Integrated Water Management
Harvest, Treat, Regenerate, Infiltrate
Westfield Community School Corporation
Elementary School Facility
Westfield, Indiana

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Abstract

The intent of this project is to explore innovative techniques for managing water in order to create a new management model. Water management techniques including rainwater harvesting, treatment and filtration, reuse and regeneration are applied to an integrated system model. The design goal is to manage all stormwater and wastewater on site, while minimizing overall consumption of imported water. All non-collected rainwater is addressed where it lands and allowed to infiltrate whenever possible through rain gardens, bioswales, and other infiltration techniques. All wastewater is treated and regenerative processes maximize the services provided by water through reuse, before allowing it to infiltrate and restore ground water and base flow.

This management model has been applied to an elementary school facility in Westfield, IN. This elementary facility provides the model for onsite water management through integrated techniques for wastewater treatment, and runoff management. The existing drainage conditions played an important role in designing the system. Water flow analysis was used to identify relationships in the landscape in order to properly place program elements.
Acknowledgements

First and foremost I would like to thank my parents. I owe them everything. They have always been there with support and love, no matter what choices I made. I would also like to thank my advisors Ron Spangler, Meg Calkins, and Chris Marlow for guiding me through this design problem. The last person I want to thank is my good friend Paul Weir for editing my work and always being there for me.
# Table of Contents

Title Page ....................................................................................................................... 5  
Abstract ......................................................................................................................... 7  
Acknowledgements .................................................................................................... 9  

1. Introduction .............................................................................................................. 12  
2. Problem Statement ................................................................................................. 13  
3. Project Significance ................................................................................................. 14  
4. Project Requirements ............................................................................................. 15  
    Project Goals ........................................................................................................... 15  
    Clients ..................................................................................................................... 15  
5. Case Studies ............................................................................................................ 16-19  
    Adam Joseph Lewis Center for Environmental Studies ............................................. 16-17  
    Marry Lea Environmental Learning Center ................................................................. 17-18  
    Mount Tabor Middle School ...................................................................................... 18-19  
6. Program ..................................................................................................................... 20-23  
    Facilities Program ................................................................................................... 20-22  
    Water Management Program .................................................................................. 23  
7. Methodology ............................................................................................................ 24-28  
    Design Process ....................................................................................................... 24  
    Site Context ........................................................................................................... 24-25  
    Site Inventory ........................................................................................................ 26-27  
    Site analysis .......................................................................................................... 28  
8. Master Plan ............................................................................................................... 29-42  
    Master Plan ............................................................................................................ Insert  
    Facilities ............................................................................................................... 29-31  
    Water Management ............................................................................................... 31-42  
    Infiltration Zone ................................................................................................... 32-35  
    Collection and Treatment Zone .............................................................................. 36-42  

Appendices .................................................................................................................... 42-52  
    Appendix A. Review of Literature ......................................................................... 42-51  
    Appendix B. Definition of Terms ............................................................................. 51-52  

Works Cited .................................................................................................................. 53-54
Introduction

There is a growing body of research that suggests that we need a new approach to water management. Water is a fundamental element that all living organisms require for life. The relationship between human development and water is a complex one. It is necessary for our survival and we use it for many services daily. In a modern industrialized society, water is not only a basic need for life. It is a fundamental element that provides us with many services that are an integral part of our daily lives.

Our traditional water management methods have inherent problems that disrupt the stability of the supply of potable water. Increasing amounts of impervious surfaces from increasing urban sprawl prevents ground water recharge, increases occurrences of floods, and degrades water quality. Historically, the sewage and stormwater systems solved devastating public health problems for cities around the world. Now, a century later the aging systems are undersized and a source of increasing economic costs and environmental devastation. Current development techniques and traditional management systems have many inherent problems that put stress on our ability to ensure future water supplies.

The stability of a potable water supply is a matter of utmost importance to all of humanity. A new water management model is needed to address these increasing problems. This project is an exploration of non-traditional methods of water management and the application of these techniques to an elementary school in Westfield, Indiana. This elementary facility provides the model for onsite water management techniques though containing all runoff on site with 100% infiltration, wastewater treatment, and adaptive reuse.
Problem Statement

Design an elementary school, which fulfills the role as a new model for integrated water management. All water fallen or imported for use on site must be treated and allowed to infiltrate to restore ground water and base flow. The design should maximize student interaction and create a dynamic environment that fosters ecological learning.
Project Significance

Over the past 150 years our society has changed drastically from the industrial age to age of modern technology and the Internet. “During this period, the level of science and technology, as well as our understanding of interconnections between human actions and their environmental consequences, have changed drastically.” (Field et al.: 45) However, the way we think and manage our water has changed very little. We now know that our centralized water management system has inherent problems and high costs associated with maintenance, expansion and adaptation. This demands a new integrated systems management approach with full on site source control to reverse the effects of urban development, and reduce the workload of the centralized collection and treatment system. “Source control can be implemented through retention of roof rainwater (rainwater tanks), stormwater detention, on-site treatment of grey water (laundry, sinks and drains) and black water (toilet), use of water efficient appliances and practices, on-site infiltration and aquifer recharge/recovery.” (Coombes & Kuczera: 4-5)

The problems in occurrence with our water management program and development trends demand new approaches for on site water management when developing a site. Therefore, the design of Westfield Elementary incorporates alternatives methods of water management. Water use is reduced to address increasing scarcity. Efficient mechanical systems and the use of native plantings have shown to reduce water consumption by up to 30% in similar school facilities. Additionally, all non-potable needs such as water for toilets and irrigation will be supplied by harvested rainwater.
**Project Requirements**

**Project Goals**

- Harvest water for all non-potable needs
- Manage all rainwater on site
- Treat all wastewater on site
- Infiltrate all water on site
- Create dynamic outdoor learning environment that illustrates the water management system
- Reduce water consumption through native planting

**Clients**

- School children – The water management techniques employed in the design provide for learning opportunities. The design is intended to engage and highlight water movement, filtration and reuse.
- Educators / Employees
- Community Members – The town of Westfield does not currently have a parks and recreation center. Therefore, the school facilities are open to the public after school hours and receive a lot of use from community members and organizations
Adam Joseph Lewis Center for Environmental Studies

The AJLC is an integrated building and landscape system that functions as a core component of Oberlin College’s Environmental Studies curriculum. The landscape features a variety of constructed ecosystems that simulate native Northern Ohio ecosystems, incorporate cultigens that produce food, treat wastewater and manage runoff. Rainwater that falls on the roof, sidewalk and parking lot first drain into a wetland, which functions both as a temporary storage basin and filtration system before the water is drained into an underground cistern. Water from the cistern is used to supplement the wetland during dry periods to maintain a desirable aquatic habitat. Wastewater is treated through a system known as a “Living Machine.” The first steps of this system are very similar to that of traditional wastewater treatment. The water first goes through an anaerobic tank where the majority of solid waste falls out while the liquid portion moves on to a closed aerobic tank where oxygen is introduced. After these two tanks, 90% of the total inorganic matter has been removed. Next it moves to the Open Aerobic tanks, which are the most visible and unique component of the Living Machine. These tanks are located in the building’s greenhouse and are planted with rafts of large tropical plants. Next the water enters the Clarifier basin. Calm conditions in the Clarifier allow solids to settle and clear water to separate. Water then flows into the greenhouse floor, which is a planted gravel wetland. The water is then stored, disinfected, and re-used in toilets.
Project Highlights

- Rainwater harvesting, storage and filtration through wetland system
- Innovative “Living Machine” wastewater treatment system
- Dynamic functional greenhouse space with integrated water treatment system
- Systems monitoring
- Urban agriculture
- Restoration of indigenous ecosystems
- Immersive ecological and water management learning environment

Merry Lea Environmental Learning Center

Merry Lea, located in Noble County south of Wolf Lake in Northern Indiana, is a 1,150-acre natural sanctuary for the region’s plants and animals. It is owned and operated by Goshen College. The Rieth Village at Merry Lea Environmental Learning Center is an immersive learning facility that employs innovative green technologies to reduce the village’s ecological footprint. Two cottages housing 32 undergraduate students and a third cottage serving as an initial classroom and office space has already been constructed. Phase two includes four more cottages and a 20,000-square foot academic building. The project goal has been to create as much energy as is consumed, harvest rainwater for all non-potable uses, treat all wastewater on site and integrate proper storm-
water management. Their intent is that all water leaving the site is as clean as when it arrived. Their wastewater treatment process includes an initial septic settling tank, then it flows into a submerged bed constructed wetland and finally through a recirculating sand filter.

**Project Highlights**

- Integrated stormwater management
- Harvested roof runoff for non-potable uses
- Wastewater treatment through a constructed wetland system
- Immersive ecological learning environment
- Preservation of native landscapes

**Mount Tabor Middle School: Rain Garden**

In 2007, Mt. Tabor Middle School in Portland, OR underwent a stormwater retrofit. It was a joint project between the Bureau of Environmental Services and Portland Public Schools. The project is intended to manage stormwater on site, so that nearby residents are protected from sewage backing up into basements during heavy rains. The project included a rain garden, parking-lot bioswale, six planters, and three drywells. The rain garden is technically an infiltration bed. It has a footprint of 1,900 square feet and a maximum ponding depth of six to eight inches. Runoff enters the garden through concrete runnels from downspouts off the roof and through a large trench drain from the
pavement area. This single rain garden collects and manages about 30,000 square feet of roof and asphalt area. The parking lot bioswale runs down the center of the parking lot and is 1,4000 square feet. The swale together with a 200 square feet planter manages runoff from about 12,000 square feet of asphalt. Multiple check dams are incorporated into the swale to retain runoff and promote infiltration.

Water movement was a very important part of the rain garden design, as an educational opportunity. The rain gardens act like a courtyard, enclosed on three sides by the school building and an asphalt covered play area on the fourth. This makes it a very visible place for students. The water needs to be visible, especially the processes of collection. Children are attracted to water, especially in movement.

Water falling from the roof lands on an exposed runoff before entering the rain garden. A wrought iron grate covering the large trench exposes the water movement from asphalt play area to rain garden. By exposing the movement and collection of the water, the designer was able to engage and create a dynamic learning environment.

**Project Highlights**

- Integrated stormwater management retrofit
- Dynamic learning environment through presentation of water movement
Program

The program is divided into two sections. The first involves all the typical elements of an elementary facility, including playgrounds, car and bus drop-off areas, parking and open recreational lawn space. The second is designated for water management techniques that will be employed on site.

Facilities Program

School Building: 100,000 sq. ft.

- Westfield School Corporation has worked with CSO Architects out of Indianapolis and has devised a building plan that has been used as a basic template for future elementary schools and will be used for this project. (See Fig. 6.1 for building floor plan.)

Parking

- The parking area must provide ample space for all teachers and faculty during school hours, but also must provide enough spaces for special event parking during times such as sporting events and graduation. Due to the community context of Westfield (sprawl community reliant upon vehicular transportation) parking requirements are very high. In past projects in Westfield, the paved area used for basketball recreation space is also used for overflow parking.
- Parking or holding area for buses is also required. A typical elementary school in Westfield has 15 buses in service.

Circulation

- There are multiple aspects of vehicular circulation that are a required part of the program. There must be a service and delivery area that has adequate ac-
Figure 6.1  Floor plan provided by CSO Architects.
access and turning radius for a semi-truck. There must also be two drop-off loops for parents dropping kids off in the morning and picking them up in the afternoon. The first is a main loop that directs kids to the main entrance. The second is for kindergarten kids and should be directed to the entrance at the end of the kindergarten wing.

- Pedestrian circulation must provide ample connection from building to vehicular and bus loading points, building to outdoor classrooms and play areas, and with potential development surrounding the site.

Play Grounds
- The playground requirements are divided into three areas. The first is a hard surface area, typically used for basketball and games like four square that require a hard surface. The second area is a soft surface play area, which will house the playground equipment for all grades except kindergarten. These two areas should be located in close proximity to each other and would also benefit from being located near an open lawn space that could double as ball fields. The final play area is a soft surface area for the kindergarten playground equipment. This area must be enclosed.

Lawn Space
- An open lawn space providing additional recreation space.
Water Management Program

It is the design goal to retain all rainwater, collect a portion for use for non-potable services and treat all used water on site before allowing it to infiltrate. This management program should incorporate multiple integrated techniques in order to accomplish this goal. It is the intent to address stormwater runoff, as close to the source as possible, therefore bio-swales and rain gardens will be incorporated into the entire site. A certain amount of rainfall will be collected to supply toilet water and any needed irrigation. All wastewater should be treated on site and allowed to infiltrate. It is a goal to maximize the use and services provided by water before allowing it to naturally reenter the hydrological cycle.
Methodology

Design Process

The design methodology was a synthesis of the biophysical characteristics and contextual analysis of the site to determine character elements and placement. The characteristics of the land and site context provide the palette, which will dictate the types, characteristics and extents of the water management system. The elements of system must be arranged according to the topography of the site. Flow models will be used to synthesize possible solutions. Soil analysis will determine the degree of soil amendment necessary for desired infiltration and collection rates. A combination of soil analysis, topography, and solar orientation will determine the location and orientation of the building. Due to the fact that the building floor plan is pre-determined, this will dictate the location of several elements such as drop-off zones, parking areas, service access and play areas. The physical characteristics of the site direct the location of elements. The summation of this physical analysis is presented in the rest of this section.

Site Context

The town of Westfield is located north of Indianapolis approximately 20 miles. The center of town lies at the cross roads of highways 31 & 32. Historically Westfield has been a small farm community. Until 2008, it was not even an incorporated town. However, over the past decade Westfield has begun to grow very rapidly along with the rest of the north side of Indianapolis. Westfield is the fastest growing community in Indiana and in the top 20 in the nation. With the extreme amount of growth, schools are going up left and right. The school district is expected to build three new elementary facilities within the next 8-10 years. The community is very dedicated and proud of its school system and is known as “The Learning Community.”

The majority of the surrounding areas are relatively flat agriculture fields, which is very typical of the central Indiana region. According to Nick Verhoff, the business director of Westfield Schools, much of this surrounding agriculture land is expected to be devel-
oped and a very large development in close proximity to the north of the site is already underway. Any new development in this area is assumed to be primary or solely residential, as has been the current trend in the area.

Site Context Diagram

Figure 7.1 Site Context Diagram: Aerial images provided by Google Earth.
Site Inventory

Currently, the site is an agriculture field. There is no vegetation on site except for the annual crops. There are clumps of trees bordering the site along the northern border. The property has some gradual undulation including a small ridge separating the southwestern corner, and creating two micro-watersheds or drainage areas on the site. The southwestern corner of the property drains at a fairly even and steady cross-slope toward Little Eagle Creek. A slight ridge separates this corner from the rest of the watershed. The rest and majority of the property drains into one of two swales starting near the eastern two corners of the property, and converging just before leaving the property at the northwest corner (Fig. 7.4). The soils which are heavily dictated by the water flow are primarily silt loam or silt clay loam, which indicates moderate to slow infiltration rates (K values listed in Table 7.1). If this project were to be built field tests would need to be performed to ensure accuracy of infiltration rates. For this theoretical application the generic infiltration rate for that soil type will be used.

Figure 7.2 Site Inventory Diagram: Aerial images provided by Google Earth.
**Methodology**

### Site Soil

Figure 7.3 Site Soil Map: Provided by USDA: Natural Resource Conservation Service

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Abr.</th>
<th>% of Site</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookston - Silt Clay Loam</td>
<td>Br</td>
<td>40</td>
<td>0.12</td>
</tr>
<tr>
<td>Crosby - Silt Loam</td>
<td>CrA</td>
<td>56</td>
<td>0.54</td>
</tr>
<tr>
<td>Miami - Silt Loam</td>
<td>MmB2</td>
<td>4</td>
<td>0.54</td>
</tr>
</tbody>
</table>

K = soil infiltration rate, feet per day

Table 7.1 Soil Infiltration Rate: Provided by USDA: Natural Resource Conservation Service

### Site Drainage

Figure 7.2 Site Drainage Diagram: Topographic information provided by Hamilton County GIS services.
Site Analysis

The drainage lines and topography were the primary factors for dictating areas of opportunity and constraint. The higher areas indicated in green are most suitable for locating a building. Lower areas indicated in red are least suitable for building, but are important in considering water management goals. Vegetative buffer zones indicated by the yellow squiggles near the residential units should be increased. Because two roadways border the property it increases the total access points noted by the orange arrows.

Site Analysis Diagram

Figure 7.2 Site Inventory Diagram: Aerial images provided by Google Earth.
School Building

- The sighting of the building was the first step in laying out the master plan. The building itself is the most restrictive program element and dictates the location of other elements. The building is located in the center of the site in the area identified by the analysis as most suitable. The building was orientated to the south to maximize day lighting.
- In addition to the given building floor plan, a greenhouse has been added. It has been located on the exterior of the cafeteria and will provide for additional lunch seating and classroom space. The greenhouse will provide for a dynamic indoor educational space that will bring the “outdoors” in and engage students with nature all year long. The living machine, which treats wastewater, will also be located in the greenhouse but will be in a separate section from the cafeteria.

Parking

- The parking has been divided into two primary areas. The first is orientated towards the main entrance containing approximately 180 spaces. A second parking area of 130 spaces is orientated towards the service entrance but has access to the main entrance as well.
- The bus parking zone is located on the east side of this site and is oriented to the exits at the end of the classroom wings. The bus zone is completely separate from the rest of the vehicular traffic. This is done both for safety reasons and to prevent non-bus vehicles from entering into the bus zone.
Circulation

- Vehicular access is provided from both Towne Road and Little Eagle Creek Avenue. Both entrances are directed towards the main entrance. The entrance off of Little Eagle Creek Avenue is intended to be the main entrance because of its orientation to the water management system. Part of the design intent was to incorporate the water management system into other aspects of the design in order to engage users as much as possible.
- The bus loading zone has a completely separate entrance and exit that is located on Towne Road.
- An extensive pedestrian path system is included in the plan. This path system creates connections from the building to the: parking lots, play areas, outdoor classrooms and community gardens. A key element of the path system is its integration with the water management system. Throughout the parking lots, pedestrian pathways cut through the parking aisles. This accomplishes two goals. First, it breaks up the large expanses of parking while promoting pedestrian safety. Secondly, the pathways act as check dams in the bio-swales, which slow down and help to control runoff.

The path system is designed to connect to future development in the area with access points along both roadways, creating the potential for a larger network of trails.

Playgrounds

- As determined in the program, there are three separate playground areas. The hard surface area designed primarily for basketball is located just outside of the gymnasium, adjacent to the soft play area designated for playground equipment. This hard play area will also be used for event overflow parking. The soft play
area is located near an entry point at the end of the northern most classroom wing. The third area that is designated for kindergarten playground equipment is located just outside the kindergarten wing. This area is to be enclosed by an ornamental metal fence.

Recreational Fields

- The recreational field, located in the northwest corner of the site, is split in half for two reasons. The first is because of the slight topography change; the field farther to the north is at a lower elevation than the other field. The second reason the fields are divided in two is to serve multiple functions. The area at a higher elevation contains an underground cistern located under the lawn area. The second is located at one of the low points on site and will double as a rainwater overflow retention area.

Water Management

The primary intent of this design is to demonstrate that all stormwater can be managed on-site through an integrated management system that maximizes infiltration and limits or eliminates runoff. Figure 8.1 and Table 8.1 indicate all the impervious surfaces on site and the total volume of runoff that will need to be managed. The design goal is to manage all rainwater from a 2 year event in 24 hours or less and a 100 year event in 72 hours or less. Figure 8.2 diagrams the entire management system, but has been broken into two zones in the following sections. Having two drainage areas became an important element in the design of the water management system. It allowed for two separate infil-
This allowed for separate systems: one for water that has been collected, used and treated; and a second system that was intended to strictly retain runoff and allow for infiltration.
Infiltration Zone

The design intent in the infiltration zone (Fig. 8.1) is to manage rainwater as close to where it lands as possible. This is accomplished through a network of bioswales and rain gardens that overflow into a detention area where water is allowed to infiltrate over a period of 72 hours or less. Table 8.3 shows the amount of infiltration that would

<table>
<thead>
<tr>
<th>Storm Event</th>
<th>V (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Year 30 Min.</td>
<td>18,685</td>
</tr>
<tr>
<td>100 Year 30 Min.</td>
<td>36,646</td>
</tr>
</tbody>
</table>

Table 8.2: Infiltration Zone Runoff Volumes

Figure 8.4: Infiltration Zone Flow Diagram
take place over a 24 and 72 hours period with the infiltration area allotted and the overflow volume that must be accommodated for through trenches. To calculate the necessary trench volume the total runoff volume is divided by .35 or the average porosity of the trench material. Trench depth is calculated by taking the trench volume needed by the trench area. In the infiltration zone the trenches, highlighted in orange in Figure 8.X, require a depth of 16” to accommodate for a 100 year storm.

**Bioswales**

- Bioswales are incorporated along parking and loading zones and are used to convey overflow water. These swales are thickly vegetated to slow runoff and allow for the maximum amount of infiltration and absorption by plant material.

**Rain Gardens**

- Rain gardens are integrated into the spaces between classroom wings to address rainwater coming off of the roof. Overflow from these gardens will be directed into the overflow retention area (recreation field #1) via bioswales. Rain gardens can be planted with a variety of plants and should be heavily vegetated for maximum absorption. In order to manage all stormwater, an underground trench will be incorporated into the construction of the rain gardens. This trench will act as an underground storage space, expanding the volume of
water that can be managed in each rain garden over the appropriate infiltration period. Tables 8.3 and 8.4 show the trench area and calculated volume and depth required.

Infiltration Beds

• During large rain events, overflow from the rain gardens and bioswales will drain into a detention area (recreation field #1). This open field area operates much like the rain gardens and will contain an underground trench in order to accommodate large amounts of run off during peak storm events. However, the field will be planted with turf grass in order to function both as a recreation field and a detention area.

Total Infiltration Floor Area: 32,723 Sq. Ft.

<table>
<thead>
<tr>
<th>V (ft^3)</th>
<th>Overflow (ft^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Hr. Infltr. Volume</td>
<td>18,685</td>
</tr>
<tr>
<td>72 Hr. Infltr. Volume</td>
<td>36,646</td>
</tr>
</tbody>
</table>

Overflow Volume (Q): 17,000 Cubic Ft

Trench Volume: 
\[ Q = T / 0.35 \]
\[ V = 48,600 \text{ Cubic Ft} \]

Trench Depth:
\[ D = V / A \]
\[ D = 48,600 / 37,050 \]
\[ D = 1.31 \text{ ft} \]
Collection and Treatment Zone

In the collection and treatment zone, a portion of the water is collected and filtered through a constructed wetland before being stored in an underground cistern. This water is then used to supply all non-potable services in the building. All wastewater

Collection Management Model

<table>
<thead>
<tr>
<th>Storm Event</th>
<th>V (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Year 30 Min.</td>
<td>16,503</td>
</tr>
<tr>
<td>100 Year 30 Min.</td>
<td>43,366</td>
</tr>
</tbody>
</table>

Table 8.5: Collection Zone Total Runoff Volume
coming from the building will be treated through a Living Machine and submerged reed bed system. The water will then be stored in a retention pond that doubles as an aquaculture lab for the school. Water from here will supply for irrigation of community gardens and any overflow will spill into a series of infiltration beds. An important aspect of the system is the feedback loops connecting the cistern to the wetland and the retention pond. It is important to maintain the water level of the wetland to ensure its stability as a habitat; therefore water must be able to be pumped from the cistern to the wetland. Due to imported water for potable services there will be a constant source of water entering the treatment process. This water will maintain the level of the retention pond and when required can be directed to the cistern during times of drought.
Bioswales

- Bioswales are incorporated into all parking areas, which will collect and allow rainwater to infiltrate. A percentage of this water will be collected and directed to a constructed wetland to be filtered before being stored in the cistern located under a section of the open lawn area (recreation field #2).

- Figure 8.15 illustrates how the bioswales collect and direct runoff. The parking lot bioswales would operate much like the rain gardens except that a perforated pipe in the bottom of the trench would direct overflow to the constructed wetland.

- Tables 8.6 - 8.8 show the volumes of runoff from the impervious area highlighted in figure 8:16 and the required trench depth for that bioswale.
Master Plan

**Constructed Wetland**
- A constructed wetland will be located near the entrance of the building, which will filter and treat all rainwater that is harvested. All runoff coming from the roof in the collection zone will go directly to the wetland. Overflow from the wetland will be gravity fed into the underground cistern.

**Underground Cistern**
- The underground cistern will supply all non-potable uses in the building and any irrigation that is required. This cistern will be located under recreation field #2. Water from the cistern will be able to be pumped to the building, irrigation system, and the constructed wetland. Water coming into the cistern from either the wetland or retention pond will be gravity fed.

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**Table 8.8: Bioswale 1: Trench Volume and Depth**

<table>
<thead>
<tr>
<th>Volume Type</th>
<th>V (ft³)</th>
<th>Overflow (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Hr. Infiltr.</td>
<td>1,033</td>
<td>1,297 (2 Year)</td>
</tr>
<tr>
<td>72 Hr. Infiltr.</td>
<td>3,100</td>
<td>1,470 (100 Year)</td>
</tr>
</tbody>
</table>

**Overflow Volume (Q): 1,500 Cubic Ft**

- **Trench Volume:**
  - Q = T / 0.35
  - V = 4,285 Cubic Ft

- **Trench Depth:**
  - D = V / A
  - D = 4,285 / 2,580
  - D = 1.66 ft

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Figure 8.17: Bioswale 1: Infiltration Volumes

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Table 8.7: Bioswale 1: Infiltration Volumes

- 24 Hr. Infiltr. Volume: 1,033 ft³
- 72 Hr. Infiltr. Volume: 3,100 ft³
- Overflow Volume: 1,297 ft³ (2 Year)
- Overflow Volume: 1,470 ft³ (100 Year)
Living Machine
- The living machine is the first step in treatment process. It is located in a portion of the greenhouse, so that the system can function year around. Water coming out of this system is clean enough for reuse but will be treated further by the reed bed system before any reuse will take place.

Reed Beds
- After water is treated in the living machine it will be pumped to a reed bed system, which will further filter the wastewater. The reed beds are located at a higher elevation so that the water will flow down hill for the rest of the treatment and reuse process.

Retention Pond / Aquaculture Lab
- After all treatment is finished, water will be stored in a retention pond that will serve as a reserve source of water for the cistern. This could also provide an opportunity for a small-scale aquaculture system and an outdoor aquatic lab for the school.

Community Kitchen Gardens
- This is the primary reuse element. Water will flow off the top of the constructed wetland through an integrated irrigation system for the gardens. The gardens will supply locally produced organic produce for the surrounding community and provide outdoor classroom space for immersive hands on learning.
Infiltration Beds

- The final process for all water will be infiltration. This will allow all water used and fallen on site to be infiltrated into ground water replenishing the base flow. These infiltration beds will function much like the detention area (recreation field #1) except that there will be a series of them, and as one fills up it will spill into the next one down.
Appendix A: Literature Review

Introduction

The relationship between the built environment, development, and its impacts on our water quality and supply is a complex one. The problems faced by this system can only be solved through a broad exploration into possible solutions. This literature review is broken up into 6 sections beginning with a review of common water issues and how they relate to development. The next 5 sections are divided into areas of solution exploration and are as follows, Decentralized Integrated Management, New Sources, Reuse, and Recharge.

Water Issues and Development

Water is one of humanity’s invaluable resource. Durham et al. in the article Integrated Stormwater Resource Management – through reuse and aquifer recharge describes fresh water as being “finite, vulnerable and that it is essential to sustain life, economic development and the environment (333-334).” For these reasons water is humanity’s most valuable resource and should be addressed as such.

Urban development puts stress on water supplies. The fact that toxins and heavy metals are picked up by urban runoff, especially from streets, parking lots and industrial areas, can be easily found in literature sources (Graham: 45; Marsh: 136; Horner: 29-40). However, that is not the only water quality issue that is created from urban development and our water management system. According to the United States Environmental Protection Agency, many municipalities have combined sewage and stormwater systems (CSS). During periods of wet weather, the hydraulic capacity of the CSS can become overloaded, causing overflows of untreated sewage and stormwater to be discharged into local surface sources (1). Pollution is not the only water issue that is facing development, it only adds to the larger issues, which is the growing scarcity of clean fresh water.

Our continuing physical growth and development patterns have put stress on our ability to ensure a sustained water supply. Bruce Ferguson is a Landscape Architecture professor and has published several books on water management. In his book Stormwater Infiltra-
tion, he states, “Urban impervious surfaces alter all parts of the hydrologic balance. They deflect rain water away from infiltration, soil moisture, recharge, subsurface storage and base flow (24).” This understanding of impervious surfaces is commonly found throughout literature on hydrology and landscape planning. William Marsh, also a Landscape Architecture professor, in his book Landscape Planning: Environmental Applications illustrates the changes in the coefficient of runoff with land use change. In forested or native prairie 80-100% of rainwater infiltrates into the ground compared to only 10% in urban areas (156). In Fundamentals of Urban Runoff Management the entire first chapter is dedicated to the hydrologic impacts of land use change. It is explained that runoff is really a phenomenon of land use change and does not happen that often in nature, where only in extreme storm events does any water become surface runoff. It further states that:

“…the amount and rate of urban runoff from a given storm event depends not only on the rainfall but also on the characteristics of the land on which runoff falls, changing the land characteristics can increase the runoff amount and/or rate, sometimes with disastrous results (5).”

Not allowing water to infiltrate can cause several problems. First, it prevents ground water and aquifer recharge, which is the primary source for fresh potable water. Secondly, during periods of intense rainfall it sends more water at once into rivers and surface sources creating increased flooding.

The UN Environmental Program documented that severe water shortage affects 400 million people today and could affect as many as 4 billion by 2050 (Thomas & Durham: 1). In many areas of the world local rainwater does not supply nearly enough to replenish water abstracted for municipality supplies. Bruce Ferguson in Stormwater Infiltration talks about peoples living in dryer regions tapping into “fossil” water that cannot be replenished.

“In some areas, precipitation is so scanty that only occasionally does enough fall to add any appreciable amount to the phreatic zone, yet wells encounter great masses of ground water. In such areas water is being pumped that accumulated under a different climatic regime. This is fossil water; in the sense that it was deposited in earlier geologic ages; to pump it out is to mine it like any other nonrenewable resource. Such water use is clearly
not sustainable, as water that took thousands of years to deposit is being mine at a rate that will exhaust it in relatively few years (26)."

Water extraction at unsustainable rates is not only problematic in the long run, but also in the immediate future as Durham et al. documents:

“Over abstraction of groundwater results in rising salinity of the produced water due to saline ingress. This has resulted in 25% of the irrigated agricultural land being salinised in some areas. Soil salinisation kills the agricultural industry, stops local food production and creates unemployment. This is a global problem with 10% of global water usage being sourced from over abstracted groundwater. 20% of global irrigated agricultural areas have been salinised (336).”

Salinity issues only add to the growing water scarcity problem, which will only worsen with the rapid growth of the global population.

**Decentralized Integrated Management**

There are several problems with the current centralized water management system. The first is that it is not flexible or adaptive. In Constructed Wetlands in Innovative Decentralized Rainwater Management it states that:

“…traditionally investment into rainwater management is investment into centralized disposal systems either via the combined or via the separated sewers. Limitations especially regarding stormwater management are evident today. The centralized system is not flexible, causing growing problems when new areas are developed and more surfaces are sealed (2).”

It is not only costly to change the system, it is also expensive to maintain as Peter Graham notes in Building Ecology:

“The pipes and pumps of many cities’ sewers are old, some exceeding 100 years of service, and are in need of constant maintenance. In countries like Australia, increasing population densities
in inner urban areas are increasing the pressure on antiquated sewers. This means that the cost of running sewerage system is becoming increasingly expensive (43).”

Graham also notes that not only are centralized systems difficult to adapt and maintain; they also contribute to the degradation and overuse of water.

“A typical large city is served by a sewage system that consists of thousands of kilometers of pipeline connecting buildings to centralized treatment facilities. Vast quantities of water are required to move faeces, urine, and, in many cases, trade waste through the labyrinth of pipes, creating a dangerous effluent (42).”

The majority of this effluent is treated, however leaks in aging infrastructure allow large amounts to enter directly into the ecosystem. According to Graham the average US city losses around a quarter of their total water supply because of leaks (74).

The book Integrated Stormwater Management declares that a new integrated systems approach is needed. This would include both structural and nonstructural elements. It would look for small-scale solutions instead of technological large-scale thinking because it is less expensive to construct small-scale treatment units that large ones. It would deal with source control solutions instead of the “end of the pipe” approach; again it is less expensive to reduce stormwater volumes at the source than through the construction of huge conduits. It would look for local disposal and reuse and it would take an ecological approach through the use of biological systems for wastewater, stormwater, and solid waste management (Field et al., 46-48). According to Integrated Stormwater Management solutions come in many forms and must be part of an integrated site-specific systems approach instead of the traditional centralized system.

**New Sources**

An integrated management approach must include new ways of allocating potable water. To find the solution here we must look skyward. According to Klaus Daniels, author of The Technology of Ecological Building, “A dramatic increase of water costs is inevitable in the near future and the utilization of rainwater will become a matter of
course (222).” Rainwater harvesting technologies have been around for centuries and are as relevant and important today as they have ever been. “Although rainwater is relatively clean when it falls on roofs its potential value in replacing water imported via expensive reticulation networks from remote river systems that are subject to environmental stress is largely ignored.” (Coombes & Kuczera: 3) Certain parts of the world, including Bermuda and the US Virgin Islands are feeling the impacts of water scarcity and now require rainwater-harvesting systems by law. Many others like Germany, Japan, and the State of California offer tax credits or financial incentives (http://www.greenbuilder.com/sourcebook/Rainwater.html).

According to Daniels in The Technology of Ecological Building rainwater is in some aspects better suited for domestic uses than chlorinated water from the central water system. “Rainwater is generally considered a safe and hygienic alternative for laundry water, with the additional advantage of needing less detergent, since rainwater is naturally softer than sterilized or treated water.” (56) This view is agreed and expanded upon by Greenbuilder.com, “The softness of rainwater is valued for its cleaning abilities and benign effects on water-using equipment. As an irrigation source, its acidity is helpful in the high PH soils of our region and, as one would expect, is the best water for plants (http://www.greenbuilder.com/sourcebook/Rainwater.html).” Graham in Building Ecology offers an alternative use: toilets.

“Ostratorn School’s roofs collect rainwater which is then used to flush toilets. Rainwater is stored in two 9,000-litre tanks in the basements. From here it is pumped via dedicated pipes to water-efficient split-pan toilets. The 18,000-litre holding capacity of the two tanks is enough water to flush water-efficient toilets for 200 people with an allowance in for a two-month period of no rain.” (247)

There are even more possibilities for harvesting rainwater for industrial uses where it has been found to be technically feasible and more economically attractive (Field et al.: 333).

Runoff from the roofs of buildings is cleaner when compared to runoff from roadways and other paved surfaces, for this reason harvesting rainwater is typically limited to roof runoff. However, this is a limitation that can easily be overcome with simple treatment measures, which for many purposes such as toilet water is unnecessary. In larger residential developments in Germany where roof runoff is not sufficient for an economic
application of rainwater usage they have demonstrated that runoff from roadways when treated properly through constructed wetlands can have great reuse potential (Teshner: 2). The potential for rainwater use is really limitless. There has been apprehension for using it as a drinking source, but it is estimated that over 3 million Australians currently use rainwater for drinking and there have been no reported epidemics or widespread adverse health impacts (Coombes & Kuczera: 6).

Rainwater is not the only onsite source. Water can be harvested from plants, which absorb ground water through their roots, but most of that water is dispersed into the air through perspiration. This water can be harvested and is one of the cleanest sources of water because the plant and soil have absorbed most pollutants. Smart Architecture documents projects from a studio in Germany that is working at designing buildings that are completely disconnected from a municipal water supply. One such project is called a tree bag:

“It is a bag that catches tree sweat, or water as we call it. And when you're thirsty you can drink it. Trees 'breathe' carbon dioxide and collect water through their roots to feed the process of photosynthesis by which they produce oxygen in their leaves. As it happens only one percent of that life-preserving root fluid is actually used. All the rest evaporates, unless of course you catch it…” (Hinte el al.: 108)

Finding new sources for our potable water supply will be increasingly needed, especially when looking at economic and environmental costs of desalination.

**Reuse**

Given the scarcity facing many areas, there is good reason to reuse water. However, our traditional water system methods do not allow for reuse. Every ounce of water in the average building in America is used only once before being dumped down the drain. That is to say it is used to accomplish only one service, no matter how efficient the use is. “Clean water is an increasingly scarce resource yet many buildings force people to use fresh water only once.” (Graham 74-5) Integrated systems water reuse has great potential and demands rethinking how we design our water systems.
Grey water reuse has the most potential for increasing efficiency in the use of water. Harvested rainwater could also be part of a grey water reuse system. Reuse of grey water requires a completely separate water system (local system) and must not merge with potable or black water systems (Daniels: 222). It can be used for cooling, irrigation, industrial purposes, and flushing toilets, often without any treatment. (Roaf et al: 261; Daniels: 222). Reuse of grey water requires skillful systems design. This often means stricter codes. In Austin, Texas, where efficient use of water is encouraged, the health department requires sub-surface distributions systems whenever grey water is used for irrigation (Greenbuilder.com). Reuse of grey water must be managed carefully and thus requires a more extensive local water system, but has potential to drastically reduce water consumption.

Wastewater also has potential for re-use, but requires more treatment and care because of toxic pathogens present that are not dealt with in grey water reuse. According to the US EPA, “Wastewater has been treated and reused successfully as a water and nutrient resource in agriculture, silviculture, aquaculture, golf course and green belt irrigation (1).” As part of an integrated decentralized design solution, wastewater can be treated and reused on site. There are several ways to treat wastewater on site. Several are highly technical, but constructed wetlands are a relatively low-tech and cost effective solution. Constructed wetlands have quickly become a favorite and often “can be the least cost advanced wastewater treatment and disposal alternative (EPA: 1).” These wetland systems are easy to produce on a small scale, which improve their viability as a decentralized treatment for reuse (Coombes & Kuczera: 7). Thomas and Durham in their paper Integrated Water Resource Management: looking at the whole picture documented a case in southern Spain where wastewater has been successfully reused for irrigation: “Because of over abstraction of groundwater resources, saline ingresses became an issue. The alternative was a water resource project using wastewater for irrigation… The capacity of the system, which has been running since 1997, is 32000 m³/d, for an irrigated surface of 3,000 ha. The wastewater treatment plant includes activated sludge. The effluent is then stored in a 10,000-m³ reservoir and treated through rapid sand filtration (28 sand filters at seal level). The filtrate is pumped 10 km to an elevation of 116 m where it is treated with an ozonation system and is stored in a 120,000-m³ reservoir before gravity distribution to the farmers (25).”
Recharge

Groundwater recharge is the final process in an integrated water management program. Recharge through infiltration is the link between water use today and a sustained potable water supply for the future. In order to maintain the availability and quality of fresh water supplies, we must reverse the nature of the urban environment and allow water to infiltrate. Instead of sheeting water off of paved surfaces and into pipes or streams it must be slowed and allowed to infiltrate. This allows not only for filtration, but recharges and maintains aquifers and ground water levels that supply base flow for our rivers and streams. "By returning runoff to the earth, it eliminates pollutant discharge, eradicates floods, replenishes ground water supplies and restores aquatic habitats (Ferguson: 1)."

Infiltration has been proven to be an effective tool in water management. "Bank Filtration and groundwater recharge are known as low cost and efficient technologies for treating drinking water." (Durham et al.) There are many methods and technologies used for increasing rainwater infiltration in urban areas including Low Impact Development, Best Management Practices, and infiltration sumps. The upper northwestern part of the United States, particularly Portland, OR, has been leading in urban infiltration technologies. The Stormwater Solutions Handbook assembled by the Environmental Services department of the City of Portland outlines many methods for dealing with runoff, as well as provides an extensive plant palette that has proven to be successful in specific methods.

However, recharge must not be limited to rainwater management, especially if scarcity issues demand rainwater collection. Instead, it must be an integral part of the entire water management system. The current method of disposal for treated wastewater is to dump it into the nearest water body: the river, lake, bay, or ocean. This is a complete waste of this valuable resource and often adds to flooding and water scarcity issues. In Southern California where water demand surpasses local supply, treated wastewater has been used to replenish water supply through an aquifer recharge project:

"To meet the increased demand, the Orange County Water District (OCWD) and Orange County Sanitation District (OCSD) have developed a cost-effective solution to provide a supplemental source of high quality water. The two agencies are sponsoring a water purification project, known as Ground Replenishment..."
Appendix

System (GWRS) that will purify for reuse highly treated waste-water that is currently discharged to the ocean… The aquifer recharge project provides 75-80% of the potable water source for the area through direct injection and surface percolation ponds in the Santa Ana river basin (Durham et al. 2002: 336).”

Southern California has had to be retroactive in order to maintain a water supply and to avoid over salination because of imported water. Groundwater and aquifer recharge must be the final use of all water used in order to maintain our base supply of clean fresh water.

Appendix B: Definition of Terms

- **Aquifer** – an underground layer of water bearing permeable rock or unconsolidated materials from which groundwater can be extracted through a water well.
- **Base Flow** – water discharged to surface water that is not attributed to runoff from precipitation, but comes from groundwater.
- **BedZED** – the Beddington Zero Energy Development, is an environmentally friendly housing development that only uses energy from renewable sources generated on site.
- **Black Water** – wastewater that contains feces and urine, also known as brown water or sewage.
- **Biophysical characteristics** – the physical, biological, ecological, and chemical qualities and attributes of the land.
- **Coefficient of Runoff** – coefficient of the amount of runoff to the amount of precipitation received.
- **Desalination** – any process that involves the removal of excess salt and other minerals from water.
- **Ecological Industry** – industry that inmates natural processes through integrated management of resource among multiple firms to minimize waste and increase economic efficiency.
- **Grey Water** – wastewater that is generated from domestic processes such as washing dishes, laundry, and bathing.
Appendix

- **Groundwater** – water located beneath the ground surface in soil pore spaces and in the fractures of rock formations.
- **Infiltration** – the process by which water on the ground surface enters the soil.
- **McHarg Overlay** – the superimposing of layers of geographical data based on ecological and social factors so that their spatial relationships can be used to make land use decisions.
- **Phreatic Zone** – the layer(s) of soil or rock below the water table in which voids are permanently saturated with groundwater.
- **Recharge** – the process by which groundwater is replenished.
- **Xeriscaping** – landscaping that does not require supplemental irrigation.
Works Cited


