a feasibility standpoint that the rain gardens be added to only the new additions. The current construction was not designed for the excess rain garden load and redesigning the roofs to incorporate rain gardens may be a daunting task.

The rain gardens, tree trenches and green roofs all require watering during dry periods in order to maintain the vegetation. We recommended storing rainwater captured on the roofs into cisterns. Water captured in these cisterns would then be used to water the vegetation on site to help promote a sustainable development.

Pervious pavement will also be incorporated into the design at a surface area of 10,000 square feet. It is recommended that the material of construction is pervious asphalt. Given the relatively high cost and location of the northeast pond, it is designed to be constructed at the northeast corner of the parking lot. In addition, tree trenches can be incorporated within the area of pervious pavement section.

Figure 7: Ridgedale Mall Proposed Design

Proposed Cost Estimate

Table 5: Proposed Design Cost Estimate

	Cost of Project	Maintenance Cost (per year)
Rain Garden	$438,686.56	$5,000.00
Tree Trench	$450,000.00	$1,000.00
Pervious Pavers	$39,270.00	$700.00
Green Roof	$3,330,000.00	$11,100.00
500,000 gallons of tank	$1,000,000.00	-
Total Cost	$5,257,956.56	$17,800.00

Proposed Removal Efficiency

In order to comparatively quantify each stormwater management option, a removal efficiency analysis was performed. Using the HydroCAD output, removal efficiency for each design option were calculated based on how much volume was treated for each option for the 1 inch storm. Based on the Average Rainfall in Minnetonka per year the volume treated per year was calculated (The Weather Channel). Then based on the treated volume and the removal efficiency of options, the Removal Efficiency was determined (Center For Watershed Protection).

Table 6: Removal Efficiency

	TSS Removal (%)	TP Removal (%)	Volume/year	lb/year TSS	lb/year P	$/year	$/lb TSS	$/lb P
Rain Garden	89	65	3974109	40627.8	93.5	$ 26,934.33	$ 0.66	$ 287.97
Tree Trench	89	65	1111433	11362.3	26.2	$ 23,500.00	$ 2.07	$ 898.40
Pervious Pavers	89	65	28125	287.5	0.7	$ 2,663.50	$ 9.26	$ 4,023.87
Green Roof	100	100	624375	7172.0	22.6	$ 177,600.00	$ 24.76	$ 7,855.87

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