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A critical Examination of Storm Water Runoff Management Techniques: The Mill Creek Watershed Case Study, Ohio

Approved by:

Dr. Mahyar Arefi
Dr. Roger J. Barry
Andy Swift
A Critical Examination of Storm Water Runoff Management Techniques: The Mill Creek Watershed Case Study, Ohio

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Puchun Cai

B.E., Shandong Architecture and Civil Engineering Institute, 1997

Committee Chair: Dr. Mahyar Arefi
Faculty Member: Dr. Roger. J Barry
Reader: Andy Swift
ABSTRACT

Storm water runoff has been one of the significant problems in the Mill Creek watershed since the early 20th century due to the expansion of urban areas and the occupation of undeveloped area. The main objective of this study is to examine the storm water runoff management techniques that could help the Mill Creek watershed. The other objective is to propose a solution based on the comparison of the environmental benefits and cost-efficiency of these different techniques.

The application of the techniques in Mill Creek watershed is the key part of the research. The study includes the developmental history of Mill Creek, illustrating the necessity of controlling storm water runoff and flood, and the analysis of its environmental and economic benefits. Knowing that water runoff reduction is the main objective to obtain, ArcView GIS 3.2 extension TR55 model is a useful tool to measure the impact of land use conversion.
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Chapter 1. Introduction

1.1 Introduction/Problem statement

Mill Creek is located in Butler and Hamilton Counties in southwestern Ohio. It runs 28 miles from the southeast rural part of the Butler County to the south across the densely populated Hamilton County to its confluence with the Ohio River (See Map 1.). The flood and storm water runoff have created major problems for the watershed area for years. The focus of the study is this watershed area of 133 square miles in Hamilton County which including the city of Cincinnati and other 30 political jurisdictions. In the city of Cincinnati alone, an estimated 41 neighborhood are located within the watershed (See Map 2.).

Storm water runoff has been one of the significant problems in the United States since the early 20th century due to the expansion of urban areas and the occupation of undeveloped area. There are three primary concerns associated with uncontrolled water runoff (Source Water Protection Practices Bulletin, 2001):

(1) Due to the increased urban land use, the peak discharge and velocity water runoff increases during storm events which results in flood and erosion;

(2) The ground water is not recharged during the rain because the excessive amounts of impervious surface prevents the fast-running water runoff from infiltrating into the subsurface;

(3) Urban runoff brings sediment deposited in streams and transports pollution to waterways that are used as a source of drinking water.

Mill Creek watershed is also experiencing the same problems. Although much
effort has been made in recent years to relieve the runoff and flooding in the Mill Creek watershed area, the problem still persists. Should a major storm hit, the severe situation, which arises from increased storm water runoff caused by rapid development in the Mill Creek flood plain, still continues. Today, a relatively heavy storm could raise mill creek a foot higher, “sending water into homes and businesses” (Amrhein, 1998). In this place, asphalt parking lots and subdivisions, as well as other impervious surfaces have dramatically increased the amount and speed of runoff rushing into the Mill Creek.

Furthermore, as a tributary of Ohio River running through the heart of Cincinnati, Mill Creek is the epitome of a “trashed urban stream” suffering from industrial waste, sediment, human sewage, and other chemical pollutants (Ohio River, 2000). With the increasing development in these areas, all kinds of pollutants including the CSOs (Combined Sewer Overflows), which is the most severe source of pollution, are discharged into the Mill Creek and thus severely obstruct the water flow. As the water runoff running overland, it makes the toxic substance spring out. This, in turn, exacerbates the urban environmental condition.

1.2 Objective

The main objective of this study is to examine the storm water runoff management techniques, which would help the Mill Creek watershed. The other objective is to propose a solution based on the comparison of the environmental benefits and cost-efficiency of these different techniques for the Mill Creek watershed.
Map 1: Location Map of Mill Creek Watershed

Map 2: Jurisdictions in the Mill Creek Watershed
Chapter 2. General Overview of Storm Water Management Techniques

2.1 Storm Water Runoff

Most of precipitation reaching the landscape produces three types of processes: interception, infiltration and runoff. Interception is a process in which water is taken up on the surface of vegetation; infiltration is a process where water is absorbed directly by the soil. The remainder flows off the land from streets, rooftops, lawns, and eventually joins streams and rivers. This is storm water runoff. It is now becoming one of the most serious problems associated with land development, which changes the rate and amount of runoff reaching streams and rivers (Marsh, 1998:148).

2.2 Impervious Surface

Impervious surfaces seen in buildings and pavements primarily include roofs, roads, walks, and parking lots. As impervious surfaces increase, storm water is not able to infiltrate through the soil to groundwater (Water Quality, 2001). Figure 1 demonstrates EPA’s estimation of the impact of impervious surfaces on the percentages of storm water that runs off, infiltrates, and evaporates. When an entire site is natural ground cover, normally 10 percent of precipitation runs off the land into nearby rivers or lakes; while when a site is 75-100 percent impervious, 55 percent of the precipitations run over the land into nearby waters.

The impact of the increased impervious surfaces, during the urbanization and development of agricultural land, is serious both environmentally and economically:
property damage from flooding incurs high social and economic costs and hence, “water quality is reduced, channel erosion is accelerated, and habitat is degraded (Marsh 1998:148).”

Figure 1: Impact of Impervious Surfaces on the Amount of Storm Water That Runs Off, Infiltration, and Evaporation

Source: Water Quality, 2001

2.3 Impact of urban development on storm water runoff and flood level

Wide ranges of water-related problems are associated with the urbanization process: water runoff and flooding, pollution and sedimentation, etc. In the process of population expansion, people need more land for housing and accommodations. The growing housing demand in urban areas is typically associated with increased storm water runoff and flood.
A study of river basins in the Boston metropolitan region has found that urban development similarly inhibits the natural absorption of storm water (Fabos, 1985: 34). As a result, the magnitude of any given flood is increased. In some basins, where considerable urban expansion occurs, normal flood frequency of once per one hundred years could now be expected to happen in about every twenty years (Fabos, 1985: 34).

Urbanization has a profound impact on the existing natural and constructed drainage systems. The consequences of these surface changes are numerous, but are primarily rooted in the fact that developed sites lose much of their natural storm water storage capacity. Nathan and Strom pointed out that the loss of vegetation, organic litter, and changes in surface characteristics, such as roughness and perviousness, result in the rapid conversion of rainfall to storm water runoff (Strom and Nathan, 1997: 133).

Environmental impacts, which result from changes in the storm drainage pattern, vary widely. These include: “increased flood potential due to increases in peak flow rates of storm water; decreased ground water supply caused by reduced infiltration; increased soil erosion and sedimentation due to greater runoff volumes and velocities; increased petrochemical pollution from street and highway runoff; and the contamination of winter runoff by salt and sand in colder regions (Strom and Nathan, 1997: 133).” Furthermore, Fabos (1985:34) referred to flooding as “the most widespread landscape hazard in urban region”. He also emphasized, “due to the relative infrequency of flooding, flood risks in local growing communities have been generally ignored”. As a result, with the increased development occurring in the floodplain, the severity of the damage raised when a flood
disaster strikes.

2.4 Different Storm Water Runoff Management Techniques

2.4.1 Principles of Storm Water Runoff Management

Storm water management refers to the controls used to mitigate or eliminate the negative impacts of storm water runoff. It must be realized that the storm water management is important and requires consideration at the regional and larger land planning scale. It is also an issue that has environmental, social, and regional impacts. With respect to the storm water management principles, “Land-of-Sky” regional council has identified two approaches: a “traditional approach” and a “system approach.”

a. Traditional approach

“A traditional approach to manage storm water is to drain runoff into a pipe to prevent ponding as quickly as possible (Stormwater Control Principles and Practice).” However, this approach neither attempts to minimize the generation of storm water runoff, nor to prevent or control the water pollution. Most of the time, it even results in flooding.

b. System approach

The system approach aims to manage storm water runoff. The regional council considers a set of goals, consisting of an integrated system of preventive and control practices, as a basis to manage storm water in the government document. Preventive practice is mainly comprised of land use planning and management techniques, pollution prevention techniques, erosion and sedimentation control program. In addition,
detention/retention practices and infiltration devices are the major methods of control practices. According to the regional council, the first principle of this approach is to minimize the generation of runoff and pollutants through a variety of techniques. The second principle is to manage any runoff with its associated pollutants to minimize its impact on humans and the environment in a cost-effective manner (Storm water Control Principles and Practice).

The system approach is widely used in storm water management in the United States. In this article, four commonly used approaches will be examined on the Mill Creek watershed (See Figure 2). The greenway and disconnect program contribute to minimize the generation of storm water runoff and serve as an amenity to the environment; while the other two help to manage storm water runoff and mitigate its impact on the environment. Table 1 shows their different functions in solving water problems.

**Table 1: Different Storm Water Management Measurements**

<table>
<thead>
<tr>
<th>Storm Water Management Measurements</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runoff Management</td>
</tr>
<tr>
<td></td>
<td>Flood Management</td>
</tr>
<tr>
<td></td>
<td>Pollution Prevention</td>
</tr>
<tr>
<td>Greenway Approach</td>
<td>✓</td>
</tr>
<tr>
<td>Disconnect Program Approach</td>
<td>✓</td>
</tr>
<tr>
<td>Constructed Wetland Approach</td>
<td>✓</td>
</tr>
<tr>
<td>Tunnel Approach</td>
<td>✓</td>
</tr>
</tbody>
</table>
2.4.2 Greenway approach

The National Park Service defines greenway as a “corridor of protected open space managed for conservation, recreation and non-motorized transportation (Benefits of Greenways, 1990).” Greenways often follow natural geographic features such as ridgelines, stream valleys, and rivers, but may also be built along canals, utility corridors, or abandoned rail lines. Widths may vary from thirty to a thousand feet. Most greenways include a trail or bike path, but others may be designed strictly for environmental or scenic protection (Benefits of Greenways, 1990).

Greenways, as vegetated linear parks, provide tree cover, wildlife habitat, and riparian buffers to protect streams. The environmental benefits include reduced storm water runoff, flood reduction, water quality protection, and preservation of biological
diversity (Benefits of Greenways, 1990). Parks, green spaces and trees conserve rainwater and reduce water pollution. By removing paved surfaces to plant trees and other vegetation, groundwater recharge is increased and surface runoff is decreased. Storm water flowing from our streets often carries a variety of pollutant directly into the ocean. When this water is allowed to soak into the ground instead, many pollutants are removed and don’t reach the ocean, Roots act as filters down through the soil (Greening & Tree Planting).

When trees are part of the landscape, their canopies interrupt and slow the rainfall and lessen its impact on the soil. The roots of the trees help to hold the soil together, and absorb and use water and excess nutrients that would otherwise pollute a nearby waterway (Watershed protection and the urban forest). Portland Environmental Services estimates that “a single mature tree with a 30-foot crown can intercept 4,600 gallons of water per year and regards “trees and native vegetation are the backbone of a healthy ecosystem (Plant Trees, Native Vegetation and Created Buffer and Shade along Streams, Action 2).”

Many cities have been successful in developing greenway programs, like Louisville, KY; Pittsburgh, Pa; and Washington D.C., etc. The Anacostia River in Washington D.C. shares some common historical and geographic characteristics with the Ohio Mill Creek. Mill Creek Restoration Project (MCRP) regards it as a model for how a degraded urban river can be restored to a community asset (MCRP). The plan is working in that it will better manage storm water runoff and improves water quality, and restores the ecology environment as well.
2.4.3 Disconnect program

The design of systems, which mimic natural process, helps mitigate the negative impacts of urbanization on the storm water runoff and flooding. Disconnecting building downspouts from the storm sewer system can help direct water to more natural systems and reduce the amount of storm water runoff (Reduces Storm Water Flow and Pollutants Reaching Our Streams, Action 3). Roof drain redirection is a relatively simple and low-cost option for reducing storm water flow into sewerage system.

However, EPA reports that in order for a downspout disconnection program to be successful, the public must be educated as to the benefits and methods for implementing such a program (Source Water Protection Practices Bulletin, 1999). This can be time-consuming and will most likely require some sort of rebate program or other incentives for compliance. Furthermore, because the effect per individual downspout disconnection is small, implementation of this program is necessary in a wide service area.

2.4.4 Constructed wetland

Those wetlands are intentionally created on sites, which are not wetlands for the primary purpose of wastewater or urban runoff treatment and are managed as such (Developing Successful Runoff Control Programs for Urbanized Areas, 1994). When the storm water washes down the streets, the parking lots and roofs, it picks up pollutants along the way. Traditionally, pipes convey the polluted water to the nearest water body. By filtering this water through wetlands the natural microbes in the soil break down pollutants
and clean the water. Therefore, constructed wetlands are normally considered as part of the urban runoff collection and treatment system (Developing Successful Runoff Control Programs for Urbanized Areas, 1994). They act as a holding area for large quantities of surface water, which can be slowly released into a watershed. A one-acre wetland, one foot deep, can hold approximately 330,000 gallons of water (Miller, 1990).

Constructed wetland can be used in many different land use types. Residential, commercial and industrial areas are all contributing to it depending on the soil types, land use area, and depth to groundwater and bedrock. Due to the permanent ponding of water, constructed wetland can remove large amount of pollutants and are more effective in removing nutrients than most other management practices (Constructed Wetland, 2002). The large volume of storage helps to reduce peak discharges from storm events, which could mitigate down-stream flooding and stream bank erosion. In addition, constructed wetland can serve as a wildlife habitat and amenity of the environment if designed properly.

2.4.5 Tunnel approach

According to MSD (Metropolitan Sewer District of Greater Cincinnati), “tunnel is not a new concept; it is being used in the local cities of Cleveland, Columbus and Toledo, Ohio. Other cities such as Chicago, Portland, Milwaukee, Rochester, and Toronto have had tunnels for many years.” The tunnel holds over 2 billion gallons of combined sewerage, reducing the pollution loads in the Chicago area river by 85% (Source Water Protection
Practices Bulletin, 2000). Anne Spray Kinny, MMSD (Milwaukee Metropolitan Sewer District) director said, “The impact is that the water quality of the rivers and the Milwaukee harbor has improved and been brought back to life.” The deep tunnel system in Milwaukee prevented 32 overflows and captured more than 6.6 billion gallons of untreated wastewater. MMSD reports that, “Since its inception, the tunnel system has avoided more than 227 overflows and prevented about 40 billion gallons of diluted wastewater from being overflowed (MMSD).”

MSD describes in the feasibility study report that the tunnel of 100-year level of protection in Mill Creek watershed is designed to provide significant conveyance capacity, as well as considerable storage volume. The Mill Creek tunnel, while primarily intended for flood relief, would at the same time afford a high degree of capture and control for the combined sewer overflows (CSOs) that discharge into the lower Mill Creek.

2.5 ArcView GIS with TR55 Model

Urban development increases impervious areas and alters storm water flow patterns, which can produce significant increases in downstream peak-flow discharges and storm water drainage volumes. Herzog and Labadie also pointed out that prevention of storm water control system failure requires frequent recalculation of hydrologic response as urbanization extends and intensifies. “Geographic Information System (GIS) has become a popular tool in storm water management for efficient preprocessing and post processing spatially oriented hydrologic data (Herzog and Labadie, 1999).”
In storm water management, the full power of GIS is often best realized in conjunction with an application-specific model and other computer-based, problem-solving methods (Herzog and Labadie, 1999). A variety of GIS package and hydrologic models have been linked, such as Arcinfo/TR55. The Runoff Curve Number method is used to estimate the amount of precipitation, which becomes runoff, and the amount that infiltrates into the soil. The method is presented in Technical Release 55 (TR-55) published by the Soil Conservation Service (Computer Program for Project Formulation Hydrology, U.S. Dept. of Agriculture, 1986). It is now becoming a basic method for storm water runoff calculation.
Chapter 3. Case Study: Existing Condition of Mill Creek

3.1 Development History and Background

Mill Creek, as seen in the topography map of watershed (See map 3), has its origin in southern Butler County. It flows south through the Union Township and then into Hamilton County, passing through the City of Cincinnati and runs into Ohio River. Mill Creek has several major tributaries which including East Fork Mill Creek, Sharon Creek, West Fork, Cooper Creek and Beaver Run.

“Mill Creek has been the source of life, activity and commerce for more than 1,000 years (MCRP).” About 200 years ago, settler from the east cleared over 80% of the land, which seriously degraded and abused the Mill Creek watershed. Pig-based industries and corn, at early nineteenth century, brought major early industrial pollution to Mill Creek. Accompanying with these pre-development of the city is the huge immigrants from Western Europe, who settles down in the rapid developed area and contributed to the prosperity of the Mill Creek valley. However, the development of industries and urbanization along the Mill Creek still continued to suffer from various sources of pollution and consequently, it led to extensive flooding, which occurred about every other year during the nineteenth and the first half of the twentieth century (See table 2).

“Twelve lives and about $9 million in property was lost as a result of the 1937 flood (MCRP)”, The Army Corps of Engineers, therefore, constructed the “Barrier Dam, floodwalls, and pump station” across the Mill Creek and along the Ohio River, thereby protecting the Mill Creek Valley from Ohio River backwater flooding. In 1959, after more
flooded in the valley occurred, a flood reduction project was initiated, including channelization of parts of Mill Creek in Hamilton County by the Army Corps of Engineers, beginning in 1981 (MCRP).

<table>
<thead>
<tr>
<th>Years</th>
<th>Events</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800s’</td>
<td>Settlers from the East cleared over 80% of the land for lumber, firewood and farmland</td>
<td>Led to higher floods, longer drought compared to the past</td>
</tr>
<tr>
<td>1913</td>
<td>Early industrial pollution of Mill Creek can be attributed to corn and pig-based industries</td>
<td>One quarter of every gallon flowing from Mill Creek consisted of industrial waste and sewage from the area's ever-growing population</td>
</tr>
<tr>
<td>1940</td>
<td>Mill Creek was listed by the Cincinnati City Manager as one of the major sources of Ohio River pollution</td>
<td>Continues to suffer from various sources of pollution</td>
</tr>
<tr>
<td>1997</td>
<td>Mill Creek was designated by American Rivers as the most endangered urban waterway in the country</td>
<td></td>
</tr>
</tbody>
</table>

Source: Mill Creek Restoration Project

Nevertheless, the river is still afflicted by a host of interrelated problems including polluted storm water runoff, solid and toxic wastes, flash flooding, sewage, sedimentation, channelization, contaminated fish, and aesthetic blight. Recently, “the U.S. Environmental Protection Agency (EPA) designated a third Superfund site in the watershed, which already has 31 potential hazardous waste sites identified by the Ohio EPA and 158 sites with combined storm water and sanitary sewer overflows every time it rains (MCRP).” The Ohio EPA has documented that “channelized sections of the creek created by the Army Corps of Engineers (Corps) cannot meet the goals of the Clean Water Act (Mill
Up to now, there are many organizations as well as government taking effort to rescue Mill Creek from its problems. The MCRP proposed a greenway master plan to contribute to the quality of life for the watershed; MSD examined the deep tunnel as the mean of flood relief. The participated organization include: Army Corps of Engineers, MSD, MCRP, US EPA-Region 5, Ohio EPA, MGA, ORSANCO, Mill Creek Watershed Council, Ports of Authority, Office of Economic Development and Environment Department, and the City of Cincinnati.

3.2 Topography

According to MSD report, the headwaters of Mill Creek begin in Butler County and flow generally southward approximately 28 miles through Hamilton County. “The stream drops in elevation about 336 feet over a distance is 28 stream miles from its headwaters to where it flows into the Ohio River.” The average gradient is about 12 feet per mile. “In the upper half of the basin the valley bottom is wide, averaging 1-1/2 miles, but it narrows in the downstream reaches, averaging only one-half mile through the City of Cincinnati. In the lower portions of the basin, valley walls are steep, rising 200 to 300 feet above the valley floor, but are much less steep in the up stream areas. The topology of the Mill Creek bed rises from approximately elevation 480 to approximately elevation 570 feet or a rise of 90 feet over the 16 miles in Hamilton County (Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati, 2002).”
The distinct elevation differences determine the flood and storm water would attack the Mill Creek frequently as the deep slopes and dramatically increased impervious surfaces are natural thoroughfare for the water runoff.

Map 3: Topographic map of Mill Creek Watershed
3.3 Land Use

The Hamilton County portion of the Mill Creek watershed is one of the most industrialized areas in the United States. Nearly half of the land uses have been modified from agricultural and forestry to urban, predominantly residential as well as significant amount of industrial uses (MCRP). A summary of land use in the Mill Creek is presented in Table 3 and Map 4. Residential, industries and commercial uses occupy 70% of total land use in the Mill Creek watershed.

Mill Creek is one of the primary reasons for this “industrialized land use pattern” (MCRP). The Creek attracted a variety of industries and commercial depend on its steady supply of water and convenient waste disposal system. Eighty percent industrial in Hamilton County are located in the watershed area due to the less expensive and easy to construct on the flat floodplain. The industry development of the Mill Creek has created prosperity throughout the watershed, on the other hand, over-depending on the river results in the vulnerability of local economy. MCRP identified that by-products of this industrialization are severe and further threaten the economic well being of the watershed:

- 68 severe brownfield sites are identifies in existing watershed
- Landfills and garbage dump can be found along the banks of Mill Creek
- “164 locations of CSO in the watershed area (Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati, 2002).”

“Communities and residential neighborhoods are dominantly land use types
surrounding the heavily industrialized Mill Creek watershed. Mill Creek shares benefits and loss with its neighborhoods; most of them are developed because of their proximity to the industries and businesses located along Mill Creek (MCRP).” As the pollution brought by industries gets more aggravated, the living quality and condition began to decline, which indirectly led to the recession of the economy and digression of the neighborhood. As the Mill Creek Restoration Project (MCRP) states “Thousands of people living near Mill Creek bear a disproportionate burden from the polluted and degraded environment and its associated health risks (MCRP).”

<table>
<thead>
<tr>
<th>Watershed Name</th>
<th>Mill Creek (Cincinnati) Watershed, Ohio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area (Square Mile)</strong></td>
<td>133</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td>453,800</td>
</tr>
</tbody>
</table>
| **Land Use** | Residential 36%  
Commercial 5%  
Industrial 8%  
Agricultural 1%  
Public and Recreational 40%  
Undeveloped 10% |
| **Key Problems** | Water pollution, flooding, CSOs, SSOs, storm water runoff, landfill, "agriculture and construction activities, superfund sites, "failing home treatment systems" |

Source: Section 4: Progress with the Watershed Approach for the Mill Creek. ESRI
Map 4: Land use map of Mill Creek Watershed
3.4 Water Management Projects and Storm water

As early as 1820s, Cincinnati started up the construction of a storm sewer system. It was the initiate of stormwater management in the Cincinnati area. In order to take the great advantage of the system to convey storm water and meanwhile carry excessive wastewater, in the late 1800s, Cincinnati converted the storm sewer to combined sewer system. In the following fifty years, the system expanded consistently in the whole Hamilton County, mainly concentrated on the watershed area. At present, estimated 85 percent of the drainage system consists of combined sewer; only 15 percent is separate storm sewer system (Cincinnati, OH).

With the process of rapid development, the land coverage confronted the unprecedented historically change in Mill Creek watershed. More and more concrete surfaces covered the agriculture and green land, which weakened the permeation capacity of soil and blocked the stream system. The stormwater and wastewater consequently gushed overland and the existing sewerage system was no longer large enough to capacitate the millions of combined volumes of stormwater and wastewater. The overland flows taking along a great mass of contaminant flow into Mill Creek and Ohio River.

Beside CSOs, stormwater runoff is also one of the major issues that closely related to the prosperity and degradation of the Mill Creek Valley. Mixed with industrial and commercial waster, water runoff is now becoming a major pollute source of drinking water. MCRP report expands the contribution of storm water runoff on it:
“Stormwater runoff from major highways, streets, parking lots and other urban and suburban properties carries a variety of heavy metals, petroleum products, and other pollutants that impair water quality. Accidental releases and spills and permit violations from industries and businesses contribute as well. Runoff from agricultural fields in the upper portions of Hamilton County and from Butler County add more nutrient loading to a stream system that is above capacity. Surrounding communities and residential neighborhoods contribute their share to the problem through the improper disposal of household hazardous waste, reliance on polluting forms of transportation, the removal of vegetation which leads to erosion, and the use of chemical fertilizers and pesticides. Water quality is a concern throughout the watershed. While historically regulatory agencies required “end-of-the pipe” treatments of point source pollution, today there is growing recognition that a comprehensive watershed approach is needed to ensure watershed and ecosystem health.”

Another related contributor of disaster is flood. Since the late of the 19th century, flooding has been the persistent plague that exacerbated the environment and economic loss with the unceasingly expansion of the urban area in this watershed. How to govern the flooding so as to reduce the loss generated by the flood at the maximum degree is not an original topic. From the early 1900’s, Army Corps of engineer and MSD have put effort to relieve the impact of floodwater on urban land. The texts below describe the efforts that different departments tried in recent history.

(1). The flood in 1937 deprived of “12 lives and $9 million” property loss (MCRP). The Army Corps of Engineers, therefore, “constructed the Barrier Dam, flood walls, and pump station across the Mill Creek and along the Ohio River” to protect the Mill Creek Valley from Ohio River backwater flooding (MCRP), and two addition pumps were added in 1991.
(2). In 1981, Army Corps of Engineers initiated a flood reduction project, that was to channelize the Mill Creek in the Hamilton County to mitigate the more frequent flooding since 1959.

However, these efforts did not solve the flood problem affectively. The situations were getting even worse in this struggle for protecting our lives and fortunes. “The creek system has serious water quality problems that at times can threaten human health. In fact, the Ohio EPA has recommended that no human contact occur with the waters in Mill Creek in most of Hamilton County. This warning extends not only to the main stem, but to some or parts of some of the tributaries as well (MCRP).” The out-of-repaired combined sewer systems at the time of heavy rain greatly contribute to the problems.
Chapter 4. Methodology

Since the purpose of this paper is to examine the different storm water management techniques in reducing the storm water runoff, I start with four widely used methods first and then analyze them in term of their special characteristics in controlling water runoff and flooding.

(1) The first technique is the greenway plan

The basic idea is to convert the identified industrial vacant lands and brownfield sites into trees. By comparing the runoff produced after development of planting tree with that before development, as well as with all the land are developed into impervious surface, we could derive that the greenway’s function in mitigating the storm water runoff.

(2) The second one, tunnel approach, is to build a 16-mile long tunnel under Mill Creek

The tunnel is designed to hold most of the storm water in case of a flood. It is a new project proposed by MSD (Metropolitan Sewer District) and the Army Corps of Engineers as a potential solution for the CSO and flood problem threatening the Mill Creek Watershed. The deep tunnel was designed to capacitate water flows for 100-year flood. “The tunnel profile depth is currently set at 300 to 350 feet below existing ground surface. And the estimated tunnel flow carrying capacity would be 9,700cfs at the Barrier Dam with a storage volume of 469 million gallons (Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati, 2002).”

The proposed tunnel would be mainly located in the Hamilton County. It would
start from the confluence of the Ohio River and Mill Creek, where the Barrier Dam locates, and then “it would follow the Mill Creek upstream for 16 miles, terminating just north of the junction of the East and West Fork of the Mill Creek, north of I-275 (Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati).” Floodwater would be intercepted at five intake shafts, some of them are distributed on the watershed and others are located on tributaries to prevent the tributary flood from occurring. Meanwhile, CSO flows would go into the tunnel through twenty-drop shafts. Among the 99 CSOs in the Mill Creek Watershed, 73 of them would be controlled by the construction of proposed deep tunnel.

(3) The third technique is constructed wetland.

This approach advocates the construction of artificial wetland in residential, commercial and industrial areas. Both of them are making use of the natural resources as well as man-made environmental solutions.

(4) The last one is a disconnect program.

This program involves more contribution from the public participation. Since it is unrealistic to get the accurate data, this program is just serving as a reference.

Trees benefit the environment in different ways. They absorb harmful gas and release clean air; they help water seep into the soil and filter the toxic substances. Economically, it is low-cost to plant trees and they do not need many maintenance fees after they grow up. The greenway plan is assumed to be the most effective because of its
greater environmental benefits and higher cost-efficiency compared to the other three. TR55 is a tool that helps reflect the volume change of water runoff in the greenway method. To make the objective measurement of its impact on controlling storm water runoff, the TR55 is used to get the definite number of runoff volume showing the change between the predevelopment and post development. However, due to the lack of information and unpredictable consequences, only estimated results are available for the other three techniques based on the management manuals of the EPA and data from other experienced cities.

The application of these techniques in the case of the Mill Creek watershed is the key part of the research. The study includes the developmental history of Mill Creek, illustrating the necessity of controlling storm water runoff and flood. Consequently, environmental and economic analysis will be done based on the data stated above. In the environmental analysis, I will list both advantages and disadvantages for all the techniques, including their impact on water quality, water runoff, and visual value and so on. In the economic analysis, I will examine the financial feasibility of executing them based on the cost of construction, the maintenance fee and many other kinds of costs.

4.1 Data Collection

Current land use coverage within the whole watershed of Mill Creek will be collected. Because most of the land in the Mill Creek watershed has been developed, it is unrealistic to make much change on the existing conditions due to the limited financial
budget of the city. This part will help identify how much impervious coverage and brownfield sites can be converted to future green lands or trees. A current land use map will be shown, as well as the volume of water runoff will be calculated by using the TR55 model based on the curve number, precipitation and soil type. The map and data will be mainly from Cincinnati Area Geographic Information System (CAGIS) and the Mill Creek Restoration Project. The GIS data are from HCDC (Hamilton County Development Center) and Economic Department. The soil type is from the Ohio department of natural resources.

MSD in recent years proposed to build tunnels to solve the water and flooding problem in Mill Creek. Although the Army Corps of Engineers has once constructed part of the channel, it is suspended because of the financial problem and objection of the local residents. The uncompleted channels even worsen the flooding problem in Mill Creek. In this part, the advantage and disadvantage of constructing the tunnel will be examined financially and environmentally. MSD provides all the data regarding this deep tunnel project.

The data of the impact on runoff with regards to disconnect programs and constructed wetlands come from the analysis of research in the literature review and the storm water management manual from EPA. Only general ideas will be presented in the two parts because of the lack of information. Bulletins and reports from the MCRP and the MSD are also part of the data source.
4.2 Data Analysis

Upon completion of the inventory of existing conditions in Mill Creek, the next step will be to formulate the most probable future direction for it. The ArcView GIS 3.2 extension TR55 model will be mainly used for the analysis. The impact of new development will be shown on the map of future land use. Knowing that water runoff reduction is the main objective to obtain, by using the TR55 model, the impact of land change on it could be measured. The changes of pervious surfaces, such as farmland, weed land, to trees are insignificant, while the conversion of impervious surfaces to trees or green land is obvious. Therefore, the changes of impervious vacant and brownfield sites are considered as the primary convertible lands.

Although the constructed wetland technique is complicated and to some degree difficult to measure its impact and real cost, by using the TR55 model, a suitability land use analysis could be done to show the places suitable for wetland construction within the convertible land layer used for greenway plan. The EPA documents describe the criteria capacity of wetland and corresponding construction fee. Some local government documents provide thorough information for operation of the disconnect program and its impact on reducing the storm water runoff. The MSD and the Army Corps of Engineers provided detailed information about the tunnel project. Considering the data above as a basis of analysis, a brief analysis of the techniques could be made.
4.3 Measurement criteria: TR55 model

4.3.1 ArcView GIS with TR55 extension

The SCS curve number method is used to compute the portion of the rainfall that becomes surface runoff. All the data are from CAGIS.

A. Define the existing site: 133-square mile watershed

B. Calculate the runoff hydrograph for existing conditions
   a) Define the formula. The formula on the right side is applied to a single slow rainfall event.

   b) Precipitation (P): SCS Type II Distribution. Mill Creek watershed area is defined as average 2.75-inch rainfall per event.

   c) Curve Number (CN): It is calculated based on soil type (valued by hydro group), and land use cover (valued by land use code). CAGIS provides all the data regarding the runoff volume calculation.

C. Hydrograph generation: A unit hydrograph approach is used to determine the distribution of runoff over time.

D. Define proposed conditions drainage patterns and sub basins

E. Compute unit water runoff volume value for proposed conditions using ArcInfo (convert to tree or impervious surface)
F. Calculation of the total water runoff volume: The total volume in the 2.75inch rainfall event is equal to unit value multiplied by the value counts.

4.3.2 Model Operation

A. In the first step, I found out the convertible lands based on the parcel theme (including industrial vacant and designated brownfield sites) and merge all the lands to form a shapefile named convertland", which is 12.75% of the total area of Mill Creek Watershed.

![Figure 3: Map of convertible land](image)

Data source: CAGIS
B. In the attribute table, I added a new field “Value” to the “convertland” shapefile. (1)

The first assumption is to calculate the value of the shapefile to tree’s value as 70. (2)

The second assumption is to calculate the value of the shapefile to impervious surface’s value as 80.

**Figure 4: Data Conversion**

Data source: CAGIS
C. Buffer the 1-, 2-, 3-, 4-, 5-, and 6-mile’ distance from the Mill Creek stream based on aforementioned two shapefiles, one with tree’s value 70, and the other one with impervious surface’s value 80. Limit them within watershed boundary. Thus, we could get seven different shapefiles in each of the two groups, land converted to trees and land converted to impervious surface.

**Figure 5: Map of Buffer**

Data source: CAGIS
D. Convert all the fourteen shapefiles to grid files (data input); defined cell size=50 feet

**Figure 6: Covert to grid file**

Data source: CAGIS
E. Merge each grid files with previously created watershed land coverage layer.

Figure 7: Map of Land Coverage

Data source: CAGIS
F. Join the soil classification table (cw_sl.dbf) to the attribute table of soil using the common field soil_symbo, and convert the revalued file to a grid file using the conversion field: value (left bottom map).

Figure 8: Join Attribute Table

Data source: CAGIS
G. Add the merged land use coverage layer to the soil grid file to get the combination file.

The Info table designed by CAGIS contains the Curve Number corresponding to each combo value. Join this table with combo table. Then, reclassify the combo file. Press Reclassify-Look up, select zcn. The CN value now is assigned to the grid file, which is used to calculate the water runoff volume. Reclassify the grid file by “Value.”

Data source: CAGIS
H. Start up ArcInfo to calculate water runoff. The following figure contains the simplified program to get the value and count on cell-base.

**Figure 11: ArcInfo programming**

```
Arc: grid
&sp 2.75
&scellsize 50

merge_grid = merge (convertland_grid, landcover_grid)
add_grid = merge_grid + Soilgroup_grid
CN = reclass (add_grid, Info_table, Data, Zlu, Zcn)

S = float((1000 / float(CN)) - 10)
Q1 = (%precip% - 0.2 * S) * (%precip% - 0.2 * S)
Q2 = (%precip% + 0.8 * S)
Q' = Q1 / Q2

Q = int(Q3 / 12 * %cellsize% * %cellsize%)

list Q vat
```

Author: Andy Swift

I. Get result of predevelopment, post development of greenway, and post development of impervious surface.

The current land cover type will produce 402,557,506 cubic feet volume of runoff in the defined rainfall event (Table 4). With more land cover converted to trees, the runoff volume decreases. When more land cover is converted to impervious surfaces, the runoff volume increases remarkably. The volume decreases by 3% when all the convertland is covered by trees. Runoff will be 8% more than the current level if all the convertland is
changed to impervious surfaces (Figure 12).

### Table 4: Change of Runoff Volume with Land Cover Change

<table>
<thead>
<tr>
<th>Buffer Distance</th>
<th>Runoff Volume after Land Cover is Converted to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Tree (ft$^3$)</td>
</tr>
<tr>
<td></td>
<td>402,557,506</td>
</tr>
<tr>
<td>1mile</td>
<td>397,833,315</td>
</tr>
<tr>
<td>2miles</td>
<td>395,233,021</td>
</tr>
<tr>
<td>3miles</td>
<td>393,295,538</td>
</tr>
<tr>
<td>4miles</td>
<td>392,014,715</td>
</tr>
<tr>
<td>5miles</td>
<td>391,642,697</td>
</tr>
<tr>
<td>6miles</td>
<td>391,376,247</td>
</tr>
<tr>
<td>Convert All</td>
<td>391,064,167</td>
</tr>
</tbody>
</table>

**Figure 12: Change of Water Runoff Volume**

4.3.2 Conclusion

As mentioned before, the land area selected for calculation just occupies 12.75% of total land use area of the Mill Creek Watershed. Moreover, because some of the vacant
lands identified as “convertland” are actually already covered by tree, this results in the weakening of tree’s value in mitigating the volume of water. The Figure 12 shows the change of runoff volume generated by the land use plan. The upper line represents the change with impervious surface method and the bottom one is on behalf of the change by planting tree. The 12.75 percent increase of impervious surface produces 8 percent more water runoff. Thus the expansion of impervious surface significantly exacerbates the water problem in the Mill Creek Watershed.

4.4 Research Limitation

Because of the absence of information for the other three techniques, the volume of runoff for the greenway approach was calculated by using the TR55. The data for other techniques will be from the EPA evaluation report, other experienced cities, and other sources. Hence, the approximate numbers showing the change of runoff by using greenway plan, disconnect program and constructed wetland are major productions.

4.5 Analysis of Mill Creek

The main purpose of this study is to examine the best technique(s) that can be applied to Mill Creek, so the tasks in this part are divided into two sections: economic analysis and environmental analysis. The first section is composed of two major components: cost estimation and water runoff volume calculation (if feasible). Meanwhile, environmental benefit analysis is the theme of the second section.
4.5.1 Economic Analysis

It is not easy to measure the cost efficiency and impacts of the management. Storm water issues are complex and require a great deal of social, political and environmental understanding. As a result of the case studies, this project attempts to provide a basis for illustrating the relationships between the storm water controls and greater cost benefits. It is estimated that this systemic management strategy will reduce storm water management construction costs of the new development by 75% when completed (Houk, 2000).

Scenario comparison: in order to demonstrate the cost-effectiveness of the greenway system of the Mill Creek watershed, comparing the average cost of greenway plan to the cost of the proposed centralized remedy to flood and storm water runoff control in the watershed, tunnel, and constructed wetland and disconnect program. The major goals of this part are to examine the effect of these techniques in water runoff mitigation and financial cost.

4.5.1.1 Greenway approach

Basically, the cost of planting trees, the cost of removing impervious site and the cost of planning (buying land) compose of the frame of cost estimation with considering a limited future facility development. MCRP report provides the main source of the cost. The MCRP bulletin lists detailed financial budgets for planting greenery; it is the reference of the cost analysis in this chapter.

Since the cost reference listed in MCRP report is based on the dollar value in 1985,
the inflation through the year needs to be considered. Regarding the inflation rate, U.S. Department of Labor- Bureau of Labor Statistics provides us with the recent inflation based on the year 1985. Therefore, multiply all the value we get from the MCRP report by 168.9%, which is the inflation rate (1985 base), we will get the corresponding constant dollar in 2003 (See table 5).

The costs estimated for constructing greenway may include soil engineering, facilities and parking lots, sometimes it is necessary to build some detention basins, wet ponds, or infiltrate trenches and basins. Among them, soil engineering is the primary component, which includes various sectors intently relevant to the tree planting, such as stone selection, tree planting and sort chosen, the size of parking lot, and other detailed engineering construction sectors. Costs for greenway planning may consist of land acquisition costs (26.66 per acre) or labor costs ($15 per hour), and the engineering and design development are estimated at 10-15% of construction costs. All of the costs of sectors have been converted to constant dollars.

The total cost of converting the available land would be the sum of above expenditure. And the acres of land converted to trees are computed using GIS. First, we assume the cost of greenway plan is the same for every acre land regardless of soil types and land condition. Figure 13 illustrates a sample of greenway plan on a one-acre base. Professor Virginia Russell referred to the red oak as a common sort of tree in the Cincinnati area. She mentioned that a typical red oak is 30 feet tall and has a 30-foot wide drip line; therefore diagonal alignment of the trees with a 30-foot interval between the trees would be
a better arrangement pattern. Considering Prof. Russell’s suggestion, figure 14 is a tree alignment drawing of a one-acre area, or 209 square feet. The oblique distance between the centers of trees is 30 feet. The one-acre area could encompass approximately 33 trees with grass underneath them (See figure 14).

**Figure 14: Alignment of Tree of One-acre Area Plan**

Note:
1. The small circle with number represents trees’ position.
2. Unit: Foot
3. The area of the land is one acre (209 square feet)
4. The eight trees on the upper right shaded area might be reserved for parking lot and other facilities development
Then, based on this one-acre area plan, it will cost $49,929 per acre for greenway construction, which includes 30% contingency fee to handle other uncertainty expenses not covered in the discussion (See table 5). Multiplying one-acre expenditures by the total acres of convertible land (10920 acres), the total cost of the greenway plan would be $545,225,772.

<table>
<thead>
<tr>
<th>Table 5: Greenway Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenway Construction (with limited facilities)</td>
</tr>
<tr>
<td>Soil Engineering</td>
</tr>
<tr>
<td>Tree Plantings</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Live Stakes</td>
</tr>
<tr>
<td>Live Fascines</td>
</tr>
<tr>
<td>Prairie Seeds Mixes</td>
</tr>
<tr>
<td>Parking Lots</td>
</tr>
<tr>
<td>Signature sign</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Furniture/Furnishing</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
</tr>
<tr>
<td>Planning</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
</tr>
<tr>
<td>Total per acre</td>
</tr>
<tr>
<td>Contingency 30%</td>
</tr>
<tr>
<td>Total Cost</td>
</tr>
</tbody>
</table>

Source: Adapted from Mill Creek Restoration Project (MCRP)
In addition, in order to improve the greenway’s performance in governing the storm water, construction of detention basin and infiltration trench or basin could be a great help. The development of trees could make best contribution with the construction of these practices. MCRP also provides the inventories of applied formulas for construction and maintenance fees of these water management practices, which are included in the following table 6.

Table 6: Application Practices and Cost Estimations

<table>
<thead>
<tr>
<th>Applications</th>
<th>Formula</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detention Basin</td>
<td>C=(18.09V^0.69)1.25</td>
<td>1. “Annual maintenance costs: $300 - $500 per acre”</td>
</tr>
<tr>
<td></td>
<td>V=Volume of storage of pond to emergency spillway crest; 1.25 for a contingency factor</td>
<td>2. “Non-routine maintenance costs”: 1-2% of the base construction cost.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. “Base construction costs: 3-5%”</td>
</tr>
<tr>
<td>Infiltration Trench</td>
<td>C=44.93(V * 0.63)</td>
<td>1. “Excavation Cost: 20-25% of total cost”</td>
</tr>
<tr>
<td></td>
<td>V = Volume of storage; Multiply by 1.25 for contingency factor</td>
<td>2. “Stone Fill: 45-55% of total cost”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chapter 2. “Inlet and Outlet Pipes: 10-30% of total cost”</td>
</tr>
<tr>
<td>Infiltration Basin</td>
<td>C=18.07(V * 0.69)</td>
<td>Not Available</td>
</tr>
<tr>
<td></td>
<td>V = Volume of storage; Multiply by 1.25 for contingency factor</td>
<td></td>
</tr>
</tbody>
</table>

Source: MCRP

4.5.1.2 Tunnel approach

MSD provides the tunnel-estimated costs, which dependent upon the length of the tunnel, the shape of the tunnel and the geology through which the tunnel passes (MSD). In
the feasibility report, it states, “a reasonably detailed estimate of these features affecting the production and the method of support are of great importance.” The tunnel will be essentially following the Mill Creek. “The tunnel profile depth is currently set at 300 to 350 feet below existing ground surface. Floodwaters would be intercepted at five intake shafts, and CSO flows would enter the tunnel through twenty-drop shafts.” The tunnel is designed to capacitate 6.2 trillion gallons of water, which equals a 100-year flood (Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati, 2002) (See proposed tunnel corridor map 5).

Therefore, in the following part A, MSD developed a detailed description of tunnel design costs based on the local

Map 5: Proposed Tunnel Corridor
economic condition and operation. In this part, costs of six local sections are examined. They are: “local wage rates and benefit; equipment operating expense and ownership costs; expendable supplies; materials cost; subcontract costs; geotechnical data from the historical and recent exploration work plus laboratory test data (Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati, 2002).”

Although MSD and COE proposes two tunnel project: deep tunnel and high rock tunnel, only the former is discussed here because it costs less money and attract more attention from public. In part B, MSD provided tunnel construction costs upon considering the configuration of the tunnel and geology profile of the Mill Creek. The depth to bedrock in the central portion of the valley ranges from approximately 100 ft. at the mouth of the Mill Creek at the Ohio River to approximately 200 ft. near I-275. The elevation of the top of bedrock in the central portion of the valley generally ranges between 370 and 420 as the topography rises along the Mill Creek watershed (MSD report).

Considering the design and construction cost, the total expenditure of the deep tunnel project would be $841,087,025 including 30% contingency fee. Table 7 minutely lists the construction fees for the deep tunnel including the cost for design and maintenance.
Table 7: 31-foot Diameter Deep Tunnel

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Ave.Unit Bid $</th>
<th>Bid Amount $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization Contract #1,2,3</td>
<td>3</td>
<td>LS</td>
<td>13,294,087</td>
<td>39,882,261</td>
</tr>
<tr>
<td>TBM Tunnel Excavation</td>
<td>82900</td>
<td>LF</td>
<td>2,538</td>
<td>210,378,704</td>
</tr>
<tr>
<td>Tunnel Cip Lining</td>
<td>82900</td>
<td>LF</td>
<td>1,456</td>
<td>120,696,374</td>
</tr>
<tr>
<td>Tunnel Grouting for Water Control</td>
<td>1</td>
<td>LS</td>
<td>7,614,109</td>
<td>7,614,109</td>
</tr>
<tr>
<td>Dewatering in Tunnel</td>
<td>1</td>
<td>LS</td>
<td>634,509</td>
<td>634,509</td>
</tr>
<tr>
<td>200 MGD Pump Station and Overflow Structure</td>
<td>1</td>
<td>LS</td>
<td>31,725,435</td>
<td>31,725,435</td>
</tr>
<tr>
<td>Construction Shaft</td>
<td>25</td>
<td>LS/EA</td>
<td>5,843,731</td>
<td>146,093,266</td>
</tr>
<tr>
<td>Instrumentation and Flow Control System</td>
<td>1</td>
<td>LS</td>
<td>824,862</td>
<td>824,862</td>
</tr>
<tr>
<td>Construction Monitoring and Mitigation</td>
<td>1</td>
<td>LS</td>
<td>824,862</td>
<td>824,862</td>
</tr>
<tr>
<td>CSO Consolidation Piping #1-20</td>
<td>20</td>
<td>LS</td>
<td>2,755,500</td>
<td>55,110,000</td>
</tr>
<tr>
<td>Vent Shaft and Odor Control</td>
<td>1</td>
<td>LS</td>
<td>575,000</td>
<td>575,000</td>
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<tr>
<td>Emergency Power Supply</td>
<td>1</td>
<td>LS</td>
<td>2,538,036</td>
<td>2,538,036</td>
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<tr>
<td>Contaminated Material Management soils</td>
<td>5000</td>
<td>Tons</td>
<td>57</td>
<td>285,529</td>
</tr>
<tr>
<td>Maintenance and Control of Traffic</td>
<td>1</td>
<td>LS</td>
<td>1,269,018</td>
<td>1,269,018</td>
</tr>
<tr>
<td>Utility Relocations</td>
<td>1</td>
<td>Allow</td>
<td>2,538,036</td>
<td>2,538,036</td>
</tr>
<tr>
<td>Keper conduit and Detension Area</td>
<td>300</td>
<td>Allow</td>
<td>10,000,000</td>
<td>10,000,000</td>
</tr>
<tr>
<td>UPS Tributary Conduit</td>
<td>600</td>
<td>Allow</td>
<td>6,000,000</td>
<td>6,000,000</td>
</tr>
<tr>
<td>Sharon Creek Conduit</td>
<td>3400</td>
<td>Allow</td>
<td>10,000,000</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td></td>
<td>646,990,019</td>
<td></td>
</tr>
<tr>
<td>Contingency 30%</td>
<td></td>
<td></td>
<td>194,097,006</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>841,087,025</td>
<td></td>
</tr>
</tbody>
</table>

Source: MSD report Bid Tabulation

*Note:*

*EA* - Each

*LS* - Linear Square

*LF* – Linear Foot

*CSO* – Combine Sewer Overflow
4.5.1.3 Disconnect program approach

Downspout disconnect program is an effective solution to manage stormwater runoff. Before putting the program into practice, an area-wide questionnaire would help to determine the probable relief that results from the program. The USEPA reports that the program is most effective at where the residential area is a dominant section. And the more area it covers the more accurate the data. For the convenience of the analysis, we assume that the program will cover the entire residential area located in the watershed.

The Portland Regional Council recorded that roof drain redirection would cost range from $45-$75 for individual homeowners to disconnect. Redirecting rooftop runoff is a significant measure for reducing downstream impacts and can decrease annual runoff volumes by as much as 50%. Theoretically, “engineers estimate each roof sends 12 gallons of water during a rainstorm into the sewer every minute (MMSD).” At present, 85% of 150,084 residential buildings in the watershed are connected to the combined sewer overflows. Presume that these 85% residential buildings are located in the sewerage area, and distributing evenly throughout the watershed. Taking the 12 gallons runoff per minute and multiplying them by 127,571 (150,084*85%) houses, it equals about 30 million cubic feet of water per event (defined as 2.5 hours) that could be diverted or delayed from entering the combined sewer system.

The calculation process of volume of water runoff is based on the result of the current water volume of the greenway plan. First, highlight the parcel-based residential areas. Then, intersect the layer of all the buildings locate within the highlighted area using
the GeoProcessing extension. The following screen caption displays the GIS application process in computing the housing numbers, where only residential buildings are selected. The statistics button under the table menu presents the numbers of residential buildings situated in the area, which is in amount of 127,571 as mentioned previously. The final estimated cost would be the quantities of these houses times the average cost ($60), which is $7,654,284 totally in the watershed area.

**Figure 15: Map of Residential Area**

![Figure 15: Map of Residential Area](source: CAGIS)
4.5.1.4 Constructed wetland approach

According as USEPS report on 1999, constructed wetland “is an appropriate technology for small communities.” The factors that would influence wetland construction are: the feasibility of the program to the Mill Creek watershed; how much land could be convertible; cost of construction; cost of facilities; cost of maintenance; and cost of land acquisition (Constructed Wetlands Treatment of Municipal Wastewaters Manual, 1999).

There are two categories of constructed wetland: “Free water surface wetland (FWS)” and “Vegetated submerged bed system (VSB)”. The first type bears resemblance to the natural wetlands in that “they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland and water flows through the leaves and stems of plants (See Figure 16) (Constructed Wetlands Treatment of Municipal Wastewaters Manual, 1999).”

Owning to the low construction cost, visually anesthetic, available to wildlife and easily maintained of FWS wetland, it is overwhelmingly used throughout the United States. Considering the practical situation of the study area, where residential land use exceeds 30% of the land use coverage and consists of scores of small community. FWS would be a better choice. Thus, the application of FWS wetland is objectively feasible to the watershed area. A small-scale wetland system usually consists of a septic tank, a wetland cell and an infiltration bed.
The septic tank serves as a water holder; a substrate of saturated gravel in the wetland cell functions to support a cover of wetland; and lastly, the infiltration bed distributes the water discharged from the wetland. The cell size of wetland varies according to seasonal variation and community scale. Rationally, a typical wetland covers nearly 1-5 percent of watershed area (Jones, 1995), which is 851 to 4256 acres for the Mill Creek watershed. And it will cost two weeks to complete a purifying process for an average sized household, which purifies 350 million gallons of water per day.

In addition, wetland site selection and maintenance are crucial to appropriately develop the wetland functionality of purifying wastewater. And certain buffer distance away from the residential areas is necessary. The costs for establishing of multi-species riparian buffer strip systems have been estimated at $358 to $396 per acre; annual maintenance costs are estimated at $20 per acre. And the establishment and maintenance costs do no include any existing governmental cost-share or other subsidy (NonPoint

Source: Constructed Wetlands Treatment of Municipal Wastewaters Manual, 1999
GIS can be applied to the wetland site selection and site area calculation. The wetland is designed in linear with 30-foot width and 200-foot length for each system regardless of the soils type and land condition (See Figure 17). All of the wetlands hypothetically locate within 150 feet buffer distance to the major streams with a 60 feet riparian buffer strip for each side. Nevertheless, it is unlikely to convert all of them to wetland. Standing on the assumptions, table 8 from USEPA lists the approximate costs of FWS constructed wetland per acre. The sum area of constructed wetland is 1344 acres, among which 900 acres are adequate based on Jones’s statement. Hence, the total construction cost is derived by multiplying the cost per acre by the total acreage of 900; and the total cost exclude other factors such as cost of labor, land acquisition, buffer strip and facilities (Table 8).

As mentioned previously “a one-acre wetland, one foot deep, can hold approximately 330,000 gallons of water (Miller, 1990).” Based on this statement, a total volume of reduced runoff could be calculated through multiplying the 900 acres of land by the 330,000 gallons of water. Therefore, totally 39,728,578 cubic feet volumes of water runoff could be hold in the watershed with 900-acre wetland constructed.
However, as the lack of information on the constructed wetland and the gradually occupation by the post construction development, seldom has wetland in the Mill Creek area nowadays. As a result, it is difficult to accurately measure the wetland’s effect in managing the polluted storm water and its feasibility in the watershed area. The analysis is quite general.

Table 8: Cost of one-acre FWS Constructed Wetland

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Unit Price</th>
<th>Total Cost ($)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation/Compaction</td>
<td>m³</td>
<td>$2.30</td>
<td>13,000</td>
<td>19.4</td>
</tr>
<tr>
<td>Soil (45 cm)</td>
<td>m³</td>
<td>$1.30</td>
<td>2,800</td>
<td>4.2</td>
</tr>
<tr>
<td>Gravel (60 cm)</td>
<td>m³</td>
<td>$20.95</td>
<td>Na</td>
<td>—</td>
</tr>
<tr>
<td>Liner (30 mil PC)</td>
<td>m²</td>
<td>$3.75</td>
<td>19,250</td>
<td>28.7</td>
</tr>
<tr>
<td>Plants</td>
<td>Each</td>
<td>$0.60</td>
<td>7500 (60 cm o.c.)</td>
<td>11.2</td>
</tr>
<tr>
<td>Plumbing</td>
<td>Lump sum</td>
<td></td>
<td>7,500</td>
<td>11.2</td>
</tr>
<tr>
<td>Control Structures</td>
<td>Lump sum</td>
<td></td>
<td>7,000</td>
<td>10.4</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Acre</td>
<td>20.00</td>
<td>313</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Lump sum</td>
<td></td>
<td>10,000</td>
<td>14.9</td>
</tr>
<tr>
<td>Total/Acre</td>
<td></td>
<td></td>
<td>67,363</td>
<td>100</td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td></td>
<td>60,664,994</td>
<td></td>
</tr>
</tbody>
</table>

Source: Constructed Wetlands Treatment of Municipal Wastewaters Manual, 1999
4.5.2 Environmental Analysis

Environmental impact is another factor worth assessing. Its impact is relatively simple to measure by common knowledge. As more and more environmental issues are taken seriously, no techniques will be accepted or applied if degrading the natural ecosystem. Environmental analysis is becoming indispensable to all development aspects.

Scenario comparison: so as to display the environmental benefit of the greenway system to the Mill Creek watershed, comparing the environmental value of the greenway to the value of the tunnel, the constructed wetland and the disconnect program. In this part, the impacts of these techniques on the environment are examined, like water quality, volume of water runoff, soil erosion, and visual amenity. The environmental benefits are relatively easy to measure. Many articles and research projects have been done regarding their impact on environment. EPA, APA and many other cities’ planning departments provide sufficient illustration for the environmental benefits of these programs.

4.5.2.1 Greenway approach

The greenway’s function in mitigating the storm water runoff has been well recognized. It provides a green corridor that harmonizes human activity with natural environment (Table 9). Trees are typical less expensive approach to the prevention of water problems, which are the major problems threatening the Mill Creek watershed. When a big storm attacks, it slows down the velocity of storm water and at meantime, serves as the storage zones. In this regard, it not only infiltrates the chemical pollutants so that prevent
them from sprawling widely, but also reduces the damages it brings to the watershed area.

Due to the densely industrial and residential uses in the Mill Creek watershed, converting the proposed lands to trees will to a great degree improve the degraded natural environment of the area. The 164 combine sewer overflows devastates the ecosystem of the area by discharging a large quantity of toxic effluent, which mixes sanitary water with storm water, into the Mill Creek and Ohio River.

Trees release fresh air, and provide community with pleasant settings. Undoubtedly, trees provide a better living environment and protect the natural resources. Because of the rich advantages and great benefits trees possess, it is worthwhile to mobilize to make the plan into reality. To development the greenway plan in the watershed will not be a long-term goal.

Meanwhile, the greenway design is a key factor that will influence the efficiency of the greening. Generally, 30 foot vegetated buffer distance to low density area and 100 foot distance to high density area are required to fully explore its superiority. The table below elaborately expresses the advantages and disadvantages of trees.
Table 9: Summary of Environmental Issues for Greenway Program

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Flood control and protect wetland as well as improve water quality</td>
<td>• A minimum 30 foot vegetated buffer is required for low density development; and a 100 foot buffer is required for high density development; and only unpaved paths are allowed in the buffer</td>
</tr>
<tr>
<td>• Serve as a conduit for plants, animals, water, sediment, and chemicals</td>
<td></td>
</tr>
<tr>
<td>• As a habitat for plant and animal communities and improve the visual amenity</td>
<td></td>
</tr>
<tr>
<td>• Filter nutrients and pollutants as water percolates down through the soil</td>
<td></td>
</tr>
<tr>
<td>• Slow stormwater velocity, thereby reducing soil erosion and stream sedimentation</td>
<td></td>
</tr>
<tr>
<td>• Protect the stream from pollutants transported by urban stormwater runoff</td>
<td></td>
</tr>
</tbody>
</table>

Source: Streamlines, 1998

4.5.2.2 Tunnel approach

Deep tunnel project proposed by MSD and COE is a disputable topic in recent years, so it took MSD a few years to deeply investigate the feasibility of the deep tunnel in controlling floodwater. MSD is the source of all the information and data for the tunnel part.

The deep tunnel project will greatly impact the composition of Mill Creek, and the sewerage system of the watershed area as well. The deep tunnel aims to ameliorate the unyielding combine sewer overflow, which is a persistent ailment in the Cincinnati area.
through years. Most importantly, the tunnel will rescue the whole area in the event of flooding by pumping the floodwater and contaminated substances. Beside these advantages, it will be a huge process to practice the tunnel proposal. Ten to fifteen years is estimated to spend on the construction of the tunnel, which not including three to five years of inspection. Among the factors influence the tunnel, most of them are uncertain and even hardly to predict, which increase the difficult of pursing it.

Considering the above aspects, environmental benefits are often difficult to quantify directly. Nevertheless, table 10 presents the types of benefits and losses that MSD proposed.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CSO abatement exceeding USEPA and Ohio EPA requirements</td>
<td>• “Require a large land area”</td>
</tr>
<tr>
<td>• Reduce stream bank erosion, resulting from containment of frequent storms and impacts on the Ohio River</td>
<td>• Hardly to measure the results</td>
</tr>
<tr>
<td>• Enhance opportunity for restoration and rehabilitation</td>
<td>• “Improperly constructed tunnel may aggravate natural environment”; sometimes even results in worsen flood.</td>
</tr>
<tr>
<td>• Enhance stream anesthetics through control of floatable materials</td>
<td>• Highly Cost</td>
</tr>
<tr>
<td>• Enhance public health from the abatement of sanitary and combined discharges</td>
<td>• Long term construction</td>
</tr>
<tr>
<td>• Enhance recreation opportunities</td>
<td></td>
</tr>
</tbody>
</table>

Source: Mill Creek Flood Control and CSO Tunnel Feasibility Study Report for Metropolitan Sewer District of Greater Cincinnati, 2002
4.5.2.3 Disconnect program approach

Periodically, the combine sewer overflows (CSOs), which mix storm water runoff with sewage, pours into the Mill Creek and Ohio River even in the event of a medium precipitation. The flowing from roofs of innumerable buildings in the watershed makes big contributions to aggravate the combine sewer overflows (Table 11). The accumulated roof flows accelerate the velocity of the water runoff, taking along large quantities of pollutant and clogging the stream networks. By redirecting the downspouts drain to the gardens and lawns, especially in the densely residential areas, it is an effective way to reduce the water drained to the street. Compared to other stormwater management techniques, the disconnect program is easy to be put into practice and the effect will be remarkable.

Meanwhile, a widely and thorough survey is necessary to perceive the chance of partner with house owners, local communities and other environmental services. Only with the participation of the local residences, could the program perform as an effective function. The following table describes the disconnect program in much details. With respect to the Mill Creek watershed area, only a few communities have corresponding plans dealing with redirecting downspouts, and MCRP also put forward the idea. Therefore, it is still unknown whether the program could be carried out in the watershed area.

The city of Portland successfully eliminated the CSOs to one of the main streams and aims to reduce 94% of the overflows to another river by 2011. The city mapped out a plan that “residents can do the work themselves and earn $53 per downspout, or they can
have community groups and local contractors disconnect for them. Community groups earn $13 for each downspout they disconnect.” As a result, more than 38,000 homeowners have disconnected downspouts that eliminated more than 768 million gallons of storm water runoff per year from the combined sewer system (Downspout disconnect program, Portland).

Table 11: Summary of Environmental Issues for Disconnect Program

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reducing the volume of stormwater in the CSO system will reduce the size of the tunnels and other pipes needed to convey combined sewage</td>
<td>• Telephone, mail, or door-to-door surveys are necessary to determine the extent of roof drain connections to the Combined Sewer System (CSS)</td>
</tr>
<tr>
<td>• Reduce the directly drained impervious area in the watersheds by 900 acres to capture and control 150 million gallons of stormwater runoff each year.</td>
<td>• Public must be educated as to the benefits and methods. This can be time-consuming and will likely require some sort of rebate program or other incentive for compliance</td>
</tr>
<tr>
<td>• Can be done easily by individual homeowners</td>
<td>• Should be implemented in a wide service area to be effective</td>
</tr>
</tbody>
</table>

Source: Downspout Disconnect Program

4.5.2.4 Constructed wetland approach

As the particular functions of the wetland for impure water and creating delightful environment, it is obtaining widely approval especially in the United States and Canada. It provides creature with a natural habitat to live and linger.

Constructed wetland is a good stormwater management facility both in runoff quantity reduction and water quality improvement (See table 12). By holding or delaying a large quantities of water runoff in its cells, wetland can be used to manage storm water
runoff peak discharges and make uncommon mitigations in overall runoff quantity. Furthermore, a properly designed and maintained wetland is capable of removing much solid and soluble pollutant from the runoff. It uptakes the pollutants and releases or seeps water into soil, thus improving the runoff quality.

On the other hand, the construction of wetland depends largely on the local climate condition, soil type and land use. The implement of this program needs the cooperation of environmentalists and engineers, and a good site planning is also important to develop wetland with least side effect.

Table 12: Summary of Environmental Issues for Wetland Program

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Wildlife habitat is created when the ponds are properly designed and maintained, including “habitat for mosquito predators”</td>
<td>• Require a large open land area</td>
</tr>
<tr>
<td>• Can be aesthetically pleasing if designed properly, which can increase adjacent property values</td>
<td>• Generally requires a large contributing watershed</td>
</tr>
<tr>
<td>• Capable of removing both solid and soluble pollutants from the runoff</td>
<td>• Pond discharges usually consists of warm water, so their use may be limited in areas with “temperature sensitive fisheries”</td>
</tr>
<tr>
<td>• Reduce peak flows</td>
<td>• Improperly maintained wetlands may result in nuisance odors, algae blooms, and rotting debris</td>
</tr>
<tr>
<td></td>
<td>• Depends largely on climate condition, soil type, and drainage system</td>
</tr>
<tr>
<td></td>
<td>• Cost</td>
</tr>
</tbody>
</table>

Source: Constructed wetland, 2002
4.6 Comparison

Comparing the four techniques’ functions in mitigating storm water runoff, and their environmental and economic impacts on the Mill Creek watershed, we discern the noteworthy differences among these techniques. The greenway plan was initially assumed to be the best fit for the watershed owing to its merits for environmental improvement and enhancement. As table 13 shown below, each technique has its unique character dealing with water runoff and environmental/economic benefit.

**Table 13: Comparison of Different Techniques**

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Flood Control /Average Annual Rainfall (Million Gallon)</th>
<th>Total Cost (Million $)</th>
<th>Unit Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenway plan</td>
<td>1,350</td>
<td>545</td>
<td>49,929/Acre</td>
</tr>
<tr>
<td>Disconnect program</td>
<td>3,450</td>
<td>8</td>
<td>60/Home</td>
</tr>
<tr>
<td>Constructed wetland</td>
<td>4,500</td>
<td>61</td>
<td>67,363/Acre</td>
</tr>
<tr>
<td>Deep tunnel</td>
<td>6,200</td>
<td>841</td>
<td>46,727,057/Mile</td>
</tr>
</tbody>
</table>

Note: 6,200 refers to tunnel storage capacity, not annual run off reduction, so they are not comparable.

These are four techniques for mitigating storm water runoff and flooding. The second column illustrates the flood relieve of average annual rainfall. According to MSD data, the average annual rainfall is 40.89 inches, and the average rainfall per event is 3.75 inches. All the numbers are calculated based on the data from MSD feasibility report. 1). The first technique is the constructed wetland. The uses of wetlands are successful in many cities. Parallel and close to the main streams, constructed wetland shields the streams from industrial and waste water piped directly into them. The reduction of runoff depends on how much water could permeate the soil. 2). The second technique is the disconnect program technique for its overwhelming function in redirecting the roof drain. As
impervious surface could significantly change the quantities of water runoff, the program would be a good way to solve the runoff problem. 3). The third approach is the greenway technique. Trees are natural protective screens for the ecosystem. They remedy and defend from many kinds of environment pollutants by slowing down the runoff peak discharge and they are capable of filtering the pollution. 4) The deep tunnel is designed to relieve flood and CSOs, which have no impact on water runoff reduction.

On the economic side, 1). The disconnect program is the most economical technique because it only cost $7 million, which is far less than the other three techniques. However, the execution of this program depends largely on local policy and the willingness of residents to participate the program. Too many uncertain factors make it difficult to accurately estimate the cost of the program. 2). Comparing with the disconnect program approach, constructed wetland technique spends more because of its complex composition, construction process and functioning. The average cost of per acre wetland is 26% more than the cost of greenway plan. While, the total cost of constructed wetland is less than the greenway because the former has less acres of convertible land. 3). The greenway plan is unexpectedly costly, which is far more expensive than the former two techniques, although greenway’s benefits are easily acceptable by residents for the value of trees is well known. 4). Tunnel program has the highest cost. MSD put a lot of effort into surveying the feasibility of a deep tunnel. Because of its impact on the watershed, this program is objected to by many environmentalists and local residents.
Chapter 5. Conclusion and Recommendation

5.1 Conclusion

It is more effective to prevent the ground water runoff problem instead of attempting to restore the environment after the problem occurs. Improving the environmental quality and increasing the economic vitality of Mill Creek are imperative. The case study illustrates that storm water management could help Mill Creek using different techniques in water runoff/flood reduction, environmental improvement, and cost efficiency.

Table 14 describes and compares four separate techniques in disposing of water and environmental problems. Each technique has its unique set of functions and how they could contribute to solving the problems. The checklists in this table depict what each technique can and cannot accomplish.

The greenway plan was expected to offer the best treatment to the watershed due to the great advantages trees provide. Trees not only mitigate water problems such as decreasing the flow peak discharge and water volume, and relieve flood, but also help increase recreational opportunities. However, while the greenway program is undoubtedly a valuable method, the 10,920 acres of greenway still could not affectively reduce the water runoff. Runoff control only through tree planting is not sufficient. And the dispersed greenway is not so helpful as to efficiently stop the polluted water from flowing into the waterways.
Table 14: Description of Different Techniques

<table>
<thead>
<tr>
<th>Issues</th>
<th>Techniques</th>
<th>Greenway Plan</th>
<th>Disconnect Program</th>
<th>Constructed Wetland</th>
<th>Tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Problems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Where to store water</td>
<td>Soil/Root</td>
<td>Soil/Lawn/Garden</td>
<td>Wetland cells/plant</td>
<td>Tunnel</td>
<td></td>
</tr>
<tr>
<td>When water reduction occurs</td>
<td>Rainfall/Flood</td>
<td>Rainfall/Flood</td>
<td>Rainfall/Flood</td>
<td>Flood</td>
<td></td>
</tr>
<tr>
<td>Water purification/Water quality improvement</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Peak flows reduction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water volume reduction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flood relieve</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>CSOs abatement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Environment Improvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air quality/noise improvement</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stream protection</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Reduce stream bank erosion</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Recreation opportunity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment amenity</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildlife habitat</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

By comparing with other techniques, the greenway plan does not turn out to be the best environmental remedy to the area even though it seems to be the favorable option. The Disconnect Program functions well on mitigating the water runoff and CSOs, which result in more flooding. Nevertheless, due to the minor reduction of runoff by each home, the Disconnect Program needs to be widely implemented in order to be effective. Another unfavorable factor is that the Disconnect Program has nothing to do with embellishing the landscape and environment improvement. For this reason, the greenway plan is more acceptable.
The Wetland approach also results in a favorable outcome in managing the water runoff problem. Even though the calculation result is far less accurate, taking the assumption that 900 acres of wetland could be constructed in the area, may demonstrate that wetland would be an effective approach. It may reduce the water runoff by three times more than the Greenway Plan with less acres of land. Furthermore, wetlands considerably protect the streams and increase the environment amenity as well. Nevertheless, the construction of wetland should be along the existing streams to make it effective and certain buffer distance is also indispensable to eliminate its side effect, like smelly odor and rotten mess, to the nearby neighborhoods. At this point, the greenway plan is more flexible and could be dispersedly planted throughout the watershed area.

The deep Tunnel project is not a good way of dealing with water runoff and cost benefit either. The project aims to eliminate most of the CSOs drained to the streams upon its completion. However, this program is not acceptable to some of the communities and individuals. The sizable expenditure of the program will significantly delay or even halt the construction process, which will seriously degrade the local environment. Therefore, the tunnel project will not be considered in the following content.

Hence, it can be argued that a single technique will not greatly help the watershed, while a combination of all three techniques would be the best possible alternative. The application of the three systemic management techniques, (the greenway plan, constructed wetland and disconnect program) will significantly upgrade the Mill Creek watershed. In view of trees’ unique character in purifying air quality and meanwhile absorbing the
pollutants, the greenway plan is invaluable on improving and recovering the natural environment as well as contributing to solving the water problems. But as the greenway is converted from a huge amount of dispersed vacant lands, it will not provide a systemic strip protection to the Mill Creek watershed along the river. In terms of constructed wetland, it compensates this shortage of greenway by following the streamlines. By this means, wetland can purify the polluted water before it flows into the streams. Furthermore, to highly optimize the program, a disconnect program will be necessary for its great effect in reducing quantities of water runoff.

Figure 18 below presents the change of water runoff quantities by applying these three techniques. The bottom line represents the runoff volume by application of the combined techniques. In comparison to volume reduced by individual techniques, the application of systemic management (combination technique) decreases the water volume most effectively, which is almost 20% of current total volume.
Map 6.2 and 6.4 illustrate the combined impact of the three techniques of stormwater runoff management discussed previously. Comparing them with current land coverage (Map 6.1) and land use map (Map 6.2), more green land appears on the area and the wetlands form a green protection strip for the waterway. The impervious surface decreases 15%, and the water runoff reduces 20%. Although the combined method of this proposal may not be entirely practical since most of land is already developed, the Mill Creek watershed will still benefit from it even if partially implemented.
Map 6.1 Current land Coverage

Map 6.2 Post-Development Land Coverage
5.2 Recommendations

The purpose of this study is to examine the best water runoff management technique for the Mill Creek watershed. A comparison of four techniques indicates that a single program is not effective enough to benefit the watershed. To take advantage of the different techniques and put them into effect flexibly would be a great help to the problems. The following points address limitations of this research and how to improve the effects of the techniques.

- The absence of data and the unpredictability of social and physical factors make the construction cost hard to measure.
- GIS provides a good analytical instrument for assessing hydrology based on the following three factors: land use, soil type and precipitation.
- The unavailability of data reduces the accuracy of runoff calculation of constructed wetland and disconnect program approaches.
- Additional techniques can implement the four approached already discussed throughout this document, such as onsite infiltration trench, vegetated island, and good site planning to regulate the impervious surface percentage.
- The Greenway plan should be connected to the existing parks and open space systems so as to make the program more effective.
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