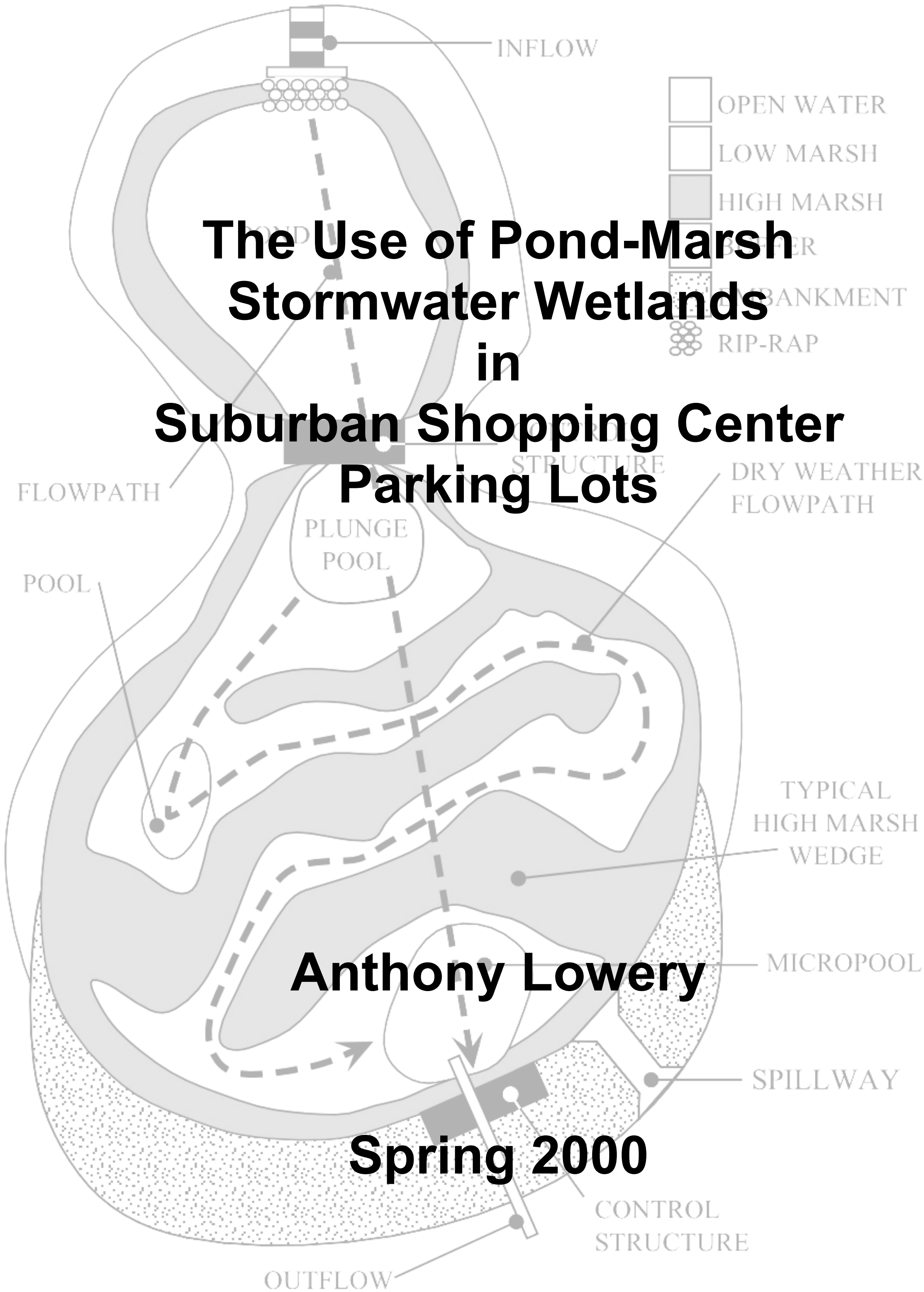
The Use of Pond-Marsh Stormwater Wetlands in Suburban Shopping Center Parking Lots



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THE USE OF POND-MARSH STORMWATER WETLANDS IN SUBURBAN SHOPPING CENTER PARKING LOTS

A Thesis

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by
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DEDICATION

This work is dedicated to Gina, Michael and Nicholas. Without their love, support and faith, I doubt I would have ever finished.

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ABSTRACT

"The Use of Pond-Marsh Stormwater Wetlands in Suburban Shopping Center Parking Lots" examines the feasibility of integrating a Pond-Marsh stormwater wetland into suburban shopping center parking lots. Chapter One outlines the background, problem statement, objective, methodology and scope of the thesis.

Chapter Two is an examination of three issues associated with the typical parking lot. These issues are increased runoff volume, poor runoff water quality and decreased aesthetics. It discusses general and localized effects of these issues. How shopping center parking lots add to these effects is explored.

Chapter Three is an investigation of stormwater wetlands as a solution to these issues. The abilities of a Pond-Marsh stormwater wetland to deal with the issues described above are discussed. Chapter Four discusses the problems of using a Pond-Marsh system and possible solutions are developed.

Chapter Five details the design of a Pond-Marsh. Chapter Six proposes guidelines for developing a Pond-Marsh. The guidelines are focused on integrating such a system into shopping center parking lots.

Chapter Seven is a case study used to test the feasibility of integrating a Pond-Marsh system into a large suburban shopping center. Design criteria, providing maximum runoff detention while maintaining runoff treatment and aesthetic values, are developed using the guidelines. Three design options, using different configurations, are created to explore integration possibilities. The results show none of the design options can be successfully used on the case study site.

Chapter Eight examines why these design options cannot be integrated into the case study site. Discussion moves to why these particular design options failed to

prove the hypothesis. Suggestions and examples of changes in the design criteria and/or the case study site are made. The limitations of the thesis and suggestions for further research are made.

CHAPER 1

INTRODUCTION

1.1 BACKGROUND

The use of parking facilities has both encouraged and followed the modern urbanization patterns of the United States. After World War II, the growth of urban areas was made possible, in part, by the choice of the automobile as the primary method of transportation. This dependence on cars means nearly any project or facility includes a parking component. In many cases, parking can become the principle program consideration of a project. Because of its necessity, parking is one of the most significant features on the American landscape.

Parking brings with it important environmental and aesthetic consequences. Three of these problems are increased runoff, lower runoff water quality and visual deterioration of the landscape. While these are not the only consequences or are they limited to parking lots, they are easily identified with parking.

Recently, there has been a re-examination of the traditional methods of stormwater management and parking lot design. These traditional methods, in most instances, cause or exacerbate the problems noted above. This realization has led to search for alternative best management practices (BMPs).

One such BMP is a stormwater wetland. Stormwater wetlands are a specialized form of constructed wetland. They mimic natural wetlands by providing a wide range of aquatic and terrestrial habitats. This creates the opportunity for many species of plant and animal life to become established.

Stormwater wetlands are used to improve the water quality of wastewater and runoff. Stormwater wetlands can also be used to detain runoff. An additional benefit of these wetlands is creation of a visually and physically pleasing environment.

1.2 PROBLEM STATEMENT

Currently, stormwater wetlands are built predominately for two specific uses. One is to reduce contamination from runoff from single use sites such agricultural or mining operations. The second is for general contaminant reduction and stormwater control from mixed use areas.

Little, however, has been done with integrating a stormwater wetland exclusively to suburban shopping center parking lots. Stormwater wetlands combine the ability to control stormwater, improve runoff quality and increase the aesthetic character of these parking lots. A stormwater wetland could provide an ideal solution to these problems of parking lot design.

1.3 OBJECTIVE

This thesis will develop a method for introducing stormwater wetlands into parking lots to retain stormwater, improve runoff quality and provide visual enhancement.

1.4 METHODOLOGY

The first step is a literature search. The literature search can be divided into two main areas of study. The first area looks at the traditional methods of handling runoff retention and water quality. It will also explore traditional parking lot design and standards with an emphasis on suburban shopping parking lots. The second area is focused on the current research of stormwater wetlands.

The second step is the synthesis of the two main areas of research. In this step the techniques, benefits and limitations of traditional methods and stormwater wetlands are defined and explored. This synthesis forms the basis for the next step.

The third step is generation of design guidelines. These guidelines are broken into two areas. The first evaluates the possibility of introducing a parking lot stormwater wetland to a site. The second area guides the landscape architect through the process of implementing a parking lot stormwater wetland.

The last step is an illustration of these guidelines by applying them to an actual site. This demonstrates the process of evaluating a site for parking lot stormwater wetland introduction.

1.5 SCOPE OF THESIS

This thesis focuses on the use of stormwater wetlands in large suburban shopping center parking lots. These lots magnify the large runoff volumes, poor runoff quality and unappealing aesthetics associated with all parking lots. This presents a unique situation for testing the ability of stormwater wetlands to address all three issues.

Much of the current research in stormwater wetlands is taken from more temperate climates. For this reason, this thesis is limited to the area of the Southeast United States (Figure 1). This region's mild climate provides a good environment for stormwater wetlands.

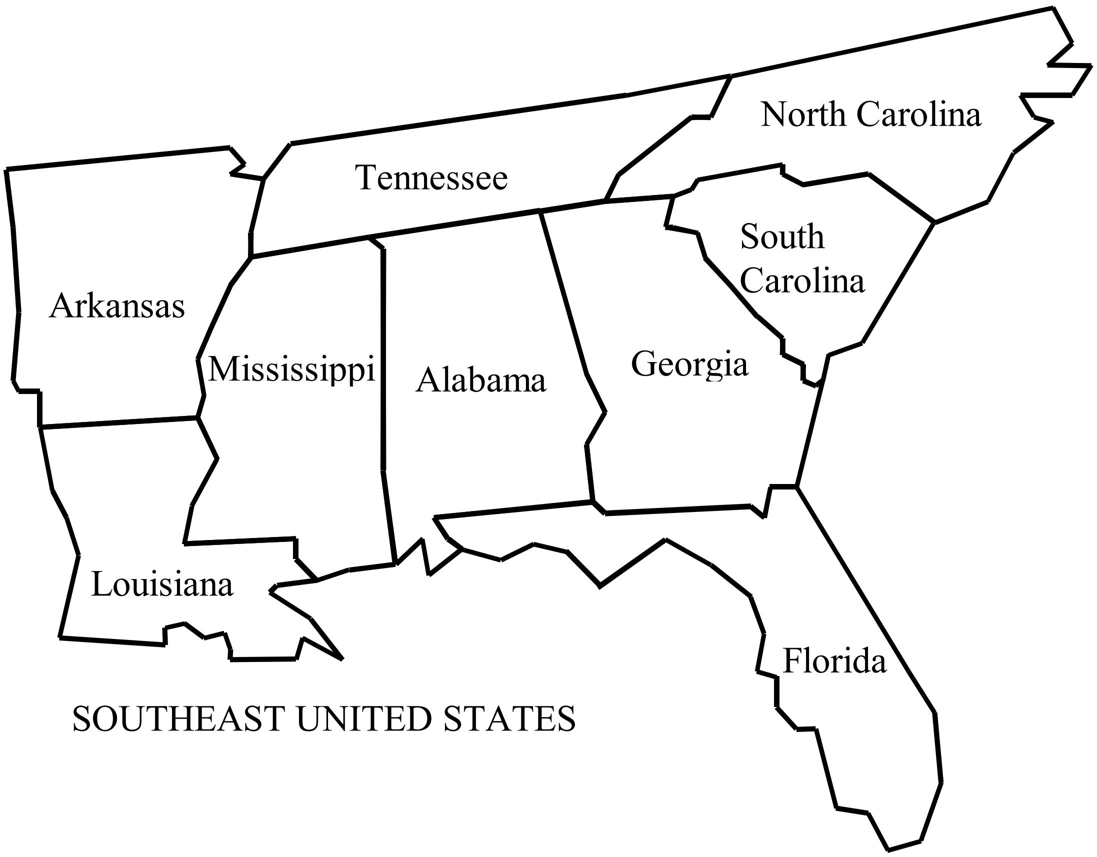

Figure 1 Study Region

CHAPER 2

ISSUES

2.1 STORMWATER QUANTITY

2.1.1 Hydrologic Cycle

To understand a parking lot's effect on a watershed, it is important to discuss what happens to stormwater on undeveloped sites. Stormwater runoff is part of the natural hydrologic cycle (Figure 2). "The hydrologic cycle is the continuous, unsteady circulation of the water resource from the atmosphere to and under the land surface and, by various processes, back to the atmosphere" (Walesh 1989, 53). The cycle begins with precipitation, some of which evaporates before reaching the ground or is intercepted and then evaporates. Once on the ground, precipitation can follow several routes.

A major route is infiltration into the soil. Once stormwater infiltrates, it can take several paths. One path is to remain in the soil becoming part of the groundwater. Another path is to be taken up by plants and returned to the atmosphere through evapo-transporation. A third path is to evaporate directly from the soil to the atmosphere. The amount of stormwater that infiltrates is determined by a number of conditions such as the permeability of the surface and the amount of moisture present in the Stormwater can also move across the ground becoming surface runoff. Here it can come across depressions, complex topography and obstructions such as plants and plant debris. These obstacles can slow or hold the runoff until it evaporates. Unevaporated runoff runs into larger water bodies. Held in rivers, lakes and ponds, it will eventually evaporate into the atmosphere.

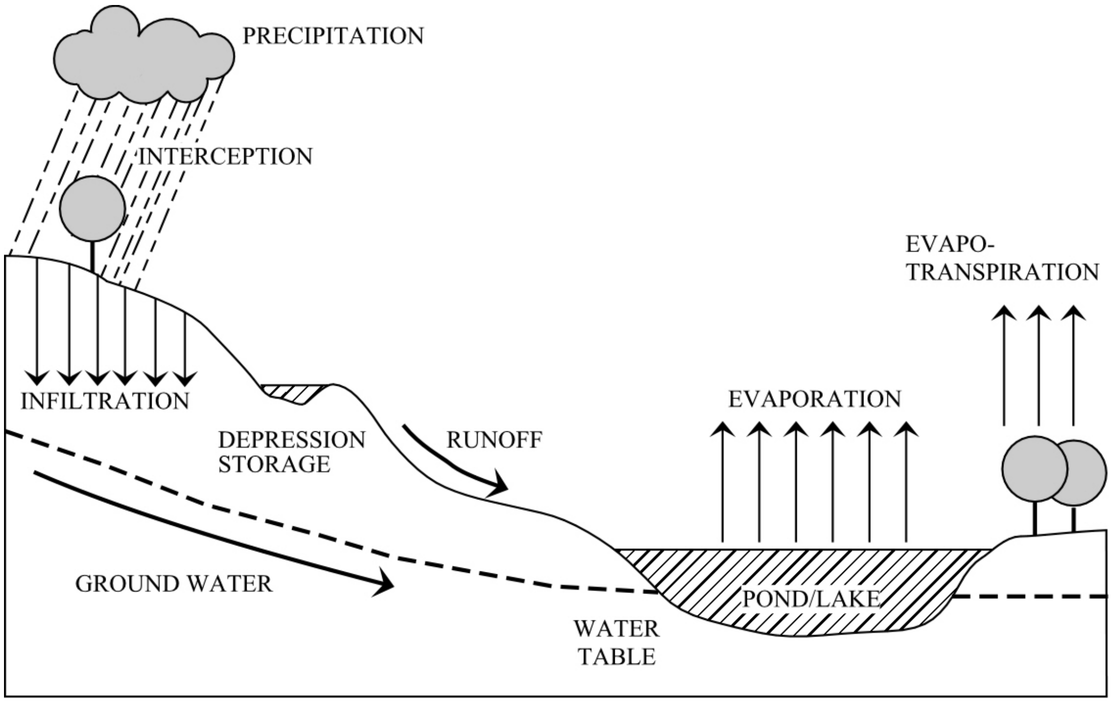

Figure 2 Hydrological Cycle

2.1.2 Effects of Parking Lots on the Hydrologic Cycle

Parking lots can severely disrupt the hydrologic cycle. Urbanization, and parking lots, in particular usually increases the quantity of stormwater runoff (Figure 3). This increase in runoff results because of two basic disruptions of the hydrological cycle.

One disruption is the blocking of almost all infiltration of stormwater into the soil. Parking lots in urban and suburban areas are most commonly constructed with concrete or blacktop. Along with the facilities served by the lot, these surfacing materials can effectively block almost all infiltration of stormwater. Except for the smallest storms, most stormwater will leave the site as runoff. By blocking infiltration, these surfaces also prevent stormwater from percolating down to become groundwater. Figure 3 illustrates the increased runoff and decreased infiltration accompanying urbanization.

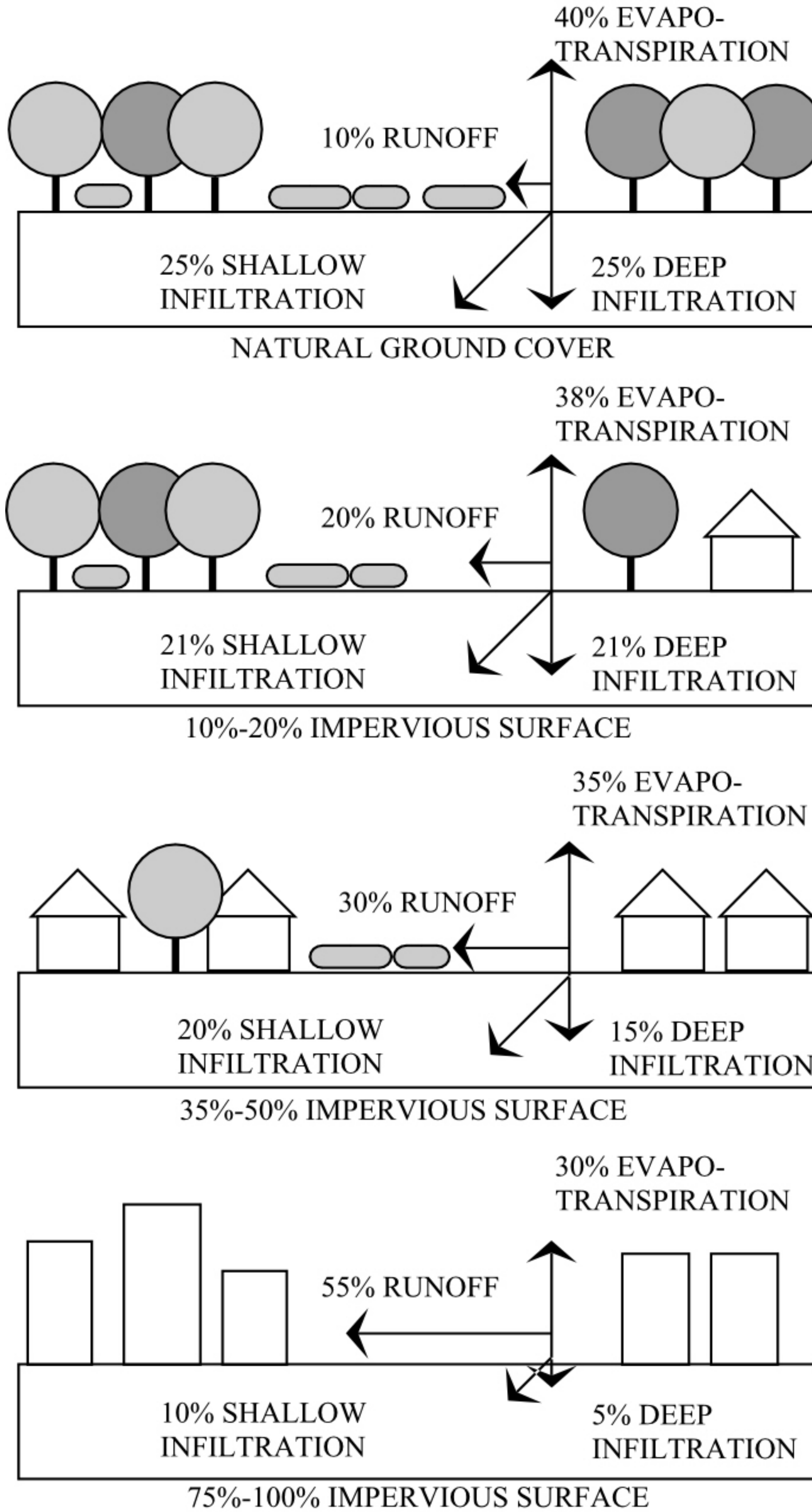

Figure 3 Urbanization Effect on Hydrological Cycle

Parking lots often have small landscaped islands or areas where soil is exposed. These areas may not provide any relief from the use of impervious materials. Often severe soil compaction occurs during the construction phase of development. This compaction can result in the soil losing its pre-development infiltration ability (Walesh 1989, 57).

Another disruption is through simplification of the natural drainage system. A parking lot has a relatively simple topography designed in part to quickly guide runoff. This reshaping of the surface eliminates the complex topography, which contains and slows stormwater. Barriers to runoff movement such as plant material and debris are for the most part removed. Also the surfacing materials used are usually much smoother than the pre-development surfaces (Walesh 1989, 57).

The increase of impervious surface and simplification of the natural drainage pattern can affect runoff from a site. These changes can lead to an increase in direct runoff and in the velocity of the runoff. These changes can also lead to a decrease in runoff detention time and a reduction in the amount of precipitation becoming groundwater (Walesh 1989, 57).

2.1.3 Stormwater Runoff Management Systems

As has been shown, the construction of a parking lot causes drastic changes in the natural hydrologic cycle. These changes require implementing a stormwater runoff management system. A stormwater runoff management system is defined as a system composed of both natural and man-made elements. These elements contain and convey excess stormwater (Urban Land Institute 1975, 13). It includes all components "that guide, control or otherwise modify either the quantity, rate of flow or quality" (Urban Land Institute 1975, 13). It is a single system with two main purposes. The first is to "prevent or minimize property damage and physical injury from an infrequent or unusual storm" (Urban Land Institute 1975, 13). The second is to "prevent or minimize inconvenience or disruption of activity from frequently occurring, less significant storms" (Urban Land Institute 1975, 13). Because some of these components are designed for frequently occurring storms, property damage may result from an unusually heavy storm volume (Urban Land Institute 1975, 13).

2.1.4 Traditional Stormwater Management

- Advantages of Traditional Management

As noted earlier, the development of a site can greatly disturb the natural hydrological cycle. The increases in stormwater runoff volume and velocity can create flooding problems on or adjacent to the site. Historically, the answer to this problem has been conveyance. "Conveyance is a design for moving water away. It is disposal of stormwater in surface water systems" (Ferguson and Debo 1987, 13). The use of conveyance began early in the history of civilization. For example, street gutters have been discovered in ancient Pompeii, Italy leading to specific discharge points (Ferguson and Debo 1987, 13).

Traditional runoff management systems have emphasized the use of man-made structures. In a typical design, excess stormwater is sometimes conducted either to a retention or detention pond and then to a catchbasin. More often, the runoff is channeled directly to a catchbasin. From the catchbasin, the stormwater moves through a series of constructed ditches, canals or underground pipes. The stormwater discharges directly into a water body such as a coastal marsh, river or lake. In rare cases, it may be treated for contaminants and then discharged.

This typical design is considered a surface system for managing stormwater. This is because the system allows for only lateral movement of runoff. All parts of the system, including underground pipes and catchbasins, confine the runoff. Until discharge, there is little or no opportunity for infiltration (Ferguson and Debo 1987, 13).

The chief advantage to the traditional stormwater management system is "applicability to both existing and newly developing urban areas" (Walesh 1989, 26). The traditional system has a relatively small surface space requirement. This system is easy to retrofit in areas having already experienced development.

Another advantage is the speed runoff is removed from the site. This helps eliminate flooding from storms at or below the design capacity. If the design capacity is exceeded, the system can quickly remove runoff. This reduces the amount and duration of flooding.

A third advantage of the traditional stormwater management system is the ease of design. The principles and construction methods of this system are widely understood and dependable. It is highly adaptable and can be applied to almost any site.

Fourth, the traditional system also has the advantage of ease of calculating the construction and management costs. Reference guides like the Means Building Construction Cost Data detail material, labor and equipment costs for the individual pieces of a traditional stormwater management system. A total cost for installation and maintenance of the system can be simply and quickly determined.

• Disadvantages of Traditional Management

As adaptable and simple as this traditional method of stormwater runoff management system is, there are significant disadvantages to its use. The ability to quickly move runoff can be an advantage for the area being drained. However, the runoff reaches "the natural drainage system (streams and waterways) sooner and with much higher velocity" (Ohio 1980, 20). This can be devastating for the area receiving the excess runoff.

These conditions combine to have important on and off site effects (Figure 4). One effect can be increases in flooding which exceed pre-development depths and areas. These floods can be quite severe because they are unexpected. Homes and businesses that historically do not flood may suddenly become inundated (Walesh 1989, 57).

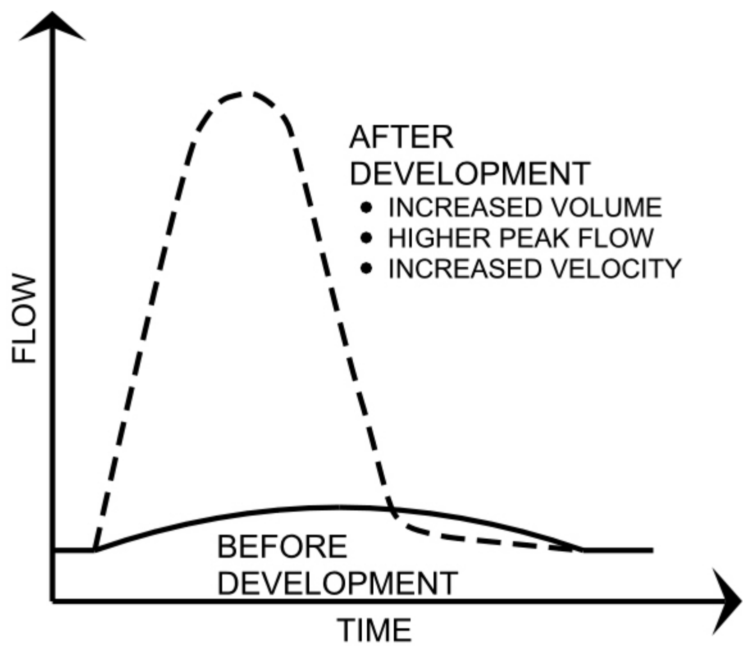

Figure 4 Urbanization Effect on Runoff
Source: After Walesh 1989, 26

These increased flows and velocities also increase downstream erosion. The higher runoff flows and velocities combine to cut into stream banks and beds. This can lead to bank instability, loss of vegetation and damage to structures (Walesh 1989, 57, Ohio Division of Natural Resources 1981, p.7).

Another disadvantage is the emphasis on impervious materials used in the construction of traditional stormwater management systems. Because these materials are effective at containing stormwater, little runoff is allowed to infiltrate the ground. This can result in groundwater not being recharged and the lowering of the local water table. These losses can have important consequences in streams depending on groundwater. The loss of water can raise temperatures and lower flow rates in these streams. This can radically change the stream's ecosystem and lower the stream's ability to absorb pollution. The effect is heightened if surface runoff has been diverted or during times of drought (Ferguson Stormwater Infiltration 1994, 24-25).

A further disadvantage to traditional methods is introduction of contaminants into receiving waters. Contaminants are deposited on to ground surfaces. When a runoff generating storm event occurs, these contaminants are picked up by the runoff and swept into the stormwater management system. The higher flows and velocities allow the runoff to carry greater loads of contaminants. If the stormwater is left untreated, the contaminants are eventually discharged into receiving waters. This particular aspect will be discussed in greater detail later in this work.

2.1.5 Shopping Center Parking Lot Effect on Stormwater

By its very nature, the typical suburban shopping center parking lot increases both stormwater runoff volume and velocity. Most of these parking lots use traditional stormwater management methods for handling the increases in runoff volume and velocity. Traditional methods, while providing good control for a particular lot, can intensify the effects of these higher volumes and velocities on adjacent and downstream sites. In effect, runoff can be mismanaged twice, first by the typical suburban shopping center parking lot design and second by traditional stormwater management design.

2.2 STORMWATER QUALITY

2.2.1 Nonpoint Source Pollution

Nonpoint source pollution (NSP) was identified as an important source of water pollution in the 1960's. NSP can be defined as:

1) Discharges entering surface waters in a diffuse manner and at intermittent intervals that are related mostly to the occurrence of meteorological events.

2) Pollution arising over an extensive area of land and is in transit overland before it reaches surface waters.

3) Nonpoint sources generally cannot be monitored at their point of origin, and their exact source is difficult or sometimes impossible to trace.

(Novotny and Chesters 1981, 7)

NSP is one of the greatest environmental concerns in the United States today. Approximately seventy percent of water contamination is caused by nonpoint source pollution (Ferguson, Landscape Architecture 1994, 46). This figure is "up from under fifty percent of the total two decades ago" (Mitchell 1996, 113).

Stormwater runoff is the major component of NSP. As stormwater moves across surfaces, it picks up deposited contaminant residues. The stormwater eventually carries the contaminant load to its receiving waters.

The amount of contaminants carried by stormwater can be quite high. For example, in Florida, stormwater pollution is responsible for:

1) Eighty to ninety-five per cent of the heavy metals loading to Florida surface waters.

2) Virtually all of the sediment deposits in state waters.

3) 450 times the suspended solids going to receiving waters and nine times the loads of BOD_5 (Biochemical Oxygen Demand) substances when compared to loads from secondarily treated sewage effluent.

4) Nutrient loads comparable to those in secondarily treated sewage effluent discharges.

(U.S. Environmental Protection Agency 1985, 289)

2.2.2 Contaminant Types

The types and levels of contaminants occurring in urban areas vary widely from site to site. This is because different land uses generate different contaminants. These differences can occur even within the same land use classification.

The EPA, in the "Nationwide Urban Runoff Program" (NURP), examined urban runoff. To keep from being overcome by the number of possible contaminants, the EPA developed a list of standard contaminants found in urban runoff (Table 1).

Table 1 Urban Runoff Standard Contaminants

TSS	Total Suspended Solids	BOD	Biochemical Oxygen Demand
TP	Total Phosphorous	COD	Chemical Oxygen Demand
SP	Soluble Phosphorous	Cu	Total Copper
TKN	Total Kjeldahl Nitrogen	Pb	Total Lead
$NO_{2\&3}$	Nitrite & Nitrate	Zn	Total Zinc

Urbonas and Stahre 1993, 309

"The list includes pollutants of general interest which are usually examined in nonpoint source studies and includes representatives of important categories of pollutants-namely solids, oxygen consuming constituents, nutrients and heavy metals" (Urbonas and Stahre 1993, 309).

These contaminants and others can be divided into several broad groups based on their sources or their effect on the environment. The groups are suspended solids, nutrients, oxygen consuming elements, heavy metals, organic compounds, debris and microorganisms. The groups of contaminants and their effects are discussed below.

• Suspended Solids

Suspended solids are the most common contaminant in urban areas. This contaminant group is measured as Total Suspended Solids (TSS). Much of this contaminant group is caused by soil particles eroding from construction sites. Another important source is dryfall blown in from off-site as dust, smoke and other airborne pollutants. Further sources include rust and rubber from vehicles and decomposing building and paving material.

Suspended solids have many detrimental effects. These solids can increase the turbidity of water and prevent light from penetrating streams and lakes. This can lead to a reduction in aquatic plants and animals.

Suspended solids can clog storm sewers and drainage channels. This reduces the ability of these structures to move runoff. These reductions increase the chance for flooding.

Suspended solids can also be a source of chemical contamination. Chemical contaminants can become bonded to individual particles. The contaminants are then spread as the suspended solids move through the environment (Ferguson 1994, 160).

• Nutrients

Nutrients enter stormwater mainly as runoff from heavily fertilized spaces such as golf courses, residential areas and office parks. Other sources are leachate from trash containers and some vehicle organic compounds from highways and parking lots. Composed chiefly of various forms of Phosphorus and Nitrogen, (Total Phosphorous-TP, Soluble Phosphorous-SP, Total Kjeldahl Nitrogen-TKN, and Nitrite & Nitrate-$NO_{2\&3}$) these contaminants move easily through the environment. They can encourage increased plant growth leading to ecological imbalances. Additionally, nitrogen in excessive levels can be a direct human health hazard (Ferguson 1994, 162-163).

Elevated nutrient levels also create high biological and chemical oxygen demands (BOD and COD). BOD and COD measure the amount of the oxygen used by aerobic microorganisms and chemical action in water. These consume oxygen in the water reducing the amount available for aquatic life (Ferguson 1994, 162-163).

• Heavy Metals

Heavy metals present in urban areas present an additional category of contamination. These contaminants are composed chiefly of Copper (Cu), Lead (Pb) and Zinc (Zn) but can also include metals such as Cadmium, Chromium and Magnesium. Metals have a wide variety of sources ranging from vehicle exhaust to gutters to lead based paint (Ferguson 1994, 161-162).

• Organic Compounds

Though not included in the EPA standard pollutants characterizing urban runoff, organic compounds represent a significant contaminant category. Organic compounds are composed of complex hydrocarbon chemicals found in petroleum products. The chief sources for these contaminants in urban areas are gasoline and oil. They are often highly concentrated on streets, highways and parking lots. Other sources of organic chemicals are the fertilizers, herbicides and pesticides used on golf courses, homes and office parks (Ferguson 1994, 163-164).

• Trash and Debris

While technically not a pollutant, the miscellaneous trash and debris found in urban areas can be considered a contaminant. Besides being an aesthetic problem, debris can create blockages in a stormwater management system. These blockages can result in a reduction of the effectiveness of the system.

- Microorganisms

Another category of contaminants not included on the EPA standard list of urban runoff pollutants is microorganisms. Microorganisms are found in surface waters and surface soils. While most are benign or beneficial, some do represent a hazard. Sources of these pathogenic microorganisms in urban areas include animal waste, runoff from restaurants or trash receptacles and contact with faulty sewer systems (Ferguson 1994, 160-161).

2.2.3 Contaminants Levels

The NURP report mentioned previously examined runoff from 2,300 storm events across eighty-one sites in twenty-two cities nationwide. The data was collected during 1981 and 1982. The data was analyzed to find the Event Mean Concentration (EMC) of contaminants for all storms. The EPA released the results of the sampling and analysis in 1983. Portions of these results are shown in Table 2 in the NURP Final Report.

Table 2 Urban Site Median Event Mean Concentration (EMC) of Contaminants in Milligrams per Liter

Contaminant	Median Site	90th Percentile	Contaminant	Median Site	90th Percentile
TSS	100.000	300.000	TKN	1.500	3.300
COD	65.000	450.000	$NO_{2\&3}$	0.680	1.750
BOD	9.000	15.000	Cu	0.034	0.093
TP	0.330	0.700	Pb	0.140	0.350
SP	0.120	0.210	Zn	0.160	0.500

Urbonas and Stahre 1993, 312

Several significant conclusions resulted from the NURP study. One conclusion is there are few, if any, statistical differences in EMCs. In other words the median EMCs of contaminants varied little between geographical regions, cities, land uses or individual storms.

The NURP study also points out that actual contaminant levels on individual sites can vary widely from the medians. For example, ninety percent of individual storm EMCs had TSS levels with a range three to five times of the median site EMC. Contaminants other than TSS had levels ranging from two to three times the median site EMC. This means while national average contaminant levels can give a good general picture, local sampling and analysis are important to determine the actual range of contaminants (Urbonas and Stahre 1993, 311-313).

2.2.4 Effects of Urban Areas on Runoff Contamination

The urban environment itself magnifies runoff quality problems in two ways. One is the quantity of contaminants in urban areas. With numerous land uses in a concentrated area, there is an increased risk of introducing contaminants into runoff.

Another way is the increased runoff amounts and velocities created by impervious surfaces. Contaminants accumulate on ground surfaces during dry weather. When a runoff generating storm event occurs, the contaminants are picked up and carried by the runoff. If runoff amount or velocity is increased, it picks up a greater amount of contaminants. This, in turn, washes more contaminants at a faster rate into receiving waters (Walesh 1989, 67). If the stormwater is left untreated the contaminants are eventually discharged into receiving waters.

To date the Environmental Protection Agency does not set requirements for limiting contaminants in urban stormwater from non-industrial sites. This is changing; however, as the EPA recognized the high levels of contaminants being discharged from urban storm drains. The EPA has designated stormwater from communities with a population over 100,000 as a point source. As a result of this designation, communities with 100,000 or more people must submit an application for a National Pollutant Discharge Elimination System (NPDES) permit. These permits are an early step in developing contaminant standards and enforcement policies (Bernard 1996).

2.2.5 Suburban Shopping Center Parking Lot Contamination of Runoff

Some contaminants are present at higher levels on parking lots. These include organic compounds, suspended solids, heavy metals and debris. These contaminants are present in higher concentrations because the sources are present on or near parking lots.

Cars are a major source of contaminants in both terms of variety and quantity. Many organic compounds are deposited on parking lots through gas leaks, oil leaks and grease drippings from the cars. Cars deposit heavy metals from items such as exhaust and brake pads. They also contribute suspended solids like rust and tire rubber.

Another major source of contaminants on a parking lot is dryfall. These airborne pollutants are blown in from off-site. Since a parking lot is an open space, there is no chance for interception of airborne contaminants. Dryfall can also contribute heavy metals and nutrients that have bonded to the airborne solids.

Users of the lot and the facility it serves can be a source of many contaminants. Debris from users and trash areas of the facility adds to contaminants entering from off-site. Suspended solids and heavy metals can be produced by the facility itself. The type of activity taking place in the facility can also have an effect on the contaminants found on the parking lot.

2.3 AESTHETIC DETERIORATION

2.3.1 Parking Lot Design Factors

Parking is an essential aspect of all suburban development. This is especially true of shopping centers. Many times suburban shopping centers, like other suburban complexes, are not served by adequate public transportation (Stocks 1983, 42). Developers then are required to provide parking for both patrons and employees. Because of the relatively inexpensive land costs in suburbs, this need is usually satisfied with a parking lot rather than a parking garage (Stocks 1983, 44).

Suburban shopping center lots are typically laid out with two components in mind. These components are the number of spaces needed and the spatial and engineering guidelines. Each is discussed below.

- Number Of Spaces

One of most important issues in parking lot design is the determining the number of spaces needed (Urban Land Institute 1985, 63). The most critical factor in determining the number of spaces is the size of the shopping center (Urban Land Institute 1982, 7).

It is important to note the size of the center is not its total square footage. Instead only the Gross Leaseable Area (GLA) of the center is considered in determining parking lot requirements. The GLA includes only those areas designed for tenant occupation and use. Calculated by adding the square footage allowed in each tenant's lease, the GLA gives a more accurate representation of the area available to the center patrons and employees (Urban Land Institute 1982, 7).

The Urban Land Institute (ULI) had recommended shopping centers have 5.5 parking spaces per 1000 square feet of GLA regardless of the size of the center. More recent studies indicate the demand for parking varies with the GLA of the center. The revised recommendations are as follows.

1) 4.0 spaces per one thousand square feet of GLA for centers having a GLA of 25,000 to 400,000 square feet.

2) From 4.0 to 5.0 spaces in a linear progression, with an average of 4.5 spaces per one thousand square feet of GLA, for centers having a GLA of 400,000 to 600,000 square feet.

3) 5.0 spaces per one thousand square feet of GLA for centers having a GLA of over 600,000 square feet.

(Urban Land Institute 1982, 2)

• Spatial and Engineering Guidelines

Spatial and engineering guidelines are another issue in parking lot design. These guidelines establish the physical design standards for a parking lot. Examples of these guidelines are the minimum spatial requirements for parking stalls, driving lanes and the like. Currently these standards are in a state of change. American automobiles have been steadily decreasing in size since the oil crisis of the 1970's. This trend may not necessarily continue. However, an examination of parking stall and driving lane size is in order.

Many older lots are based on a ten foot wide by twenty foot long stall for 90 degree parking. Current parking design standards recommend a parking stall size of 9 feet wide by 18 feet long. The current guidelines represent a saving of 38 square feet per stall. This stall size, along with the recommended lane width of 26 feet, gives an overall length of sixty-two feet for two stalls (Breeden 1998, Lots of Parking: Design, Required Dimensions, 1).

Engineering standards also set items such as recommended slopes within a parking lot. Design standards recommend these large areas be graded at a slope of one percent minimum to five percent maximum. These relatively level slopes provide for both ease of walking and stormwater removal. Because of their importance, this gradient range is often the major determinant for the grading of a site (Harris and Dines 1988, Section 320-21).

2.3.2 Aesthetic Issues

The number of spaces, spatial requirements and engineering guidelines combine to make the typical shopping center parking lot a broad flat open area composed almost completely of impervious material. The shopping center parking lot can be described as having an unprotected and exposed feeling. "There is no defined enclosed space, no sense of privacy, no protection from objectionable sights and sounds, and no defense against sun and wind" (Booth 1983, 35). When a lot is full of cars, it is" usually unsightly. When the parking lot is empty, it is barren and desolate" (Robinette 1976, 2). The current standards for parking space requirements do little to alleviate the aesthetic problems associated with parking lots.

Parking lots are almost universally condemned as eyesores in the landscape and have been identified by public as a negative symbol of development. As an example, a study comparing visual elements at chemical manufacturing plants found parking lots ranked last in visual appeal. Even the study's researcher was surprised the participants ranked the visual appeal of parking lots below heavy industry elements as storage tanks, above ground pipelines and manufacturing facilities (Baker, Douglas 1993, 87).

Unlike chemical plants, shopping centers are designed to lure people. To this end, large amounts are spent on details such as climate control of indoor areas, ornate entrances, decorative storefronts and thematic furnishings. Developers and tenants of shopping centers willingly incur these expenses to increase the pleasure and comfort of the shopping experience.

What is often forgotten however is parking will be the shopper's first contact with a center. The experience should be pleasant (Urban Land Institute 1985, 63) and can help set the tone for a positive shopping experience. Unfortunately, this is not the case for most shopping centers parking lots.

The opportunity to increase the overall shopping experience by incorporating aesthetic features in the parking lot design seems to have been overlooked even by the shopping center developers. In "Winning Shopping Center Designs No.2", the International Council of Shopping Centers presents a variety of centers. Except for a brief mention of the number of spaces available at each center, the issue of parking design is not addressed. Instead these centers are recognized as "outstanding shopping center projects" (International Council of Shopping Centers 1995, 9) based on the exterior facades and interior spaces. The attention focused on the shopping center in both terms of design and money results in the parking lot being developed simply as a car storage area. Rather than seen as an amenity to the shopping center, the parking lot is developed as inexpensively as possible and with only car storage in mind.

CHAPER 3

STORMWATER WETLANDS

3.1 DESCRIPTION

A stormwater wetland is a stormwater management component explicitly designed to mitigate the impacts of runoff quality and quantity (Schueler 1992, 5). Designed to temporarily store runoff, stormwater wetlands mimic conditions in natural wetlands. The runoff storage, complex micro-topography and the presence of macro and microorganisms are an ideal filter for removing urban pollutants (Schueler 1992, 5). By resembling natural wetlands, stormwater wetlands have a positive aesthetic aspect not found in traditional methods for stormwater control and runoff improvement.

A stormwater wetland is a type of constructed wetland. Constructed wetlands are "intentionally created, managed and monitored for the sole purpose of wastewater or stormwater treatment from nonwetland sites" (Hammer 1991, 7). Constructed wetlands are considered water treatment components for wastewater and stormwater runoff.

Constructed wetlands should not be confused with created or natural wetlands. Created wetlands are "wetlands intentionally created from nonwetland sites to produce or replace natural habitat" (Hammer 1991, 7). They are usually built as mitigation for disturbing a natural wetland.

Natural wetlands are defined by presence of hydratic soils, aquatic plants and/or having standing water during part of the growing season. The presence of any one or combination of these characteristics can be used in determining the existence of a natural wetland.

In Design of Stormwater Wetland Systems, Schueler describes four basic kinds of stormwater wetlands. These are Pond-Wetland, Shallow Marsh, Extended Detention Wetland and Pocket Wetland. This work focuses on the use of the Pond-Wetland type. For clarity, this type of stormwater wetland will be referred to as a Pond-Marsh stormwater wetland (Figure 5).

Of these stormwater wetlands the Pond-Marsh is the most flexible in its design. First, it can address large amounts of stormwater. Second, it is "the most reliable overall performance" (Schueler 1992, 28) for contaminant removal. Third, it can introduce green space and water features into the design of suburban shopping center parking lots.

A Pond-Marsh stormwater wetland is a two-stage design. The process begins by conducting stormwater to a retention Pond section for initial runoff collection. The stormwater then passes a control structure into the Marsh section.

Once in the Marsh, the stormwater collects in a micro-pool. From here the runoff flows slowly though the wetland. The Marsh is graded to provide a permanent water depth ranging from zero to eighteen inches. The Marsh bottom is graded to provide an uneven and irregular surface. This surface guides the water along an extended route through the wetland. The surface also allows for diverse plant and animal communities. At the end of the wetland is a second pool. This pool insures proper drainage out of the stormwater wetland by creating an area of open water.

Surrounding the Pond-Marsh is a buffer area extending a minimum of twenty-five feet (Schueler 1994, 104). The buffer provides a separation from the Pond-Marsh

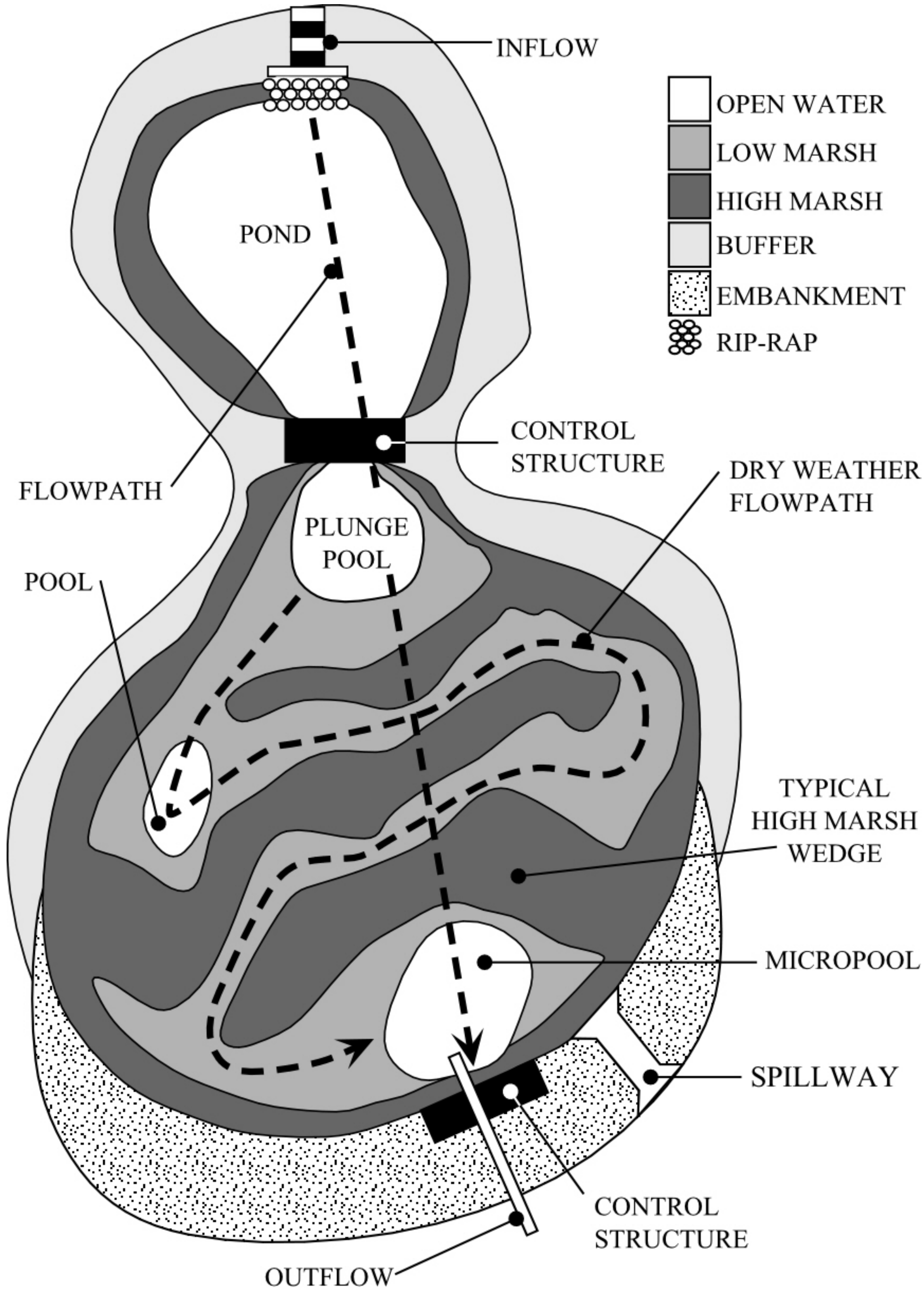

Figure 5 Pond-Marsh Plan View

and property or individuals. It can be used to block views and public access of control structures and reduce the impact of potential animal and insect pests.

3.2 DETENTION ABILITIES

In a Pond-Marsh system the Pond section holds the majority of runoff. The Pond greatly reduces the space required for the stormwater wetland (Schueler 1992, 7). The wetland provides the remaining runoff storage.

The two water control structures in the Pond-Marsh play key roles in its detention ability. The first structure separates the Pond and Marsh sections. It determines the flow of runoff entering the Marsh from the Pond and establishes the draw down time of the Pond.

The second structure manages the outflow of the Pond-Marsh. It determines the rate and velocity of runoff entering the larger stormwater management system. This controls the impact of runoff from the site on downstream areas.

At times the normal detention abilities of the Pond-Marsh design will be exceeded. This could be due to a major storm larger than the capacity of the design or several large storms coming close together. When this occurs, the design emphasis of the Pond-Marsh becomes critically important.

If the primary function of the stormwater wetland is runoff control, the excess can be directed to the Marsh section. With normally low water levels, the wetland can contain large amounts of runoff. The excess can then be released when the larger stormwater management system is better able to accept it.

Repeated severe inundation, however, may have an adverse impact on the Marsh section. There may be reductions in biodiversity, loss of contaminant removal ability and physical damage to the wetland. Therefore careful planning and design are needed to minimize the effect of excess stormwater inundation. It is important to properly size the Pond section to reduce the need for introducing excess runoff in all but extreme cases.

Emphasizing the contaminant removal abilities requires handling excessive runoff differently. One option is to temporarily store the runoff outside the Pond-Marsh. This allows the Pond-Marsh to treat existing stormwater before receiving the excess.

Another option is to treat only the first part of the runoff. Known as first flush, this early runoff will be discussed in greater detail later. Suffice to say this practice can greatly reduce the amount of runoff needing to be contained by the Pond-Marsh. Runoff in excess of the first flush amount bypasses the Pond-Marsh and is directed to the larger stormwater handling system.

3.3 CONTAMINANT REMOVAL ABILITIES

A Pond-Marsh employs a combination of physical, biological and chemical processes to remove contaminants from stormwater. As with detention, both sections of the Pond-Marsh play a role in removing contaminants. The difference of each section's contaminant removal role is not as clearly defined. Therefore, the removal processes will be discussed individually.

3.3.1 Microbe Action

Probably the most important removal process is the microbe action resulting from bacteria present in the Pond-Marsh. The bacteria are able to remove a wide variety of contaminants. Bacteria are able to directly consume contaminants such as carbon and nitrogen compounds within the water and organic sediments. Nitrogen is removed though the nitrification/denitrification process. Organic material and sediments are consumed through aerobic decomposition.

Bacteria also can remove trace metals from stormwater. While consuming organic material, bacteria create anaerobic conditions in the top layer of marsh sediments. This combination of decomposing organic material and low oxygen levels can immobilize trace metals into sulfide, oxide and hydroxide compounds. These compounds are less mobile and therefore less likely to be reintroduced into the water system (Schueler 1992, 26)

3.3.2 Sedimentation

Sedimentation plays a major role in contaminant reduction as the primary removal process for particulate pollutants. The Pond-Marsh creates an ideal environment for sedimentation. The long detention time, sheetflow, slower runoff velocities and the hydraulic resistance caused by vegetation increases sedimentation in the Pond-Marsh. The roots of vegetation help to stabilize the sediments thus reducing the possibility of resuspension (Schueler 1992, 25-26).

3.3.3 Absorption to Sediments, Plants and Organic Material

Another important process for contaminant removal is through the absorption to various surfaces. Phosphorus, trace metals and some hydrocarbons can become chemically bonded to the surfaces of suspended and bottom sediments, plant material and decaying organic material. The increased detention time created by the Pond-Marsh increases the possibility of such a chemical bonding occurring (Schueler 1992, 26).

3.3.4 Uptake by Algae

Algae are recognized as an effective removal process for nutrient contaminants such as phosphorus and ammonia. These contaminants are consumed by the algae and then deposited on the bottom sediment when the algae die. The large amount of still water in a Pond-Marsh provides a good environment for these algae (Schueler 1992, 27).

3.3.5 Uptake by Plants

Once considered a major process for contaminant removal, uptake by plants is now believed to play a relatively minor role. Except for submerged and floating species, plants can only remove contaminants through their roots. This means the contaminants must already be deposited in the soil. Contaminants taken up by a plant's roots may return to the water system when die back occurs. The major role plants play in contaminant removal is as places for other processes to take place (Schueler 1992, 27).

3.3.6 Physical Filtration by Plants

The dense plant growth present in a Pond-Marsh acts as a physical filter for incoming stormwater. While not exceptionally effective for pollutant removal, the filtration by plants does a good job removing trash and debris that would otherwise clog a Pond-Marsh. The filtration also slows the velocity of water and increases detention time thereby strengthening the effect of other processes (Schueler 1992, 26).

3.3.7 Increased Detention

While not a removal process, the increased detention afforded by a Pond-Marsh greatly enhances the removal rate of the processes listed above. The slower discharge rates allow a longer time for these various processes to have an influence on the stormwater runoff. The extra time the runoff spends in the Pond-Marsh becomes even more important during the non-growing season when some of the pathways may not be as effective (Schueler 1992, 27).

3.3.8 Natural and Chemical Decay

Many contaminants will decay into harmless compounds even without the processes noted above. Interactions with sunlight, atmospheric gases, water and simply time itself will cause the breakdown of some contaminants. Long detention time, complex micro-topography and the variety of environments present in a Pond-Marsh maximize the effect of decay (Tchobanoglous 1993, 29).

3.3.9 First Flush

The idea of first flush was developed in the 1970's during the infancy of alternative contaminant removal BMPs. Early studies indicated the majority of stormwater contaminants were contained in the first half inch of runoff. The belief was contaminants were collected as dryfall on the site then swept away in the early stages of a storm. Communities, developers and stormwater managers saw a way to collect the majority of contaminants in a smaller amount of stormwater.

Today, however, there is some evidence the first flush effect may not be as pronounced as once believed. The amount of impervious surface and the type of contaminants may have an impact on the timing of contaminant presence in runoff (Schueler 1994, 88-89). Because further research is needed in this area, runoff from the site should be monitored before basing runoff treatment volumes on the first one half inch.

3.4 AESTHETICS

Unlike most other stormwater management components a Pond-Marsh has the opportunity to serve as an aesthetically pleasing element in a parking lot. One of the most important visual benefits offered by a Pond-Marsh is water. As noted by Booth, "Water is one of the most magnetizing and compelling of all design elements. Few people can ignore or fail to react to its presence in the outdoor environment. Humans seem to be instinctively drawn toward water" (Booth 1983, 254).

One of water's most appealing characteristics is its ability to be either still or active. All the Pond-Marsh components can be designed to provide the full range of these characteristics. The Pond section can be either a still pool or active depending on the weather. The Marsh section provides calm, highly reflective water. The various control structures can be designed to feature active water movement long after a runoff producing storm is over.

With its inherent emphasis on plant materials, the Pond-Marsh is an excellent method to introduce plants into a site. "Plant materials provide a touch of life and beauty in an environment" (Booth 1983, 66). The presence of vegetation can produce a positive visual benefit in urban areas such as shopping center parking lots.

Plant materials create this pleasing aesthetic by generating a green space. This green space provides visual interest or a pleasant contrast to the harsh nature of an expansive paved parking lot. Plant materials provide screening, accents and directed viewsheds. The seasonal and succession changes of plant materials bring visual change to a site. Plants also can provide a sense of scale to an environment. All these factors combine to provide relief from the surrounding man-made environment.

The Pond-Marsh can also be used to visually break a large parking lot creating a series of smaller scale spaces. These smaller spaces provide visual buffering from off-site and between other parts of the lot. The views within these smaller spaces can be directed toward the shopping center thus making it the focal point of the parking section. Besides directing sight lines, the buffers reduce the wind, which in part make parking lots physically uncomfortable.

CHAPER 4

CONCERNS AND SOLUTIONS

Any management strategy raises some concerns. This is especially true with a stormwater wetland. These concerns are due in large part to the relatively recent development of stormwater wetlands as a BMP. The concerns along with possible solutions are discussed below.

4.1 LAND REQUIREMENTS

Probably one of the most important of these concerns is the large amount of land required for a Pond-Marsh as compared to other runoff management systems. This concern is especially true if it is to be used as both a quantity and quality control system (Horner 1993, 5). In areas where land costs are extremely high, the amount of space needed could be the deciding factor on the feasibility of a Pond-Marsh.

More states and communities, though, are passing "green laws". These regulations "take the form of zoning ordinances, policy statements, administrative arrangements or specific actions" (Weant and Levinson 1990, 5). Some of these regulations address spatial and environmental issues like site detention of stormwater, increased ratios of open versus developed space, limiting runoff to pre-development levels and the placement and amount of parking (Weant and Levinson 1990, 5).

Green laws also address aesthetic concerns and can be written with particular attention paid to parking lots. "Given the visual prominence of parking lots, many jurisdictions seek to regulate their appearance and design" (Dale 1994, 9). These regulations attempt to preserve or enhance the character around a parking lot's vicinity, minimize the lot's visual impact and lessen the effect of sun and wind on the parking lot (Foster 1988, 8-9).

The incorporation of a Pond-Marsh is one way to meet these provisions. If the use of "green laws" continues to increase, the land requirements of a Pond-Marsh could become part of the normal development cost as a means of satisfying landscape requirements.

4.2 EXCESSIVE CENTER SCREENING

Shopping center developers and tenants spend a great deal publicizing themselves. The sight of buildings and individual storefronts has been a major part of publicizing and marketing shopping centers. The placing of a green space in a prominent place that may screen the building may appear counter productive to luring customers.

This objection can be overcome in several ways. One is by providing breaks in the screen. The use of "conceal and reveal" to improve views has been practiced since ancient time. By adjusting the breaks for passing cars, the visual appeal of the shopping center can be raised. Street side signage, appropriately designed, can be used to make up for the loss of direct views to the center.

Another way to counter the screening objection is to emphasize the positive effect a Pond-Marsh may have on the shopping experience. Properly integrated into a shopping center parking lot, a Pond-Marsh would make the parking lot more attractive and comfortable. Shopping centers rely on repeat customers and word of mouth referrals to be successful (McClusky 1987, 125). By making the center a more pleasurable place to shop, the Pond-Marsh can more than make up for revenue lost due to screening storefronts and buildings.

4.3 REDUCED CONTAMINANT REMOVAL

A further concern is the delay in contaminant removal after initial installation. Because a Pond-Marsh depends on plant material for some pollutant removal, there can be a delay in removal efficiency until the plant material is well established. Some contaminants can increase during this establishment period. For example, water flowing through an undeveloped marsh area may cause erosion and thereby increasing the total suspended solids in the runoff (Schueler 1992, 109).

Proper planning can minimize this problem. Construction of the Pond-Marsh early in new development can give enough time for the establishment of the plant materials. Other measures such as building an erosion fence during the establishment period can also reduce erosion.

4.4 STREAM WARMING

Outflow from a Pond-Marsh can have a higher temperature than outflow from some other BMPs or which occurred at pre-development. The extended detention time and shallow water depths in the marsh may cause this rise in water temperature. The increase in temperature can average between five to ten degrees warmer with short term increases of fifteen degrees possible. These increases can be high enough to seriously affect downstream aquatic life requiring cool or cold water (Schueler 1992, 95).

Proper design and site selection can help control this problem. One control method is the inclusion of a pool at the outflow. Another is routing part of the flow around the Marsh section of the Pond-Marsh. Both of these can lessen the rise in temperature. In cases where these measures would be ineffective, the outflow can be directed away from sensitive receiving waters (Schueler 1992, 95).

4.5 CONFLICT WITH NATURAL WETLANDS

Stormwater wetlands, because of larger land requirements, have greater chance to come into conflict with natural wetlands than other stormwater BMPs (Schueler 1992, 97). Proper siting of the Pond-Marsh can drastically reduce the chance of conflict. A careful delineation of existing wetlands should be done as part of any development. After delineation, every attempt to eliminate consequences such as outflow and overflow into the existing wetlands should be made (Schueler 1992, 97).

4.6 UPSTREAM CHANNEL LOSS

If a Pond-Marsh is incorporated into an existing stream, there is concern up-stream waters will not receive proper hydrological control. This can lead directly to a loss of the upstream channel and then to a general decrease in aquatic biodiversity. This situation is particularly a problem with a Pond-Marsh receiving runoff from large watersheds in the range of 100 to 400 acres (Schueler 1992, 97-98).

The solution is to provide hydrological control for the upstream channel. One method of control is routing excess stormwater from the upstream channel to the Pond-Marsh. Another method is the construction of storage pools "at the terminus of the storm drain system into the upstream channel" (Schueler 1992, 98).

4.7 PUBLIC UNDERSTANDING

Wetlands can have negative connotations to the general public. The historical view of wetlands as wastelands persists to this day. Even stormwater professionals voice concern about stormwater wetlands. These attitudes have limited the use of stormwater wetlands in some areas (Carlisle, Mulamoottil and Mitchell 1991, 423).

These views are mainly a perception problem. It is due in part to "a lack of knowledge about the use of artificial wetlands...because of the relative newness of the strategy" (Carlisle, Mulamoottil and Mitchell 1991, 426). The solution is public and professional education about stormwater wetlands.

A good case in point is Arcata Marsh and Wildlife Sanctuary located in Arcata, California. This wastewater treatment wetland was at first opposed by the community and state regulatory officials. Today, however, it is popular as a birding site and green space. It "has become a major form of low-cost recreation" (Gearheart and Higley, 566).

4.8 GROUNDWATER CONTAMINATION

A concern raised by stormwater management professionals is the possible contamination to groundwater by the various pollutants carried by stormwater runoff. The worry is these pollutants, when trapped in a Pond-Marsh, will migrate into groundwater. Once there these pollutants could affect water quality.

Though more research in this area is needed (Price 1994, 478, Schueler 1992, 99), it appears contamination of groundwater may not be a major concern. Contaminants typically found in stormwater runoff go through complex physical and chemical processes. This lessens the possibility of groundwater contamination.

4.9 SEDIMENT CONTAMINATION

Another contamination concern deals with the sediment present in a Pond-Marsh. A major removal method for many pollutants is binding chemically and physically with sediments. These sediments must be removed periodically as normal maintenance of a Pond-Marsh. The concern arises from the pollutant level present in this dredged soil and the measures needed for its disposal.

As with groundwater contamination, more research of sediment contamination is needed (Schueler 1994, 45). Studies done so far indicate the land use of the watershed determines the hazard level of sediment, with residential areas having the lowest contamination levels followed by commercial areas, roads and highways and finally industrial areas as the most contaminated (Schueler 1994, 42).

It appears sediment taken from a Pond-Marsh serving residential, commercial and most road and highways are not hazardous. The sediment "can be safely land applied with appropriate techniques to contain any leachate as it dewaters" (Schueler 1994, 45). Sediment from a Pond-Marsh serving heavily traveled highways or industrial areas may be hazardous. These sediments should be tested to determine contamination levels (Schueler 1994, 45).

4.10 INVASIVE AND PROBLEM SPECIES

Stormwater wetlands provide an opportunity for introducing plant and animal life into urban/suburban areas. Some species, however, may present problems from either an aesthetic or nuisance aspect. Rapidly growing plant species, such as cattails (Typha spp.), can form monoculture stands. These stands may eliminate other more desirable plant species. The presence of large numbers of these types of plants may have an unaesthetic effect, reduce the efficiency of the stormwater wetland and limit available food or cover for wildlife.

Animal species can have a more direct impact on facility users. Geese and ducks, while looked on with favor by the public may reach populations high enough to cause health problems because of the amount of waste produced. Excessive waste can lead to high levels of nutrients and fecal coliform levels. These waterfowl can also cause damage to the wetland system by "overgrazing" the plant material. In addition, geese can become quite territorial and may attack people who venture to closely.

Mosquitoes are another concern. Besides the general irritation they generate, mosquitoes can also spread dangerous diseases such as St. Louis Encephalitis. The idea of creation of a habitat favorable for these insects causes concern even among stormwater management professionals (Carlisle, Mulamoottil and Mitchell 1991, 423).

The problems of invasive and problem species can be eliminated or reduced by proper design, implementation and management of the stormwater wetlands. For example, the creation of the correct ratio of shallow and deep water areas and using proper planting produces reduces the risk of a monoculture developing. Waterfowl populations can be controlled with proper water levels and reducing open lawn areas in buffer zones.

Mosquitoes can be controlled by the introduction of predator species and proper water level ratios. What is more important, the problem of mosquitoes has been shown to be more of a perception problem. Surveys of ponds and wetlands in various parts of the country and anecdotal evidence from constructed wetland professionals indicate stormwater wetlands do not carry significant mosquito problems (Garbisch Lecture, 1995, Schueler 1992, 88, 93 passim).

CHAPER 5

POND-MARSH DESIGN

The Pond-Marsh was originally designed with runoff treatment as the main function. In this work, the purpose is expanded to include stormwater detention and aesthetic enhancement. The original design requirements, as well as the effects of these additional roles are explored below.

5.1 POND-MARSH

In Design of Stormwater Wetland Systems, Schueler provides size and treatment guidelines for a Pond-Marsh. This information is presented in Table 3. These guidelines should not be considered as fixed rules for designing a Pond-Marsh (Schueler 1994, 46). Some adjustment to these guidelines can be expected to occur depending on site requirements and client needs.

Table 3 Components of a Pond-Marsh Stormwater Wetland

Category	Surface Area Percentage	Treatment Volume Percentage	Water depth	Frequency of Inundation
Deepwater (Includes Pond, Pools & Water Channels)	40%	60%	-1.5 feet and deeper	Below Normal Pool
Micro-pool	5%	10%	-1.5 feet and deeper	Below Normal Pool
Low Marsh	25%	20%	-1.5 feet to -0.5 feet	Below Normal Pool
High Marsh	25%	10%	-0.5 feet to Normal Pool	At or Below Normal Pool
Semi-Wet	5%	N/A	Normal Pool to 2 feet	Frequent Inundation
Buffer	N/A	N/A	1 foot to 6 feet+	Frequent to Seldom
	100%	100%		

Source: Schueler 1992, 48

5.2 WATER LEVELS

In a typical detention pond, the permanent water level is set primarily for ease of design. In a Pond-Marsh, the Marsh Permanent Level represents both the treatment volume and the Marsh viability volume. Accordingly, great care must be taken when setting the Pond-Marsh Permanent Levels.

Schueler recommends the volume of runoff to be treated should be based on capturing the water from ninety percent of runoff producing storms (Schueler 1992, 39). Schueler also outlines the treatment volume each section of the Pond-Marsh is to provide (Schueler 1992, 48). A potential problem exists if the Marsh section is over-sized from the standpoint of wetland viability.

The size of the Marsh section needs to be checked to ensure there is enough runoff to support it. If the Marsh is oversized, adjustments to the size of the Pond will be needed. If adjusting the Pond cannot make up the shortfall, there needs to be a re-assessment of the Pond-Marsh design.

5.2.1 Pond

The Pond section contains the largest amount of treatment volume and is the most flexible to design. The Pond basin can be expanded to contain a much larger amount of stormwater. This can be useful if the detention volume exceeds the capacity of a Pond-Marsh designed for the treatment volume. Standard pond design guidelines should be used for this section.

5.2.2 Marsh

The Marsh is designed to mimic a natural wetland. It has a complex topography ranging from 2 feet above the permanent water level to six feet below. The majority of the Marsh area, though, ranges from the permanent water level to 18 inches below.

Within the Marsh are wedges or berms of soil that create the high marsh areas and above permanent water level berms. These wedges have several uses. First, they increase the topography of the Marsh section and therefore can increase the diversity of the vegetation. Second, they are used to increase the flow path length in the Marsh (Schueler 1994, 106). Third, the wedges, if above permanent pool level, can be used as access into the Marsh for maintenance.

5.2.3 Micro-pool

Micro-pools are located at the beginning and end of a Marsh section. The first micro-pool is used for sediment collection and to dissipate energy of the runoff entering from the Pond section. The second micro-pool provides an area of clear water to protect the outlet. These pools should be four to six feet deep.

5.2.4 Flow Path Length

To fully exploit contaminant removal, the longest flow path possible through the Pond-Marsh should be created. By lengthening the flow path, detention time and contact with the many surfaces is increased. There are two ways to do this.

The first is by increasing the overall length/width ratio. This ratio can be determined by "dividing the straight line distance from the inlet to the outlet by the average width of the" Pond-Marsh (Schueler 1992, 49). It should equal 1:1 at a minimum with a preferred ratio of 3:1 (Schueler 1992, 105). The greater this ratio, the less chance contaminants will exit the Pond-Marsh too quickly.

The second is by increasing the dry weather flow path through the Marsh section. These wedges are placed at a right angle to the flow at roughly fifty foot intervals (Schueler 1994, 106). This increases the distance water must flow to reach the outlet and adds distance to the length/width ratio during non-storm periods. The minimum ratio for the dry weather flow is 2:1 (Schueler 1992, 105). The dry weather flow path is illustrated in Figure 5.

5.2.5 Control Structures

Placed between the Pool and Marsh sections and at the Marsh outflow, control structures determine flow rates and water levels. These rates and levels may need fine tuning after construction of the Pond-Marsh is completed. Furthermore, necessary maintenance will require draining of both sections. The structures, therefore, should include a method for flow adjustment and draining.

5.2.6 Buffer

The buffer surrounding the Pond-Marsh should extend a minimum of twenty-five feet around the water's edge (Schueler 1994, 107). If the buffer is included in the area used for detention, this amount should be increased depending on the detention volume. A fifteen foot setback from the buffer is recommended for any structures (Schueler 1994, 107). Because the Pond-Marsh will be located in a parking lot, the setback should also be established for regularly used parking areas.

5.3 CONSTRUCTION

The construction phase begins with the general excavation of the Pond-Marsh, followed by installation of an infiltration barrier if needed. The general locations and elevations of wedges, pools and channels within the Pond-Marsh are constructed. The rough grades in the Marsh section should be between three to six inches below the estimated final grade. This allows for adding soil amendments and mulches and final adjustments to bring the final grade to the correct elevation. Areas above the permanent level should be planted with a temporary cover to prevent erosion.

Once the Pond-Marsh has been graded to final elevations, the Marsh section should be filled to the permanent pool level. Runoff equal to and less than the Marsh treatment volume should be allowed to enter for several months. This allows for a final check of water levels and flow paths. Runoff more than the Marsh treatment volume should be diverted to prevent damage to the complex topography within the Marsh.

Immediately before planting the Marsh section, a survey of the permanent pool depths should be taken. This insures plants are placed in the proper depth. It also allows for final grading.

When the survey is complete, the marsh should be drained for planting. The methods for planting a wetland will not be discussed here. Determination of the method to be used should be made in consultation with the landscape architect and wetland plant material specialists.

5.4 MAINTENANCE

5.4.1 Monitoring

The most important maintenance requirement is visual and water quality monitoring. Water quality monitoring may be required to assess runoff quality and detention performance. Close monitoring will help evaluate if the Pond-Marsh is performing correctly. It will also identify problems such as improper water levels, damage to the Marsh, and the appearance of invasive or undesired plant and animal species.

5.4.2 Marsh Establishment Period

Until the plant material becomes established, the water level and velocities must be watched closely. Establishment time should usually be one full growing season. Climate and the type of wetland environment can extend this period though.

At this early stage, too much or too little water can result in dieback of the plants. Excess water velocities can damage the complex topography. The plant materials and Marsh need to be protected from these extremes until the plants are adequately established and are able to effectively hold the soils in place.

Little or no contaminant treatment will occur in the Marsh section during the establishment period. In fact, there may be an increase in some contaminants, notably suspended sediments. There is, unfortunately, little to be done to reduce the establishment time. Methods, such as silt fences and temporarily diverting runoff around the Marsh, may be considered. These methods are necessary to reduce the amount of contaminants that can be generated until the Marsh becomes fully established.

5.4.3 Sediment Cleanout

Among the most expensive maintenance items is removal of sediment. For the Pond-Marsh, Schueler estimates sediment cleanout will need to be done every ten to fifteen years (Schueler 1992, 85). This estimate is highly variable, however. The type and level of contaminants and the size of the Pond-Marsh will determine the time interval. If possible, an on-site storage area should be located for sediment disposal. Unless located very close by, off-site disposal of the sediment can significantly add to the cost of the cleanout.

5.4.4 Harvesting Plant Material

Another item of maintenance is harvesting of above ground plant materials. Harvesting may increase the removal of nutrient contaminants from runoff. Harvesting should be done just before fall dieback. The Marsh is would first be de-watered. The vegetation is then manually cut back with a scythe. The plant material is then removed from the Marsh.

However, harvesting has serious drawbacks. It is expensive in terms of labor, time and money. Also, some jurisdictions may require a stormwater or wetlands permit before harvesting can occur.

Harvesting may result in a loss of habitat and winter cover for wildlife. Cutting only part of the vegetation can reduce this outcome. The area harvested should be rotated yearly.

5.4.5 Reinforcement Plantings

It is inevitable not all the original plantings will survive. Drought, flood, poor stock and predators will take some toll during the first year. Additional plantings may be needed during the second and even the third year until desired cover is achieved.

5.4.6 Mowing

The Pond-Marsh by its nature and function minimizes the amount of mowing needed. The only required mowing is on the control structures and any access roads to prevent tree growth. The Marsh section should not be mowed.

As a rule, the buffer should not be mowed regularly. Besides reducing the cost of maintaining the Pond-Marsh, an unmown buffer can increase the effectiveness of the Pond-Marsh in removing some contaminants. An unmown buffer also reduces the problem of permanent waterfowl by reducing available habitat.

5.4.7 Invasive Plant Species

Invasive plants will occasionally appear in the Pond-Marsh. Control by herbicide or manual removal is difficult, expensive and a short term solution. De-watering can provide some relief, but can kill desired species. The best method for controlling unwanted plant species occurs during the design phase. The presence of a wide range of depth zones and proper plant selection should limit the spread of unwanted volunteer plant species.

5.4.8 Animal Pests

Animals, such as geese, nutria and deer, can have a devastating effect on new plants. Cases exist where nearly all plant life in newly established wetlands was eaten or destroyed in less than 24 hours (Garbisch lecture). Often the removal of these animals from the area is difficult if not impossible. Deterrents such as noisemakers and chemical sprays have only short term effectiveness. Practical experience seems to point to fencing as the best method for reducing new planting destruction (Garbisch lecture).

CHAPER 6

GUIDELINES FOR INTEGRATION AND DESIGN

The general design process for site development used by landscape architects and other site design professionals is key for the successful implementation of a Pond-Marsh stormwater wetland. The site design process is more than adequately described in other references and will not be reviewed in detail here. This said, there are specific issues to be considered when planning, constructing and maintaining a Pond-Marsh stormwater wetland in a suburban shopping center. These issues and where they fall into the design process are discussed below.

6.1 INVENTORY

6.1.1 Site Inventory

- Existing and New Watersheds

Determination of the extent of the watershed served by the stormwater wetland is a first critical step. It is one of the crucial factors on which the success of the wetland depends. Accurate watershed delineation helps guide the sizing and placement of the wetland. It can also identify the possible contaminants and their sources.

It is important to include adjoining property in determining the extent of the proposed wetland watershed. Watersheds rarely exactly match the artificial boundaries of property lines. Runoff entering from off-site can greatly affect the total runoff available for the stormwater wetland. The runoff from off-site areas can also radically affect the type and amounts of contaminants present in stormwater. For example, new construction on adjoining property can produce heavy loads of sediment contamination.

• Past and Existing Wetlands

It is important to determine the presence of any existing natural wetlands on or nearby the site. Stormwater wetlands should not introduce runoff into or be sited within existing natural wetlands. If the stormwater wetland must affect natural wetlands, approval from wetland permitting agencies will be necessary (Schueler 1992, p.101).

Evidence of existing or historical wetlands on-site or nearby can play another role. It can be one of the best predictors of a stormwater wetland's viability. The presence of past or existing wetlands may indicate suitable soils and sufficient volumes of water are or have been available.

• Topography, Geology and Soils

Site topography has always been a factor affecting construction costs, drainage patterns and project feasibility. The relatively large level areas required for stormwater wetlands may increase construction costs on steep or rolling topography. "Since earth moving to create level to very gently sloping terrain is second only to land costs in most projects, accurate, detailed contour mapping is essential" (Hammer 1992, 133).

Topographic maps published by the United States Geological Survey (USGS) show contour lines at five foot intervals. These maps can be used for preliminary design purposes. Maps showing one foot contour intervals though will be needed for final design and construction plans (Hammer 1992, 133). Areas within the stormwater wetland may require maps showing contour intervals at six inches or less.

Soils should be examined for their infiltration characteristics. This will determine the need for placing an infiltration barrier in the stormwater wetland. For example, a site with very sandy soil will require installing a water proof barrier in any extended detention or marsh area of the stormwater wetlands. The barrier, usually a capping of heavy clay soil or a man-made product, will increase the installation cost of the wetland and may increase maintenance costs as well.

For some soil types, even relatively porous ones, a barrier may not be necessary in the Marsh section. This is because the wetland environment produced by the Marsh can over time seal itself. As debris, sediment and dead micro-organisms accumulate on the bottom on the Pond-Marsh, infiltration is blocked. The soils where this blockage occurs are Hydrologic Soil Group B (silt loam only), C and D as described in Soil Conservation Service publications (Garbisch 1995, 102). However, the blocking of infiltration can take a year to occur. Until then, water may have to be added to replace the infiltration (Garbisch 1995, 102).

The geology of a site also plays a major role in the cost and feasibility of a stormwater wetland. Some geological characteristics may increase the cost and effort needed to install and maintain a stormwater wetland. Karst geology, for example, may require installation of a water proof barrier. On the other hand, bedrock near the surface may require drilling or blasting.

The presence of natural and man-made underground features need to be located. Items, such as sinkholes, underground springs or underground pipes and lines, can cause significant problems and may be difficult to change. Their presence may complicate any large excavations needed for a Pond-Marsh system.

• Climatology

The climatology of an area can be a determining factor of the success of a Pond-Marsh stormwater wetland. Climatology includes elements such as precipitation amounts and timing, evaporation rates, seasonal temperatures, humidity levels and growing seasons. Of these elements, precipitation is probably the most important (Hammer 1992, 136).

Precipitation amounts and timing can vary greatly over the year. Probably the best predictor of precipitation is the monthly water budget of an area. The water budget compares precipitation amounts with evaporation rates. This result is presented as a positive or negative amount.

A small positive or negative water budget during some or all months may indicate a stormwater wetland may not be feasible. In these areas, runoff may be augmented with groundwater if available. However, groundwater can be highly variable and should not be the primary water source (Schueler 1992, 11).

Airports, National Oceanic and Atmospheric Administration (NOAA) weather stations, some universities and other agencies can provide local climatological information. Care must be taken when using this information though. Usually these sources are not site specific. The presence of lakes, wooded lands and urban areas, for example, can create different conditions at a site than those generally found in the region (Hammer 1992, 136).

• Existing and Proposed Development

A survey of existing and proposed development is necessary. This survey should include both on-site and near by development. The type and degree of on and off-site development can greatly influence runoff amounts and possible contaminants. This survey is especially important when working in or near undeveloped areas. Rarely does development of a site exist in a vacuum and the adjacent empty field may soon be developed. Any additional development may adversely impact the

Pond-Marsh stormwater wetland. Depending on the type, scale and placement of any new development, runoff volumes may increase or decrease to the point where the Pond-Marsh is no longer effective. New development may also introduce new or change the levels of the contaminants entering the Pond-Marsh.

• Contaminants

An investigation of the types and levels of possible contaminants that might be present in the stormwater should be done. While the typical composition of contaminants in urban stormwater is known, the levels of individual contaminants may vary widely. Existing sites need careful and accurate monitoring to determine the type and level of contaminants. For proposed sites, an estimate based on the type and level of activities should be made.

• Amount and Type of Surfacing

The amount of precipitation is an indication of the possible amount of runoff available for the Pond-Marsh. The types of surfacing material present play a large part in creating the runoff. The types of surfacing, their level of imperviousness and their percentage of coverage will influence the amount and velocities of runoff.

• Parking Stall and Lot Size

In most developments, the space requirements for the various elements and facilities on the site is a prime concern. The introduction of a Pond-Marsh, with its land requirements, can increase this pressure. One way room for the Pond-Marsh can be found is by examining the parking standards for shopping centers. Newly revised standards can decrease both the number and size of parking stalls. The use of these revised standards can free up space for use in developing a Pond-Marsh.

• Tenant Mix

The types and Gross Leaseable Area (GLA) of each tenant type in the center should be examined. The mix of tenants will, in part, determine the parking demand at the center. The building requirements and placement of any possible expansion to the center should also be considered. Factoring in possible expansions, at this stage, allows determining changes in drainage areas, runoff volumes and contaminant types and levels.

The type and number of tenants can also be an indication of the contaminants present in the runoff. The EPA's NURP Final Report indicates the contaminants found in stormwater vary little nationwide. However, individual sites may differ greatly from the national averages.

A tenant may introduce a contaminant not normally found in urban runoff. Alternatively, a high concentration of a particular type of tenant may produce higher levels of a particular contaminant. For example, a center with an emphasis on restaurants may produce a higher level of microbial contaminants than found on average.

This illustrates an important point. Nationwide or even local contaminant level standards can help develop general design guidelines. It is necessary however to examine each shopping center individually for the potential types and levels of contaminants that might be generated.

6.1.2 Program Inventory

• Focus of Pond-Marsh

The issues to be addressed by a Pond-Marsh need to be looked at early in the design process. The abilities of a Pond-Marsh to address the problems of detention, contaminant removal and aesthetic enhancement make it a flexible solution.

Discussions with the developer, major tenants and government bodies will identify if any of these problems should take precedence.

The choice between detention, water quality or aesthetics as the primary goal can change the design emphasis. This does not mean the other issues will be ignored. The Pond-Marsh inherently addresses all three. It may be decided, though, the primary goal will be sought at the expense of the other issues. Consequently, the use of the Pond-Marsh should be re-evaluated. It may be that another BMP will be a better solution. For example, it may become apparent the site only requires stormwater detention. In this case, all that may be needed is a detention pond.

• Design Storm Selection

All stormwater management systems are designed for a specific storm event, for example a 25 year one hour storm. In some cases, there may little control over choosing this size of the storm event. Often times governmental bodies decide the minimum storm event the stormwater wetland must handle. Other times it may be a matter of satisfying insurance requirements.

It should be noted this storm event is usually a minimum requirement. Every effort should be made to choose the maximum design storm possible. One of the major reasons for using the stormwater wetland is the reduction of excessive stormwater volumes and velocities entering downstream areas. Proposed design should take full advantage of the ability of the stormwater wetland to restore pre-development stormwater volumes and velocities.

• Detention Time and Outflow

Closely tied to the selection of the design storm are the detention time and the outflow. Both of these items can have a significant impact on the volume of stormwater to be stored. As with the design storm, the proposed Pond-Marsh design should utilize detention time and outflow to preserve pre-development volumes and velocities.

6.2 ANALYSIS

6.2.1 Amount of Water

A determination of the amount of water the developed site generates will have to be made. One source for the water is groundwater. However, groundwater levels and flows can fluctuate greatly. These fluctuations can be due, for example, to periods of heavy rain, drought and surrounding land development. Accordingly, the inclusion of groundwater in the overall stormwater calculation is, at best, uncertain. However it is important to consider the potential impact of groundwater on the Pond-Marsh.

Typically, the most significant source of water is runoff. Runoff will make up the majority of the detention and treatment volumes and determine the viability of the Marsh Section. The methods and rationale for these calculations are discussed below.

- Detention Volume

The amount of stormwater to be detained can be calculated by several methods. The most common of these methods are the Rational Method, the Modified Rational Method and the Soil Conservation Service (SCS) Method. The use of these methods is described in numerous works and will not be detailed here. It should be noted each method has its strengths and limitations. It may be necessary to use more than one of these methods to get an accurate estimate of stormwater volume.

One of the advantages of using a Pond-Marsh in a parking lot is the flexibility of managing different design storms. For example, the Pond-Marsh alone can be designed to detain a twenty-five year one hour storm. In emergency situations, such as a one hundred year one hour storm, little used parts of the lot can be included as temporary storage. In this case, detention volumes for both the twenty-five year one hour and one hundred year one hour storm will be calculated.

Whatever the final design storms are, it is important the desired outflow from the Pond-Marsh be determined early in the calculation process. While a governmental body may at times set the design storm, every effort should be made to limit the outflow to pre-development levels. This ensures the development puts little or no additional strain on downstream areas.

• Treatment Volume

Treatment volume is calculated in much the same way as detention volume. The major difference is the size of the design storm. Schueler recommends ninety percent of runoff producing storms be captured for the purposes of treatment by the Pond-Marsh (Schueler 41, 1994). This ensures the Pond-Marsh will hold runoff from most storms for treatment.

It also increases detention time of smaller storms. Runoff from these storms will be held until more enters the Pond-Marsh. The result is a long detention time that emphasizes the contaminant removing abilities of the Pond-Marsh.

• Volume for Wetland Viability

Traditionally, stormwater volumes have been calculated using precipitation amounts for storms occurring once or less during in any given year. Unfortunately these storms are of little use when determining if enough stormwater will be generated to sustain a marsh environment. The Marsh section requires, "seasonally or regularly, a reliable supply of water from usual (i.e. weekly or bi-weekly) rain events" (Garbisch 1995, 88) to maintain the Marsh's viability

In <u>Freshwater Wetlands Construction, Restoration and Enhancement</u>, Garbisch illustrates a method for estimating the potential viability of a wetland. This method looks at the water requirements of the wetland, evaporation losses and infiltration. A comparison to the bi-weekly rainfall amount during the growing season and the volume of runoff needed to fill the wetland is made. The difference is expressed in terms of how often the wetland fills and dries. This estimate is used to gauge the viability of an established wetland. During the first year while the Marsh is establishing itself, additional water may be needed during times of low rainfall.

It should be pointed out this method is, at best, a rough estimate. Bi-weekly rainfall amounts are highly variable. Different types of wetlands vary widely in their water requirements. Adjustments in the type, placement and amount of plant materials, fine tuning of water levels and other items will probably be necessary until the wetland is fully established and operating as intended.

6.2.2 Availability of Space

After calculating the space needed for items such as parking, driving lanes and the shopping center, a determination of the area available for Pond-Marsh can be done. If there is insufficient room, a Pond-Marsh may not be feasible. However, other options such as redesign of the center or acquisition of additional property can be explored.

6.3 DESIGN FACTORS

6.3.1 Integration into Parking Lot

A suburban shopping center parking lot can be a harsh and visually bleak environment. Even small storms can produce large amounts of fast moving runoff. This runoff can contain high levels of many types of contaminants. The lot's open and exposed nature together with extensive paved surfaces produces visually unappealing surroundings.

Using a Pond-Marsh stormwater wetland to address these issues brings with it special challenges. To meet these challenges, some changes are needed to the traditional methods of suburb shopping center parking lot design. These changes can help improve the success of a Pond-Marsh.

- Storage of Excess Stormwater

There will be times when the detention abilities of the Pond-Marsh will be exceeded. Whether the excess stormwater runoff comes from an unusually large storm or several storms close together, it must be handled in a safe and effective manner. This is especially true in shopping center parking lot. If handled incorrectly, significant damage can result to the shopping area and the vehicles in the lot.

However, this does not preclude using the parking lot as an emergency storage area for excess stormwater. Being underutilized most of the time and with its open, impervious surface, a parking lot creates an ideal space for temporary storage. Designed with emergency storage in mind, a lot can be integrated into the overall stormwater management strategy.

- Aesthetics

One of the most important benefits brought to a parking lot by a Pond-Marsh is increased aesthetics. However, with space sometimes at a premium, the developer may overlook these improvements. This requires an attitudinal change from seeing the parking lot as something to be developed as quickly and cheaply as possible. Instead, the parking lot should be seen as an extension of the shopping center. By regarding the parking lot as a positive feature of the center, the developer creates an extra amenity that furthers a pleasurable shopping experience and perhaps creates a competitive edge over other shopping centers in the area.

6.3.2 Size

The different volumes of runoff detained by Pond-Marsh determines it size. The overall size including buffers should be, at a minimum, large enough for the normal detention requirements. Providing there is sufficient room, the Pond-Marsh can be sized for the emergency detention volume. If this is not the case, the parking area immediately surrounding the Pond-Marsh could be designed to provide emergency storage stormwater storage.

6.3.3 Parking Lot Detention

The parking lot can be an important location for emergency stormwater detention. Successfully using the parking lot though requires ponding be kept to a minimum (Urbonas and Stahre 1993, 36). Occurring no more frequently than every five to ten years, the ponding should have a depth of no more than eight inches (0.66 feet). Excess stormwater should also drain quickly from the lot, preferably in less than thirty minutes (Urbonas and Stahre 1993, 36). It should be stressed these are minimum guidelines. Every effort should be made to reduce the storage depth and detention time to depths and times below these minimums.

Parking areas used for detention should be designed so they can be closed off when water is present. This will prevent cars from entering while the lot is detaining the stormwater. The method of closure can be simple as long as it is clear and can be quickly implemented.

6.3.4 Safety

The safety of the public is a major concern when designing the Pond-Marsh. Water is a natural magnet for people of all ages, especially the young. Care must be taken in the design of constructed wetland to reduce or eliminate possible safety hazards.

As outlined by Marcy and Flack (1982 p 332), a few situations cause the majority of incidents occurring in or near water. These situations are unexpected depths, currents, cold water temperature and accidental slips and falls on slopes, banks and submerged rocks.

They also cite four general methods to reduce these hazards. These are hazard elimination, restricting access, gradual hazard onset and escape route provision. The additional method of warning signs should be included.

The design of the Marsh section of the constructed wetland intrinsically helps eliminate some of the hazards associated with water bodies. This section with its slow water velocity, relatively small topographic changes, complicated structure, and increased water temperature has few hazards. The most hazardous elements of this section are the micro-pools, which can be placed in relatively inaccessible areas of the Marsh.

The Pond section, on the other hand, has several dangerous aspects. These are falls, currents and being swept through the discharge. These hazards can be reduced or eliminated by incorporating the four general hazard reduction methods referred to above and through proper design.

Ideally, the slopes at the Pond edge should not exceed a ratio of 4:1. These slopes help minimize falls into the Pond. "Slopes of 3:1 should be avoided unless the entire Pond is fenced" (Urbonas and Stahre 1993, 44).

At the permanent water level a shelf with a maximum depth of eighteen inches should be maintained. This shelf should extend out into the Pond for fifteen feet. After this distance, maximum slope percentages for Ponds may be used to reduce the amount of land used (Schueler 1994, 106).

Proper control structure design can also reduce hazards. While it is beyond the scope of this thesis to discuss specific designs of these structures, they should be built to prevent an accidental sweep through. For example, the use of a grate, while reducing the amount of trash entering the outflow structure, can also prevent injury. The structure can also be placed in an inaccessible area or screened to reduce visibility (Urbonas and Stahre 1993, 44).

Signage can also play an important role. Warning signs can be placed in conspicuous places to advise the public of the dangers such as rapid water level changes, currents and the presence of contaminants. Fencing is also a possibility but may run counter to purposes such as increasing the public's appreciation and understanding of wetlands.

6.3.5 Location

In most cases, the optimum location for the Pond-Marsh, for drainage considerations, is the lowest area of a site. By locating the Pond-Marsh in the lowest area, the amount of grading needed for directing stormwater is reduced. Yet, other factors besides elevation need to be considered when locating the Pond-Marsh. Some of these factors such as the presence of porous soil or existing utilities require extra work to make the low area suitable.

Other factors may preclude the use of the low area for the Pond-Marsh. One of these is aesthetics. One of major reasons for using a Pond-Marsh in a parking lot is to increase aesthetic appeal. It is extremely important to locate a Pond-Marsh at a prominent location.

Prominent placement has additional benefits apart from aesthetics. Placed in a back corner of the parking lot, the Pond-Marsh may be seen as abandoned property. Wetlands especially have a negative connotation for many people. The Pond-Marsh then becomes a target for dumping and vandalism. This increases maintenance and may reduce the detention and contaminant reduction abilities of the Pond-Marsh.

Prominence extends a sense of value to the Pond-Marsh. The increased value translates into a greater appreciation of the Pond-Marsh by the public. This in turn can lead to a reduction in overall maintenance. Placement in a prominent area can also help ensure maintenance is carried out in a regular and timely manner.

The use of parking areas for emergency detention is another factor affecting placement. If the Pond-Marsh is designed to use parking areas as emergency detention it should be located so damage to property is minimized. Any parking areas designed to serve as emergency detention should be areas of low use.

CHAPER 7

CASE STUDY

7.1 GENERAL DESCRIPTION

The site chosen as a case study for this thesis is the Mall of Louisiana (Figure 6). The Mall is located at 1410 Bluebonnet Road near the intersection of Interstate 10 and Bluebonnet Road in Baton Rouge, Louisiana. The main shopping area consists of six major department stores and a mall. There will be twelve outparcel buildings for retail and restaurants.

Ward's Creek serves as the boundary on the north side of the site. Just beyond Ward's Creek is a small undeveloped tract of land and Interstate 10. To the south, the Kansas City Southern Railroad right of way separates the site from Jimmy Swaggert Ministries. The west side is bounded by Bluebonnet Road, which serves as the primary access to the Mall.

An undeveloped tract of land lies to east of the site. The future plan for this tract is unknown. However with construction of the Mall, this tract may be a prime candidate for development.

Along with the retail areas of the Mall, a community center is planned for the site. For several reasons, this center will not be included in the case study. First, the center will not be directly in the shopping center building or lot. Second, the center is not a typical facility for a shopping center. Third, from a design viewpoint, the center is likely to have little in common with the Mall.

Figure 6 Site Plan

7.2 SITE INVENTORY

7.2.1 Watersheds

The overall property consists of a central ridge with existing wetlands along the northern boundary of the site. This central ridge drains into Ward's Creek and one of its tributaries, Dawson Creek. Under pre-development conditions, approximately forty percent of the area drained into Ward's Creek. The remaining sixty percent drained into Dawson Creek (Owen and White 5).

Development of the Mall changed the natural drainage pattern. Fifty-six percent of the runoff now drains into Ward's Creek. The remaining forty-four percent drains into Dawson Creek (Owen and White 1995, 6).

The development lends itself to be divided into three proposed drainage areas. These proposed areas, as shown in Figure 7, slope away from the Mall. Areas 1 and 2 have their lowest elevation generally along the inner edge of the ring road the surrounds the Mall parking. Area 3 has its lowest elevation in the parking lot. This grading plan allows for drainage away from the Mall. For Areas 1 and 2, the grading directs the runoff away from the outparcels. For Area 3, the runoff is directed away from the wetlands to the north and east. Because the site is higher than the surrounding area, there is little, if any off-site runoff entering the Mall.

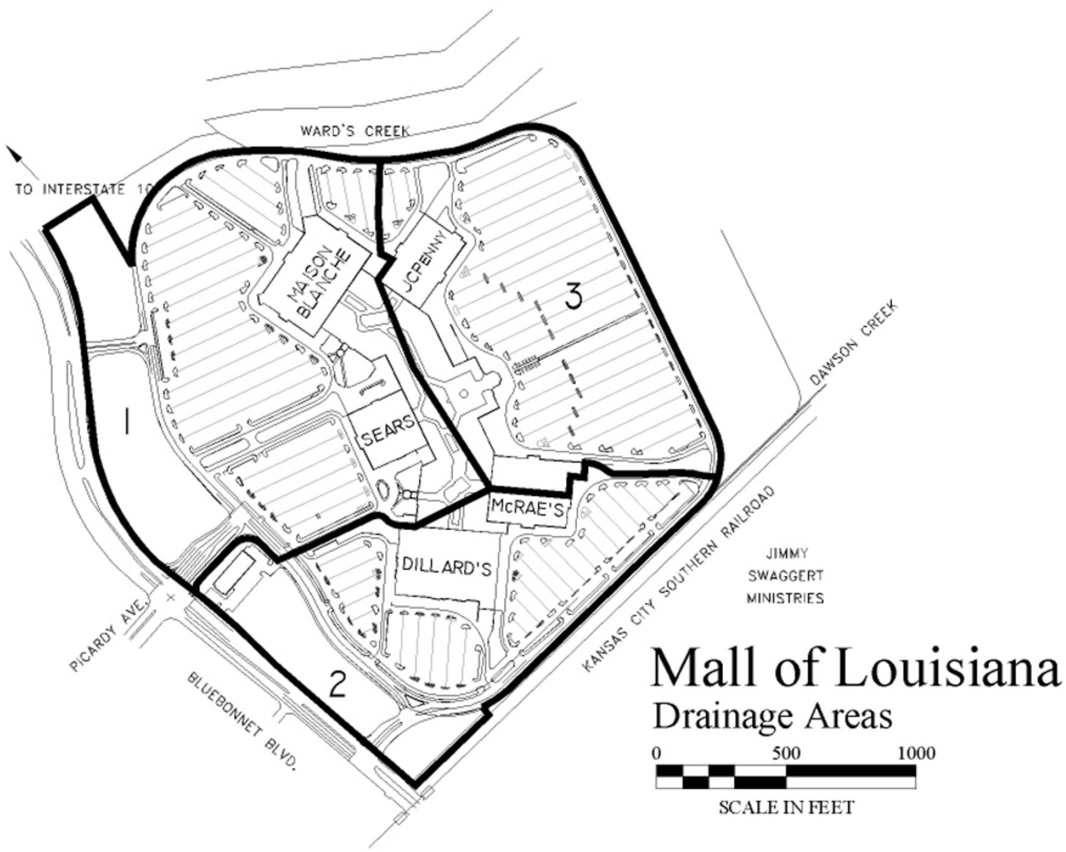

Figure 7 Drainage Areas

7.2.2 Existing Wetlands

Wetlands are present in several areas along the boundaries of the site in the drainage servitude of Ward's Creek and Dawson Creek. These wetlands are outside the development area and were not directly affected. However there is probably a significant impact due to the increased runoff from the Mall.

7.2.3 Topography

The topography of the site consists of a central ridge running roughly north to south. Pre-development elevations on this ridge are above thirty five feet. The site is relatively level to near the edges of Ward's Creek and Dawson Creek. The elevation drops quickly at these edges to below fifteen feet (U.S. Department of the Interior, Geological Survey, 1992).

After development, the site has a high elevation of 47.6 feet at the Mall's upper level and 29.11 feet at the lower level (Crawford McWilliams Hatcher Architects, Inc. 1996, Sheet 807-C7). The grading of the site is relatively gentle, except in areas that transition between the two levels. The low elevations at the creek edges remain unchanged.

7.2.4 Geology

The geology of the site is unremarkable for this area. There are no known major geological features that preclude the installation of a stormwater wetland.

7.2.5 Soils

On the central ridge, where the site was developed, the soil consists of an Oliver silt loam. This soil has a low permeability rate (Owen and White 6) and is suitable for developing a stormwater wetland.

7.2.6 Depth to Groundwater

For this case study, the edges of Ward's Creek and Dawson Creek are assumed to represent the depth to groundwater. The edges of these creeks have an elevation of fifteen feet (U.S. Department of the Interior, Geological Survey, 1992). This puts the water table approximately ten feet below the lowest areas of the finished development.

7.2.7 Climatic Information

• Growing Season

Based on information from the Water and Climate Center of the Natural Resources Conservation Service, the length of wetland growing season, for Baton Rouge is March 1 to November 24 (Table 4). The wetland growing season has a fifty percent chance of occurring between these dates. This case study uses November 30 as the ending date. This was done to ease calculating the bi-weekly precipitation amount.

Table 4 Wetland Growing Season Dates

	Temperature		
Probability	24 F or higher	28 F or higher	32 F or higher
	Beginning and Ending Dates *Growing Season Length*		
50 percent * *Growing Season Length*	1/25 to 12/31 340 *days*	2/ 9 to 12/12 307 *days*	3/ 1 to 11/24 269 *days*
70 percent * *Growing Season Length*	> 365 days > 365 *days*	2/ 1 to 12/19 322 *days*	2/23 to 11/30 281 *days*

* Percentage that the chance of the growing season occurring between the Beginning and Ending dates.
Source: U. S. Department of Agriculture 1999

• Bi-Weekly Precipitation Amounts

For this case study, 2.3 inches was determined to be the bi-weekly rainfall average during the wetland growing season. This amount used data from the Water and Climate Center of the Natural Resources Conservation Service for the Baton Rouge area. This data was manipulated using very basic methods. More rigorous and precise statistical methods should be applied for actual designs.

7.2.8 Development

• Pre-Development Cover and Runoff Coefficient

The Mall had a pre-development cover of overgrown pasture with a few volunteer trees (Owen and White 6). The runoff coefficient for this type of cover is 0.20.

• Level of Development

The Mall development covers approximately ninety seven acres. This figure includes the Mall, outparcel buildings, internal drives and parking. Except for some minor landscaping and turf areas, the ninety seven acres will be covered with hardscape or buildings. The area calculations listed below are estimated from a CAD drawing of the site (Table 5 and 6).

At the time the data was collected, only one lot of the twelve outparcels had a development plan. As a result, the percentages of outparcel Hardscape/Pavement Area, Building Area and Landscape/Turf Area are assumed to be the same as the Mall. These estimates are included in the totals.

• Post-Development Cover and Runoff Coefficients

The site cover is typical for a shopping center. It is mostly hardscape/paving and buildings with a small amount of landscape and turf. Below is a breakdown of the runoff coefficients for each cover type (Table 7).

Table 5 Total Land Use Types and Amounts

Hardscape/Pavement Area	3122467.55 Square Feet	71.68 Acres	73.75%
Building Area	852248.97 Square Feet	19.57 Acres	20.13%
Landscape/Turf Area	259298.53 Square Feet	5.96 Acres	6.13%
Total Drainage Area	4234015.05 Square Feet	97.19 Acres	100.01%

Note: Figures do not total 100% due to rounding.

Table 6 Land Use Types and Amounts by Drainage Area

Drainage Area One			
Hardscape/Pavement Area	1278875.74 Square Feet	29.36 Acres	69.70%
Building Area	390115.47 Square Feet	8.96 Acres	21.27%
Landscape/Turf Area	165773.45 Square Feet	3.81 Acres	9.04%
Drainage Area One Total	1834764.66 Square Feet	42.12 Acres	100.01%
Drainage Area Two			
Hardscape/Pavement Area	886660.51 Square Feet	20.35 Acres	77.02%
Building Area	245285.99 Square Feet	5.63 Acres	21.30%
Landscape/Turf Area	19107.02 Square Feet	0.44 Acres	1.66%
Drainage Area Two Total	1151053.52 Square Feet	26.42 Acres	99.98%
Drainage Area Three			
Hardscape/Pavement Area	956931.30 Square Feet	21.97 Acres	76.68%
Building Area	216847.51 Square Feet	4.98 Acres	17.38%
Landscape/Turf Area	74418.06 Square Feet	1.71 Acres	5.96%
Drainage Area Three Total	1248196.87 Square Feet	28.65 Acres	100.02%

Note: Figures do not total 100% due to rounding.

Table 7 Post-Development Runoff Coefficients

Cover Type	Runoff Coefficient
Hardscape/Pavement Area	0.90
Building Area	0.95
Landscape/Turf Area	0.40

• Gross Leaseable Area

The Mall has a building footprint of approximately 852,250 square feet. A more important measurement of the Mall is the Gross Feasible Area or GLA. The GLA is 1,163,481 square feet. There are possible expansions of the Mall to raise the total GLA to 1,374,981 square feet (Crawford McWilliams Hatcher Architects, Inc. 1996, Sheet A0.2). The GLA will help determine the number of parking spaces needed.

It should be noted this GLA does not include any outparcel development. At the time the data was collected, only one of the twelve outparcels had a development plan. Information about this development was therefore unavailable. As a result, the same percentages of Hardscape/Pavement Area, Building Area and Landscape/Turf Area found for the Mall is used the outparcels.

• Spatial and Engineering Guidelines

The major issue affecting the size of the parking lot is the parking space to Gross Leaseable Area requirement. The ULI recommends 5.0 spaces per 1,000 square feet of GLA for centers having a GLA of over 600,000 square feet. The Mall, however, was developed with a two tier parking requirement. The first tier requires 5.0 spaces per 1,000 square feet for the first 1,000,000 square feet of GLA. The second tier requires 4.5 spaces per 1,000 square feet for any remaining GLA (Crawford McWilliams Hatcher Architects, Inc. 1996, Sheet A0.2).

Using these requirements the Mall needed to provide a minimum of 5,734 parking spaces for the initial development (Crawford McWilliams Hatcher Architects, Inc. 1996, Sheet A0.2). A total of 6,041 spaces were developed. If the Mall is expanded as planned, 6687 spaces will be needed (Crawford McWilliams Hatcher Architects, Inc. 1996, Sheet A0.2).

At first glance it may appear the Mall currently has a slight excess of spaces. However, the Mall parking lot would lose roughly 250 spaces if the planned expansion occurs. This expansion, then, could leave the Mall short by approximately 900 spaces.

It should be noted these figures are for the main Mall building only. The outparcel developments have their own parking requirements. It is assumed the outparcels have an appropriate GLA to parking space ratio.

• Parking Stall and Drive Size

Just as important as the number of spaces is the size of each parking stall and the driving lanes. The Mall uses a twenty foot by nine foot stall for most parking spaces. Spaces that front turf or landscaped areas are nineteen feet by nine feet. This is current size recommendation for parking stalls (Breeden 1998, Lots of Parking: Design, Required Dimensions, 1).

The typical driving lane at the Mall is twenty-one feet wide. The current recommendation for driving lane width is twenty-six feet (Breeden 1998, Lots of Parking: Design, Required Dimensions, 1). This means the lanes in the Mall parking lot are undersized.

• Tenant Mix

The tenants of the Mall are mostly retail with a food court. The outparcel tenants are retail and restaurants. The only exception to this typical mix is an auto repair center in one of the outparcels. The auto repair center may increase the amount of certain types of contaminants. However, the mix of tenants and levels of use for the Mall is not unusual.

• Contaminants

Collection and analysis of runoff from the Mall are beyond the scope of this thesis. It is assumed, then, the type and levels of contaminants are the same as those found in the NURP study. Using this information for this case study does not suggest the NURP study should be used in an actual design.

Several contaminants are not listed on the NURP study. These are organic chemicals, trash/debris and microorganisms. It is assumed the levels of these contaminants are within allowable limits for removal or reduction by a Pond-Marsh stormwater wetland.

• Drainage System for Developed Project

As developed, the runoff from the Mall is moved by a conventional drainage system. For this case study, it is assumed the existing system can be modified for use with Pond-Marsh.

7.3 PROGRAM INVENTORY

7.3.1 Focus of Pond-Marsh

The focus of this stormwater wetland is an equal combination of stormwater control, improvement of runoff quality and aesthetic enhancement. This focus was chosen to investigate the full potential of the stormwater wetland in a regional suburban shopping center development.

However, the focus does limit the flexibility of the Pond-Marsh. This means one of these items can not be sacrificed in place of the others. For example, the Pond-Marsh must not only be aesthetically pleasing and improve the quality of the runoff. It must also provide the required stormwater control.

7.3.2 Stormwater Control

• Drainage Areas

Each of three drainage areas in the Mall of Louisiana is large enough to justify a Pond-Marsh. Therefore, a Pond-Marsh system for each area will be explored.

• Detention Design Storm and Time

This case study uses two separate 100 year one hour storms for the main storm event to be detained. For the Baton Rouge area, a single 100 year one hour storm generates 4.50 inches of precipitation. The Pond-Marsh stormwater wetland will be sized for a detention time of two hours. To expand design options, a 25 year one hour storm will also be examined. For the Baton Rouge area, a 25 year one hour storm generates 3.60 inches of precipitation.

• Outflow Rate

This case study will use the pre-development flow rate as the outflow rate. The outflow from the Pond-Marsh systems will not exceed pre-development runoff amounts. The calculations for the pre-development flow are found later in this work.

7.3.3 Contaminant Removal

Successful contaminant removal is based in large part on calculating two volumes. The first is the Treatment Volume. The Treatment Volume establishes the permanent water level of the Marsh section of the stormwater wetland.

As described earlier, Schueler recommends a storm size covering ninety percent of runoff producing events be chosen to calculate the Treatment Volume. For this case study, this amount is determined to be storms generating 1.70 inches of precipitation. It was derived from daily rainfall amounts in Baton Rouge. This amount was derived using data from the Water and Climate Center of the Natural Resources Conservation Service for the Baton Rouge area.

The second volume is the Viability Volume. This volume establishes the viability of the Marsh section. Garbisch recommends using a two week rainfall amount as the basis for determining the potential viability of a wetland (Garbisch 1995, 88). For this case study, 2.30 inches was determined to be the bi-weekly rainfall average during the wetland growing season. This amount was derived using data from the Water and Climate Center of the Natural Resources Conservation Service for the Baton Rouge area.

Besides determining the viability of the wetland, the Viability Volume also determines the type of wetland. Garbisch defines these types as permanently, regularly and irregularly flooded. These wetland types are flooded at two week, four week or six week intervals respectively (Garbisch 1995, 101).

7.3.4 Aesthetic Enhancement

The aesthetic requirement for this case study is to improve the visual quality of the parking lots. By developing three Pond-Marsh systems on site, this requirement can be easily met. The introduction of water features and green space would help to both break up the large expanses of paving and bring a sense of human scale.

The Pond-Marsh systems can be designed to control and enhance views of the Mall. From off site, the Pond-Marsh can provide a visual buffer for selected portions of the Mall. On site, these areas can direct views to Mall anchor stores and entrances. There also is the opportunity to provide each drainage area with its own distinct visual character.

7.4 RUNOFF VOLUMES

7.4.1 Volume Calculations

Calculating the various volumes of runoff is one the major activities for implementing a stormwater wetland. The results of these calculations will determine the size required for the stormwater wetland and may ultimately determine the feasibility of the project.

7.4.2 Calculation Method

All runoff volumes are calculated by using the Rational Method. Arguments can be made for using other methods. The Rational Method, though, is acceptable and is most familiar to the author.

7.5 STORMWATER VOLUME CALCULATIONS

7.5.1 Design Options

Three options were explored to satisfy the design requirements of detaining two 100 year one hour storms, improving the water quality of the runoff and enhancing the aesthetics of the parking lot at the Mall. Each option was applied to each drainage area.

Briefly described, Option One uses a Pond section sized to detain the first 100 year one hour storm. The volume of the second storm is detained within both the Pond and Marsh sections. There will be no stormwater storage in any of the parking areas.

Option Two uses a Pond section sized to detain a 25 year one hour storm. The rest of the first 100 year storm and a portion of the second storm are detained in the Marsh. The remaining portion of the second storm is detained within the Pond-Marsh system. As with the first option, there will be no stormwater storage in any of the parking areas.

Option Three uses a Pond section sized to detain a 25 year one hour storm. The rest of the first 100 year storm and a portion of the second storm will be detained within the Pond-Marsh system. The remainder of the second storm will be temporarily stored on adjacent parking area.

7.5.2 Pond-Marsh Water Levels

A typical detention pond uses three water storage levels, Permanent, High and Maximum. Two of these water levels, High and Maximum, are used to detain or retain stormwater. Because a Pond-Marsh system must also remove contaminants, these and other water levels have additional requirements (Figure 9). These requirements are described below.

- Pond Permanent Level

One of the important functions of the Pond Permanent Level is providing a pleasing water feature. It is important the Pond does not completely dry down as it can be unsightly. Therefore the Pond Permanent Level should be sized in accordance to its watershed and to provide a minimum depth of four feet.

- Pond Treatment Level

The Pond Treatment Level is sized to detain seventy percent of the treatment volume. It should be noted unlike the other water levels, the Pond Treatment Level is not a distinct level. Instead, storm events larger than a ninetieth percentile storm contains the treatment volume.

- Pond High Level

For Option One, the Pond High Level is sized to detain the first 100 year 1 hour storm. For Options Two and Three, the Pond High Level is sized to detain a 25 year 1 hour storm. For all options, the Pond High Level is drained into the Marsh section by a pipe set at the top of the Pond Treatment Level.

- Marsh Permanent/Treatment Level

The Marsh Permanent/Treatment Level uses the remaining thirty percent of the Treatment volume to help determine its size. This is because the Marsh Permanent/Treatment Level is used for more than just an aesthetic purpose. It provides a major part of contaminant removal.

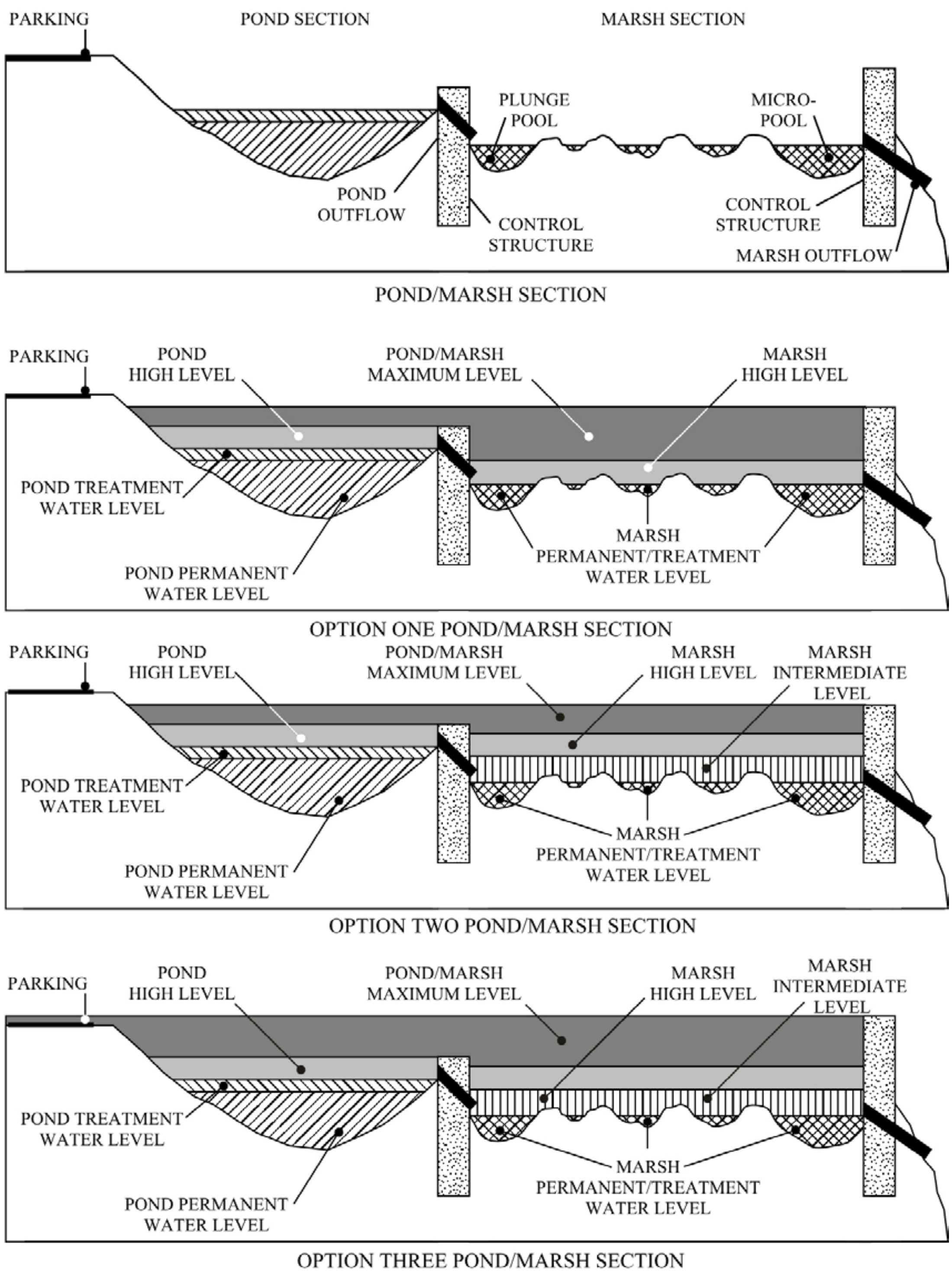

Figure 8 Pond-Marsh Water Levels

The Marsh Permanent/Treatment Level uses a variety of water depths. Schueler recommends a mix of 25 per cent of High Marsh (zero to six inches deep), 50 per cent of Low Marsh (six inches to one and one half feet) and 25 per cent of Micro-pool (one and one half feet and deeper). Using these recommendations, the average depth of the Marsh Permanent/Treatment Level is 1.37 feet.

Another component of the Marsh Permanent/Treatment Level is assessing its potential for viability. Using the method outlined by Garbisch, the Marsh section will be considered a permanently flooded wetland. This is true of all three Options in all three Drainage Areas. The Marsh viability calculations for all Options can be found in the appendix.

The Marsh Permanent/Treatment Level depends on extended detention as a major component for contaminant removal. It is important the stormwater remain in the Marsh at this level for as long as possible. Accordingly, there is no outflow for this level. However, the top of this level determines the placement for the main outflow for the Pond-Marsh system.

• Marsh Intermediate Level

The Marsh Intermediate Level is used only in Option Two and Three. Because the Pond for these options is only sized to detain a 25 year one hour storm, the excess runoff from the first 100 year one hour storm is diverted to the Marsh. This begins to equalize the water depths between the Pond and Marsh during large storms.

• Marsh High Water Level

The detention of the second 100 year one hour storm begins in the Marsh High Level. Storage of a portion of the second storm equalizes the water levels of the Pond and Marsh for all design options.

• Pond-Marsh Maximum Level

For the remainder of the second storm, the Pond and Marsh act as one detention basin. In Options One and Two, this volume is contained within the Pond-Marsh stormwater wetland. In Option Three, the surrounding parking area is used for temporary storage. As noted earlier, the maximum depth of stormwater in parking areas should not exceed eight inches (0.66 feet).

• Control Structures

There are two major control structures used in the Pond-Marsh. The first structure separates the Pond and Marsh sections. It controls the flow from the Pond to the Marsh. A pipe is set at the Pond Treatment Level and is sized for a 100 year one hour storm. This insures only volumes in excess of the Treatment volume are drained to the Marsh. An emergency overflow is set at the Pond High Level. This allows unusually large volumes to pass quickly into the Marsh.

The second structure is the outflow control for the Pond-Marsh system. Located at the end of the Marsh section, it has a pipe sized for the pre-development flow of a 100 year one hour storm. This pipe is set at the Marsh Permanent/Treatment Level. The emergency overflow is set at the Pond-Marsh Maximum Level.

7.6 RESULTS OF STORMWATER CALCULATIONS

The calculations for sizing the each of the Pond-Marsh Options are not exceptionally complicated. However, they are lengthy. To that end, a synopsis of the calculations is presented here. The full calculations for all Options can be found in the appendix.

The significant results of each Option for each Drainage Area are shown below (Table 8). These particular results were chosen to demonstrate the minimum and maximum impact of introducing Pond-Marsh systems in each of the Drainage Areas. It should be noted these are not the only results possible. Modifying any of the many variables in the calculations can produce a significant change in results.

As these figures show, the space requirements of three Pond-Marsh systems within the parking areas at the Mall would be extensive. It also appears there is no clear advantage to any of the three options. Options Two and Three have a smaller Permanent Level space requirement than Option One, but larger Maximum Level space requirements.

There appears to be little advantage to using parking areas as temporary detention. It is surprising how little of an effect the use of the parking lots as storage has on the space requirements for any of the areas. As shown above, virtually no space is saved using Option 3 for the total "Maximum" space required. Option 3 also results in 11.14 acres of parking being flooded during some large storms.

7.7 FEASIBLY

The amount of landscape/turf areas for the Mall and the outparcels total approximately six acres. The space for the Pond-Marsh systems, at Maximum Level, requires between 23.52 to 41.50 acres. The Landscape/Turf areas, if totally given over to the Pond-Marsh systems, could only provide between 14 to 25 percent of the needed space.

Unfortunately, redesigning the parking lot will not free up the addition space. The square footage of the parking stalls fall within recognized guidelines. The driving lanes are below the recommended width. Consequently, neither the stalls nor lanes should be reduced in size.

Table 8 Summary of Design Option Calculations

Option 1 Calculation Results - Pond sized to contain a 100 year 1 hour Storm with No Stormwater Storage in Parking Areas

	Pond-Marsh Permanent Level	Pond-Marsh Maximum Level
Drainage Area 1	7.00 Acres	9.80 Acres
Drainage Area 2	4.72 Acres	6.67 Acres
Drainage Area 3	4.85 Acres	7.05 Acres
Total Area Required	16.57 Acres	23.52 Acres

Option 2 Calculation Results - Pond sized to contain a 25 year 1 hour Storm with No Stormwater Storage in Parking Areas

	Pond-Marsh Permanent Level	Pond-Marsh Maximum Level
Drainage Area 1	6.18 Acres	10.21 Acres
Drainage Area 2	4.32 Acres	6.70 Acres
Drainage Area 3	4.88 Acres	6.94 Acres
Total Area Required	15.38 Acres	23.85 Acres

Option 3 Calculation Results - Pond sized to contain a 25 year 1 hour Storm with Stormwater Storage in Parking Areas

	Pond-Marsh Permanent Level	"Self-Contained" Pond-Marsh Maximum Level	"Parking Lot" Pond-Marsh Maximum Level	Total Pond-Marsh Maximum Level
Drainage Area 1	5.50 Acres	9.80 Acres	7.20 Acres	17.00 Acres
Drainage Area 2	3.22 Acres	6.70 Acres	5.30 Acres	12.00 Acres
Drainage Area 3	3.25 Acres	7.21 Acres	5.29 Acres	12.50 Acres
Total Area Required	11.97 Acres	23.71 Acres	17.79 Acres	41.50 Acres

Reducing the number of spaces is also not recommended. Using the guidelines from the ULI, the Mall of Louisiana currently has a slight excess of parking spaces. However, the parking will be undersized if the planned expansion is fully realized.

The factors of the GLA of the Mall, parking stall size, the number of parking spaces required and the amount of space needed for the three Pond-Marsh stormwater wetlands combine to make implementation unfeasible. Only a major change in the design of the Mall, its parking lots or in the design requirements of the stormwater wetlands would make the Pond-Marsh options practical.

CHAPER 8

CONCLUSIONS

8.1 SUMMARY OF OBJECTIVES

The objective of this thesis is to examine the use of Pond-Marsh stormwater wetlands in a suburban shopping center. It began by identifying three issues surrounding suburban shopping center parking. These issues are stormwater control, runoff quality improvement and aesthetic enhancement. The Pond-Marsh design was chosen because of its flexibility in solving these problems.

The ways the Pond-Marsh addresses these issues along with the Pond-Marsh's limitations are discussed. Guidelines for implementing a Pond-Marsh are developed and applied to a case study to further illustrate a method for implementation.

The case study site for this thesis is the Mall of Louisiana. Located in Baton Rouge, LA, the Mall is a regional shopping center. The Mall itself has a building footprint of approximately 852,250 square feet and a Gross Leaseable Area of 1,163,481 square feet. The total developed area is approximately ninety seven acres.

Three Pond-Marsh design options are developed and sized to meet the requirements of the hypothesis. These designs also addressed the post-development drainage pattern. The exploration of three options is an effort to increase the opportunity to integrate the Pond-Marsh into the Mall of Louisiana parking lots.

The result of these investigations is as the Mall and its parking lots are designed, with the stated focus of the stormwater wetlands and using the design options developed, a Pond-Marsh stormwater wetland system is not feasible. However, it maybe helpful to examine how a stormwater wetland could have been integrated if elements of the Mall and/or the Pond-Marsh were changed.

8.2 LIMITATIONS

There were several limitations to this work. The largest limitation to this thesis is the lack of Mall of Louisiana site plans with completed outparcel development. The assumptions made about the amount of building, hardscape and landscape in the outparcels may be very much in error. However it is doubtful if the availability of this information would have significantly affected the feasibility of integrating Pond-Marsh systems.

Another limitation was the method for calculating the average bi-weekly rainfall. Rainfall data is not available in this format. The methods used though were sufficiently accurate to give a good general idea of this rainfall amount.

A third limitation was the inability to determine the types and levels of runoff contaminants. The assumption that the types and levels would mirror the National Urban Runoff Program results is a guess at best. The Pond-Marsh systems would have removed some of the contaminants found in the runoff. It is uncertain though if they would have removed contaminants to acceptable levels.

8.3 REDESIGN ALTERNATIVES

8.3.1 Enlarging the Site

One obvious alternative is to acquire more property for the development. The additional property could be used for the Pond-Marsh systems. However, the Mall may be in the situation of not being able to acquire additional property. Both development and sensitive wetland/stream areas surround the Mall.

8.3.2 Smaller Development

Another alternative would have been to scale back the size of the development. There are several options for reducing the development. One option would have been a reduction or complete elimination of the outparcel development. Another option could have been a main mall building with a smaller GLA.

Either of these choices would reduce the amount of parking. A smaller development and parking lot increases the area available for stormwater wetlands. It also decreases the amount runoff to be detained and treated.

However, a smaller development may not have been profitable to build. Presumably, the developers of the Mall determined the need and feasibility of a large regional shopping center. Only time will tell if the Mall of Louisiana has more GLA than can be supported.

8.3.3 Parking Redesign

Several alternatives exist for redesigning the parking lot. One is the construction of parking garages. This alternative could free up enough space to install any of the Pond-Marsh designs. However the cost of constructing garages may be prohibitive. Parking garages average $7000 per space as compared to $1500 per space for surface parking. (Breeden 1998, Lots of Parking: Background, Parking FAQ, 5)

Another possibility is a revision of the GLA to parking space ratio. The research by ULI suggests this ratio changes little for shopping centers with a GLA over 600,000. Observing how well the existing parking serves the Mall though may determine if the ratio can be adjusted.

A third alternative is providing off site parking during peak demand periods. The peak parking demand periods can be reasonably estimated. During these periods, a system of shuttles could be used to move people to and from the Mall.

The Mall has a unique opportunity to use such a strategy. There are large, relatively unused parking lots available at Jimmy Swaggert Ministries. These lots are close by and could be easily adapted for overflow parking. Even closer to the Mall is the parking for an adjacent community center.

The owners of the Mall may view off site parking for general public as undesirable. The public may view the Mall as too inconvenient. The perceived or actual 'cost' in lost revenue may be too large to use off site parking for the public.

Using off site parking for employees is another alternative. Since the hours the employees would be at the Mall can be determined, the scheduling shuttles would be easier. Employees parking off site could reduce the number of spaces needed during times of peak demand.

8.3.4 Pond-Marsh Requirements

One alternative is to change the detention requirement. Initial calculations show reducing the detention requirement from two 100 year one hour storms to a single storm would reduce the space needed for the Pond-Marsh systems. For example, the maximum space needed to detain two 100 year one hour storms for Drainage Area One ranges from 9.80 acres to 17.00 acres. If the detention volume for this drainage area is limited to a single 100 year one storm, the maximum space for a Pond-Marsh could drop to 4.91 acres. The calculations for this alternative can be found in Appendix One.

Another alternative would be changing the runoff quality requirement from the Pond-Marsh systems. Initial calculations were done using only a pond to detain the runoff of two 100 year one hour storms from Area One. There is a reduction in maximum space requirement to 9.20 acres. The calculations for this alternative can be found in Appendix One.

8.3.5 Combination of Alternatives

Probably the best solution is some combination of the alternatives. By combining several alternatives no single aspect of the development or the Pond-Marsh would be completely compromised. What the proper combination is or if any combination would be successful was not investigated.

8.3.6 Feasibility for Future Developments

None of the three options devised in this thesis for integrating stormwater wetlands into the parking at the Mall of Louisiana are feasible. However, several factors may change the feasibility for future developments. One factor is the realization of the expenses associated with increased runoff volumes and velocities. These expenses, such as flooding and decline of downstream ecology, can cost governments money that could be spent on other concerns.

Another factor is the requirements from the EPA for limiting nonpoint source pollution. To date, the EPA has not determined what requirements will be imposed on cities to reduce the amount of NSP. However, the use of stormwater wetlands could certainly play a role in meeting any future requirements.

The aesthetic problems caused by large parking lots, like those found at the Mall, is a third factor. Currently, many cities are working to develop a "livable" atmosphere. A Pond-Marsh stormwater wetland can create green space and block objectionable views. These aspects help meet the desire for a more livable community.

Together, these factors can lead to changes in development requirements for future shopping centers. Once in place, the requirements could improve the feasibility of using a Pond-Marsh stormwater wetland for large shopping centers like the Mall of Louisiana.

8.4 ACHIEVEMENT OF THESIS OBJECTIVES

The objective of this thesis is to develop a method for introducing stormwater wetlands into parking lots to retain stormwater, improve runoff quality and provide visual enhancement. The ability of a Pond-Marsh stormwater wetland to address these issues is investigated. The concerns of using a Pond-Marsh are discussed along with possible solutions. Design guidelines for integrating a Pond-Marsh into a shopping center parking lot are made.

Using the Mall of Louisiana in Baton Rouge, LA, a case study is made to test the guidelines. Three design options are developed for the site. The results show for this site and the design requirements a Pond-Marsh stormwater wetland system is not feasible.

8.5 SUGGESTED AREAS OF FURTHER RESEARCH

Of interest to the author is an examination of Pond-Marsh stormwater wetlands in other scenarios. One is the use of these wetlands in shopping centers with different Gross Leaseable Areas. Applying the latest GLA/parking ratios may leave enough space available to integrate a Pond-Marsh. Older centers would be of special interest. Their parking lots were developed when vehicle sizes were generally larger and the GLA/parking ratio was not as well defined.

Integrating Pond-Marsh stormwater wetlands into other types and sizes of developments are also areas for research. Included here are large and small stand alone retail, business parks and residential developments. An examination of the designs of these and other developments may allow for integrating a Pond-Marsh.

A third area for research is examining the other types of stormwater wetlands. Each has varying strengths and weaknesses along with different space requirements. How well these other stormwater wetlands can be integrated into shopping center parking lots has not been explored.

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APPENDIX: VOLUME CALCULATIONS

In an effort to explore a larger range of design possibilities, three options for integrating a Pond-Marsh stormwater wetland were developed. Each of these options are applied to each of the three drainage areas at the Mall of Louisiana.

Option One uses a Pond sized to detain the first 100 year one hour storm. The second 100 year one hour storm is detained within the Pond and Marsh sections. This option does not use the parking lot for detention (Table 8-10).

Option Two uses a Pond sized to detain a twenty-five year one hour storm. The remaining volume of the first 100 year one hour storm is detained with in the Marsh. The second 100 year storm is detained in both the Pond and Marsh sections. This option does not use the parking lot for detention (Table 11-13).

Option Three also uses a Pond sized to detain a twenty-five year one hour storm. The remaining volume of the first 100 year one hour storm is detained within the Marsh. The majority of the second 100 year storm is detained in both the Pond and Marsh sections. The remaining volume of the second storm is detained on parking areas (Table 14-16).

Two other scenarios were developed to compare the effect of changing the design requirements of the Pond-Marsh stormwater wetland. The first reduced the detention volume to a single 100 year one hour storm (Table 17). The second eliminated the contaminant removal requirement (Table 18). These scenarios were applied to the Mall of Louisiana Drainage Area One only.

A synopsis of the calculations for each of the options is presented in the main body of the work. However, the full set of calculations should be studied. These calculations are presented here.

Table 9 Design Option One/Drainage Area One Calculations

Design Option 1-Drainage Area 1 Pond sized to contain a 100yr 1hr Storm.
No Stormwater Storage in Parking Areas.

Total Drainage Area	1834764.66 sq. ft.	42.12 acres
Hardscape/Pavement Area	1278875.74 sq. ft.	29.36 acres
Building Area	390115.47 sq. ft.	8.96 acres
Landscape/Turf Area	165773.45 sq. ft.	3.81 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
42.12 acres	4.50	0.20	=Qn
29.36 acres	4.50	0.90	=Qd(paved)
8.96 acres	4.50	0.95	=Qd(building)
3.81 acres	4.50	0.40	=Qd(turf)

37.91 =Qn

118.90	=Qd(paved)	164.04	=Qd(total)
38.29	=Qd(building)	37.91	=Qn
6.85	=Qd(turf)	126.13	=Q(resulting)
164.04	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	Volume
126.13	7200.00	908147.83 cubic ft.

Cubic Feet to be Detained - 100 year 1 hour Storm
908147.83 cubic ft.

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
29.36 acres	1.70	0.90	=Qd(paved)
8.96 acres	1.70	0.95	=Qd(building)
3.81 acres	1.70	0.40	=Qd(turf)

44.92	=Qd(paved)
14.46	=Qd(building)
2.59	=Qd(turf)
61.97	=Qd(total)

Qd(total)	x 60 min x 60sec =	Volume
61.97	3600.00	223094.41 cubic ft.

Treatment Volume (cont.)

Cubic Feet to be Detained -Treatment Volume
223094.41 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
156166.08 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
66928.32 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)

Recommended depth for Pond Permanent Level is 4.00 feet

D =	4.00 feet	Formula	
Pond Bottom	Pond Permanent Level	$\frac{(A_1+A_2)*D}{2.00}$	= V
0.50 acres	5.00 acres	958320.00 cubic ft.	= 479160.00 cubic ft.
21780.00 sq. ft.	217800.00 sq. ft.	2.00	

Pond Sizing Check (Rubenstein 1996, 199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
11.00 acres	5.50	42.12 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	263.30 feet	180.04 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	2.2%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)

Sized to contain 70% of Treatment Volume

156166.08 cubic ft. =V

A_1 Pond Permanent Level	A_2 Pond Treatment Level	Formula $\frac{V}{(A_1+A_2)/2}$	= Depth
		156166.08 cubic ft.	= 0.67 feet
5.00 acres	5.65 acres	231957.00 sq. ft.	
217800.00 sq. ft.	246114.00 sq. ft.		

Pond Treatment Water Level Sizing (cont.)

Grade Check	0.67 feet =	Pond Perm. to Pond Treatment Depth Change	
			Run btw Pond
Slope	Run	r of Pond Treatment circle	Treat. and Perm.
25.0%	2.69 feet	279.89 feet	16.59 feet
28.5%	2.36 feet	r of Pond Permanent circle	Slope
33.0%	2.04 feet	263.30 feet	4.1%

Pond High Water Level Sizing (Detention of a 100yr 1hr Storm less Treatment Volume)

751981.75 cubic ft. =V

A_1	A_2	Formula
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
5.65 acres	6.50 acres	$\frac{751981.75 \text{ cubic ft.}}{264627.00 \text{ sq. ft.}}$ = 2.84 feet
246114.00 sq. ft.	283140.00 sq. ft.	

Grade Check	2.84 feet =	Pond Treatment to Pond High Depth Change	
		r of Pond High Water	Run btw Pond
Slope	Run	circle	High and Treat.
25.0%	11.37 feet	300.21 feet	20.32 feet
28.5%	9.97 feet	r of Pond Treatment circle	Slope
33.0%	8.61 feet	279.89 feet	14.0%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

66928.32 cubic ft. =V
1.37 =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{14502.24 \text{ cubic ft.}}{1.37} = 10585.58 \text{ sq. ft.}$$

A_1	A_2		
First Marsh Permanent Level	Second Marsh Permanent Level	Marsh Bottom Acreage =	0.24 acres
2.00 acres	0.24 acres	Marsh Permanent Level	
87120.00 sq. ft.	10585.58 sq. ft.	Acreage =	2.00 acres

Marsh Permanent/Treatment Water Level Sizing (cont.)

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
66928.32179	42.12 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.51	0.90	0.46
Building	0.21	0.95	0.20
Landscape/Turf	0.05	0.40	0.02
Stormwater Wetland	0.23	1.00	0.23
			0.91 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check **ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

66928.32 cubic ft. =V
0.91 =c
42.12 acres =a

$$\frac{V}{(c)\,(a)\,(3630 \text{ cu. ft./ac. in.})} = i$$

$$\frac{66928.32 \text{ cubic ft.}}{0.91*42.12 \text{ acres}*3630 \text{ cu. ft./ac. in.}} = 0.48 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate

1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\ p\ t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Marsh Viability Check (cont.)

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth = 1.37 feet	Rainfall needed to fill Marsh = 0.48 inches
Daily Water Loss = 0.56 feet	Rainfall received Bi-Weekly = 2.30 inches
Dry Down Time = 2.45 days	

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	166.53 feet	108.48 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	58.05 feet	1.3%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Permanent Level and Pond High Water Level

D = 3.51 feet

A_1	A_2	Formula
		$((A_1+A_2)/2)\ (D) = V$
Marsh Permanent Level	Marsh High Level	$\frac{(87120.00 \text{ sq ft.}+113256.00 \text{ sq. ft.})}{2}$ (3.43 feet)
2.00 acres	3.05 acres	= 386602.67 cubic ft.
87120.00 sq. ft.	132858.00 sq. ft.	

Grade Check 3.51 feet = Marsh Perm. to Marsh High Depth Change

Slope	Run	r of Marsh High circle	Run btw Marsh High and Perm.
		205.65 feet	
25.0%	14.06 feet	r of Marsh Permanent circle	39.12 feet
28.5%	12.33 feet		Slope
33.0%	10.65 feet	166.53 feet	9.0%

Remainder of Second 100 year 1 hour storm

908147.83 cubic ft. = V of 100yr Storm
386602.67 cubic ft. = V Detained in Marsh Permanent to Marsh High Water Level
521545.16 cubic ft. = V to be Detained-Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Detains Remainder of Second 100 year 1 hour storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
9.55 acres	9.80 acres	521545.16 cubic ft. / 421443.00 sq. ft. = 1.24 feet
415998.00 sq. ft.	426888.00 sq. ft.	

Grade Check 1.24 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run	r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	4.95 feet	368.62 feet	4.73 feet
28.5%	4.34 feet	r of Pond/Marsh High circle	Slope
33.0%	3.75 feet	363.89 feet	26.2%

Total Change in Pond Water Height (Permanent to Maximum)

3.51 feet = Pond Permanent to High Water Level Height Change
1.24 feet = Pond/Marsh High to Maximum Water Level Height Change
4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 10 Design Option One/Drainage Area Two Calculations

Design Option 1-Drainage Area 2 Pond sized to contain a 100yr 1hr Storm.
No Stormwater Storage in Parking Areas.

Total Drainage Area	1151053.52 sq. ft.	26.42 acres
Hardscape/Pavement Area	886660.51 sq. ft.	20.35 acres
Building Area	245285.99 sq. ft.	5.63 acres
Landscape/Turf Area	19107.02 sq. ft.	0.44 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
26.42 acres	4.50	0.20	=Qn
20.35 acres	4.50	0.90	=Qd(paved)
5.63 acres	4.50	0.95	=Qd(building)
0.44 acres	4.50	0.40	=Qd(turf)

23.78	=Qn		
82.44	=Qd(paved)	107.30	=Qd(total)
24.07	=Qd(building)	23.78	=Qn
0.79	=Qd(turf)	83.52	=Q(resulting)
107.30	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	Volume
83.52	7200.00	601325.15 cubic ft.

Cubic Feet to be Detained - 100 year 1 hour Storm
601325.15 cubic ft.

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
20.35 acres	1.70	0.90	=Qd(paved)
5.63 acres	1.70	0.95	=Qd(building)
0.44 acres	1.70	0.40	=Qd(turf)

31.14	=Qd(paved)
9.09	=Qd(building)
0.30	=Qd(turf)
40.54	=Qd(total)

Qd(total)	x 60 min x 60sec =	Volume
40.54	3600.00	145927.29 cubic ft.

Treatment Volume (cont.)

Cubic Feet to be Detained -Treatment Volume
145927.29 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
102149.10 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
43778.19 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula

$$\frac{(A_1+A_2)*D}{2.00} = V$$

Pond Bottom	Pond Permanent Level	
0.50 acres	3.50 acres	$\frac{696960.00 \text{ cubic ft.}}{2.00}$ = 348480.00 cubic ft.
21780.00 sq. ft.	152460.00 sq. ft.	

Pond Sizing Check (Rubenstein 1996, 199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
8.00 acres	4.00	26.42 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	220.29 feet	137.03 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	2.9%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)

Sized to contain 70% of Treatment Volume

102149.10 cubic ft. =V

Formula

$$\frac{V}{(A_1+A_2)/2} = \text{Depth}$$

A_1 Pond Permanent Level	A_2 Pond Treatment Level	
3.50 acres	3.58 acres	$\frac{102149.10 \text{ cubic ft.}}{154202.40 \text{ sq. ft.}}$ = 0.66 feet
152460.00 sq. ft.	155944.80 sq. ft.	

Pond Treatment Water Level Sizing (cont.)

Grade Check	0.66 feet =	Pond Perm. to Pond Treatment Depth Change	
			Run btw Pond
Slope	Run	r of Pond Treatment circle	Treat. and Perm.
25.0%	2.65 feet	222.80 feet	2.50 feet
28.5%	2.32 feet	r of Pond Permanent circle	Slope
33.0%	2.01 feet	220.29 feet	26.5%

Pond High Water Level Sizing (Detention of a 100yr 1hr Storm less Treatment Volume)

499176.04 cubic ft. =V

A_1	A_2	Formula
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
3.58 acres	4.10 acres	$\frac{499176.04 \text{ cubic ft.}}{167270.40 \text{ sq. ft.}}$ = 2.98 feet
155944.80 sq. ft.	178596.00 sq. ft.	

Grade Check	2.98 feet =	Pond Treatment to Pond High Depth Change	
		r of Pond High Water	Run btw Pond
Slope	Run	circle	High and Treat.
25.0%	11.94 feet	238.43 feet	15.63 feet
28.5%	10.47 feet	r of Pond Treatment circle	Slope
33.0%	9.04 feet	222.80 feet	19.1%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

Formula

43778.19 cubic ft. =V

1.37 =D

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{72637.07 \text{ cubic ft.}}{1.37} = 53019.76 \text{ sq. ft.}$$

A_1	A_2		
First Marsh Permanent Level	Second Marsh Permanent Level	Marsh Bottom Acreage =	0.25 acres
0.25 acres	1.22 acres	Marsh Permanent Level	
10890.00 sq. ft.	53019.76 sq. ft.	Acreage =	1.22 acres

Marsh Permanent/Treatment Water Level Sizing (cont.)

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent (of Cover Types)	Drainage Area Runoff Coefficent
43778.18746	26.42 acres		
Land Cover Type	Percentage		
Parking/Hardscape	0.53	0.90	0.47
Building	0.21	0.95	0.20
Landscape/Turf	0.01	0.40	0.00
Stormwater	0.25	1.00	0.25
Wetland			0.93 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

43778.19 cubic ft. =V
0.93 =c
26.42 acres =a

$$\frac{V}{(c)\ (a)\ (3630 \text{ cu. ft./ac. in.})} = i$$

$$\frac{43778.19 \text{ cubic ft.}}{0.91*42.12 \text{ acres}*3630 \text{ cu. ft./ac. in.}} = 0.49 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate
1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\ p\ t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Marsh Viability Check (cont.)

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth = 1.37 feet	Rainfall needed to fill Marsh = 0.49 inches
Daily Water Loss = 0.56 feet	Rainfall received Bi-Weekly = 2.30 inches
Dry Down Time = 2.45 days	

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	129.91 feet	71.03 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	58.88 feet	1.9%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Permanent Level and Pond High Water Level

D = 3.65 feet

A_1 Marsh Permanent Level	A_2 Marsh High Level	Formula
		$((A_1+A_2)/2)\ (D) = V$
		$\frac{(53019.79 \text{ sq ft.}+87120.00 \text{ sq. ft.})}{2}$ (3.51 feet)
1.22 acres	2.38 acres	= 285703.92 cubic ft.
53019.76 sq. ft.	103672.80 sq. ft.	

Grade Check 3.65 feet = Marsh Perm. to Marsh High Depth Change

Slope	Run	r of Marsh High circle	Run btw Marsh High and Perm.
		181.66 feet	
25.0%	14.59 feet	r of Marsh Permanent circle	51.75 feet
28.5%	12.80 feet		Slope
33.0%	11.05 feet	129.91 feet	7.0%

Remainder of Second 100 year 1 hour storm

601325.15 cubic ft. = V of 100yr Storm
285703.92 cubic ft. = V Detained in Marsh Permanent to Marsh High Water Level
315621.22 cubic ft. = V to be Detained-Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Detains Remainder of Second 100 year 1 hour storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
6.48 acres	6.67 acres	$\frac{315621.22 \text{ cubic ft.}}{286407.00 \text{ sq. ft.}}$ = 1.10 feet
282268.80 sq. ft.	290545.20 sq. ft.	

Grade Check 1.10 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run	r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	4.41 feet	304.11 feet	4.36 feet
28.5%	3.87 feet	r of Pond/Marsh High circle	Slope
33.0%	3.34 feet	299.75 feet	25.3%

Total Change in Pond Water Height (Permanent to Maximum)

3.65 feet = Pond Permanent to High Water Level Height Change
1.10 feet = Pond/Marsh High to Maximum Water Level Height Change
4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 11 Design Option One/Drainage Area Three Calculations

Design Option 1-Drainage Area 3 Pond sized to contain a 100yr 1hr Storm. No Stormwater Storage in Parking Areas.				
Total Drainage Area		1248196.87 sq. ft.		28.65 acres
Hardscape/Pavement Area		956931.30 sq. ft.		21.97 acres
Building Area		216847.51 sq. ft.		4.98 acres
Landscape/Turf Area		74418.06 sq. ft.		1.71 acres
Volumes				
100 year 1 hour Storm Volume				
Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q	
28.65 acres	4.50	0.20	=Qn	
21.97 acres	4.50	0.90	=Qd(paved)	
4.98 acres	4.50	0.95	=Qd(building)	
1.71 acres	4.50	0.40	=Qd(turf)	
25.79 =Qn				
88.97 =Qd(paved)			113.33 =Qd(total)	
21.28 =Qd(building)			25.79 =Qn	
3.08 =Qd(turf)			87.54 =Q(resulting)	
113.33 =Qd(total)				
Resulting Q	x 2hr detention time x 60 min x 60sec =		Volume	
87.54	7200.00		630276.07 cubic ft.	
Cubic Feet to be Detained - 100 year 1 hour Storm				
630276.07 cubic ft.				
Treatment Volume				
Acres	90th Percentile Storm	Runoff Coefficent	Q	
21.97 acres	1.70	0.90	=Qd(paved)	
4.98 acres	1.70	0.95	=Qd(building)	
1.71 acres	1.70	0.40	=Qd(turf)	
33.61 =Qd(paved)				
8.04 =Qd(building)				
1.16 =Qd(turf)				
42.81 =Qd(total)				
Qd(total)	x 60 min x 60sec =	Volume		
42.81	3600.00	154125.45 cubic ft.		

Treatment Volume (cont.)

Cubic Feet to be Detained -Treatment Volume
154125.45 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
107887.81 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
46237.63 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)

Recommended depth for Pond Permanent Level is 4.00 feet

D =	4.00 feet	Formula	
	Pond Permanent	$\frac{(A_1+A_2)*D}{2.00}$	= V
Pond Bottom	Level		
0.50 acres	3.60 acres	$\frac{714384.00 \text{ cubic ft.}}{2.00}$	= 357192.00 cubic ft.
21780.00 sq. ft.	156816.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996, 199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
8.20 acres	4.10	28.65 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope			
Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	223.42 feet	140.16 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	2.9%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)

Sized to contain 70% of Treatment Volume

107887.81 cubic ft. =V		Formula	
A_1	A_2	$\frac{V}{(A_1+A_2)/2}$	= Depth
Pond Permanent Level	Pond Treatment Level		
		$\frac{107887.81 \text{ cubic ft.}}{158776.20 \text{ sq. ft.}}$	= 0.68 feet
3.60 acres	3.69 acres		
156816.00 sq. ft.	160736.40 sq. ft.		

Pond Treatment Water Level Sizing (cont.)

Grade Check 0.68 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	2.72 feet	226.19 feet	2.78 feet
28.5%	2.38 feet	r of Pond Permanent circle	Slope
33.0%	2.06 feet	223.42 feet	24.5%

Pond High Water Level Sizing (Detention of a 100yr 1hr Storm less Treatment Volume)

522388.25 cubic ft. =V

A_1 Pond Treatment Level	A_2 Pond High Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
3.69 acres	4.50 acres	$\frac{522388.25 \text{ cubic ft.}}{178378.20 \text{ sq. ft.}}$ = 2.93 feet
160736.40 sq. ft.	196020.00 sq. ft.	

Grade Check 2.93 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	11.71 feet	249.79 feet	23.60 feet
28.5%	10.28 feet	r of Pond Treatment circle	Slope
33.0%	8.87 feet	226.19 feet	12.4%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

46237.63 cubic ft. =V
1.37 =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{17878.77 \text{ cubic ft.}}{1.37} = 13050.20 \text{ sq. ft.}$$

A_1 First Marsh Permanent Level	A_2 Second Marsh Permanent Level	
1.25 acres	0.30 acres	Marsh Bottom Acreage = 0.30 acres
54450.00 sq. ft.	13050.20 sq. ft.	Marsh Permanent Level Acreage = 1.25 acres

Marsh Permanent/Treatment Water Level Sizing (cont.)

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
46237.63385	28.65 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.55	0.90	0.50
Building	0.17	0.95	0.17
Landscape/Turf	0.03	0.40	0.01
Stormwater	0.25	1.00	0.25
Wetland			0.92 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

46237.63 cubic ft. =V
0.92 =c
28.65 acres =a

$$\frac{V}{(c)\,(a)\,(3630 \text{ cu. ft./ac. in.})} = i$$

$$\frac{46237.63 \text{ cubic ft.}}{0.91*42.12 \text{ acres}*3630 \text{ cu. ft./ac. in.}} = 0.48 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate

1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\,p\,t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Marsh Viability Check (cont.)

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth = 1.37 feet	Rainfall needed to fill Marsh = 0.48 inches
Daily Water Loss = 0.56 feet	Rainfall received Bi-Weekly = 2.30 inches
Dry Down Time = 2.45 days	

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	131.65 feet	67.20 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	64.45 feet	2.0%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Permanent Level and Pond High Water Level

D = 3.61 feet

A_1	A_2	Formula
		$((A_1+A_2)/2)\ (D) = V$
Marsh Permanent Level	Marsh High Level	$\frac{(54450.00 \text{ sq ft.} + 95832.00 \text{ sq. ft.})}{2}\ (3.57 \text{ feet})$
1.25 acres	2.36 acres	= 283684.97 cubic ft.
54450.00 sq. ft.	102801.60 sq. ft.	

Grade Check 3.61 feet = Marsh Perm. to Marsh High Depth Change

Slope	Run	r of Marsh High circle	Run btw Marsh High and Perm.
		180.89 feet	
25.0%	14.43 feet	r of Marsh Permanent circle	49.24 feet
28.5%	12.66 feet		Slope
33.0%	10.93 feet	131.65 feet	7.3%

Remainder of Second 100 year 1 hour storm

630276.07 cubic ft. = V of 100yr Storm
283684.97 cubic ft. = V Detained in Marsh Permanent to Marsh High Water Level
346591.09 cubic ft. = V to be Detained-Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Detains Remainder of Second 100 year 1 hour storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
6.86 acres	7.05 acres	$\frac{346591.09 \text{ cubic ft.}}{302959.80 \text{ sq. ft.}}$ = 1.14 feet
298821.60 sq. ft.	307098.00 sq. ft.	

Grade Check 1.14 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run	r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	4.58 feet	312.65 feet	4.24 feet
28.5%	4.01 feet	r of Pond/Marsh High circle	Slope
33.0%	3.47 feet	308.41 feet	27.0%

Total Change in Pond Water Height (Permanent to Maximum)

3.61 feet = Pond Permanent to High Water Level Height Change

1.14 feet = Pond/Marsh High to Maximum Water Level Height Change

4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 12 Design Option Two/Drainage Area One Calculations

Design Option 2-Drainage Area 1 Pond sized to contain a 25 year 1 hour storm. No Stormwater Storage in Parking Areas.

Total Drainage Area	1834764.66 sq. ft.	42.12 acres
Hardscape/Pavement Area	1278875.74 sq. ft.	29.36 acres
Building Area	390115.47 sq. ft.	8.96 acres
Landscape/Turf Area	165773.45 sq. ft.	3.81 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
42.12 acres	4.50	0.20	=Qn
29.36 acres	4.50	0.90	=Qd(paved)
8.96 acres	4.50	0.95	=Qd(building)
3.81 acres	4.50	0.40	=Qd(turf)

37.91	=Qn		
118.90	=Qd(paved)	164.04	=Qd(total)
38.29	=Qd(building)	37.91	=Qn
6.85	=Qd(turf)	126.13	=Q(resulting)
164.04	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
126.13	7200.00	908147.83 cubic ft.

Cubic Feet to be Detained - 100yr 1hr Storm
908147.83 cubic ft.

25 year 1 hour Storm Volume

Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q
42.12 acres	3.60	0.20	=Qn
29.36 acres	3.60	0.90	=Qd(paved)
8.96 acres	3.60	0.95	=Qd(building)
3.81 acres	3.60	0.40	=Qd(turf)

30.33	=Qn		
95.12	=Qd(paved)	131.23	=Qd(total)
30.63	=Qd(building)	30.33	=Qn
5.48	=Qd(turf)	100.91	=Q(resulting)
131.23	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
100.91	7200.00	726518.27 cubic ft.

Cubic Feet to be Detained - 25yr 1hr Storm
726518.27 cubic ft.

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
29.36 acres	1.70	0.90	=Qd(paved)
8.96 acres	1.70	0.95	=Qd(building)
3.81 acres	1.70	0.40	=Qd(turf)

44.92 =Qd(paved)
14.46 =Qd(building)
2.59 =Qd(turf)
61.97 =Qd(total)

Qd(total)	x 60 min x 60sec =	
61.97	3600.00	223094.41 cubic ft.

Cubic Feet to be Detained -Treatment Volume
223094.41 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
156166.08 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
66928.32 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula: $\frac{(A_1+A_2)*D}{2.00} = V$

Pond Bottom	Pond Permanent Level		
0.50 acres	4.18 acres	$\frac{815443.20 \text{ cubic ft.}}{2.00}$ =	407721.60 cubic ft.
21780.00 sq. ft.	182080.80 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
9.36 acres	4.68	42.12 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	240.74 feet	157.48 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	2.5%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)

Sized to contain 70% of Treatment Volume

156166.08 cubic ft. =V

A_1	A_2	Formula
Pond Permanent Level	Pond Treatment Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
4.18 acres	4.36 acres	$\frac{156166.08 \text{ cubic ft.}}{186001.20 \text{ sq. ft.}}$ = 0.84 feet
182080.80 sq. ft.	189921.60 sq. ft.	

Grade Check 0.84 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	3.36 feet	245.87 feet	5.13 feet
28.5%	2.95 feet	r of Pond Permanent circle	Slope
33.0%	2.54 feet	240.74 feet	16.4%

Pond High Water Level Sizing (Detention of a 25 year 1hour storm less Treatment volume)

570352.18 cubic ft. =V

A_1	A_2	Formula
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
4.36 acres	5.25 acres	$\frac{570352.18 \text{ cubic ft.}}{209305.80 \text{ sq. ft.}}$ = 2.72 feet
189921.60 sq. ft.	228690.00 sq. ft.	

Grade Check 2.72 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	10.90 feet	269.80 feet	23.93 feet
28.5%	9.56 feet	r of Pond Treatment circle	Slope
33.0%	8.26 feet	245.87 feet	11.4%

Marsh Permanent/Treatment Water Level Sizing

(Defines Permanent Marsh Level and Treatment Level)

Sized to contain 30% of Treatment Volume

Formula

66928.32 cubic ft. =V

1.37' =D

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{14502.24 \text{ cubic ft.}}{1.37'} = 10585.58 \text{ sq ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh Permanent Level	Second Marsh Permanent Level	Marsh Bottom Acreage =	0.24 acres
2.00 acres	0.24 acres	Marsh Permanent Level	
87120.00 sq. ft.	10585.58 sq. ft.	Acreage =	2.00 acres

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
66928.32 cubic ft.	42.12 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.50	0.90	0.45
Building	0.21	0.95	0.20
Landscape/Turf	0.05	0.40	0.02
Stormwater Wetland	0.24	1.00	0.24
			0.91 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

66928.32 cubic ft. =V
0.91 =c
42.12 acres =a

$$\frac{V}{(c)\,(a)\,(3630\text{ cu. ft. /ac. in.})} = i$$

$$\frac{66928.32\text{ cubic ft.}}{0.91 * 42.12\text{ acres} * 3630\text{ cu. ft./ac. in.}} = 0.48\text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infiltration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate

1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)

8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season

72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\,p\,t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02\text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth = 1.37 feet	Rainfall needed to fill Marsh = 0.48 inches
Daily Water Loss = 0.56 feet	Rainfall received Bi-Weekly = 2.30 inches
Dry Down Time = 2.45 days	

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	166.53 feet	108.48 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	58.05 feet	1.3%

Marsh Intermediate Water Level Sizing

(Detains remainder of 1st 100yr 1hr Storm)

V = 181629.57 cubic ft

A_1	A_2	Formula
Marsh Permanent Level	Marsh Inter. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
2.00 acres	3.69 acres	$\frac{181629.57 \text{ cubic ft.}}{123928.20 \text{ sq. ft.}}$ = 1.47 feet
87120.00 sq. ft.	160736.40 sq. ft.	

Grade Check 1.47 feet = Marsh Perm. to Marsh Inter. Depth Change

Slope	Run	r of Marsh Intermediate circle	Run btw Marsh Inter. and Perm.
25.0%	5.86 feet	226.19 feet	59.67 feet
28.5%	5.14 feet	r of Marsh Perm. Circle	Slope
33.0%	4.44 feet	166.53 feet	2.5%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Intermediate Level and Pond High Water Level

D =	2.10 feet	Formula
A_1	A_2	$((A_1+A_2)/2)\ (D) = V$
Marsh Intermediate Level	Marsh High Level	(160736.40 sq ft.+177724.80 sq. ft.) (2.58 feet) / 2
3.69 acres	4.73 acres	= 384924.11 cubic ft.
160736.40 sq. ft.	206038.80 sq. ft.	

Grade Check 2.10' = Marsh Inter. to Marsh High Depth Change

Slope	Run		
		r of Marsh High circle	Run btw Marsh High and Inter.
		256.09 feet	29.90 feet
25.0%	8.40 feet	r of Marsh Intermediate circle	Slope
28.5%	7.36 feet	226.19 feet	7.0%
33.0%	6.36 feet		

Remainder of Second 100 year 1 hour storm

908147.83 cubic ft = V of 100yr Storm

384924.11 cubic ft = V Detained in Marsh Permanent to Marsh High Water Level

523223.73 cubic ft = V to be Detained in Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Detains Remainder of 2nd 100yr 1hr storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
9.98 acres	10.21 acres	523223.73 cubic ft. / 439738.20 sq. ft. = 1.19 feet
434728.80 sq. ft.	444747.60 sq. ft.	

Grade Check 1.19 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run		
		r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	4.76 feet	376.25 feet	4.26 feet
28.5%	4.17 feet	r of Pond/Marsh High circle	Slope
33.0%	3.61 feet	371.99 feet	27.9%

Total Change in Pond Water Height (Permanent to Maximum)

3.56 feet = Pond Permanent to High Water Level Height Change

1.19 feet = Pond/Marsh High to Maximum Water Level Height Change

4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 13 Design Option Two/Drainage Area Two Calculations

Design Option 2-Drainage Area 2 Pond sized to contain a 25 year 1 hour storm. No Stormwater Storage in Parking Areas.				
Total Drainage Area			1151053.52 sq ft	26.42 acres
Hardscape/Pavement Area			886660.51 sq. ft.	20.35 acres
Building Area			245285.99 sq ft	5.63 acres
Landscape/Turf Area			19107.02 sq ft	0.44 acres
Volumes				
100 year 1 hour Storm Volume				
Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q	
26.42 acres	4.50	0.20	=Qn	
20.35 acres	4.50	0.90	=Qd(paved)	
5.63 acres	4.50	0.95	=Qd(building)	
0.44 acres	4.50	0.40	=Qd(turf)	
23.78 =Qn				
82.44 =Qd(paved)			107.30 =Qd(total)	
24.07 =Qd(building)			23.78 =Qn	
0.79 =Qd(turf)			83.52 =Q(resulting)	
107.30 =Qd(total)				
Resulting Q	x 2hr detention time x 60 min x 60sec =			
83.52		7200.00		601325.15 cubic ft.
Cubic Feet to be Detained - 100yr 1hr Storm				
601325.15 cubic ft.				
25 year 1 hour Storm Volume				
Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q	
26.42 acres	3.60	0.20	=Qn	
20.35 acres	3.60	0.90	=Qd(paved)	
5.63 acres	3.60	0.95	=Qd(building)	
0.44 acres	3.60	0.40	=Qd(turf)	
19.03 =Qn				
65.95 =Qd(paved)			85.84 =Qd(total)	
19.26 =Qd(building)			19.03 =Qn	
0.63 =Qd(turf)			66.81 =Q(resulting)	
85.84 =Qd(total)				
Resulting Q	x 2hr detention time x 60 min x 60sec =			
66.81		7200.00		481060.12 cubic ft.
Cubic Feet to be Detained - 25yr 1hr Storm				
481060.12 cubic ft.				

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
20.35 acres	1.70	0.90	=Qd(paved)
5.63 acres	1.70	0.95	=Qd(building)
0.44 acres	1.70	0.40	=Qd(turf)

31.14	=Qd(paved)
9.09	=Qd(building)
0.30	=Qd(turf)
40.54	=Qd(total)

Qd(total)	x 60 min x 60sec =	
40.54	3600.00	145927.29 cubic ft.

Cubic Feet to be Detained -Treatment Volume
145927.29 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
102149.10 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
43778.19 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level`

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula: $\frac{(A_1+A_2)*D}{2.00} = V$

Pond Bottom	Pond Permanent Level		
0.50 acres	3.10 acres	627264.00 cubic ft. / 2.00 =	313632.00 cubic ft.
21780.00 sq. ft.	135036.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
7.20 acres	3.60	26.42 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	207.32 feet	124.06 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	3.2%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)

Sized to contain 70% of Treatment Volume

102149.10 cubic ft. =V

A_1	A_2	Formula
Pond Permanent Level	Pond Treatment Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
3.10 acres	3.18 acres	$\frac{102149.10 \text{ cubic ft.}}{136778.40 \text{ sq. ft.}}$ = 0.75 feet
135036.00 sq. ft.	138520.80 sq. ft.	

Grade Check 0.75 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	2.99 feet	209.98 feet	2.66 feet
28.5%	2.62 feet	r of Pond Permanent circle	Slope
33.0%	2.26 feet	207.32 feet	28.1%

Pond High Water Level Sizing (Detention of a 25 year 1hour storm less Treatment volume)

378911.01 cubic ft. =V

A_1	A_2	Formula
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
3.18 acres	4.00 acres	$\frac{378911.01 \text{ cubic ft.}}{156380.40 \text{ sq. ft.}}$ = 2.42 feet
138520.80 sq. ft.	174240.00 sq. ft.	

Grade Check 2.42 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	9.69 feet	235.50 feet	25.52 feet
28.5%	8.50 feet	r of Pond Treatment circle	Slope
33.0%	7.34 feet	209.98 feet	9.5%

Marsh Permanent/Treatment Water Level Sizing

(Defines Permanent Marsh Level and Treatment Level)

Sized to contain 30% of Treatment Volume

43778.19 cubic ft. =V

1.37' =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{72637.07 \text{ cubic ft.}}{1.37'} = 53019.76 \text{ sq ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh	Second Marsh	Marsh Bottom Acreage =	0.25 acres
Permanent Level	Permanent Level		
0.25 acres	1.22 acres	Marsh Permanent Level	
10890.00 sq. ft.	53019.76 sq. ft.	Acreage =	1.22 acres

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
43778.19 cubic ft.	26.42 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.53	0.90	0.47
Building	0.21	0.95	0.20
Landscape/Turf	0.01	0.40	0.00
Stormwater	0.25	1.00	0.25
Wetland			0.93 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

43778.19 cubic ft. =V
0.93 =c
26.42 acres =a

$$\frac{V}{(c)\ (a)\ (3630 \text{ cu. ft. /ac. in.})} = i$$

$$\frac{43778.19 \text{ cubic ft.}}{0.91 * 42.12 \text{ acres} * 3630 \text{ cu. ft./ac. in.}} = 0.49 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infiltration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate
1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\ p\ t}{36000.00} = ET$$

$$\frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth = 1.37 feet	Rainfall needed to fill Marsh = 0.49 inches
Daily Water Loss = 0.56 feet	Rainfall received Bi-Weekly = 2.30 inches
Dry Down Time = 2.45 days	

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	129.91 feet	71.03 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	58.88 feet	1.9%

Marsh Intermediate Water Level Sizing

(Detains remainder of 1st 100yr 1hr Storm)

V = 120265.03 cubic ft

A_1 Marsh Permanent Level	A_2 Marsh Inter. Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
1.22 acres	2.10 acres	$\frac{120265.03 \text{ cubic ft.}}{72247.88 \text{ sq. ft.}}$ = 1.66 feet
53019.76 sq. ft.	91476.00 sq. ft.	

Grade Check 1.66 feet = Marsh Perm. to Marsh Inter. Depth Change

Slope	Run	r of Marsh Intermediate circle	Run btw Marsh Inter. and Perm.
25.0%	6.66 feet	170.64 feet	40.73 feet
28.5%	5.84 feet	r of Marsh Perm. Circle	Slope
33.0%	5.04 feet	129.91 feet	4.1%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Intermediate Level and Pond High Water Level

D = 1.51 feet

A_1	A_2	Formula
Marsh Intermediate Level	Marsh High Level	$((A_1+A_2)/2)\ (D) = V$
2.10 acres	2.43 acres	$\frac{(160736.40 \text{ sq ft.}+177724.80 \text{ sq. ft.})}{2}$ (2.58 feet)
91476.00 sq. ft.	105850.80 sq. ft.	= 148509.49 cubic ft.

Grade Check 1.51' = Marsh Inter. to Marsh High Depth Change

Slope	Run		
		r of Marsh High circle	Run btw Marsh High and Inter.
25.0%	6.02 feet	183.56 feet	12.92 feet
28.5%	5.28 feet	r of Marsh Intermediate circle	Slope
33.0%	4.56 feet	170.64 feet	11.7%

Remainder of Second 100 year 1 hour storm

601325.15 cubic ft = V of 100yr Storm
148509.49 cubic ft = V Detained in Marsh Permanent to Marsh High Water Level
452815.66 cubic ft = V to be Detained in Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing
(Detains Remainder of 2nd 100yr 1hr storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
6.43 acres	6.70 acres	$\frac{452815.66 \text{ cubic ft.}}{285971.40 \text{ sq. ft.}}$ = 1.58 feet
280090.80 sq. ft.	291852.00 sq. ft.	

Grade Check 1.58 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run		
		r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	6.33 feet	304.79 feet	6.20 feet
28.5%	5.56 feet	r of Pond/Marsh High circle	Slope
33.0%	4.80 feet	298.59 feet	25.5%

Total Change in Pond Water Height (Permanent to Maximum)

3.17 feet = Pond Permanent to High Water Level Height Change
1.58 feet = Pond/Marsh High to Maximum Water Level Height Change
4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 14 Design Option Two/Drainage Area Three Calculations

Design Option 2-Drainage Area 3 Pond sized to contain a 25 year 1 hour storm.
No Stormwater Storage in Parking Areas.

Total Drainage Area	1248196.87 sq ft	28.65 acres
Hardscape/Pavement Area	956931.30 sq. ft.	21.97 acres
Building Area	216847.51 sq ft	4.98 acres
Landscape/Turf Area	74418.06 sq ft	1.71 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
28.65 acres	4.50	0.20	=Qn
21.97 acres	4.50	0.90	=Qd(paved)
4.98 acres	4.50	0.95	=Qd(building)
1.71 acres	4.50	0.40	=Qd(turf)

25.79	=Qn		
88.97	=Qd(paved)	113.33	=Qd(total)
21.28	=Qd(building)	25.79	=Qn
3.08	=Qd(turf)	87.54	=Q(resulting)
113.33	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
87.54	7200.00	630276.07 cubic ft.

Cubic Feet to be Detained - 100yr 1hr Storm
630276.07 cubic ft.

25 year 1 hour Storm Volume

Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q
28.65 acres	3.60	0.20	=Qn
21.97 acres	3.60	0.90	=Qd(paved)
4.98 acres	3.60	0.95	=Qd(building)
1.71 acres	3.60	0.40	=Qd(turf)

20.63	=Qn		
71.18	=Qd(paved)	90.66	=Qd(total)
17.03	=Qd(building)	20.63	=Qn
2.46	=Qd(turf)	70.03	=Q(resulting)
90.66	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
70.03	7200.00	504220.85 cubic ft.

Cubic Feet to be Detained - 25yr 1hr Storm
504220.85 cubic ft.

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
21.97 acres	1.70	0.90	=Qd(paved)
4.98 acres	1.70	0.95	=Qd(building)
1.71 acres	1.70	0.40	=Qd(turf)

33.61	=Qd(paved)
8.04	=Qd(building)
1.16	=Qd(turf)
42.81	=Qd(total)

Qd(total)	x 60 min x 60sec =	
42.81	3600.00	154125.45 cubic ft.

Cubic Feet to be Detained -Treatment Volume

154125.45 cubic ft.

Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)

107887.81 cubic ft.

Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume

46237.63 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level`

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula

$$\frac{(A_1+A_2)*D}{2.00} = V$$

Pond Bottom	Pond Permanent Level		
0.50 acres	3.63 acres	$\frac{719611.20 \text{ cubic ft.}}{2.00}$ =	359805.60 cubic ft.
21780.00 sq. ft.	158122.80 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
8.26 acres	4.13	28.65 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	224.35 feet	141.08 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	2.8%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)
Sized to contain 70% of Treatment Volume

107887.81 cubic ft. =V

A_1	A_2
Pond Permanent Level	Pond Treatment Level
3.63 acres	3.72 acres
158122.80 sq. ft.	162043.20 sq. ft.

Formula

$$\frac{V}{(A_1+A_2)/2} = \text{Depth}$$

$$\frac{107887.81 \text{ cubic ft.}}{160083.00 \text{ sq. ft.}} = 0.67 \text{ feet}$$

Grade Check 0.67 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run		Run btw Pond Treat. and Perm.
		r of Pond Treatment circle	
25.0%	2.70 feet	227.11 feet	2.76 feet
28.5%	2.36 feet	r of Pond Permanent circle	Slope
33.0%	2.04 feet	224.35 feet	24.4%

Pond High Water Level Sizing (Detention of a 25 year 1hour storm less Treatment volume)

396333.04 cubic ft. =V

A_1	A_2
Pond Treatment Level	Pond High Level
3.72 acres	4.25 acres
162043.20 sq. ft.	185130.00 sq. ft.

Formula

$$\frac{V}{(A_1+A_2)/2} = \text{Depth}$$

$$\frac{396333.04 \text{ cubic ft.}}{173586.60 \text{ sq. ft.}} = 2.28 \text{ feet}$$

Grade Check 2.28 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	9.13 feet	242.75 feet	15.64 feet
28.5%	8.01 feet	r of Pond Treatment circle	Slope
33.0%	6.92 feet	227.11 feet	14.6%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

46237.63 cubic ft. =V
1.37' =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{17878.77 \text{ cubic ft.}}{1.37'} = 13050.20 \text{ sq ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh	Second Marsh	Marsh Bottom Acreage =	0.30 acres
Permanent Level	Permanent Level		
1.25 acres	0.30 acres	Marsh Permanent Level	
54450.00 sq. ft.	13050.20 sq. ft.	Acreage =	1.25 acres

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
46237.63 cubic ft.	28.65 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.55	0.90	0.50
Building	0.17	0.95	0.17
Landscape/Turf	0.03	0.40	0.01
Stormwater	0.24	1.00	0.24
Wetland			0.92 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

46237.63 cubic ft. =V
0.92 =c
28.65 acres =a

$$\frac{V}{(c)\,(a)\,(3630\text{ cu. ft. /ac. in.})} = i$$

$$\frac{46237.63\text{ cubic ft.}}{0.91*42.12\text{ acres}*3630\text{ cu. ft./ac. in.}} = 0.48\text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infiltration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate
1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\,p\,t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02\text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth =	1.37 feet	Rainfall needed to fill Marsh =	0.48 inches
Daily Water Loss =	0.56 feet	Rainfall received Bi-Weekly =	2.30 inches
Dry Down Time =	2.45 days		

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	131.65 feet	67.20 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	64.45 feet	2.0%

Marsh Intermediate Water Level Sizing

(Detains remainder of 1st 100yr 1hr Storm)

V = 126055.21 cubic ft

A_1 Marsh Permanent Level	A_2 Marsh Inter. Level	Formula
1.25 acres	1.86 acres	$\frac{V}{(A_1+A_2)/2}$ = Depth
54450.00 sq. ft.	81021.60 sq. ft.	$\frac{126055.21 \text{ cubic ft.}}{67735.80 \text{ sq. ft.}}$ = 1.86 feet

Grade Check 1.86 feet = Marsh Perm. to Marsh Inter. Depth Change

Slope	Run	r of Marsh Intermediate circle	Run btw Marsh Inter. and Perm.
25.0%	7.44 feet	160.59 feet	28.94 feet
28.5%	6.53 feet	r of Marsh Perm. Circle	Slope
33.0%	5.64 feet	131.65 feet	6.4%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Intermediate Level and Pond High Water Level

A_1	A_2	Formula
D =	1.10 feet	$((A_1+A_2)/2)\ (D) = V$
Marsh Intermediate Level	Marsh High Level	$\frac{(160736.40 \text{ sq ft.}+177724.80 \text{ sq. ft.})}{2}$ (2.58 feet)
1.86 acres	2.39 acres	= 101466.63 cubic ft.
81021.60 sq. ft.	104108.40 sq. ft.	

Grade Check 1.10' = Marsh Inter. to Marsh High Depth Change

Slope	Run		
		r of Marsh High circle	Run btw Marsh High and Inter.
		182.04 feet	
25.0%	4.38 feet	r of Marsh Intermediate circle	21.45 feet
28.5%	3.85 feet		Slope
33.0%	3.32 feet	160.59 feet	5.1%

Remainder of Second 100 year 1 hour storm

630276.07 cubic ft = V of 100yr Storm
101466.63 cubic ft = V Detained in Marsh Permanent to Marsh High Water Level
528809.43 cubic ft = V to be Detained in Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing
(Detains Remainder of 2nd 100yr 1hr storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
6.64 acres	6.94 acres	$\frac{528809.43 \text{ cubic ft.}}{295772.40 \text{ sq. ft.}}$ = 1.79 feet
289238.40 sq. ft.	302306.40 sq. ft.	

Grade Check 1.79 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run		
		r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	7.15 feet	310.20 feet	
28.5%	6.27 feet	r of Pond/Marsh High circle	6.78 feet
33.0%	5.42 feet		Slope
		303.43 feet	26.4%

Total Change in Pond Water Height (Permanent to Maximum)

2.96 feet = Pond Permanent to High Water Level Height Change
1.79 feet = Pond/Marsh High to Maximum Water Level Height Change
4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 15 Design Option Three/Drainage Area One Calculations

Design Option 3-Drainage Area 1 Pond sized to contain a 25 year 1 hour storm. Stormwater Storage in Parking Areas.

Total Drainage Area	1834764.66 sq. ft.	42.12 acres
Hardscape/Pavement Area	1278875.74 sq. ft.	29.36 acres
Building Area	390115.47 sq ft	8.96 acres
Landscape/Turf Area	165773.45 sq ft	3.81 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
42.12 acres	4.50	0.20	=Qn
29.36 acres	4.50	0.90	=Qd(paved)
8.96 acres	4.50	0.95	=Qd(building)
3.81 acres	4.50	0.40	=Qd(turf)

37.91	=Qn		
118.90	=Qd(paved)	164.04	=Qd(total)
38.29	=Qd(building)	37.91	=Qn
6.85	=Qd(turf)	126.13	=Q(resulting)
164.04	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
126.13	7200.00	908147.83 cubic ft.

Cubic Feet to be Detained - 100yr 1hr Storm
908147.83 cubic ft.

25 year 1 hour Storm Volume

Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q
42.12 acres	3.60	0.20	=Qn
29.36 acres	3.60	0.90	=Qd(paved)
8.96 acres	3.60	0.95	=Qd(building)
3.81 acres	3.60	0.40	=Qd(turf)

30.33	=Qn		
95.12	=Qd(paved)	131.23	=Qd(total)
30.63	=Qd(building)	30.33	=Qn
5.48	=Qd(turf)	100.91	=Q(resulting)
131.23	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
100.91	7200.00	726518.27 cubic ft.

Cubic Feet to be Detained - 25yr 1hr Storm
726518.27 cubic ft.

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
29.36 acres	1.70	0.90	=Qd(paved)
8.96 acres	1.70	0.95	=Qd(building)
3.81 acres	1.70	0.40	=Qd(turf)

44.92	=Qd(paved)
14.46	=Qd(building)
2.59	=Qd(turf)
61.97	=Qd(total)

Qd(total)	x 60 min x 60sec =	
61.97	3600.00	223094.41 cubic ft.

Cubic Feet to be Detained -Treatment Volume
223094.41 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
156166.08 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
66928.32 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula: $\frac{(A_1+A_2)*D}{2.00} = V$

Pond Bottom	Pond Permanent Level		
0.50 acres	3.50 acres	696960.00 cubic ft. / 2.00 =	348480.00 cubic ft.
21780.00 sq. ft.	152460.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
8.00 acres	4.00	42.12 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	220.29 feet	137.03 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	2.9%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)
Sized to contain 70% of Treatment Volume

156166.08 cubic ft. =V

A_1	A_2	Formula
Pond Permanent Level	Pond Treatment Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
3.50 acres	3.75 acres	$\frac{156166.08 \text{ cubic ft.}}{157905.00 \text{ sq. ft.}}$ = 0.99 feet
152460.00 sq. ft.	163350.00 sq. ft.	

Grade Check 0.99 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	3.96 feet	228.03 feet	7.73 feet
28.5%	3.47 feet	r of Pond Permanent circle	Slope
33.0%	3.00 feet	220.29 feet	12.8%

Pond High Water Level Sizing (Detention of a 25 year 1hour storm less Treatment volume)

570352.18 cubic ft. =V

A_1	A_2	Formula
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
3.75 acres	5.00 acres	$\frac{570352.18 \text{ cubic ft.}}{190575.00 \text{ sq. ft.}}$ = 2.99 feet
163350.00 sq. ft.	217800.00 sq. ft.	

Grade Check 2.99 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	11.97 feet	263.30 feet	35.28 feet
28.5%	10.50 feet	r of Pond Treatment circle	Slope
33.0%	9.07 feet	228.03 feet	8.5%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

66928.32 cubic ft. =V
1.37' =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{14502.24 \text{ cubic ft.}}{1.37'} = 10585.58 \text{ sq ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh	Second Marsh	Marsh Bottom Acreage =	0.24 acres
Permanent Level	Permanent Level		
2.00 acres	0.24 acres	Marsh Permanent Level	
87120.00 sq. ft.	10585.58 sq. ft.	Acreage = 2.00 acres	

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
66928.32 cubic ft.	42.12 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.34	0.90	0.30
Building	0.21	0.95	0.20
Landscape/Turf	0.05	0.40	0.02
Stormwater Wetland	0.40	1.00	0.40
			0.93 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

66928.32 cubic ft. =V
0.93 =c
42.12 acres =a

$$\frac{V}{(c)\ (a)\ (3630 \text{ cu. ft. /ac. in.})} = i$$

$$\frac{66928.32 \text{ cubic ft.}}{0.91 * 42.12 \text{ acres} * 3630 \text{ cu. ft./ac. in.}} = 0.47 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate
1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\ p\ t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth =	1.37 feet	Rainfall needed to fill Marsh =	0.47 inches
Daily Water Loss =	0.56 feet	Rainfall received Bi-Weekly =	2.30 inches
Dry Down Time =	2.45 days		

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	166.53 feet	108.48 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	58.05 feet	1.3%

Marsh Intermediate Water Level Sizing

(Detains remainder of 1st 100yr 1hr Storm)

V = 181629.57 cubic ft

A_1 Marsh Permanent Level	A_2 Marsh Inter. Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
2.00 acres	4.25 acres	$\frac{181629.57 \text{ cubic ft.}}{136125.00 \text{ sq. ft.}}$ = 1.33 feet
87120.00 sq. ft.	185130.00 sq. ft.	

Grade Check 1.33 feet = Marsh Perm. to Marsh Inter. Depth Change

Slope	Run	r of Marsh Intermediate circle	Run btw Marsh Inter. and Perm.
25.0%	5.34 feet	242.75 feet	76.23 feet
28.5%	4.68 feet	r of Marsh Perm. Circle	Slope
33.0%	4.04 feet	166.53 feet	1.8%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Intermediate Level and Pond High Water Level

D = 2.65 feet

A_1	A_2	Formula
		$((A_1+A_2)/2)\ (D) = V$
Marsh Intermediate Level	Marsh High Level	$\frac{(160736.40 \text{ sq ft.} + 177724.80 \text{ sq. ft.})}{2}$ (2.58 feet)
4.25 acres	4.80 acres	= 521845.86 cubic ft.
185130.00 sq. ft.	209088.00 sq. ft.	

Grade Check 2.65' = Marsh Inter. to Marsh High Depth Change

Slope	Run		
		r of Marsh High circle	Run btw Marsh High and Inter.
		257.98 feet	
25.0%	10.59 feet	r of Marsh Intermediate circle	15.23 feet
28.5%	9.29 feet		Slope
33.0%	8.02 feet	242.75 feet	17.4%

Remainder of Second 100 year 1 hour storm

908147.83 cubic ft = V of 100yr Storm

521845.86 cubic ft = V Detained in Marsh Permanent to Marsh High Water Level

386301.98 cubic ft = V to be Detained in Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Detains Remainder of 2nd 100yr 1hr storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
9.80 acres	17.00 acres	$\frac{386301.98 \text{ cubic ft.}}{583704.00 \text{ sq. ft.}}$ = 0.66 feet
426888.00 sq. ft.	740520.00 sq. ft.	

Grade Check 0.66 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run		
		r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	2.65 feet	485.50 feet	
28.5%	2.32 feet	r of Pond/Marsh High circle	116.88 feet
33.0%	2.01 feet		Slope
		368.62 feet	0.6%

Total Change in Pond Water Height (Permanent to Maximum)

3.98 feet = Pond Permanent to High Water Level Height Change

0.66 feet = Pond/Marsh High to Maximum Water Level Height Change

4.64 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

0.66 foot is the maximum depth in parking areas. (Urbonas and Stahre 1993, 36)

Table 16 Design Option Three/Drainage Area Two Calculations

Design Option 3-Drainage Area 2 Pond sized to contain a 25 year 1 hour storm. Stormwater Storage in Parking Areas.

Total Drainage Area	1151053.52 sq. ft.	26.42 acres
Hardscape/Pavement Area	886660.51 sq. ft.	20.35 acres
Building Area	245285.99 sq ft	5.63 acres
Landscape/Turf Area	19107.02 sq ft	0.44 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
26.42 acres	4.50	0.20	=Qn
20.35 acres	4.50	0.90	=Qd(paved)
5.63 acres	4.50	0.95	=Qd(building)
0.44 acres	4.50	0.40	=Qd(turf)

23.78	=Qn		
82.44	=Qd(paved)	107.30	=Qd(total)
24.07	=Qd(building)	23.78	=Qn
0.79	=Qd(turf)	83.52	=Q(resulting)
107.30	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
83.52	7200.00	601325.15 cubic ft.

Cubic Feet to be Detained - 100yr 1hr Storm
601325.15 cubic ft.

25 year 1 hour Storm Volume

Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q
26.42 acres	3.60	0.20	=Qn
20.35 acres	3.60	0.90	=Qd(paved)
5.63 acres	3.60	0.95	=Qd(building)
0.44 acres	3.60	0.40	=Qd(turf)

19.03	=Qn		
65.95	=Qd(paved)	85.84	=Qd(total)
19.26	=Qd(building)	19.03	=Qn
0.63	=Qd(turf)	66.81	=Q(resulting)
85.84	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
66.81	7200.00	481060.12 cubic ft.

Cubic Feet to be Detained - 25yr 1hr Storm
481060.12 cubic ft.

Treatment Volume			
Acres	90th Percentile Storm	Runoff Coefficent	Q
20.35 acres	1.70	0.90	=Qd(paved)
5.63 acres	1.70	0.95	=Qd(building)
0.44 acres	1.70	0.40	=Qd(turf)

31.14	=Qd(paved)
9.09	=Qd(building)
0.30	=Qd(turf)
40.54	=Qd(total)

Qd(total)	x 60 min x 60sec =	
40.54	3600.00	145927.29 cubic ft.

Cubic Feet to be Detained -Treatment Volume
145927.29 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
102149.10 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
43778.19 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level`

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula: $\frac{(A_1+A_2)*D}{2.00} = V$

Pond Bottom	Pond Permanent Level		
0.50 acres	2.00 acres	435600.00 cubic ft. / 2.00 =	217800.00 cubic ft.
21780.00 sq. ft.	87120.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
5.00 acres	2.50	26.42 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	166.53 feet	83.26 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	4.8%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)
Sized to contain 70% of Treatment Volume

102149.10 cubic ft. =V

A_1 Pond Permanent Level	A_2 Pond Treatment Level
2.00 acres	2.70 acres
87120.00 sq. ft.	117612.00 sq. ft.

Formula

$$\frac{V}{(A_1+A_2)/2} = \text{Depth}$$

$$\frac{102149.10 \text{ cubic ft.}}{102366.00 \text{ sq. ft.}} = 1.00 \text{ feet}$$

Grade Check 1.00 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	3.99 feet	193.49 feet	26.96 feet
28.5%	3.50 feet	r of Pond Permanent circle	Slope
33.0%	3.02 feet	166.53 feet	3.7%

Pond High Water Level Sizing (Detention of a 25 year 1hour storm less Treatment volume)

378911.01 cubic ft. =V

A_1 Pond Treatment Level	A_2 Pond High Level
2.70 acres	3.10 acres
117612.00 sq. ft.	135036.00 sq. ft.

Formula

$$\frac{V}{(A_1+A_2)/2} = \text{Depth}$$

$$\frac{378911.01 \text{ cubic ft.}}{126324.00 \text{ sq. ft.}} = 3.00 \text{ feet}$$

Grade Check 3.00 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	12.00 feet	207.32 feet	13.84 feet
28.5%	10.52 feet	r of Pond Treatment circle	Slope
33.0%	9.09 feet	193.49 feet	21.7%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

43778.19 cubic ft. =V
1.37' =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{72637.07 \text{ cubic ft.}}{1.37'} = 53019.76 \text{ sq ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh	Second Marsh	Marsh Bottom Acreage =	0.25 acres
Permanent Level	Permanent Level		
0.25 acres	1.22 acres	Marsh Permanent Level	
10890.00 sq. ft.	53019.76 sq. ft.	Acreage = 1.22 acres	

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
43778.19 cubic ft.	26.42 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.32	0.90	0.29
Building	0.21	0.95	0.20
Landscape/Turf	0.01	0.40	0.00
Stormwater Wetland	0.45	1.00	0.45
			0.95 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

43778.19 cubic ft. =V
0.95 =c
26.42 acres =a

$$\frac{V}{(c)\ (a)\ (3630 \text{ cu. ft. /ac. in.})} = i$$

$$\frac{43778.19 \text{ cubic ft.}}{0.91*42.12 \text{ acres}*3630 \text{ cu. ft./ac. in.}} = 0.48 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate
1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\ p\ t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth =	1.37 feet	Rainfall needed to fill Marsh =	0.48 inches
Daily Water Loss =	0.56 feet	Rainfall received Bi-Weekly =	2.30 inches
Dry Down Time =	2.45 days		

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	129.91 feet	71.03 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	58.88 feet	1.9%

Marsh Intermediate Water Level Sizing

(Detains remainder of 1st 100yr 1hr Storm)

V = 120265.03 cubic ft

A_1 Marsh Permanent Level	A_2 Marsh Inter. Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
1.22 acres	2.50 acres	$\frac{120265.03 \text{ cubic ft.}}{80959.88 \text{ sq. ft.}}$ = 1.49 feet
53019.76 sq. ft.	108900.00 sq. ft.	

Grade Check 1.49 feet = Marsh Perm. to Marsh Inter. Depth Change

Slope	Run	r of Marsh Intermediate circle	Run btw Marsh Inter. and Perm.
25.0%	5.94 feet	186.18 feet	56.27 feet
28.5%	5.21 feet	r of Marsh Perm. Circle	Slope
33.0%	4.50 feet	129.91 feet	2.6%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Intermediate Level and Pond High Water Level

D = 2.51 feet		Formula
A_1	A_2	$((A_1+A_2)/2)\ (D) = V$
Marsh Intermediate Level	Marsh High Level	$\frac{(160736.40 \text{ sq ft.}+177724.80 \text{ sq. ft.})}{2}$ (2.58 feet)
2.50 acres	3.60 acres	= 333727.23 cubic ft.
108900.00 sq. ft.	156816.00 sq. ft.	

Grade Check 2.51' = Marsh Inter. to Marsh High Depth Change

Slope	Run		
		r of Marsh High circle	Run btw Marsh High and Inter.
		223.42 feet	
25.0%	10.05 feet	r of Marsh Intermediate circle	37.24 feet
28.5%	8.81 feet		Slope
33.0%	7.61 feet	186.18 feet	6.7%

Remainder of Second 100 year 1 hour storm

601325.15 cubic ft = V of 100yr Storm
333727.23 cubic ft = V Detained in Marsh Permanent to Marsh High Water Level
267597.92 cubic ft = V to be Detained in Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Detains Remainder of 2nd 100yr 1hr storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
6.70 acres	12.00 acres	$\frac{267597.92 \text{ cubic ft.}}{407286.00 \text{ sq. ft.}}$ = 0.66 feet
291852.00 sq. ft.	522720.00 sq. ft.	

Grade Check 0.66 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run		
		r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	2.63 feet	407.91 feet	
28.5%	2.31 feet	r of Pond/Marsh High circle	103.11 feet
33.0%	1.99 feet		Slope
		304.79 feet	0.6%

Total Change in Pond Water Height (Permanent to Maximum)

4.00 feet = Pond Permanent to High Water Level Height Change
0.66 feet = Pond/Marsh High to Maximum Water Level Height Change
4.65 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

0.66 foot is the maximum depth in parking areas. (Urbonas and Stahre 1993, 36)

Table 17 Design Option Three/Drainage Area Three Calculations

Design Option 3-Drainage Area 3 Pond sized to contain a 25 year 1 hour storm. Stormwater Storage in Parking Areas.

Total Drainage Area	1248196.87 sq. ft.	28.65 acres
Hardscape/Pavement Area	956931.30 sq. ft.	21.97 acres
Building Area	216847.51 sq ft	4.98 acres
Landscape/Turf Area	74418.06 sq ft	1.71 acres

Volumes

100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
28.65 acres	4.50	0.20	=Qn
21.97 acres	4.50	0.90	=Qd(paved)
4.98 acres	4.50	0.95	=Qd(building)
1.71 acres	4.50	0.40	=Qd(turf)

25.79	=Qn		
88.97	=Qd(paved)	113.33	=Qd(total)
21.28	=Qd(building)	25.79	=Qn
3.08	=Qd(turf)	87.54	=Q(resulting)
113.33	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
87.54	7200.00	630276.07 cubic ft.

Cubic Feet to be Detained - 100yr 1hr Storm
630276.07 cubic ft.

25 year 1 hour Storm Volume

Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q
28.65 acres	3.60	0.20	=Qn
21.97 acres	3.60	0.90	=Qd(paved)
4.98 acres	3.60	0.95	=Qd(building)
1.71 acres	3.60	0.40	=Qd(turf)

20.63	=Qn		
71.18	=Qd(paved)	90.66	=Qd(total)
17.03	=Qd(building)	20.63	=Qn
2.46	=Qd(turf)	70.03	=Q(resulting)
90.66	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
70.03	7200.00	504220.85 cubic ft.

Cubic Feet to be Detained - 25yr 1hr Storm
504220.85 cubic ft.

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
21.97 acres	1.70	0.90	=Qd(paved)
4.98 acres	1.70	0.95	=Qd(building)
1.71 acres	1.70	0.40	=Qd(turf)

33.61	=Qd(paved)
8.04	=Qd(building)
1.16	=Qd(turf)
42.81	=Qd(total)

Qd(total)	x 60 min x 60sec =	
42.81	3600.00	154125.45 cubic ft.

Cubic Feet to be Detained -Treatment Volume
154125.45 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
107887.81 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
46237.63 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level`

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula

$$\frac{(A_1+A_2)*D}{2.00} = V$$

Pond Bottom	Pond Permanent Level		
0.50 acres	2.00 acres	435600.00 cubic ft. / 2.00 =	217800.00 cubic ft.
21780.00 sq. ft.	87120.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
5.00 acres	2.50	28.65 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	166.53 feet	83.26 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	4.8%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)
Sized to contain 70% of Treatment Volume

107887.81 cubic ft. =V

A_1	A_2	Formula	
Pond Permanent Level	Pond Treatment Level	$\frac{V}{(A_1+A_2)/2}$	= Depth
2.00 acres	2.89 acres	$\frac{107887.81 \text{ cubic ft.}}{106504.20 \text{ sq. ft.}}$	= 1.01 feet
87120.00 sq. ft.	125888.40 sq. ft.		

Grade Check 1.01 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	4.05 feet	200.18 feet	33.65 feet
28.5%	3.55 feet	r of Pond Permanent circle	Slope
33.0%	3.07 feet	166.53 feet	3.0%

Pond High Water Level Sizing (Detention of a 25 year 1hour storm less Treatment volume)

396333.04 cubic ft. =V

A_1	A_2	Formula	
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$	= Depth
2.89 acres	3.21 acres	$\frac{396333.04 \text{ cubic ft.}}{132858.00 \text{ sq. ft.}}$	= 2.98 feet
125888.40 sq. ft.	139827.60 sq. ft.		

Grade Check 2.98 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	11.93 feet	210.97 feet	10.79 feet
28.5%	10.47 feet	r of Pond Treatment circle	Slope
33.0%	9.04 feet	200.18 feet	27.6%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)
Sized to contain 30% of Treatment Volume

46237.63 cubic ft. =V
1.37' =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{17878.77 \text{ cubic ft.}}{1.37'} = 13050.20 \text{ sq ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh Permanent Level	Second Marsh Permanent Level	Marsh Bottom Acreage =	0.30 acres
1.25 acres	0.30 acres	Marsh Permanent Level	
54450.00 sq. ft.	13050.20 sq. ft.	Acreage = 1.25 acres	

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
46237.63 cubic ft.	28.65 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.36	0.90	0.32
Building	0.17	0.95	0.17
Landscape/Turf	0.03	0.40	0.01
Stormwater Wetland	0.44	1.00	0.44
			0.94 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres
V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

46237.63 cubic ft. =V
0.94 =c
28.65 acres =a

$$\frac{V}{(c)\,(a)\,(3630 \text{ cu. ft. /ac. in.})} = i$$

$$\frac{46237.63 \text{ cubic ft.}}{0.91{*}42.12 \text{ acres}{*}3630 \text{ cu. ft./ac. in.}} = 0.47 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate
1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)
8.72 =p

t= Monthly Mean Tempurature during Marsh Growing Season
72.50 =t

36,000= Conversion factor to get "inches per month" to "feet per day"

$$\frac{(1.2)\,p\,t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth =	1.37 feet	Rainfall needed to fill Marsh =	0.47 inches
Daily Water Loss =	0.56 feet	Rainfall received Bi-Weekly =	2.30 inches
Dry Down Time =	2.45 days		

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	131.65 feet	67.20 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	64.45 feet	2.0%

Marsh Intermediate Water Level Sizing

(Detains remainder of 1st 100yr 1hr Storm)

V = 126055.21 cubic ft

A_1 Marsh Permanent Level	A_2 Marsh Inter. Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
1.25 acres	2.50 acres	$\frac{126055.21 \text{ cubic ft.}}{81675.00 \text{ sq. ft.}}$ = 1.54 feet
54450.00 sq. ft.	108900.00 sq. ft.	

Grade Check 1.54 feet = Marsh Perm. to Marsh Inter. Depth Change

Slope	Run	r of Marsh Intermediate circle	Run btw Marsh Inter. and Perm.
25.0%	6.17 feet	186.18 feet	54.53 feet
28.5%	5.42 feet	r of Marsh Perm. Circle	Slope
33.0%	4.68 feet	131.65 feet	2.8%

Marsh High Water Level Sizing (Detains portion of 2nd 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Intermediate Level and Pond High Water Level

D = 2.45 feet

A_1	A_2	Formula
		$((A_1+A_2)/2)\ (D) = V$
Marsh Intermediate Level	Marsh High Level	$\frac{(160736.40 \text{ sq ft.}+177724.80 \text{ sq. ft.})}{2}$ (2.58 feet)
2.50 acres	4.00 acres	= 347235.55 cubic ft.
108900.00 sq. ft.	174240.00 sq. ft.	

Grade Check 2.45' = Marsh Inter. to Marsh High Depth Change

Slope	Run		
		r of Marsh High circle	Run btw Marsh High and Inter.
		235.50 feet	49.32 feet
25.0%	9.81 feet	r of Marsh Intermediate circle	Slope
28.5%	8.61 feet	186.18 feet	5.0%
33.0%	7.43 feet		

Remainder of Second 100 year 1 hour storm

630276.07 cubic ft = V of 100yr Storm
347235.55 cubic ft = V Detained in Marsh Permanent to Marsh High Water Level
283040.52 cubic ft = V to be Detained in Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing
(Detains Remainder of 2nd 100yr 1hr storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
7.21 acres	12.50 acres	$\frac{283040.52 \text{ cubic ft.}}{429283.80 \text{ sq. ft.}}$ = 0.66 feet
314067.60 sq. ft.	544500.00 sq. ft.	

Grade Check 0.66 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run		
		r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	2.64 feet	416.32 feet	100.14 feet
28.5%	2.31 feet	r of Pond/Marsh High circle	Slope
33.0%	2.00 feet	316.18 feet	0.7%

Total Change in Pond Water Height (Permanent to Maximum)

4.00 feet = Pond Permanent to High Water Level Height Change
0.66 feet = Pond/Marsh High to Maximum Water Level Height Change
4.66 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

0.66 foot is the maximum depth in parking areas. (Urbonas and Stahre 1993, 36)

Table 18 Alternative Design One Calculations

Design Alternative 1-Drainage Area 1 Pond/Marsh to detain One 100 year 1 hour storm. No Stormwater Storage in Parking Areas.				
Total Drainage Area		1834764.66 sq. ft.		42.12 acres
Hardscape/Pavement Area		1278875.74 sq. ft.		29.36 acres
Building Area		390115.47 sq. ft.		8.96 acres
Landscape/Turf Area		165773.45 sq. ft.		3.81 acres
Volumes				
100 year 1 hour Storm Volume				
Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q	
42.12 acres	4.50	0.20	=Qn	
29.36 acres	4.50	0.90	=Qd(paved)	
8.96 acres	4.50	0.95	=Qd(building)	
3.81 acres	4.50	0.40	=Qd(turf)	
37.91 =Qn				
118.90 =Qd(paved)		164.04 =Qd(total)		
38.29 =Qd(building)		37.91 =Qn		
6.85 =Qd(turf)		126.13 =Q(resulting)		
164.04 =Qd(total)				
Resulting Q	x 2hr detention time x 60 min x 60sec =		Volume	
126.13	7200.00		908147.83 cubic ft.	
Cubic Feet to be Detained - 100 year 1 hour Storm 908147.83 cubic ft.				
25 year 1 hour Storm Volume				
Acres	25yr 1hr Storm in Inches	Runoff Coefficent	Q	
42.12 acres	3.60	0.20	=Qn	
29.36 acres	3.60	0.90	=Qd(paved)	
8.96 acres	3.60	0.95	=Qd(building)	
3.81 acres	3.60	0.40	=Qd(turf)	
30.33 =Qn				
95.12 =Qd(paved)		131.23 =Qd(total)		
30.63 =Qd(building)		30.33 =Qn		
5.48 =Qd(turf)		100.91 =Q(resulting)		
131.23 =Qd(total)				
Resulting Q	x 2hr detention time x 60 min x 60sec =			
100.91	7200.00		726518.27 cubic ft.	
Cubic Feet to be Detained - 25yr 1hr Storm 726518.27 cubic ft.				

Treatment Volume

Acres	90th Percentile Storm	Runoff Coefficent	Q
29.36 acres	1.70	0.90	=Qd(paved)
8.96 acres	1.70	0.95	=Qd(building)
3.81 acres	1.70	0.40	=Qd(turf)

44.92 =Qd(paved)
14.46 =Qd(building)
2.59 =Qd(turf)
61.97 =Qd(total)

Qd(total)	x 60 min x 60sec =	Volume
61.97	3600.00	223094.41 cubic ft.

Cubic Feet to be Detained -Treatment Volume
223094.41 cubic ft.
Pond treats 70% of Volume - Defines Pond Treatment Volume (Schueler 1992, 42)
156166.08 cubic ft.
Marsh treats 30% of Volume - Defines Marsh Permanent/Treatment Volume
66928.32 cubic ft. (Schueler 1992, 42)

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)

Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula

$$\frac{(A_1+A_2)*D}{2.00} = V$$

Pond Bottom	Pond Permanent Level		
0.50 acres	2.00 acres	$\frac{435600.00 \text{ cubic ft.}}{2.00}$ =	217800.00 cubic ft.
21780.00 sq. ft.	87120.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996, 199)

2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
5.00 acres	2.50	42.12 acres	Pass

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	166.53 feet	83.26 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	83.26 feet	4.8%

Pond Treatment Water Level Sizing (Defines Pond Treatment Level)
Sized to contain 70% of Treatment Volume

156166.08 cubic ft. =V

A_1	A_2	Formula
Pond Permanent Level	Pond Treatment Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
2.00 acres	2.25 acres	$\frac{156166.08 \text{ cubic ft.}}{92565.00 \text{ sq. ft.}}$ = 1.69 feet
87120.00 sq. ft.	98010.00 sq. ft.	

Grade Check 1.69 feet = Pond Perm. to Pond Treatment Depth Change

Slope	Run	r of Pond Treatment circle	Run btw Pond Treat. and Perm.
25.0%	6.75 feet	176.63 feet	10.10 feet
28.5%	5.92 feet	r of Pond Permanent circle	Slope
33.0%	5.11 feet	166.53 feet	16.7%

Pond High Water Level Sizing (Detention of a 25yr 1hr Storm less Treatment Volume)

66928.32 cubic ft. =V

A_1	A_2	Formula
Pond Treatment Level	Pond High Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
2.25 acres	2.47 acres	$\frac{66928.32 \text{ cubic ft.}}{102801.60 \text{ sq. ft.}}$ = 0.65 feet
98010.00 sq. ft.	107593.20 sq. ft.	

Grade Check 0.65 feet = Pond Treatment to Pond High Depth Change

Slope	Run	r of Pond High Water circle	Run btw Pond High and Treat.
25.0%	2.60 feet	185.06 feet	8.43 feet
28.5%	2.28 feet	r of Pond Treatment circle	Slope
33.0%	1.97 feet	176.63 feet	7.7%

Marsh Permanent/Treatment Water Level Sizing
(Defines Permanent Marsh Level and Treatment Level)

Sized to contain 30% of Treatment Volume

66928.32 cubic ft. =V
1.37 =D

Formula

$$\frac{2V - (A_1 \times D)}{D} = A_2$$

$$\frac{44340.84 \text{ cubic ft.}}{1.37} = 32365.58 \text{ sq. ft.}$$

Marsh Permanent/Treatment Water Level Sizing (cont.)

A_1	A_2		
First Marsh Permanent Level	Second Marsh Permanent Level	Marsh Bottom Acreage =	0.74 acres
1.50 acres	0.74 acres	Marsh Permanent Level	
65340.00 sq. ft.	32365.58 sq. ft.	Acreage = 1.50 acres	

Marsh Viability Check (Garbish 1995, 89-99)

Volume	Drainage Area	Runoff Coefficent	Drainage Area
66928.32179	42.12 acres	(of Cover Types)	Runoff Coefficent
Land Cover Type	Percentage		
Parking/Hardscape	0.63	0.90	0.56
Building	0.21	0.95	0.20
Landscape/Turf	0.05	0.40	0.02
Stormwater Wetland	0.12	1.00	0.12
			0.90 =c

The Stormwater Wetland area is equal to the Pond/Marsh Maximum water level for this set of calculations. It is assumed that half of the actual Landscape/Turf area will be used for the installation of the Stormwater Wetland. Any additional area needed for the installation will be subtracted from the Parking/Hardscape area. These assumptions are for the Marsh Viability Check**ONLY**.

Rainfall Needed To Fill the Stormwater Wetland

i =Usual 2 Week Precipitation required to fill Marsh, a=Drainage Area in Acres

V=Volume need to fill Marsh, c=Drainage Area Runoff Coefficent

66928.32 cubic ft. =V

0.90 =c

42.12 acres =a

$$\frac{V}{(c)\ (a)\ (3630 \text{ cu. ft./ac. in.})} = i$$

$$\frac{66928.32 \text{ cubic ft.}}{0.91*42.12 \text{ acres}*3630 \text{ cu. ft./ac. in.}} = 0.49 \text{ inches}$$

Infilitration Rate

The site is composed of a "Silt Loam" soil with an infilitration rate of 0.54 feet/day

Evapotranspiration Rate

ET = Evapotranspiration Rate

1.2= Consumptive Use of Water in inches for Rice per Month

p= Average Daytime Hours during Marsh Growing Season (3/1-11/30)

t= Monthly Mean Tempurature during Marsh Growing Season

8.72 =p

72.50 =t

36,000= Conversion factor to get "inches per month" to 'feet per day"

$$\frac{(1.2)\ p\ t}{36000.00} = ET \qquad \frac{758.64}{36000.00} = 0.02 \text{ feet}$$

Marsh Viability Check (cont.)

Total Daily Loss of Water (Infiltration rate and ET rate)

Infilltration = 0.54 feet/day
ET = 0.02 feet/day
0.56 feet/day

Biweekly Rainfall equals 2.30 inches during the Marsh Growing Season. Determined by averaging monthly rainfall amounts into two week periods for the Marsh Growing Season. Bi-Weekly Rainfall is considered as arriving in one 24 hour period.

Results

Marsh Depth = 1.37 feet	Rainfall needed to fill Marsh = 0.49 inches
Daily Water Loss = 0.56 feet	Rainfall received Bi-Weekly = 2.30 inches
Dry Down Time = 2.45 days	

Marsh will dry down every two days but will fill completely every two weeks.
Marshes classified as "Permanently Flooded" will tolerate dry conditions for 2 weeks.

Marsh Viability Check = Pass

Marsh will be a "Permanently Flooded" Marsh.

Grade Check 1.37 feet = Marsh Bottom to Permanent Depth

Slope	Run	r of Marsh Permanent circle	Run btw Marsh Perm. and Bottom
25.0%	5.48 feet	144.22 feet	42.72 feet
28.5%	4.81 feet	r of Marsh Bottom circle	Slope
33.0%	4.15 feet	101.50 feet	3.2%

Marsh High Water Level Sizing (Detains portion of 100yr 1hr storm to equalize Pond and Marsh High Water Level)

D = Difference between Marsh Permanent Level and Pond High Water Level

D = 2.34 feet

A_1 Marsh Permanent Level	A_2 Marsh High Level
1.50 acres	2.13 acres
65340.00 sq. ft.	92782.80 sq. ft.

Formula

$((A_1+A_2)/2)\ (D) = V$

$$\frac{(87120.00 \text{ sq ft.} + 113256.00 \text{ sq. ft.})}{2}\ (3.43 \text{ feet})$$

= 184856.63 cubic ft.

Grade Check 2.34 feet = Marsh Perm. to Marsh High Depth Change

Slope	Run	r of Marsh High circle	Run btw Marsh High and Perm.
		171.85 feet	
25.0%	9.35 feet	r of Marsh Permanent circle	27.64 feet
28.5%	8.20 feet		Slope
33.0%	7.09 feet	144.22 feet	8.5%

Remainder of Second 100 year 1 hour storm

908147.83 cubic ft. = V of 100yr Storm
407951.03 cubic ft. = V Detained in Marsh Permanent to Marsh High Water Level
500196.80 cubic ft. = V to be Detained-Pond/Marsh High Water Level to Pond/Marsh Maximum Water Level

Pond/Marsh Maximum Water Level Sizing

(Details Remainder of 100 year 1 hour storm within Pond/Wetland)

A_1	A_2	Formula
Pond/Marsh High Level	Pond/Marsh Max. Level	$\frac{V}{(A_1+A_2)/2}$ = Depth
4.60 acres	4.91 acres	$\frac{500196.80 \text{ cubic ft.}}{207127.80 \text{ sq. ft.}}$ = 2.41 feet
200376.00 sq. ft.	213879.60 sq. ft.	

Grade Check 2.41 feet = Pond/Marsh High to Pond/Marsh Maximum Depth Change

Slope	Run	r of Pond/Marsh Maximum circle	Run btw Pond/Marsh Max. and High
25.0%	9.66 feet	260.92 feet	
28.5%	8.47 feet	r of Pond/Marsh High circle	8.37 feet
33.0%	7.32 feet	252.55 feet	Slope 28.8%

Total Change in Pond Water Height (Permanent to Maximum)

2.34 feet = Pond Permanent to High Water Level Height Change
2.41 feet = Pond/Marsh High to Maximum Water Level Height Change
4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum. (Artunc 1994)

Table 19 Alternative Design Two Calculations

Design Alternative 2-Drainage Area 1
Pond sized to detain Two 100 year 1 hour storms
No Stormwater Storage in Parking Areas.

Total Drainage Area	1834764.66 sq. ft.	42.12 acres
Hardscape/Pavement Area	1278875.74 sq. ft.	29.36 acres
Building Area	390115.47 sq. ft.	8.96 acres
Landscape/Turf Area	165773.45 sq. ft.	3.81 acres

Volumes
100 year 1 hour Storm Volume

Acres	100yr 1hr Storm in Inches	Runoff Coefficent	Q
42.12 acres	4.50	0.20	=Qn
29.36 acres	4.50	0.90	=Qd(paved)
8.96 acres	4.50	0.95	=Qd(building)
3.81 acres	4.50	0.40	=Qd(turf)

37.91	=Qn		
118.90	=Qd(paved)	164.04	=Qd(total)
38.29	=Qd(building)	37.91	=Qn
6.85	=Qd(turf)	126.13	=Q(resulting)
164.04	=Qd(total)		

Resulting Q	x 2hr detention time x 60 min x 60sec =	
126.13	7200.00	908147.83 cubic ft.

Cubic Feet to be Detained - 100yr 1hr Storm
908147.83 cubic ft.

Sizing

Pond Permanent Water Level Sizing (Defines Permanent Pond Level)
Recommended depth for Pond Permanent Level is 4.00 feet

D = 4.00 feet

Formula $\frac{(A_1+A_2)*D}{2.00} = V$

Pond Bottom	Pond Permanent Level		
4.00 acres	8.35 acres	2151864.00 cubic ft. / 2.00 =	1075932.00 cubic ft.
174240.00 sq. ft.	363726.00 sq. ft.		

Pond Sizing Check (Rubenstein 1996,199)
2.00 acres = Number of Acres per Acre-Foot of Storage for Baton Rouge, LA

Required Drainage	Pond Volume in Acre-Feet	Acres in Drainage Area	Pond Sizing Check =
24.70 acres	12.35	42.12 acres	Pass

Pond Permanent Water Level Sizing (cont)

Grade Check 4.00 feet = Pond Bottom to Pond Perm. Depth Change

A rough idea of the slope.

Slope	Run	r of Pond Permanent circle	Run btw Pond Perm. and Bottom
25.0%	16.00 feet	340.26 feet	104.76 feet
28.5%	14.04 feet	r of Pond Bottom circle	Slope
33.0%	12.12 feet	235.50 feet	3.8%

Pond High Water Level Sizing (Detention of a 100 year 1hour storm)

908147.83 cubic ft. =V(25yr 1hr storn

A_1 Pond Permanent Level	A_2 Pond High Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
8.35 acres	8.78 acres	$\frac{908147.83 \text{ cubic ft.}}{373091.40 \text{ sq. ft.}}$ = 2.43 feet
363726.00 sq. ft.	382456.80 sq. ft.	

Grade Check 2.434116236 = Pond Permanent to Pond High Depth Change

Slope	Run	r of Pond High circle	Run btw Pond High and Permanent
		348.91 feet	
25.0%	9.74 feet	r of Pond Permanent circle	8.65 feet
28.5%	8.54 feet		Slope
33.0%	7.38 feet	340.26 feet	28.1%

Pond Maximum Water Level Sizing (Detains Second 100yr 1hr storm within Pond)

A_1 Pond High Level	A_2 Pond Maximum Level	Formula
		$\frac{V}{(A_1+A_2)/2}$ = Depth
8.78 acres	9.20 acres	$\frac{908147.83 \text{ cubic ft.}}{391604.40 \text{ sq. ft.}}$ = 2.32 feet
382456.80 sq. ft.	400752.00 sq. ft.	

Grade Check 2.319044 = Pond High to Pond Maximum Depth Change

Slope	Run	r of Pond Maximum circle	Run btw Pond Max. and Pond High
25.0%	9.28 feet	357.16 feet	8.25 feet
28.5%	8.14 feet	r of Pond High circle	Slope
33.0%	7.03 feet	348.91 feet	28.1%

Total Change in Pond Water Height (Permanent to Maximum)

2.43 feet = Pond Permanent to High Water Level Height Change
2.32 feet = Pond High to Maximum Water Level Height Change
4.75 feet = Total Change in Pond Water Height

3 to 4 foot is the prefered change. 5 feet is the maximum.

VITA

Anthony Lowery was born in 1961 in Alton, Illinois. He attended the University of Missouri-Columbia where he received the degree of Bachelor of Science in Recreation and Park Administration with an emphasis in Park Planning. He will receive the degree of Master of Landscape Architecture in May 2000. He is currently residing in Saint Louis, Missouri, with his wife, Regina and their two sons, Michael and Nicholas.