

To the Graduate Council:

I am submitting herewith a thesis written by Jeffrey Caleb Lillard entitled "Clean Water Act Phase II: How To For Development, a Case Study." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Landscape Architecture, with a major in Landscape Architecture.

Ken McCown , Major Professor

We have read this thesis
and recommend its acceptance:

Curtis Stewart

Tracy Moir-McClean

Dr. John Tyner

Dr. Andrea Ludwig

Accepted for the Council

Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

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Clean Water Act Phase II: How To For Development, a Case Study

A Thesis Presented for
The Master of Landscape Architecture
Degree
The University of Tennessee, Knoxville

Jeffrey Caleb Lillard

August 2011

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Dedication

I would like to dedicate this work to my parents, *Jerry & Karen Lillard*, and my family who have whole heartedly supported me throughout my collegiate career and have helped guide me to achieve my goals. I love all of you.

Acknowledgements

I would like to acknowledge the help granted by my committee, Ken McCown, Curtis Stewart, Tracy Moir-Mclean, John Tyner, and Andrea Ludwig. Along with my committee, I would also like to thank the rest of the LA faculty. I could not have achieved my goals without you. I would like to give a special thank you to Dr. John Tyner. Without your extra help, I could not have finished this thesis.

Abstract

I am researching the use of several stormwater techniques known to reduce runoff to provide future developers and municipal officials with tools to meet the stormwater post-construction runoff standards laid out in Phase II of the Clean Water Act. Specifically, I am looking at Smart Growth, Low Impact Development, Open Space Design, and Green Infrastructure.

Phase II states that any new development or re-development equaling one acre or greater must be able to capture and infiltrate the first inch of rain to fall on site following 72 hours with no measurable precipitation. There is no one way to solve the problem of stormwater management; therefore we must implement an integrated approach which synthesizes these design theories to effectively manage stormwater. I used the La Rue site on Kingston Pike just before Cherokee Blvd. as a testing ground for my hypothesis.

I will proceed with two design scenarios for this project. The first scenario encompasses designing the site as if it were in the pre development stages. I will keep the same building square footage, but rearrange the footprints in a more efficient layout for stormwater management. The second scenario will be a retrofit of the site to comply with Phase II standards. Though it is not a current requirement of Phase II, many professionals believe in the coming years the EPA will require the retrofit of existing developments to meet these standards. In this scenario, the building footprints will remain exactly as they are but any other features will be malleable (infrastructure, vegetation, grading, etc.).

Another component in this thesis will be to determine which design

theories are best suited to each scenario. My pre-investigation belief is that for the pre-development scenario, I will be able to implement parts of all four theories. For the retrofit, I believe that I will be limited mostly to Low Impact Development and Green Infrastructure. Though, it is possible that I may still be able to fit in some principles of the Smart Growth and Open Space Design (reduce impervious footprints, reduce road widths, etc.).

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Abbreviations and Symbols

CWA	Clean Water Act
EPA	Environmental Protection Agency
GI	Green Infrastructure
LID	Low Impact Development
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
OSD	Open Space Design
OSRD	Open Space Residential Design
ROW	Right of Way
SWMP	Stormwater Management Plan
TC	Time of Concentration

Introduction

The Clean Water Act, Phase I, and Phase II

We are faced with many issues which are ever changing within the realm of stormwater management for the sake of cleansing and maintaining the wellbeing of our country's streams, rivers, and large bodies of water. To overcome these issues requires smart regulatory policy and a will to enforce that policy. MS4s, which are essentially municipalities, are currently required under Phase II of the Clean Water Act (CWA) to establish a Stormwater Management Plan. To understand the importance of these Stormwater Management Plans, we must take a look at where we have come from and understand where we are going with stormwater regulations and standards.

In 1972, Congress passed the Clean Water Act to combat a lack of understanding exhibited by local and state governments as to the effects of pollution on American waterways and the effects it has on quality of life. The Act specified objectives to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To attain these objectives, the government sought to cleanse our waters and remove from them all human impacts that threatened human health and the health of aquatic ecosystems. The government took into consideration the necessity of maintaining the high standard of quality within our waterways and ecosystems already repaired, and also to protect waters that had escaped the impacts of pollution.

The 1972 CWA required permits to be obtained for all point sources of pollution and defined strict requirements for those permits. A point source is defined as a discrete conveyance such as a pipe or man-made ditch which originates from sources such as industrial buildings, municipal buildings, and

other facilities, and which discharge directly to surface waters. Along with these federal permits, states were required to establish water quality standards for in-state and interstate waters. From these standards, states were required to identify all waters unable to meet water quality requirements and calculate additional pollution reductions needed to meet these requirements. Due to information attained through these studies, new requirements were incorporated into the permits. An important lesson gleaned is the CWA and all legislation branching from it are continually evolving to attain a level of standards capable of meeting the needs of current issues.

One evolution of the Act came when researchers realized much of the nation's streams' and rivers' pollution was coming from diffused, non-point sources (Adler). Once significant pollution reduction had been attained by point source polluters, the EPA realized that requiring permits of those directly polluting water supplies was not sufficient if the United States aspired to protect its aquatic ecosystems. In 1990, Phase I of the CWA was passed which recognized the necessity to require National Pollutant Discharge Elimination System (NPDES) permits from large and medium sized MS4's and eliminate storm water runoff from those sources. Non-point source pollution is any stormwater runoff originating from impervious surfaces such as roads, parking lots, and rooftops and some pervious surfaces such as agricultural lands which can contribute pesticides or other pollutants capable of damaging the natural balance of an ecosystem.

Non-point source pollution can harm surface water and cause or contribute to water quality being short of its natural standards by changing

natural hydrologic patterns, accelerating natural stream flows, destroying aquatic habitat, and elevating pollutant concentrations and loadings. Stormwater runoff carries with it all the pollutants found on the surface of these areas such as chemicals, garbage, and sediment. The idea of sediment being a pollutant may seem odd considering it is nothing more than soil, but it can clog naturally infiltrating surfaces as well as fill streams, wetlands, ponds, and lakes.

In 1999, Congress created more stringent regulations on non-point source pollution when they passed Phase II of the CWA. Phase II focuses on small MS4's which include but are not limited to small municipalities (less than 100,000) and publicly owned universities. Within Phase II, there are six minimum standards which must be met. These standards include:

- public education and outreach
- public participation and involvement
- illicit discharge detection and elimination
- construction site runoff control
- post-construction runoff control
- pollution prevention and good house keeping for municipal operations.

Within this thesis, the issue of post-construction runoff control within newly and redeveloped sites will be addressed. Mandated within this section of Phase II standards newly developed or re-developed sites must contain and infiltrate the first flush (inch) of each rainfall following a period of 72 hours of no noticeable precipitation. The first inch is significant due to scientific evidence showing that it contains the highest concentration of pollutant levels of all

stormwater runoff. The state of Tennessee was granted a NPDES permit August 31, 2010 and it became effective October 1. According to the NPDES permit, all MS4's must develop, implement, and enforce a stormwater management program designed to reduce the discharge of pollutants from the MS4 to protect water quality and to satisfy the appropriate water quality requirements for the CWA. The Stormwater Management Program must include management practices including control techniques, system design, and engineering methods and such other provisions as the division determines appropriate for the control of pollutants of concern. The MS4 must document all of the elements of the Stormwater Management Program in a Stormwater Management Plan (SWMP) within the first year of the permit cycle and submit it as an attachment to the first annual report.

To meet this goal, MS4's must develop and implement strategies which include a combination of structural and/or non-structural Best Management Practices (BMPs) that effectively manage stormwater within the community. Within Tennessee's NPDES permit, these requirements are specifically addressed in section 4.2.5 titled *Permanent Stormwater Management in New Development and Redevelopment*. Under this section, the state is charged to develop and implement a set of requirements to establish, protect, and maintain a permanent water quality buffer along all waters of the state at new development and redevelopment projects to the extent allowable under state or local law. The MS4 must implement and enforce permanent stormwater controls that are comprised of runoff reduction and pollutant removal. The permitting body must require that stormwater discharges from new development and redevelopment sites

be managed such that post-development hydrology does not exceed the pre-development hydrology at the site, in accordance with the performance standards contained within section 4.2.5. Runoff reduction is the preferred control practice of the EPA as it can achieve both volume control and pollutant removal (TENNESSEE).

Thesis Intent and Hypothesis

The intent of this thesis is to look at Phase II of the Clean Water Act and study green design theories which can accommodate the standards of Phase II. This thesis is written to help me as a designer to understand implications for development so I can develop land more efficiently with natural processes in mind to meet the needs of Phase II. The EPA supports implementation of natural processes; most importantly infiltration. I agree with the advocacy of natural process and will be presenting Smart Growth, Green Infrastructure, Low Impact Development, and Open Space Design as four theories to meet Phase II goals. There are many different methods of managing stormwater runoff. Many of them will differ slightly in their emphasis or means of attaining results.

I believe that for stormwater management to be effective, an integrated approach utilizing principles from multiple theories is necessary. I chose these four theories for their abilities to enable stormwater management through a multitude of scales and through numerous techniques. They will help policy makers and developers create Stormwater Management Manuals which employ natural processes such as infiltration and evapotranspiration, address the standards of Phase II, and protect the interests of all parties. To conclude, I believe that an integration of Smart Growth, Green Infrastructure, Low Impact Development, and Open Space Design would not only be viable, but would be largely successful at meeting the standards of Phase II in an efficient fashion.

Proposal

To prove how effective these four methods are, I will provide two scenarios to show the implementation of principles from the four methods to manage the first inch of site runoff as well as maintaining flow rates equal to or less than the site's original condition. 'Original' condition will have differing meanings for the two scenarios.

The first scenario will look at the site for Phase II planning in its pre-existing condition, prior to any development. Planning stormwater management for pre development conditions will allow for flexibility in choosing BMPs as well as implementing development techniques to sustain natural hydrologic character.

The second scenario will look at the same site in its current state to test a retrofit design for an established development in reducing runoff. Though there are no current regulations requiring the retrofit of existing developments to meet Phase II standards, many professionals believe that some form of stormwater remediation will be required in the future. Retrofitting an existing development will reduce the palette of BMPs available for use and critically reduce the amount of planning to preserve existing conditions. Even so, their principles can still be taken into consideration to create an effective management plan.

Once both scenarios are developed, I will run both designs through a computer program called HydroCAD to test the results of the designs by measuring runoff volumes and peak flow rates. If successful, both plans will maintain their hydrologic peak flow rates as well as contain the first inch of runoff on site.

In order to better understand Smart Growth, Green Infrastructure, Low

Impact Development, and Open Space Design I provide an overview of each design theory in the following section. These overviews will give principles, techniques, and a brief explanation of some economic considerations for each of the theories.

Section 1

Design Theories:

Smart Growth, Green Infrastructure, Low Impact Development, & Open Space

Design

Smart Growth

Introduction

Smart Growth is a design theory which strives to reduce the impervious footprint of urban sprawl and preserve surrounding natural areas. The United States is developing land at a fast rate which diminishes the quality of natural stormwater management. "Between 1982 and 1997, the amount of urbanized land used for development increased by 45 percent. During this same time period, however, population grew by only 17 percent" (Smart Growth Network P.9). Land development was roughly three times that of population growth. An increase in population of 50% is expected between the years 2000 and 2050 (Barnett). Using a simple ratio, it is reasonable to assume that if growth patterns continue at the same rate we could be looking at an increase of urbanized land use for development by 132 percent. Some scenarios show that we can reduce the loss of open space by 43 percent through directed growth (ULI). Smart Growth encourages community leaders to critically analyze and plan how and where they want to grow. Although some ideas cannot currently be implemented due to codes, Smart Growth has the potential to champion stormwater management from the large scale down to the small.

Principles

Through my research, I found that the Smart Growth Network has been able to most clearly exemplify the principles of Smart Growth. "Smart growth principles are specifically those that embody viable alternatives to prevailing suburban sprawl" (Szold P.3). They have laid out ten principles upon which professionals will be able to understand, implement, and maintain proper Smart Growth standards. Those ten principles are:

- mix land uses
- take advantage of compact building design and efficient infrastructure
- create a range of housing opportunities and choices
- create walkable neighborhoods
- foster distinctive, attractive communities with a strong sense of place
- preserve open space, farmland, natural beauty, and critical environmental areas
- strengthen and direct development towards existing communities
- provide a variety of transportation choices
- make development decisions predictable, fair, and cost effective
- encourage communities and stakeholder collaboration in development decisions (Smart Growth Network).

Of these ten principles, I chose five that either directly or indirectly influence positive stormwater management. Those five are:

(Direct Impact)

1. Take advantage of compact building design and efficient infrastructure
2. Preserve open space, farmland, natural beauty, and critical environmental areas

(Indirect Impact)

3. Create walkable neighborhoods
4. Foster distinctive, attractive communities with a strong sense of place
5. Strengthen and direct development towards existing communities

I will now explain why these five principles are important and what their intentions are. As will be noted, many ideas exhibited by each principle overlap with other principles and create compounded benefits.

Compact Building Design

Compact building design allows communities to absorb growth and development to efficiently use land resources (Smart Growth Network). Smaller footprints for new buildings and redevelopment allows preservation of natural land which may absorb and filter rainwater. This practice can lead to reduced risk of flooding, reduced stormwater drainage needs and reduced pollution caused by runoff (Smart Growth Network). "Research shows that large-lot subdivisions increase imperviousness by 10 to 50 percent compared to cluster and traditional

town developments with the same number of households, and that they deliver up to three times more sediment into waterways” (Barnett P.32-33). Compact building design is a relative term which relates building density to existing local conditions including average densities, site and area conditions, and market demands (Porter).

Smart Growth is not a ‘one-size-fits-all’ approach. Existing development codes can make compact building designs difficult to implement. “Minimum lot size requirements and prohibitions against multi-family or attached housing are just two common practices that make it difficult to achieve more compact communities” (Smart Growth Network P.10). Even with restrictions, planners have been supportive of clustering as a method for accommodating development while retaining land in farms, forests, and other natural areas (Porter).

There are two types of urban open areas preserved through compact building design; formal and less formal. Formal areas are characterized by parks such as civic plazas, formal gardens, ball fields, and regional parks which are used for recreation. Less formal areas preserve habitat and promote environmental protection. Natural features dictate these natural areas’ use. Open spaces should accommodate the same ecological functions of the natural, undeveloped land. Their functions are integral to the success of compact building design.

Development infrastructure plays a major role in reducing impervious foot prints. “The cost of providing basic infrastructure systems for developments generally increases as densities decrease (Porter P.13). Parking surfaces represent another important piece of the puzzle that is compact building design.

Conventional approaches to parking – particularly large surface spaces between the street and the front door of the home or business – not only represent inefficient uses of valuable urban land but also... increase the amount of stormwater that quickly runs off into storm sewers and surface water, thus increasing the risk of flooding and washing pollutants into our streams, rivers, and lakes. (Smart Growth Network P.12)

The United States has a serious problem with overdeveloping parking lots. Current studies estimate that for each car actively used in America, there are eight parking spots (Smart Growth Network). To combat this ratio, on-street parking can be used to qualify towards the amount of parking required by a building or we can encourage buildings that use parking at different times of the day to share lots. Promoting parking structures as opposed to surface lots is one more way to reduce the total area of impervious surface. Another way to implement compact building design is through encouraging vertical growth along streets. This reduces horizontal development which will contribute to the impervious footprint.

Preservation of Open Space

Preservation of open space, farmland, natural beauty and critical environmental areas is the next principle directly affecting stormwater management.

Forests, woods, and groves of trees shelter wildlife, manage

stormwater flows, and cleanse and cool the air. They intercept rainwater and calm its flows, which facilitates its infiltration to groundwater and reduces erosive surges of runoff into streams and ponds. (Porter P.31)

Retaining open space and protecting stream buffers can reduce runoff by as much as 43 percent and reduce contaminant loadings (ULI). Though preserving open space may seem to be just another tool, void of much thought beyond saving some fields and trees, a formal green infrastructure plan provides a framework for future growth by prioritizing which spaces should be protected and which spaces should be open to development (Smart Growth Network). A green infrastructure plan identifying and protecting critical ecological sites and linkages in advance of planning and construction will support native species, maintain natural ecological processes, sustain air and water resources, and contribute to the health and quality of life for America's waterways (Smart Growth Network).

Better Walkable Communities

Walkable communities are created by providing safe connections and desirable routes. There is no reason why these connections cannot serve an ecological function.

Many of the suggested pedestrian friendly improvements – such as narrower streets, on street parking, or pathways through parking lots – reduce or break up large swaths of impervious cover, thereby decreasing stormwater runoff. (Smart Growth Network P.26)

There are regulations and practices which hinder the creation of walkable communities. These include but are not limited to conventional land use regulations which prohibit mixed land uses, the idea that mixed use is 'riskier' than single use, and conventional street design. Mixed land uses can be beneficial for reasons such as living above your workplace, walking to the grocery store, and reducing gas consumption. Developers may consider mixed land use to be 'riskier' since the idea is still relatively new, not many communities have been constructed, and for these reasons buyers may be hesitant to commit. Conventional street design includes wide streets, few pedestrian crossings, long blocks, and limited pedestrian infrastructure such as sidewalks, median strips, and traffic-calming features. These features excluded from conventional street design can be used to capture rainwater (Smart Growth Network).

Foster Distinctive, Attractive Communities with a Strong Sense of Place

As well as creating better walkable communities, we must also strive to foster distinctive, attractive communities with a strong sense of place. Creating distinctive and healthy places to live includes the presence of trees which play an important role environmentally. Trees slow stormwater runoff and help protect wetlands. Open spaces also contribute to the distinctive, attractive attributes of communities. Open spaces provide environmental benefits to communities as they provide space for tree growth and contain penetrable ground surfaces that filter water and mitigate stormwater runoff. People may connect open space with

public parks, but open space exists in natural forms as well. Forests, wetlands, and prairies are three examples of open space which provide stormwater managerial functions.

Efficient Use of Impervious Surfaces

The final principle related to improved stormwater management is the development of land resources near existing communities. Development encouraged in existing areas provides benefits to communities by increasing the efficiency of already developed land and infrastructure, reducing development pressure in fringe areas, preserving farm land and open space and reducing total areas of impervious surfaces. "In addition, the process of increasing development in existing communities can maximize the use of existing impervious surface, thereby improving local and regional water quality" (Smart Growth Network P.52).

Cost Overview

Smart Growth provides economic incentives primarily through two methods; reducing infrastructure and improving quality of life. Infrastructure can become quite expensive when considering the utility costs that are associated with roadways. Traditional curb and gutter systems can increase costs very quickly. Quality of life cannot be measured quantitatively, unless you consider the revenue produced in areas that have a high quality of life.

As sprawl becomes more prevalent, our infrastructure systems also become more extensive. Having our infrastructure branch out in all directions is neither efficient nor cost effective. Essentially, infrastructure costs increase as densities decrease. “Recent studies by the Center for Urban Policy Research at Rutgers University show that low-density development typically raises per-unit road costs by about 25 percent, school costs by 5 percent, and utility costs by 15 percent” (Porter P.13). Infrastructure also becomes quite extensive when considering surface parking lots. While parking structures are more expensive to construct than surface lots, the area saved from parking development can be developed in more thoughtful ways, generating tax revenues which can help to offset costs (Smart Growth Network).

We must also consider quality of life as a financial incentive. The preservation of open space can profoundly impact a community’s quality of life, and therefore can promote a regions’ economic prosperity (Smart Growth Network). A few economic stimulants provided by open space include an increase of local property values, increase in property taxes, additional tourism dollars, and the reduction of municipality’s needs to increase taxes due to the reduced need for new infrastructure (Smart Growth Network). “Large trees along a retail strip make the strip more inviting, which generates more business, thereby serving as an economic stimulus for the community” (Smart Growth Network P.36). Trees are also able to reduce energy costs by cooling homes and community spaces (Smart Growth Network).

Green Infrastructure

Introduction

Green Infrastructure mitigates the effects of urban stormwater management through Best Management Practices (BMPs) in the infrastructure and public right of way (ROW). Transportation corridors provide abundant space which can be utilized to manage stormwater. A road implementing BMPs will reduce runoff volumes more so than traditional curb and gutter systems. During storm events, curb and gutter systems become a high-speed, high-velocity conduit for pollution into rivers, lakes, and coastal waters. "Emerging green infrastructure techniques present a new pollution-control philosophy based on the known benefits of natural systems that provide multimedia pollution reduction and use soil and vegetation to trap, filter, and infiltrate stormwater" (Kloss P.1). As previously undeveloped land is paved over and built upon, the amount of stormwater running off roofs, streets, and other impervious surfaces into nearby waterways increases. The increased volume of stormwater runoff and the pollutants carried within it continue to degrade the quality of local and regional water bodies. For this reason, it is very important for communities to stop stormwater/pollution through the use of an integrated network of green infrastructure to slow runoff, filter out debris, and help get stormwater into the ground as soon as possible.

Principles

Preserving, creating, or restoring vegetated areas and natural corridors such as greenways, parks, conservation easements, and riparian buffers provide Green Infrastructure.

When linked together through an urban environment, these lands provide rain management benefits similar to natural undeveloped systems, thereby reducing the volume of stormwater runoff. With green infrastructure, stormwater management is accomplished by letting the environment manage water naturally: capturing and retaining rainfall, infiltrating runoff, and trapping and absorbing pollutants. (Kloss P.8)

Developments in Massachusetts and Illinois were conceived and designed to reduce and manage stormwater runoff by preserving natural vegetation and landscaping, reducing overall site imperviousness, and installing green stormwater controls. "Each of the sites discharges less stormwater than conventional developments" (Kloss P.12).

Through my research, I have identified three principles of Green Infrastructure that define its implementation most efficiently. They are:

1. green infrastructure should reduce the impervious foot print of a site and increase vegetative cover
2. green infrastructure should serve as a framework for conservation and development.

3. green infrastructure should be an interconnected network working together to mitigate the effects of stormwater.

Minimize Impervious Surfaces

The total area of impervious surfaces has been shown to directly relate to the health of rivers, lakes, and estuaries (Kloss). Studies show that a watershed with an impervious level of 10 percent degrades local water quality. Once impervious levels reach 25 percent, the watershed will have inadequate fish and insect habitat and host shoreline and stream channel erosion. From 35 to 50 percent impervious, the runoff volume equals 30 percent of the rainfall volume and at 75 percent impervious, the runoff volume equals 55 percent of rainfall volume (Kloss). Therefore, if a site is 50 percent impervious and a one inch rainfall event occurs, there is already 0.3 inches of runoff that must be managed. The percent of the rainfall volume that is converted to runoff will probably increase exponentially during larger events when coupled with runoff from pervious surfaces. "In urban areas, it is not uncommon for impervious surfaces to account for 45 percent or more of the land cover" (Kloss P.2). "Too often, development removes nearly all existing natural features. Simply preserving trees, open space, and stream buffers and incorporating them into the community will help maintain water quality and manage stormwater runoff while lessening the need for additional stormwater controls" (Kloss P.15). Reducing the total amount of impervious surfaces helps address stormwater management 'at the source'

through efforts aimed at restoring some of the natural hydrologic function of areas that have been urbanized.

The lengthened flow path, through a soil medium and particularly through deep-rooted vegetation, can create a significant reduction in the dissolved nutrients delivered to surface waters. Nutrients and other pollutants attached to soil systems should be used as near the source of runoff as possible and might not be appropriate where there is concern about groundwater pollution or a rise in the local groundwater level. (Taylor P.4)

Framework for Conservation

Typical modern American street systems have been designed based almost exclusively on traffic engineering considerations for motor vehicles such as providing capacity for peak hour volumes, maximizing speeds, minimizing conflicts and crash potential, and minimizing maintenance costs of the transportation agency. Environmental considerations have been narrowly construed to be the minimal required by NEPA and DEQ. This should be changed to more fully consider the impacts of streets on stormwater filtration, stream corridors, tree canopy coverage, as well as the social life of the communities through which they run. Solutions should be grounded in the appreciation that the natural process of stormwater

infiltration and natural drainage patterns are optimal for providing multiple benefits. Furthermore, careful implementation and maintenance of natural processes is affordable. (Green Streets P.9)

Street systems serve as a vast network of public land. This land is a finite resource that should provide a layering of many uses including alternative infrastructure systems promoting stormwater infiltration. Nature corridors also provide stormwater management through ecological process. "Open areas and buffer zones are often designated around urban streams and rivers to provide treatment and management of overland flow before it reaches waterways" (Kloss P.9). Trees preserved within these natural corridors reduce polluted stormwater discharges and the need for engineered controls to replace those lost functions.

Interconnected Network

Trees, vegetation, and open space create a network of stormwater mitigation features, each providing its own individual service to slow and infiltrate stormwater. "Standard infrastructure and controls fail to reduce the amount of stormwater runoff from urban environments or effectively remove pollutants" (Kloss P.2).

Recently, the concept of green infrastructure has been broadened to include decentralized, engineered stormwater controls. These green techniques are designed to mimic the functions of the natural environment and are installed to offset the impacts

of urbanization and imperviousness. Green management techniques are used to minimize, capture, and treat stormwater at the location at which it is created and before it has the opportunity to reach the collection system. Engineered systems commonly used in urban areas include green roofs, rain barrels and cisterns, vegetated swales, pocket wetlands, and permeable pavements. (Kloss P.8)

Green infrastructure encourages downspout disconnection which redirects stormwater from standard conveyance systems to vegetated areas that capture and reuse stormwater. Downspout disconnection removes stormwater volume from conveyance systems and allows green infrastructure components to manage the runoff. "Local zoning requirements and building codes often inadvertently discourage the use of green infrastructure. Provisions requiring downspouts to be connected to the stormwater collection system prohibit disconnection programs and the use of green space for treatment of rooftop runoff. These and other restrictions will have to be reconsidered so Green Infrastructure can be fully efficient.

Cost Overview

Urban stormwater retrofits can be expensive and become complicated by space constraints. "Based Upon the costs of their pilot projects, city officials in Seattle and Vancouver believe that the costs of future green infrastructure installations will be similar to or slightly more than conventional stormwater

controls” (Kloss P.12). Analysis provided by the city of Vancouver shows that retrofitting green infrastructure into areas which already have established conventional stormwater control systems will cost only marginally more than updating the conventional system. Introducing green infrastructure into new development will cost less (Kloss).

Green infrastructure provides additional benefits including the creation of more aesthetic city spaces and a significant reduction in water pollution. Benefits such as these offset some of the higher costs of green infrastructure. Green infrastructure can be less costly than conventional stormwater management programs and may provide an opportunity to decrease the economic burden of stormwater management.

Studies in Maryland and Illinois show that new residential developments using green infrastructure stormwater controls saved \$3,500 to \$4,500 per lot (quarter to half-acre lots) when compared to new developments with conventional stormwater controls. Cost savings for these developments resulted from less conventional stormwater infrastructure and paving and lower site preparation costs. (Kloss P.12)

This multi-benefit environmental approach ultimately provides controlled programs that are more diverse and can be more cost-effective than projects aimed solely at stormwater control. “Protecting and enhancing those areas that have not yet been developed is often the cheapest, most effective way to keep contaminated stormwater out of urban and suburban streams” (Kloss P.11). “Developments utilizing green infrastructure normally yield more lots for sale by

eliminating land-consuming conventional stormwater controls, and lots in green developments generally have a higher sale price because of the premium that buyers place on vegetation and conservation development" (Kloss P.12).

Low Impact Development (LID)

Introduction

Urban sprawl consumes green space, increases dependency on automobiles, and widens urban fringes. Each of these factors creates pressure upon environmentally sensitive areas. Low Impact Development (LID) is a design theory that promotes site based design with small scale de-centralized components working as a system to reduce stormwater runoff. There is a wide range of tactics available through LID which include policy as well as structural BMPs capable of combating stormwater runoff. These tactics are designed to treat and manage stormwater as close to its source as possible. "Hydrologic functions of storage, infiltration, and ground water recharge, as well as volume and frequency of discharges are maintained through the use of integrated and distributed micro-scale stormwater retention and detention areas, reduction of impervious surfaces, and the lengthening of flow paths and runoff time" (Low Impact Development P.1).

Low impact development is a relatively new concept in stormwater management. "LID techniques were pioneered by Prince George's County, Maryland, in the early 1990's" (Low Impact Development P.1). Not all sites are suitable for LID. Considerations such as soil permeability and the site's slope must be considered. If a site cannot infiltrate sufficient amounts of water in a given time, LID will not be successful. Also, sites which have steep slopes will

be less effective infiltrating stormwater due to increased flow rates across the ground surface. Due to these considerations, it is important to note that in some cases, the use of LID alone may not entirely achieve stormwater management goals without the assistance of conventional stormwater controls (Low Impact Development).

Principles

"LID is a site design strategy with the goal of maintaining or replicating the pre-development hydrologic character of a site through the use which design techniques to create a functionally equivalent hydrologic landscape. I promote an integrated approach to stormwater management; therefore it is proper for principles of different design theories to overlap. Overlapping areas should be regarded as important planning ideas if recognized and promoted by different theories. Low Impact Development focuses on site scale, decentralized systems to manage stormwater. This is a list of principles fundamental to the LID approach:

1. Conservation of natural features
2. Minimization of impervious surfaces
3. Hydraulic disconnection
4. Disbursement of runoff

Conservation of Natural Features

Larry Coffman, the associate director of programs and planning for the Environmental Resources Department in Prince Georges County describes LID as “the culmination of all our thinking about how to modify the nature of development so as to maintain natural ecological function” (Hager P.1). One of the most rational methods of maintaining pre development hydrology is through the conservation of natural features. By means of conserving greater areas of natural features, we are able to expend fewer resources trying to mimic the pre development hydrologic character of the site. When properly implemented, LID measures result in less disturbance of the developed area (Low Impact Development). A factor of preserving natural features is the preservation of existing vegetation. Trees are one of our greatest allies in slowing runoff. “Trees intercept and slow down the flow of water, help infiltrate large quantities of water, and contribute to water cycling through evapotranspiration” (Hager P.1).

Minimization of Impervious Surfaces

The ability to infiltrate stormwater is critical to LID. The sooner we can get runoff in the ground, the less we have to worry about it. “As the amount of impervious surface increases within a site, the ability to infiltrate is decreased. This causes the time for stormwater to reach downstream outlets to decrease. A decrease in the site’s Time of Concentration (TC) reduces the pollutant removal

capabilities of the site and results in an increase in the peak runoff rates.

Maintaining T_c can be achieved by: maintaining flow path lengths, increasing surface roughness, detaining flows, minimizing disturbances at the site, flattening grades in impact areas, disconnecting impervious surfaces, and connecting pervious surfaces” (Low Impact Development P.10). Among LID practices, some of the most common studied are bioretention areas, grass swales, permeable pavements and vegetated roof tops. Implementing these practices helps reduce the total area of impervious surfaces on a site. “Vegetated rooftops have been used extensively in Germany for more than 25 years and results show up to a 50 percent reduction in annual runoff in temperate climates” (Low Impact Development P.ii). Additional benefits for maintaining and creating pervious surfaces include ground water recharge and treatment of stormwater pollutants (Low Impact Development). The ability to contribute significantly to the hydrologic well being of a site is not limited to a specific scale. These techniques could be applied to a 1/4 acre lot or a development of many acres.

Hydraulic Disconnection

Along with reducing impervious surfaces, another important way to mitigate the effects of stormwater runoff includes hydraulic disconnects. Rooftops can make up a significant portion of the impervious surfaces on a site. Being able to manage stormwater received by rooftops can be an essential asset for managing the overall stormwater hydrology of a site. Some traditional

buildings have downspouts connected directly to subterranean conveyance systems which feed directly into storm water systems. This practice allows runoff no chance to infiltrate. A major component of this principle is the rain barrel/cistern, which retains stormwater from rooftops. Water retained in rain barrels/cisterns can be reused for watering lawns, gardens, and trees. Aside from rain barrels/cisterns, one could also allow spouts to drain into grassy or heavily vegetated areas. "If you can disconnect and distribute your drainage, it reduces your runoff volumes by 30, 40, or 50 percent" (Hager P.3). Disconnection of hydraulic drains constitute an effective lot-level approach to stormwater mitigation. Disconnections are an effective solution for developed sites which have little open space available for BMPs.

Disbursement of Runoff

The next principle is the disbursement of runoff on site. LID stormwater practices revolve around the concept of providing a systematic approach to stormwater management which employs a variety of on site, distributed, small-scale, landscaped features, and engineered devices that slow down runoff, enhance filtration, and filter out pollutants. Stormwater management systems can be more effective if they disburse the runoff over greater surface areas which allow for infiltration.

Conventional stormwater conveyance systems are designed to collect, convey and discharge runoff as efficiently as possible. The intent

is to create a highly efficient drainage system, which will prevent on lot flooding, promote good drainage and quickly convey runoff to a BMP or stream. This runoff control system decreases groundwater recharge, increases runoff volume and changes the timing, frequency, and rate of discharge. These changes can cause flooding, water quality degradation, stream erosion and the need to construct end of pipe BMPs. (Low Impact Development P.1-2)

A major component of LID is the ability to manage stormwater at the source using micro-scale controls that are distributed throughout the site. Highly urbanized areas do not have the luxury of open undeveloped spaces. "Rooftop retention, permeable pavements, bioretention, and disconnecting rooftop rain gutter spouts are valuable tools that can be used in urban areas" (Low Impact Development P.3). Even though conventional stormwater control measures have proven to remove pollutants, the sites' natural hydrological patterns are still negatively affected, causing detrimental effects to ecosystems even when water quality is not compromised. This is due to a lack of groundwater recharge. Another benefit provided by implementing LID techniques is the preservation of lot space typically reserved for conventional stormwater management systems such as detention basins.

Cost Overview

In addition to creating an effective stormwater management system, LID

can provide economic incentives as well. “In general, LID measures are more cost effective and lower in maintenance than conventional, structural, stormwater controls” (Low Impact Development P.i). “Cost savings for control mechanisms are not only for construction, but also for long-term maintenance and life cycle cost considerations” (Low Impact Development P.2). The construction of less infrastructure within a developed site requires less maintenance as time goes on. An area of concern lies within construction measures within LID developments. The costs of these systems are a source for much discussion. For instance, permeable pavers are more expensive to implement than conventional asphalt pavement, but costs for these systems can be offset by the reduction in costs for traditional curb and gutter systems.

Open Space Residential Design

Introduction

Open Space Residential Design is a design theory currently used in innovative development projects whose purpose is to conserve as much open space, natural features, historical amenities, and ecological processes as possible while still developing the same number of residences as within a conventional development. Open space residential design (OSRD) is known by several names such as conservation development and cluster development. Located within suburban and rural areas on the outskirts of towns and cities, people migrated

to developments known as “subdivisions” as urbanized areas have grown.

Subdivision development follows traditional design and has become known to some as ‘checkerboard’ or ‘cookie-cutter’ housing development (Church).

Open Space Residential Design is one alternative to the stormwater management problem created by these standardized communities. Most development styles will differ slightly in a few aspects of their implementation; whether they argue for mixed use development, high density development, what kinds of open spaces are a higher priority for preservation, or a number of other details. One area in which they all agree is the preservation of open space which will help the site maintain its original hydrologic identity, protect unique amenities, and increase property values.

I chose to represent this design technique with OSRD due to its many ecological benefits but most importantly to assist our developers in understanding that profit mustn not always suffer for environmental responsibility.

Principles

To promote a collaborative approach to site planning, OSRD requires developers and local planners to collaborate early in the design process (Smart Growth / Smart Energy Toolkit). OSRD is a three step process. Planning begins with looking at the site and determining, using conventional development patterns, how many residences a developer could fit on this property. The next

step is to identify land areas on the site which are important ecologically and culturally, and set these areas aside not to be developed. These designated open spaces include wetlands and floodplains as well as other ecological resources worth protecting, such as steep slopes, mature woodlands, prime farmland, and meadows. From the remaining land area, the developer will draw lot lines which include multiple lot sizes and densities so that he/she will maintain the same number of residences. Due to reduced infrastructure costs and increased property values, developers realize there is significant economic benefit (Smart Growth / Smart Energy Toolkit). By focusing on open space preservation and a flexible design approach, OSRD mitigates suburban sprawl impacts. And, through the maximization of both resource protection as well as economic profit, this technique has proven to be an innovative form of subdivision design (Smart Growth / Smart Energy Toolkit).

The three principles of OSRD are:

1. maximization of preserved open space
2. the preservation of natural and cultural resources
3. the preservation of the number of homes constructed on a given site.

Maximize Preserved Space

The maximization of preserved open space reduces the area of impervious surfaces. "The Open Space alternative represents a hybrid of the more dense,

mixed-use development pattern of the Neighborhood Village alternative in combination with greater open space and networks designed for stormwater management” (Girling P.103). The development’s stormwater management system is able to be responsive to the lands’ environmental characteristics (Mega). This can include a natural series of stormwater management techniques such as bioretention cells and rain gardens to recharge water aquifers (Smart Growth / Smart Energy Toolkit). These techniques will maximize overland flow and combine the use of plants and landforms to slow, hold and treat runoff from development (Mega).

OSRD concentrates the development of structures on to smaller areas of a site. This is contrary to the practices that would take place under conventional zoning practice. Concentrating development on to smaller areas conserves open space, enables more efficient use of infrastructure, and preserves more mature canopy on site.

Preservation of Natural and Cultural Resources

The preservation of natural and cultural resources can be beneficial to a community for environmental reasons. Natural areas include “wetlands, floodplains, buffers to streams, wildlife habitats, and historic features” (Smart Growth / Smart Energy Toolkit P.1). Planning for OSRD developments encompasses protecting land and water resources and promotes recharging underlying aquifers” (Smart Growth / Smart Energy Toolkit).

Local officials are increasingly turning to OSRD as an alternative to standard 'cluster zoning' provisions as the 'resource-based' approach in OSRD offers more pointed answers to the specific needs of the community. Simply setting aside mandatory levels of open space on a site has not provided the specific resource protection appropriate to a region characterized by rich cultural, natural and aesthetic resources.

(Smart Growth / Smart Energy Toolkit P.3)

Less clearing and grading is required of OSRD developments due to more land being preserved. Increased grading "can compact the soil and increase runoff even on areas where there is no construction.

Road ditches in cluster designs are often grass swales instead of curb and gutter. Grass swales are culturally relevant for these 'suburban' developments constructed in rural settings. These grassy areas allow for more water infiltration and are often less costly for developers and require less maintenance from the homeowners' association or community" (Church P.3).

Preserve Housing Units/ Cost Overview

OSRD can allow developers to maintain profitable returns on investment. "By allowing the same number of units, landowners and developers aren't penalized financially" (Mega P.2) for implementing OSRD practices. Developers are able to maximize access to open spaces and provide more views due to the placement of housing sites (Smart Growth / Smart Energy Toolkit). "OSRD

provides the flexibility to minimize and allow various lot sizes, setbacks, and frontage within the development” (Smart Growth / Smart Energy Toolkit P.2). “OSRD adds valuable amenities that can enhance marketing and sale prices, according to the National Association of Home Builders Research Center. OSRD subdivisions in Massachusetts have shown to appreciate faster and increase resale value more than those in conventional subdivisions” (Smart Growth / Smart Energy Toolkit P.4). These Massachusetts OSRD subdivisions “have demonstrated that well-designed OSRD developments create higher property values than conventional developments with the same type of housing. This increase in value is the direct result of the increased site amenities including open space, views, and preservation of historic resources” (Smart Growth / Smart Energy Toolkit P.4). In most communities, new ordinances will be required in order to create new standards and regulations for open spaces and density standards (Mega). Many communities currently have regulations on minimum lot sizes which would impede upon the ability to implement Open Space Residential Design. “Road frontages, lot size, setbacks, and other traditional regulations must be redefined to permit the preservation of environmentally sensitive areas, rural architecture, historical sites, and other unique characteristics of the parcel of land being developed” (Church P.1-2).

Section 2

Case Studies

After deciding upon which design theories to focus upon in order to meet the standards of Phase II, I began researching existing projects which exemplify characteristics of these theories. I looked at many projects but have narrowed down my search to eight so that I can show at least two examples of each design theory. Some of these projects actually incorporate more than one of the design theories. All projects that I found worthy of note were large scale developments with the exception of the Green Street Program and the Street Edge Alternatives Program. I decided to go ahead with these case studies because though they are not of the same scale as my case study, they still exemplify the principles and techniques I am implementing. Some measures taken within the projects were done so with alternative goals, but were still able to be used for stormwater management. This is the kind of multi-use stormwater management that we should strive for. The eight projects that I examined are:

- Stapleton**, Denver, Colorado
- Prairie Crossing**, Grayhurst, Illinois
- Coffee Creak**, Chesterton, Indiana
- Heritage Park**, Minneapolis, Minnesota
- Green Street Program**, Portland, Oregon
- Street Edge Alternatives Program**, Seattle, Washington
- Caldwell Farm**, Newbury, Massachusetts
- Woodbury Ridge**, Wellingham, Massachusetts

In Table 1, Table 2, and Table 3, I showed design features present in each case study, features of the design theories, and which theories are present in each

of the case studies. Table 1 and Table 2 allow you to visualize which design theories are present in the case studies by comparing which design features belong to both the case study and the design theory. Interestingly, I found that all 8 case studies include some design features of each design theory. Though all of these cases would not be coined smart growth, green infrastructure, low impact development, and open space design, it is encouraging to see that they can integrate feature from each into the design. This is the approach I am taking, integrated design with no specific label.

Stapleton

Denver, Colorado

Stapleton is a 1,328 acre development with 12,000 dwellings located on the former Stapleton International Airport site. The development includes a large commercial area, business parks, schools, recreation centers, and industrial centers, all of which abuts mature residential areas of Denver. "It is noted for its extensive system of parks and open spaces woven within a mixed-use community modeled after the street patterns and neighborhood character of Denver's older residential areas" (Girling P.29). Stapleton utilizes its natural amenities, orienting its open space network as a form-giving system incorporating eight High Plains habitat types which will be restored. The development also utilizes parks and boulevards within the neighborhoods to create an efficient transportation infrastructure for mixed modes of transportation. Stapleton also tries to maximize use of the open space network utilizing 49 percent of the open space for park land, and saving 51 percent for natural areas and habitat. Through the study of Stapleton, I have realized the importance of an open space network and how they can be efficiently incorporated with roadway infrastructure to create an effective transportation network which allows for greater infiltration.



Figure 1: Photograph of Stapleton (n.d.). Note: copyright Chris Palmeri

Prairie Crossing

Grayhurst, Illinois

The Prairie Crossing development is an example of a fully integrated approach to stormwater management over 677 acres. Of those 677 acres, 60 percent of them will remain as open, agricultural land, restored prairie land, wetlands, a lake, and park land. Prairie Crossing implements a four step process in order to infiltrate, treat, and detain runoff from all of the development, with the exception of the high density village center. Runoff from roads and yards flows through vegetated swales which removes pollutants. From the swales, runoff travels in the form of sheet flow over the restored prairie land. From the prairies, runoff travels to wetlands, and from there to a constructed lake where it is detained until it can infiltrate or evaporate. "Infiltration and evaporation along the way reduce stormwater volumes by 65 percent" (Girling P.133). This natural process is shown to be effective and helps to restore the natural character of the prairies and wetlands. The system serves as an invisible stormwater management process which looks like nothing more than the natural state of nature at work. This study shows how naturalized features on a site can be integrated to become a functional system and functional landscape.



Figure 2: Photograph of Prairie Crossing (n.d.). Note: copyright Vaughn Wascovich

Coffee Creek

Chesterton, Indiana

Coffee Creek is a 634 acre development planned for 3,000 dwellings, mixed-use neighborhoods, and commercial centers, all of which is centered around the Coffee Creek ecological preserve. It is most recognized for its mission to protect and restore the wetland located at its center. It has a gridded road system but for the sake of the wetlands, has few connections between the neighborhoods which cross the wetland. The preservation of this natural system is important ecologically as well as culturally for the area, but this system also serves a purpose for the development. The wetland is utilized as a stormwater management system, serving to capture runoff, filter, store, and slowly release that runoff back into the water table. This study shows the important of preserving ecological features of a site while also utilizing them to engage natural processes on the site and theoretically pay for its own restoration and preservation.



Figure 3: Photograph of Coffee Creek (n.d.). Note: copyright Kimberly Wester

Heritage Park

Minneapolis, Minnesota

The Heritage Park Development is located on 256 acres and incorporates 900 dwelling units along with schools, service centers, churches, and industrial centers. It is located in a former public housing area located near downtown Minneapolis. Heritage Park's green network (greenway) was a prominent public amenity which was conceived as a Bassett Creek resurfacing project. Bassett Creek is a creek system which had formerly been buried deep beneath the housing framework. This greenway serves as an important stormwater management feature for the development which provides stormwater catchments to treat and detain runoff from nearly 400 acres of the city. An important aspect of the greenway is that it is all reclaimed green space and will be maintained as park land. This shows that even though the green infrastructure of the development is in no way natural, it can still serve as a prominent stormwater management feature and public amenity.



Figure 4: Photograph of Heritage Park (n.d.). Note: copyright Prairie Restorations, Inc

Green Street Program

Portland, Oregon

The Green Street Program was started in Portland in 2007. It was the mission of the city to assist in managing stormwater at its source among other goals. Portland defined a green street as “a street that uses vegetated facilities to manage stormwater runoff at its source” (Portland Green Street Program P.1).

Using a natural systems approach to stormwater management, they are able to reduce flows, improve water quality, and enhance their watershed health.

Through this program, Portland outlined several specific ambitions which were:

- Reduce polluted stormwater entering Portland’s rivers and streams
- Divert stormwater from the sewer system and reduce basement flooding, sewer backups and combined sewer overflows (CSOs) to the Willamette River
- Reduce impervious surface so stormwater can infiltrate to recharge groundwater and surface water
- Increase urban green space to improve infiltration
- Reduce demand on the city’s sewer collection system and the cost of constructing expensive pipe systems

A study of this program showed me the importance of utilizing infrastructure within stormwater management and the many assets that the integrated approach brings to the table. This approach provides many community improvements directly and indirectly related to stormwater management.



Figure 5: Photograph of Green Street Program (n.d.). Note: copyright City of Portland

Street Edge Alternatives

Seattle, Washington

The Street Edge Alternatives project was completed in Seattle in the Spring of 2001. It was “designed to provide drainage that more closely mimics the natural landscape prior to development than traditional piped systems” (Street Edge Alternatives P.1). In order to attain this natural drainage system, the city reduced the amount of impervious surface by 11 percent compared to a traditional street, implemented swales which provide surface detention, as well as adding extensive vegetation. “Two years of monitoring show that SEA Street has reduced the total volume of stormwater leaving the street by 99 percent” (Street Edge Alternatives P.1). The combination of contoured swales along with traditional drainage measures such as culverts, catch basins, flow control structures and slotted pipes greatly assisted in attaining this result. These measures helped to maximize the sites time of concentration and the site’s total detention volume. This study showed me the importance of utilizing surface detention and just how effective this measure can be.



Figure 6: Photograph of Street Edge Alternative (n.d.). Note: copyright Seattle Public Utilities

Caldwell Farm

Newbury, Massachusetts

Caldwell Farm is a 66 unit housing project built on a 125 acre site in Newbury, Massachusetts. It was developed according to Newbury's Open Space Residential Design (OSRD) bylaw which allowed for 100 of the 125 acres to be maintained as open space including fields, forest, freshwater, and saltwater wetlands adjacent to the Parker River National Wildlife Refuge. Caldwell Farm was awarded "the Best Overall Community" in 2007 by the National Association of Homebuilders (Open Space Residential Design (OSRD) Rural Case Study). Through use of the OSRD bylaw, this development is able to assist in preserving the town's natural and historic character as well as a natural system for stormwater management. According to the OSRD bylaw, by preserving so much open space and historic character, the developer was give the right to establish 66 units through unit bonuses as opposed to the 62 units establishing by zoning. "The open space amenities bolstered the market prices in the development, including a clubhouse, swimming pool, gate house, walking paths and trails throughout the property and adjoining conservation lands" Open Space Residential Design (OSRD) Rural Case Study P.1). This study helped to show me that the preservation of open space which is utilized to manage stormwater in a natural system is a viable option for developer and is profitable.



Figure 7: Photograph of Caldwell Farm (n.d.). Note: copyright C.P. Berry Construction

Woodbury Ridge

Bellingham, Massachusetts

Woodbury Ridge is an OSRD development which utilizes LID practices on 16.4 acres in Bellingham, Massachusetts. Practices used within this development include clustered homes, reduced automobile infrastructure, as well as swales which accept runoff from open space and disconnected rooftop drainage. This helps to reduce or eliminate stormwater drainage infrastructure. The developers placed all of the housing units on the southern portion of the site where the land was already in a state of disturbance. This allowed preservation of more natural areas. The development also allowed for an existing wetland and stream crossings. The wetlands were protected with 50 to 100 foot vegetated buffers which filter out pollutants from runoff. One more important asset to the site was the reduction of impervious roadway surface by 50 percent which allowed for more open space and greater infiltration capabilities. Clustered homes were accommodated on 6 acres of the site while the town of Bellingham gained 10.4 acres of protected natural land to serve as an amenity and to provide natural stormwater management. The study helped me to understand the importance of limiting automobile infrastructure, clustering homes to reduce the development footprint, and utilizing LID measures to create a decentralized, integrated approach to drainage management.



Figure 8: Woodbury Ridge. Note: copyright Weston & Sampson Inc.

[illegible]

Table 2: Design Theory Features

		Smart Growth		Green Infrastructure		Low Impact Development		Open Space residential Design
Stapleton		•		•		•		•
Denver, Colorado								
Prairie Crossing		•		•		•		•
Grayhurst, Illinois								
Coffee Creek		•		•		•		•
Chesterton, Indiana								
Heritage Park		•		•		•		•
Minneapolis, Minnesota								
Green Street Program		•		•		•		•
Portland, Oregon								
Street Edge Alternatives Project		•		•		•		•
Seattle, Washington								
Caldwell Farm		•		•		•		•
Newbury, Massachusetts								
Woodbury Ridge		•		•		•		•
Bellingham, Massachusetts								

Figure 3: Design Theories Within Case Studies

Section 3

Method

I chose the La Rue community in Knoxville, TN shown in Figure 1 to test the hypothesis. As I stated in my proposal, I will be simulating two scenarios within the site boundaries. The first scenario will be that of examining the site in its pre-existing conditions before it was ever developed and planning a new development which incorporates the four design theories mentioned before to create an efficient stormwater management system within a desirable community. The second scenario will look at the site's existing conditions and determine how best to retrofit the site with an effective stormwater management system.

I will be testing each of the scenarios using a program called HydroCAD. HydroCAD is a computer aided modeling program which uses a system of nodes in order to recreate a simplified version of the design and then uses that model to calculate the amount of runoff produced by the system as well flow rates. The systems are comprised of four types of nodes. Those nodes are classified as subcatchments, reaches, ponds, and links. For this project, I will only be using the subcatchments and ponds. To effectively use this program, I will have to first break down the site into sub-watersheds. Any area where water is collected and all areas which drain to that area will be classified as a sub-watershed. Once the site has been divided, each of those sub-watersheds will be run through the program separately.

To begin, we will look at the subcatchment node. Any areas where rain water will fall are considered to be a subcatchment. More than likely, each sub-watershed will have at least two subcatchments: pervious surfaces and



Figure 9: La Rue Entrance
Source: Caleb Lillard

impervious surfaces. These subcatchments can be manicured lawn, vegetated swales, rooftops, driveways, or any other of a multitude of possibilities.

Each surface that will have differing infiltrative properties will need its own subcatchment. Even our detention ponds and rain gardens will be included within a subcatchment's area; rain can fall there and be detained. Each subcatchment will have its own curve number which dictates how much stormwater is infiltrated; like a percentage. We will be connecting our subcatchments to our pond in order to determine runoff amount as well as flow rates. The amount of runoff coming off the subcatchments will also dictate the sizing of the ponds.

The pond node represents detention ponds, rain gardens, retention ponds, cisterns, or any other area where runoff will be detained. These areas rely heavily upon the subcatchments which flow into them. These areas will be sized to detain or contain the total amount of runoff from the subcatchments. It is from these ponds that I can determine the total depth of runoff from the subcatchments and if an outflow is necessary, I can determine the peak flow rate exiting the pond. I have provided an example layout in Figure 2.

To be sure that I am creating no runoff from a 1 inch event, I will set the rainfall amount to 1 inch and determine that I am collecting all of it. I must also make sure that the design does not exceed the original 2, 5, 10, 25, and 50 year peak flow rates. To simulate these events, I will use data for the state of Tennessee. That data is as follows:

- 2 year – 3.4 inches

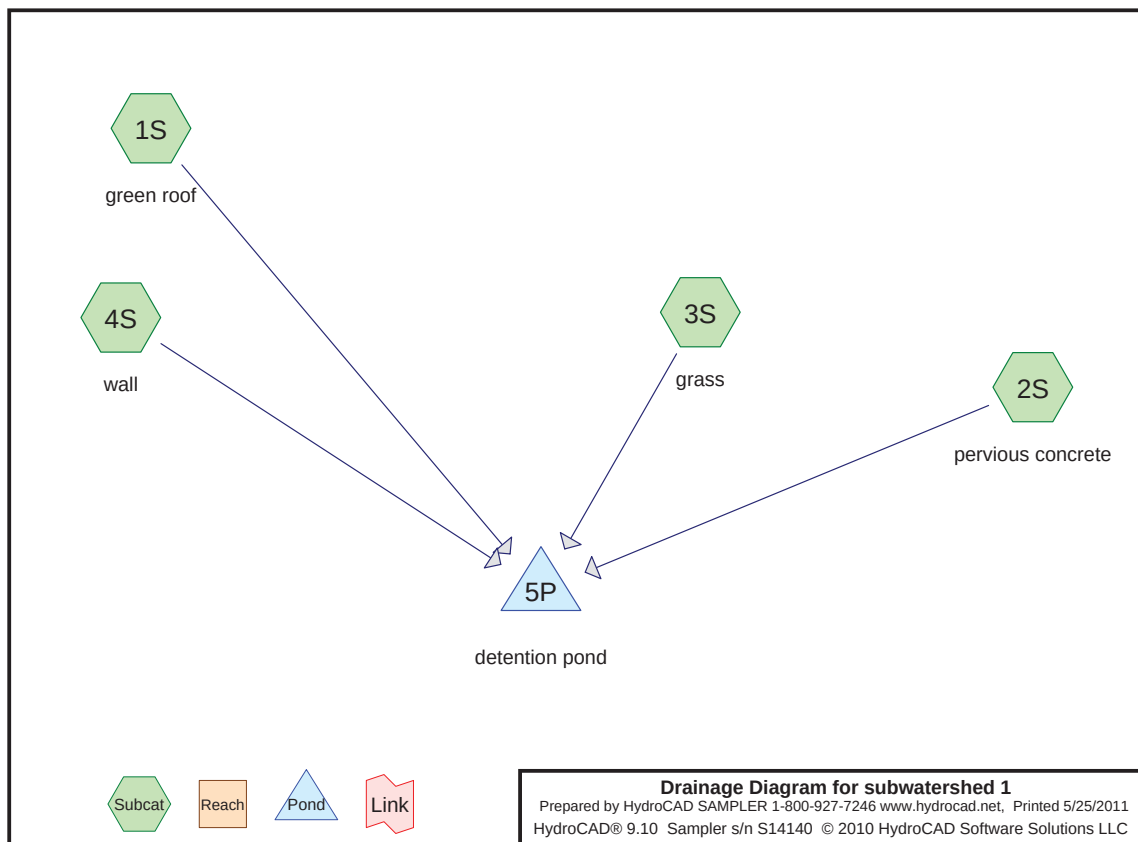


Figure 10: Example HydroCAD Layout
 Source: Caleb Lillard

- 5 year – 4.2 inches
- 10 year – 4.7 inches
- 25 year – 5.5 inches
- 50 year – 6.2 inches

Before I design these scenarios, it is important to first understand characteristics of the site which will hold true for both scenarios. La Rue is a gated community containing two condominium buildings within 2.81 acres. One of the buildings is shown in Figure 3. It sits on the crest of a hill and within the Tennessee River watershed. This site was recommended by my Major professor and upon further investigation, I found the site to be within the criteria of new Phase II specifications. This site creates a challenge due to its small area of pervious surfaces available for use and high percentage of surface area covered by housing and roadway.

The soil profile is important to understand for the sake of stormwater infiltration. Soils that have a high concentration of clay at the surface will not sufficiently infiltrate water for some stormwater BMPs. Fortunately, La Rue's surface is made of silt loam and silty clay loam. The soil on site is classified as Dewey-Udorthents-Urban Land Complex by the USGS. The soil profile of the surface layer is divided into two categories. The first two inches of soil are brown silt loam and from the second inch to the ninth inch, the soil is dark brown silty clay loam. As for the subsoil, from inch nine to inch sixty-six, the soil is red and yellowish red clay. These soils drain well, with moderate permeability, and have a high water capacity. This site will support infiltrative BMPs to assist with the



Figure 11: La Rue Condominium
Source: Caleb Lillard

stormwater management. Without this infiltrative characteristic, La Rue's options would be reduced to capturing rainwater within cisterns or retention ponds.

Since I will be producing two designs, one for each scenario, from this point on I must inventory and analyze pre development conditions theorized from surrounding area conditions as well as existing conditions for the retrofit design.

Section4

Scenario 1: New Development

Introduction

The new development will be situated upon the pre-existing conditions of the La Rue site. Within this development, I am keeping the same building footprints but have the ability to orient them in any alternate form I deem to be most effective for the site's stormwater management system. Other than the buildings' footprints, there are no other restrictions on what can or cannot be placed within the site. This scenario will have full use of the four design theories due to the site being a "clean slate". Before I go into depth with the design approach for this development, it is first important to understand the pre-existing conditions and inventory of the site.

Site Inventory

The La Rue community has been established for years and no record of conditions on the site prior to development could be found. Therefore, the pre-existing condition of the site is estimated based upon surrounding conditions and data retrieved from a GIS model. Woody shrub like undergrowth covers the entire site and roughly 68% of the site is covered with tree canopy as shown in Figure 4. The tree canopy is most dense on the lower elevations of the site. The topography of the site was retrieved from a DEM file using ArcGIS to extract the data. Having been on the site, I find this data believable when looking at how developers graded the site. The topography slopes from west to east. Due to its location

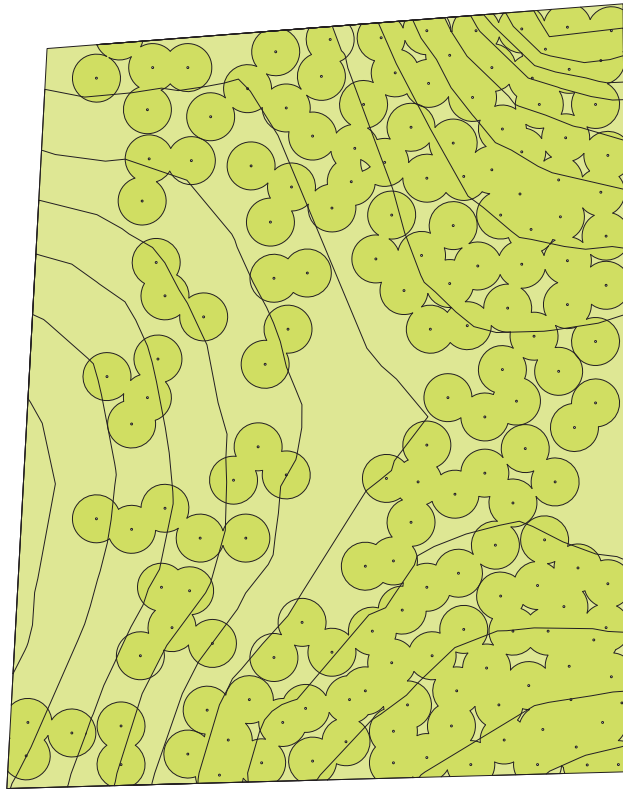


Figure 12: Pre-Existing Vegetation and Grade
1"=100'

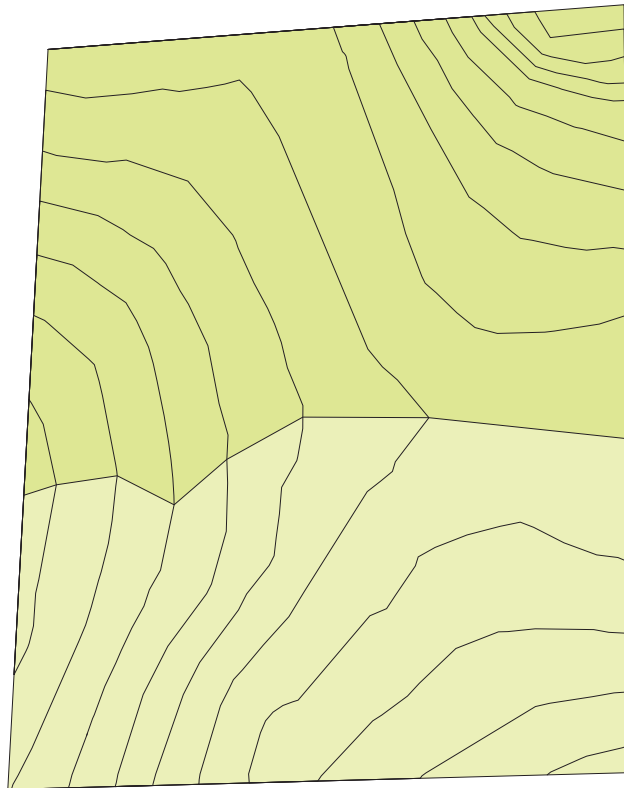


Figure 13: Pre-Existing Subwatersheds
1" = 100'

on the hill crest, the stormwater flow across the site will run from west to east and eventually split to run northeast and southeast. This creates the two subwatersheds on site shown in Figure 5.

Design Approach

For the New Development scenario, I began with the pre-existing conditions of the site. For this development scenario, I treated the site as if it were a clean slate with only one restriction: I would maintain the same building footprint square footage. Before designing anything on the site, I looked at the topography to see where the stormwater would flow. Existing low elevation areas will need some form of detention to capture stormwater not infiltrated or captured prior to reaching these areas. There are two areas that I have termed to be “collection areas”. These are in the northeast and southeast corners of the property.

Another feature of the site that I looked at was the existing tree cover. It is beneficial to maintain as much existing canopy as possible in order to intercept as much rain water as possible before it reaches the ground. Even more importantly, tree canopies increase evapotranspiration on the site. Evapotranspiration is the combined environmental uptake of water vapor through evaporation and transpiration. Although there is no way to calculate the amount of water intercepted or evapotranspired by tree canopies, it is believed to be an important factor in reducing stormwater runoff.

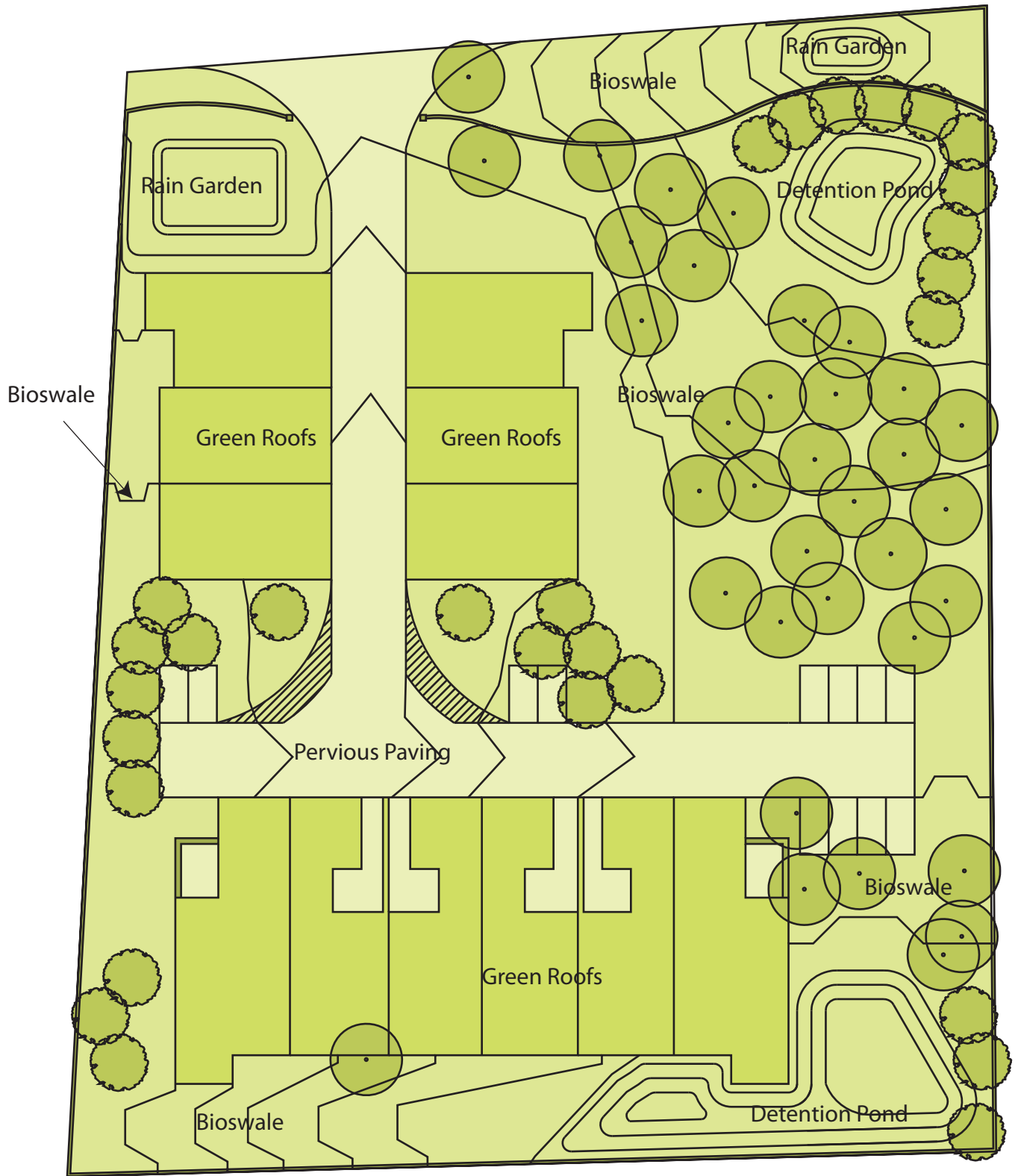


Figure 14: New Development

1"=50'



I then looked at the roads on the site and how best to lay it out. For the infrastructure, it is beneficial to impact the natural hydrologic flow across the site as little as possible, remove as little tree canopy as possible, and keep the road at a minimal square footage. Doing this would maintain natural flow paths, maintain existing levels of evapotranspiration, and cut back on the square footage of impervious surface on the site. To maintain the character of the current development, I kept the same number of guest parking spots. I have placed the entrance for the development on the west side of the property to minimize interference with collection areas on the east side. I laid the drive out in a "T" configuration and made the width of the road 26 feet to cut back on the square footage occupied by the drivable surface, conserving open space (grass lawn/ existing vegetation) which can be utilized for infiltration. Also, I have specified for the drive to be laid with porous paving as opposed to the conventional concrete which exists there currently. Porous paving is also specified for patio areas.

As for the buildings, I placed a row of condos along the southern edge of the property. The buildings have slanted green roofs that drain to the southern edge of the property. To accommodate this flow as well as flow from the infrastructure, I placed a bioswale along the southern edge and southeastern corner of the site. Stormwater captured within the swale that is not infiltrated will flow to the detention pond located in the southeast corner. I placed the other buildings along the entrance drive on either side. They also have slanted green roofs. The buildings on the west side of the drive drain to the western edge of the site where the stormwater is collected within a bioswale and then flows to a rain

garden. The buildings on the east side of the drive drain to the east and flow along another bioswale until it reaches the detention pond in the northeast corner of the site.

Allowing all of the stormwater from all of the rooftops to runoff onto vegetative surfaces plays a significant role. This allows for greater infiltration which reduces runoff volume and minimizes peak flow rates. In many cases, downspouts are connected directly to impervious surfaces which lead to drains. In worst case scenarios, downspouts are connected directly to these drains which allows the least chance for infiltration. Disallowing infiltration is a major contributor to increased runoff volume and increased peak flow rates.

To maintain the private nature of the site as it currently sits, I placed a serpentine wall around the perimeter of the site. The wall prevents runoff of neighboring properties from entering the site with the exception of weep holes. It was necessary to create a detention feature along the northern edge of the property to assist in runoff capture outside the development's wall. Another swale and a rain garden accommodate drainage in that area. I maintained some of the existing tree canopy which is an added bonus for the site. I also placed new trees to contribute to the interception and evapotranspiration on site.

New Development Principles

The New Development has a plethora of principles from the four design theories to choose from to attain runoff management meeting the standards of Phase II. I was able to implement many within the design such as pervious paving for the driveways which reduces the amount of impervious surfaces on the site and providing more open space to enhance the amount of infiltration taking place on site. On the following pages, I outlined the main principles being employed on the site along with graphics showing where the principles are applied. Those principles are:

- Decentralized System
- Downspout Disconnection
- Preservation of Existing Trees
- Efficient Use of Infrastructure
- Preservation of Open Space

The decentralized system is composed of pervious paving, green roofs, detention ponds, and rain gardens. Pervious surfaces including swales are connecting these features.

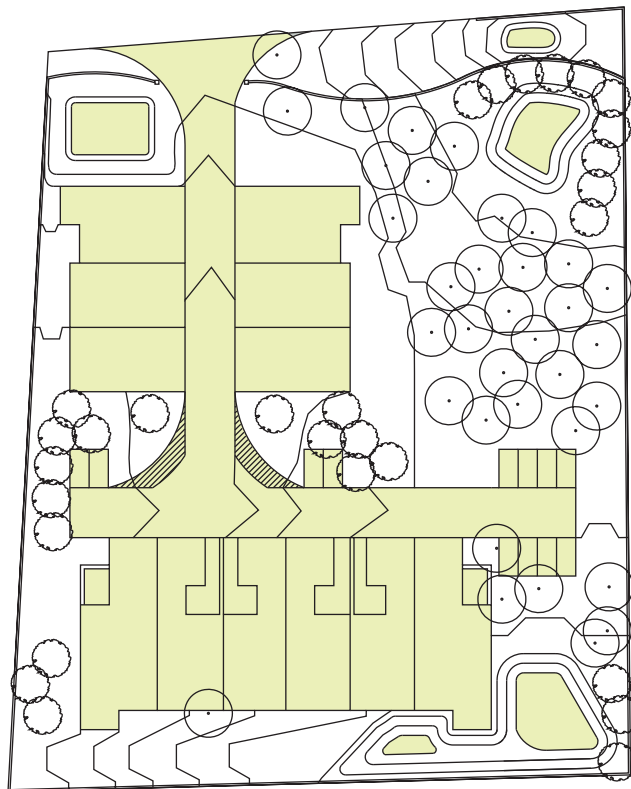


Figure 15: Decentralized System

1" - 100'

The greenroofs have downspouts which flow onto pervious surfaces (grass) and eventually flow into swales. Having stormwater flow onto pervious surfaces increases infiltration, reduces runoff, and reduces peak flow rates.

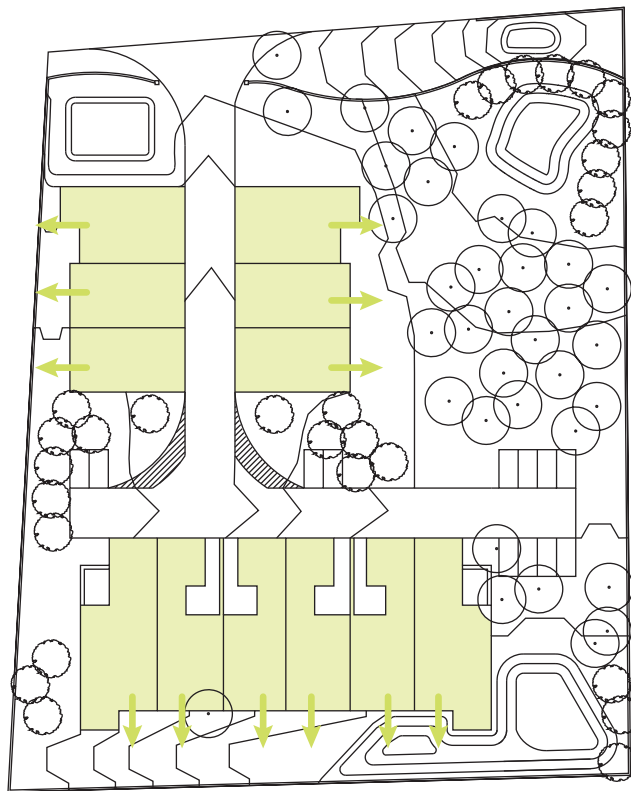


Figure 16: Downspout Disconnection

1" - 100'

Preserving existing trees on the site increases interception during rain events, reducing the amount of rainfall reaching the ground surface. The mature canopies also provide increased evapotranspiration which is essential to reducing runoff.

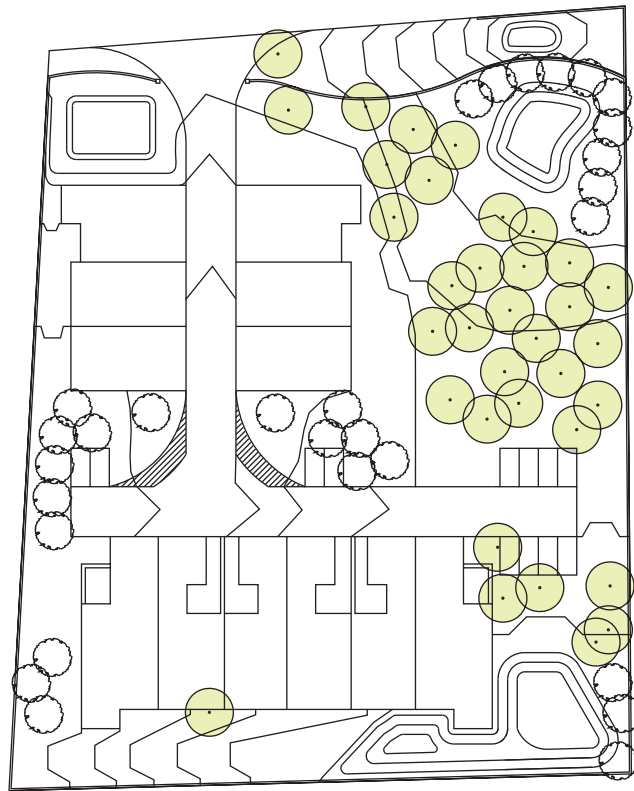


Figure 17: Preservation of Existing Trees

1" = 100'

Using the minimum width requirements for the drive is an easy solution to reduce the amount of impervious surface on site. Also, implementing pervious paving transforms the infrastructure into a stormwater management feature which reduces runoff and peak flow rates.

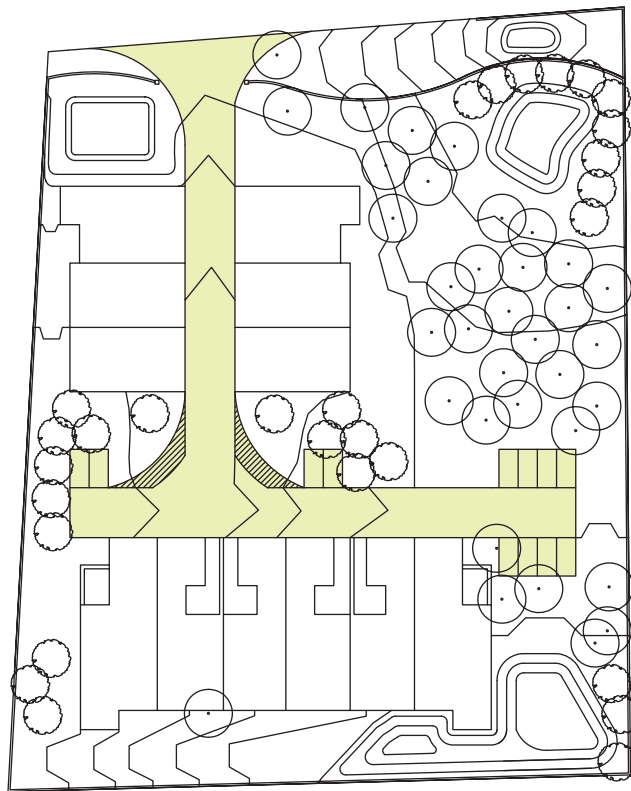


Figure 18: Efficient Use of Infrastructure

1" = 100'

Preserving open space in new developments is essential to providing pervious surfaces which can slow runoff, increase infiltration, reduce runoff, and reduce peak flow rates. Having greater amounts of pervious surfaces creates sites with better stormwater management.

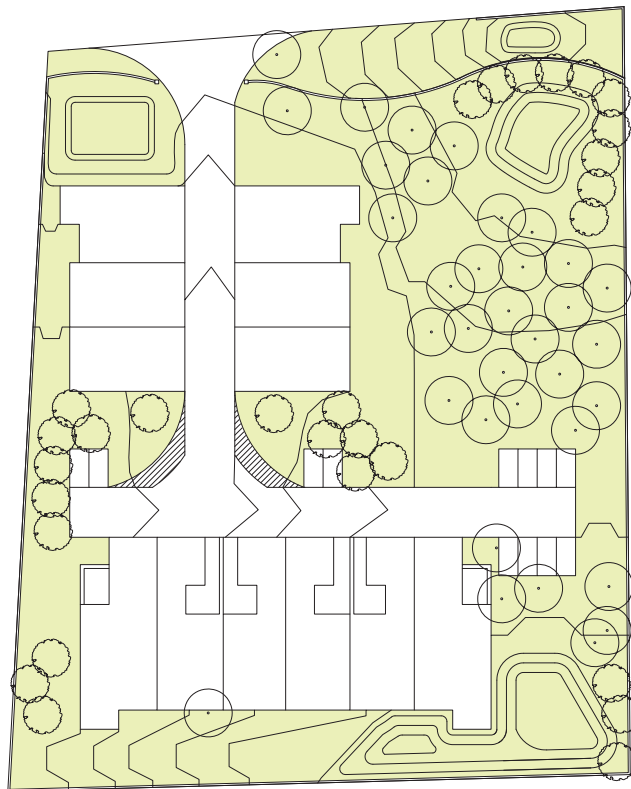


Figure 19: Preservation of Open Space

1" = 100'

Results

After running the HydroCAD calculations, I found that the New Development scenario had a total runoff of 0 inches during the 1 inch event. The design also greatly reduced peak flow rates on the site. Employing the principles shown here has proven effective in mitigating stormwater runoff and meeting the standards of Phase II.

Section 5

Scenario 2: Retrofit Development

Introduction

The retrofit development is based upon current conditions that exist on the La Rue site. In this scenario, I am keeping the building footprints in the same location as they already exist, but any other features such as infrastructure, grading, or vegetation are candidates for change. Within this scenario, the principles available from the four design theories will be reduced greatly from the first scenario. This is due primarily to keeping the building footprints in place which reduces the amount of planning going into the orientation of the site. Design theories such as OSRD which require special organization of development will not be available. The ability of influence the road is also limited to area not occupied by buildings. Before I go into great detail on the design of this development, it is important to first understand the existing conditions and inventory of the site.

Site Inventory

The site has been graded relatively flat. Although slope has little effect on the volume of runoff on a site, it can impact peak flow rates. Basically, an increased slope on the site correlates with increased peak flow rates. Also, having a flat site is more suitable for creating areas of detention where stormwater can be held and infiltrated.

The site contains two buildings and a concrete entrance that bisects

the site and contains overflow parking. These surfaces as well as sidewalks compose the greatest percentage of impervious surfaces on site shown in Figure 12. The walls create restrictions on designing systems by restricting water flow. Determining how much of the site is occupied by impervious surfaces is crucial because impervious surfaces create a much greater volume of runoff than pervious surfaces. Having more impervious surfaces on a site will require a greater number of measures taken in order to mitigate its effects on runoff volume. The site is currently 56.64 percent impervious. A breakdown of that impervious surface coverage is 55.2 percent concrete, 43.1 percent rooftop, and 1.7 percent is made up of walls.

The pervious surfaces on site make up 43.36 percent of the total area shown in Figure 13. Not all impervious surfaces provide the same rate of infiltration. For instance, native vegetation which provides a combination of plant types (e.g. grasses, shrubs, etc.) will promote more infiltration than a manicured lawn will due to reduced flow rates and a greater intake of stormwater by larger plants. The majority of the impervious surface on site is made up of manicured lawn (78.6 percent). The next largest portion is made up of shrub plantings which border the condominium buildings. They make up 21 percent of the impervious surface coverage.

Tree cover intercepts rainwater on its way to the ground and increases evapotranspiration. Trees contribute to reduced flow rates on the ground level and helps to increase infiltration through water uptake in the roots. Tree branches and bark provide interception year round, but trees have a greater impact when

leafs are present since they provide increased surface area to intercept rainwater. Of the 122,421 square feet on site, a mere 19,981.1 square feet is covered by tree canopy. This is 16.3 percent of the site shown in Figure 14.

The constructed site drainage sends stormwater directly to a drain or directly to the adjacent road. The condominium buildings' downspouts connect directly to a conveyance system, piping stormwater directly off site, more than likely straight to the Tennessee River. Aside from the rooftop runoff, roughly 2/3 of the site drains to a storm drain in the Southeast corner of the site and roughly 1/3 of the site drains to Kingston Pike. The site is graded so that the majority of stormwater travels directly south across the site over impervious concrete surface parallel to the buildings until it reaches the drain. What is left drains towards the entrance of the site, which is paved concrete, and slopes down toward Kingston Pike. The current system provides little opportunity for infiltration to take place. In fact, under current conditions the La Rue site exports 0.4 inches of runoff from a 1 inch storm event.

Design Approach

For the Retrofit Development, I analyzed the existing conditions of the site and identifying weakness. The glaring weakness to meeting Phase II goals is the amount of impervious surface occupying the site. The site contains 56 percent impervious surfaces shown in Figure 12. Even worse, the impervious surfaces are connected and drain into the street/conveyance with little

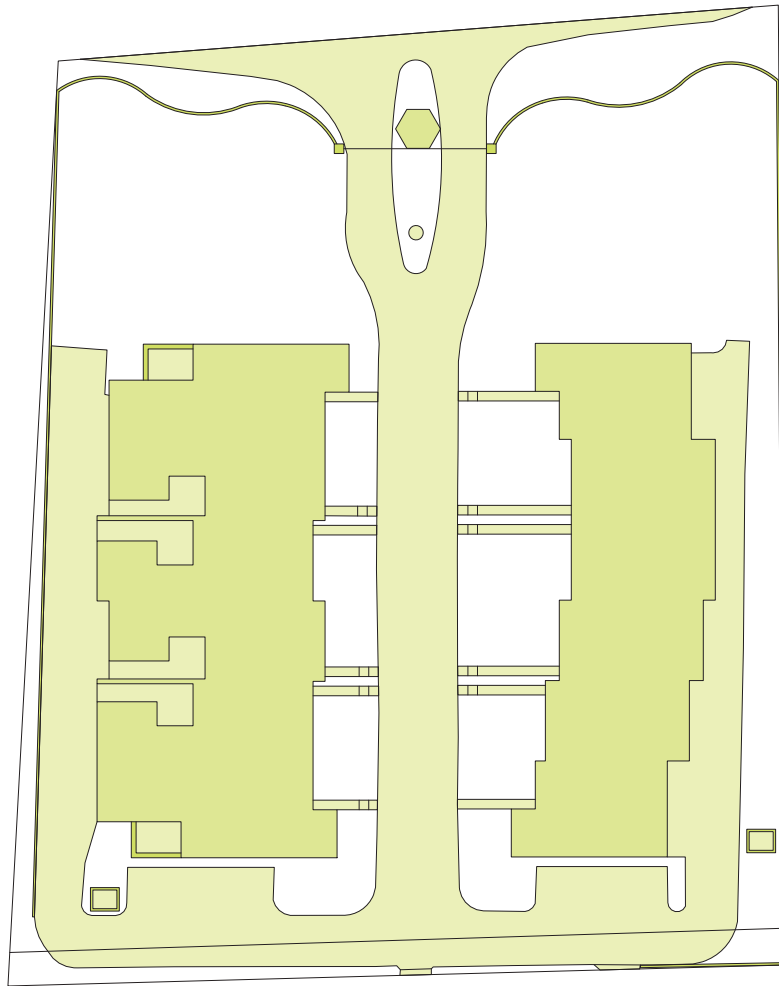


Figure 20: Existing Impervious Surfaces

1" = 100'

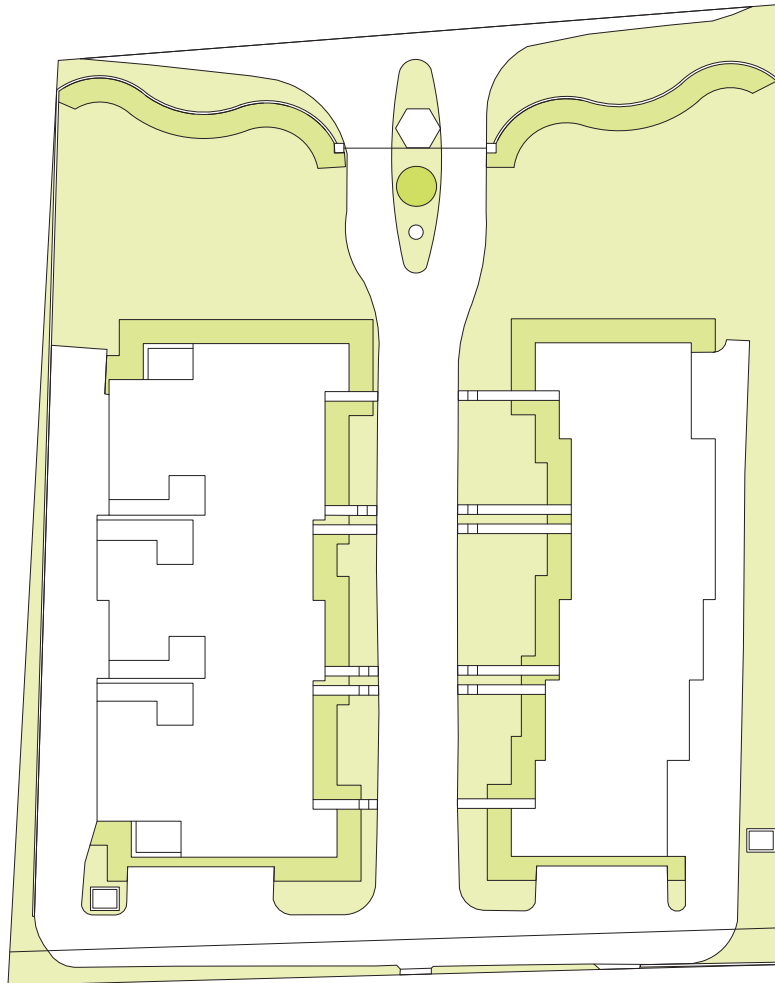


Figure 21: Existing Pervious Surfaces

1" = 100'



Figure 22: Existing Tree Cover

1" = 100'

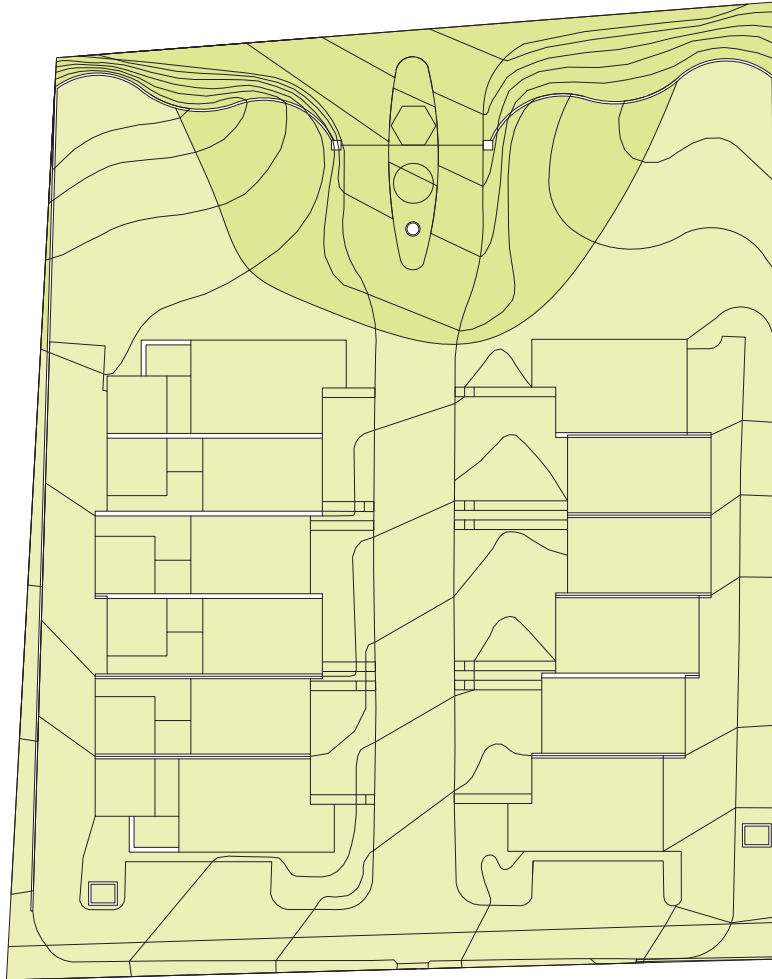


Figure 23: Existing Subwatersheds

1" - 100'

opportunity to infiltrate. The majority of the runoff from these surfaces runs to the conveyance which in turn runs directly to the river. My goal was to create a decentralized stormwater management system to increase site infiltration. With the retrofit development, it was my intention to leave the building footprints as they are but have the ability to alter any other feature of the site (infrastructure, grading, etc.). My first step was to reduce the amount of impervious surface on the site in order to increase the amount of infiltration. Considering how costly retrofitting green roofs can be, I decided to focus on the sites infrastructure.

I removed the center strip and the southern portion of the drive and placed a strip perpendicular to the entrance to reach the alleys. This reduces the road area and allows room for more open space. I specified porous concrete for all roads, sidewalks, and patios. To retain the runoff from the gate house, I placed a cistern in the ground within the island at the entrance. This cistern will collect all runoff from this island and can be reused to water plantings. I implemented a central channel system which can infiltrate stormwater and guide excess flow to the detention pond at the southern edge of the site.

The detention pond at the southern edge of the site is quite large as it is the main component of the management system. It will collect the majority of the site's runoff. I placed two overflow pipes within the detention pond so that it may handle the water levels associated with the 50 year storm event.

Another important consideration is the disconnection of the roof downspouts from impervious surfaces. Now, instead of draining onto the impervious infrastructure, the roofs drain onto either porous concrete or the open

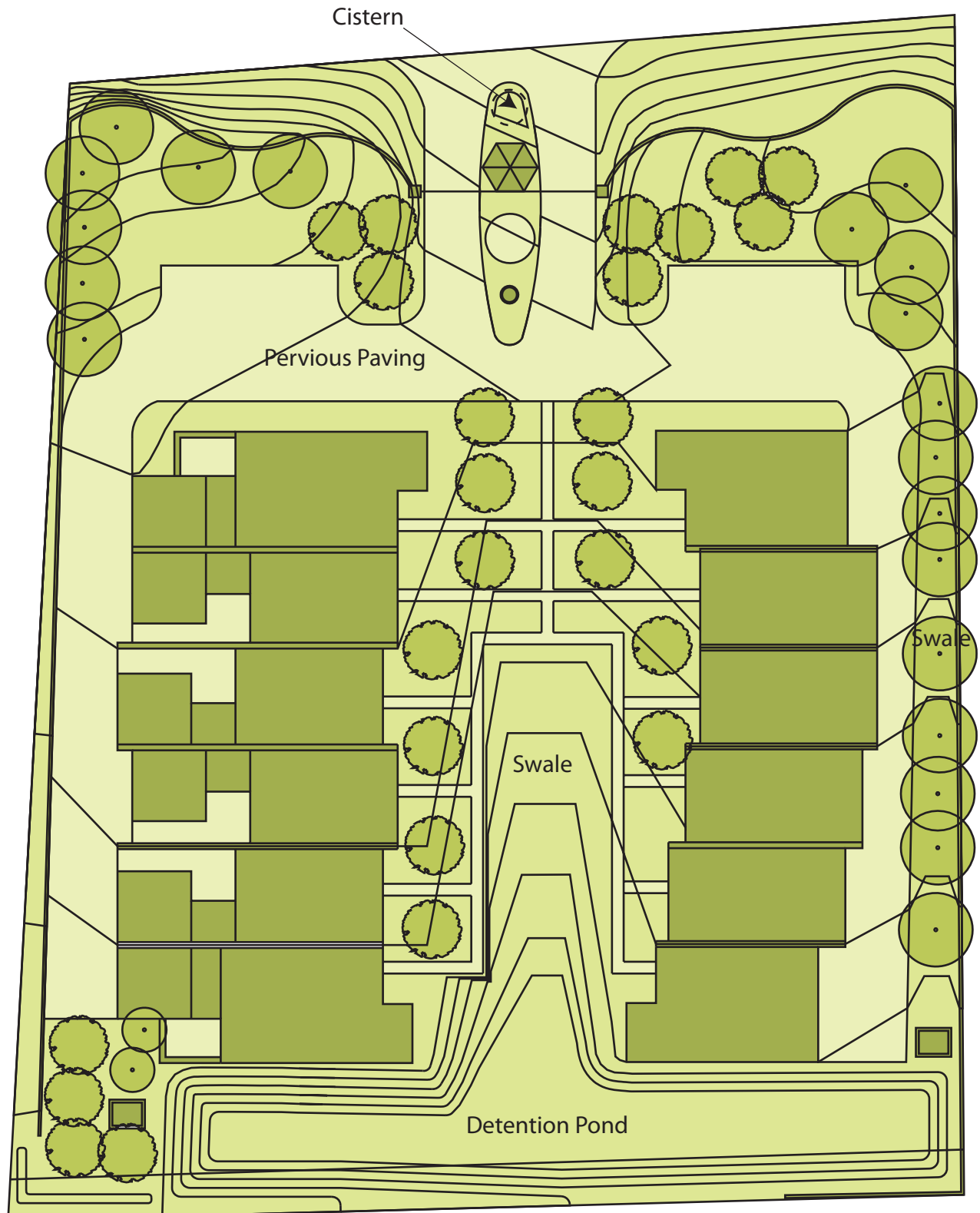


Figure 24: Retrofit Development

1" = 50'



green in the interior of the site. This will greatly aid the infiltration on site. One last point to make is that I was able to preserve almost half of the existing tree cover. I also placed new trees in the plan to help increase the interception and evapotranspiration on site.

Retrofit Principles

The Retrofit Development has a limited selection of principles to choose from compared to the New Development. Though there are fewer options, the Retrofit development can still employ principles from each of the four design theories to choose from to attain runoff management meeting that standards of Phase II. I was able to implement many of the same principles as within the New Development such as preserving existing tree cover to maintain interception and evapotranspiration rates and creating a more efficient use of the infrastructure. On the following pages, I outline the main principles being employed on the site along with graphics showing where the principles are applied. The principles highlighted are:

- Decentralized System
- Downspout Disconnection
- Preservation of Existing Trees
- Reduce Impervious Surfaces
- Efficient Use of Infrastructure

I created a decentralized system by replacing the concrete infrastructure with pervious paving which receives stormwater from the rooftops. The detention pond on the south side of the site collects the majority of the runoff which has not infiltrated. The island at the entrance also has its own management system.

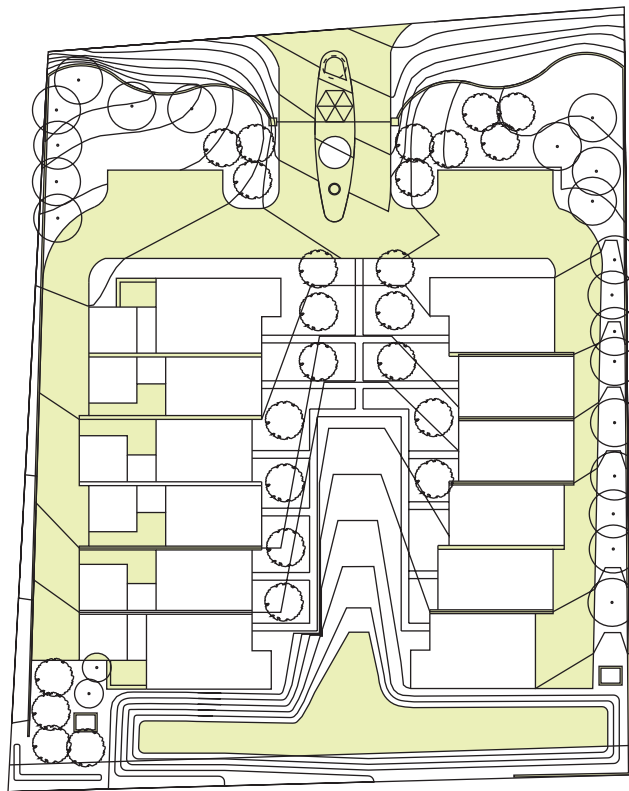


Figure 25: Decentralized System

1" - 100'

The existing condition of the site has stormwater coming off the rooftops and running directly onto the impervious concrete infrastructure. Having the downspouts drain to the new pervious paving and the central green space increases infiltration and reduces flow rates.

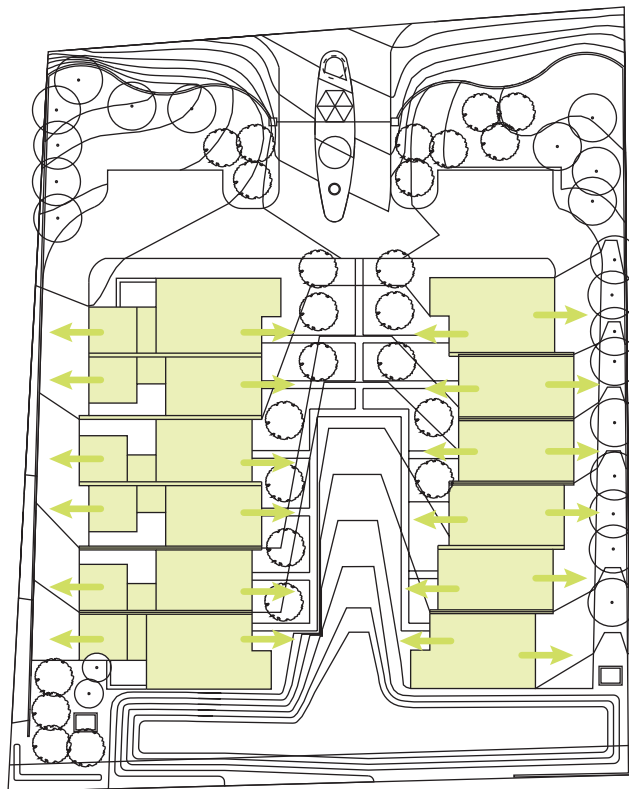


Figure 26: Downspout Disconnection

1" = 100'

Preserving existing trees on site which have mature canopies helps maintain interception during rainfall events and also helps to maintain evapotranspiration rates.

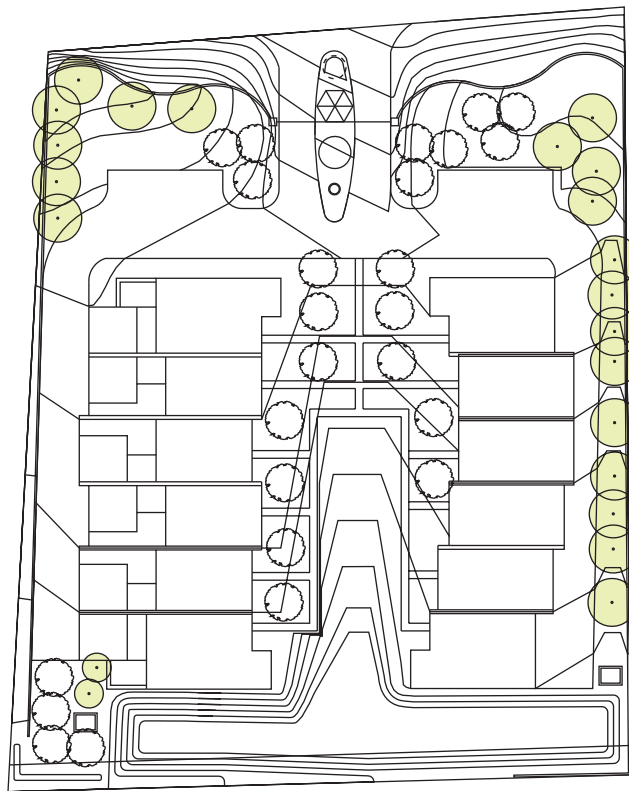


Figure 27: Preservation of Existing Trees

1" = 100'

The diagram that I have provided shows all of the impervious surfaces left on the site post-retrofit. By replacing the concrete infrastructure with pervious paving, I have reduced the total impervious area by more than half. The more pervious area on site, the more infiltration can take place.

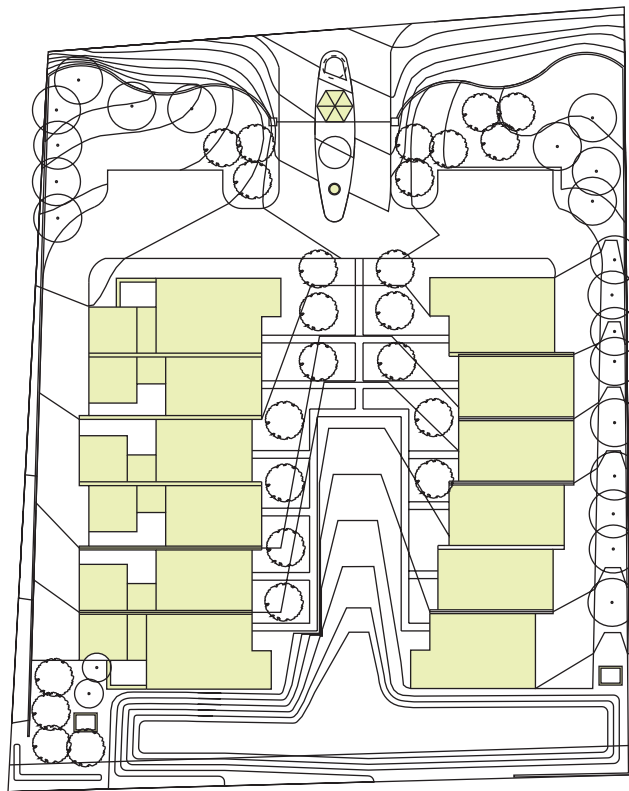


Figure 28: Reduce Impervious Surfaces

1" - 100'

The new layout for the driveway reduced the area occupied by infrastructure, and even if it weren't pervious paving, would occupy less open space which can increase infiltration. Using pervious paving, the infrastructure has also become a stormwater management tool.

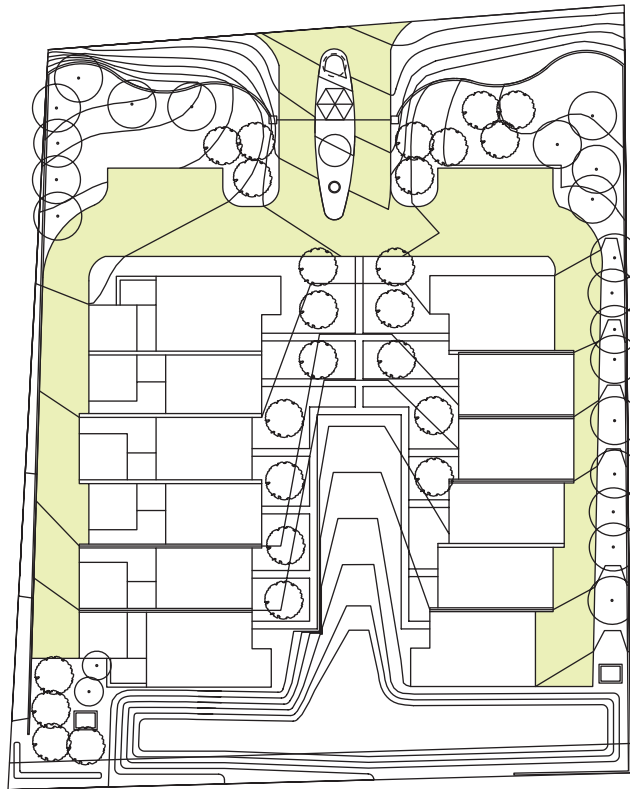


Figure 29: Efficient Use of Infrastructure

1" - 100'

Results

Using the design techniques outlined within the design process and focusing on the principles highlighted, the Retrofit Development was able to reduce the existing runoff of 0.4 inches to 0 inches during the 1 inch event. The development also greatly reduced peak flow rates. This development now meets the standards set forth by Phase II.

Conclusion

In the new development and the retrofit Development, using smart growth, green infrastructure, low impact development, and open space design, I was able to achieve a runoff of 0 inches as well as significantly lower the peak flow rates coming off the site during the 2, 5, 10, 25 and 50 year storm event. It is even more important to understand how these results were achieved. To better understand the systems that are at work within the designs I provided comparative diagrams showing the similarities and differences of the pre-existing condition, new development, existing condition, and retrofit development. It is important to understand that the pre-existing condition, the new development, and the retrofit met the volumetric standards of Phase II with 0 inches of runoff while the existing condition had 0.4 inches of runoff during the 1 inch storm event. The diagrams exemplify five conditions on the site and they are:

- Preserved Tree Cover
- Open Space Vs. Infrastructure
- Downspout Disconnection
- Sub-watersheds
- Pervious Vs. Impervious

The increased amount of pervious surfaces on the site versus the amount of impervious surface played the significant role in reducing runoff for both scenarios. Reducing the amount of impervious surface allows more surface area to infiltrate stormwater over a dispersed area. Most importantly, it allows more surface area to control stormwater at first contact as it falls. This reduces large flows that can accumulate and places less burden on management features at

lower elevations.

I have also provided peak flow charts, documenting the resulting flow rates exiting each of the sites during the 5 specified storm events. These can be seen in Figures 32 and 33. It is clear that implementing features of smart growth, green infrastructure, low impact development, and open space design help to reduce the peak flow rates greatly. Also shown is the increase in peak flow rate on the site after the current development was constructed. Peak flow rate standards have not always existed in development codes. Since La Rue was developed prior to existing flow rate regulations, it was not required to maintain flow rates during the five storm events. This accounts for the higher flow rates shown for the existing condition opposed to the lower flow rates of the pre-existing condition.

Both of the sites employ similar stormwater management techniques like swales, detention ponds, and rain gardens. It is the differences in the two designs which provide an idea of the different approaches required for each. There are two significant differences:

1. the amount of pervious surface
2. the efficiency of roads

Within the New Development, the pre-existing conditions are all pervious and we can specify all development to be at least partially pervious. The green roofs are the only surfaces in the New Development design. The Retrofit design faces a different circumstance. The site had existing impervious roads and rooftops. In the design, I have specified the concrete roads being removed and replaced with a new layout of pervious paving. For the rooftops, I left them

impervious surfaces to show how their runoff can be mitigated. There are cost issues associated with removing large areas of impervious surface also. I do not believe it would have been realistic to remove all impervious road surface and also specify an expensive retrofit greenroof. The retrofit designs require more innovation in managing runoff due to existing impervious surfaces.

The efficiency of roads within the two scenarios constitutes the second major difference in the design. With the New Development, the site is a clean slate which allows me to lay the buildings out where I find them best suited and design an efficient road to support them. In the Retrofit scenario, the buildings are already in place which limits how I can lay the roads out. As shown in Figure 32 and Figure 33, the infrastructure of the new Development is slightly more than half of the infrastructure in the Retrofit scenario. This is due to designing around the buildings. Reducing the infrastructure allows for more open space and infiltration. Designing around the buildings will require more finesse in laying the roads to allow for the greatest amount of open space.

Another point to note is that a Phase II development is capable of accomodating effective stormwater management without the loss of housing units. In both scenarios, I was able to design effective management systems while maintaining the square footage of the two condominium buildings. This is important for two reasons:

1. new developments can maintain profits through the sale of housing units
2. retrofitting existing developments to maintain Phase II goals is attainable

Maintaining housing units is very important to developers. Eliminating potential housing units for detention ponds or other management features can be very costly considering the loss of profit in that piece of land. This would not be an issue for larger developments which can set aside large areas of land to preserve as open space. This is more important to the small developments, such as La Rue, that have limited space to accommodate stormwater management.

Retrofitting developments to meet Phase II standards is not currently required but it is encouraging to show a site can be retrofitted to meet those goals. Without retrofitting existing developments, water quality could only be maintained as it is. To improve the quality of waterways, we must retrofit existing sites to manage their runoff and the runoff of new developments. In both scenarios, the site was encompassed within a wall which eliminated the potential for any neighboring runoff to come on site. Runoff coming on the site could potentially disrupt the management systems and render them ineffective to meet their standards. All sites will not be able to build walls keeping out neighboring runoff. Retrofitting existing developments will at least reduce the amount of runoff traveling from site to site.

Preserved Tree Cover



Figure 30: Preserved Tree Cover Diagrams (Pre-Existing)

Pre-Existing Condition

~84,452 sf of coverage

New Development Condition

~17,185 sf preserved

~14,239 sf new

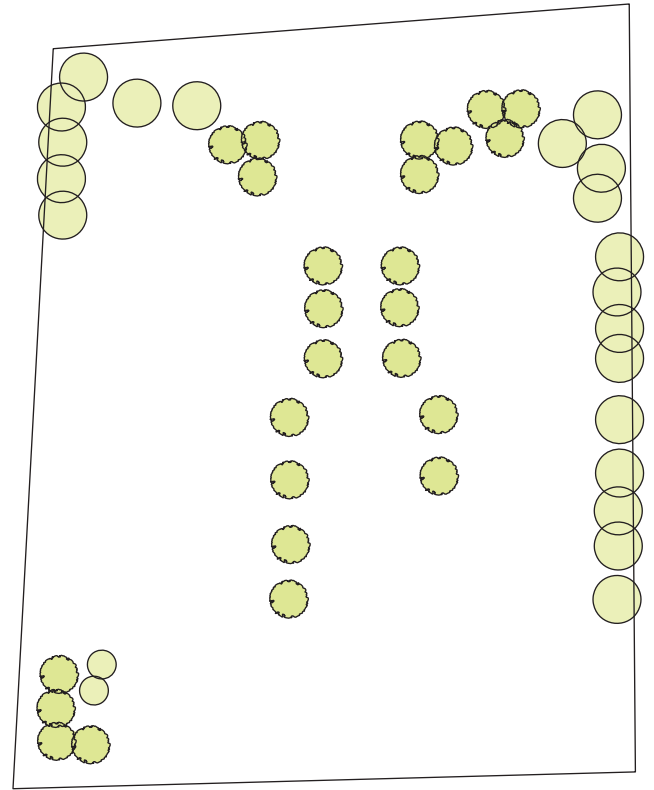
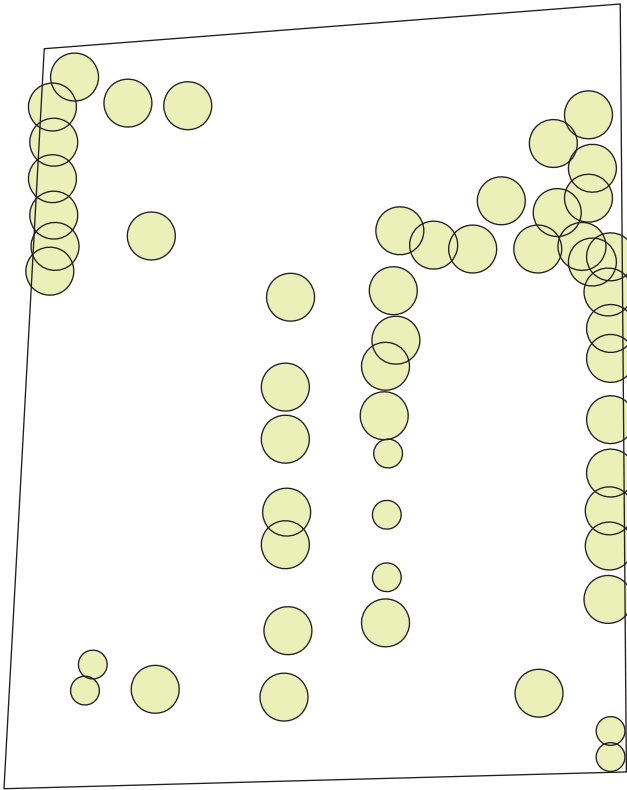


Figure 31: Preserved Tree Cover Diagrams (Existing)

Existing Condition

~25,532 sf of coverage

Retrofit Development Condition

~10,802 sf preserved

~12,275 sf new

Open Space Vs. Infrastructure

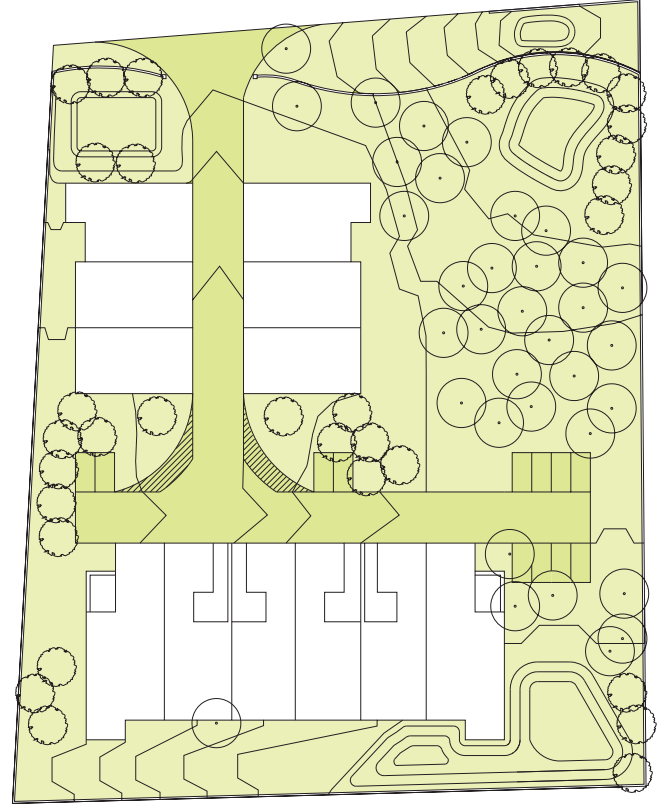
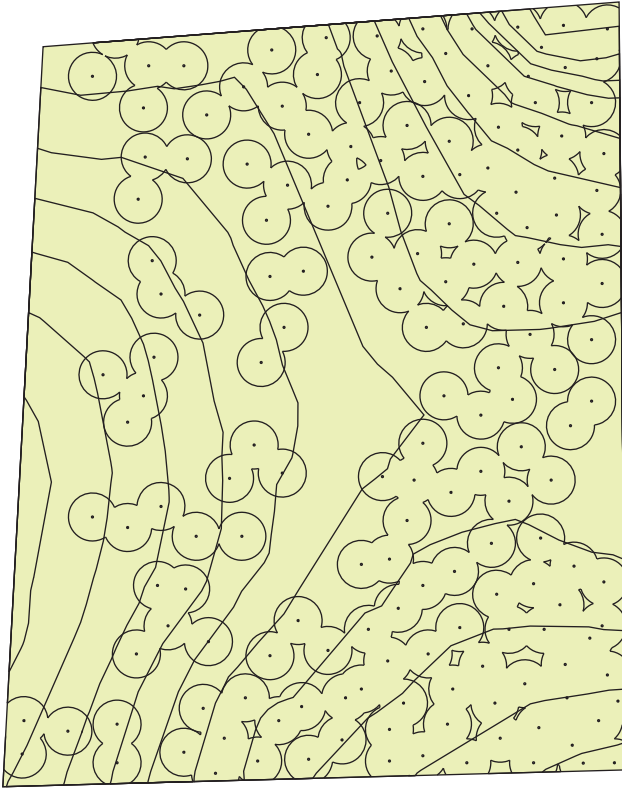


Figure 32: Open Space Vs. Infrastructure Diagrams (Pre-Existing)

Pre-Existing Condition

100% open space

New Development Condition

~62% open space

~13% infrastructure

(Pervious)

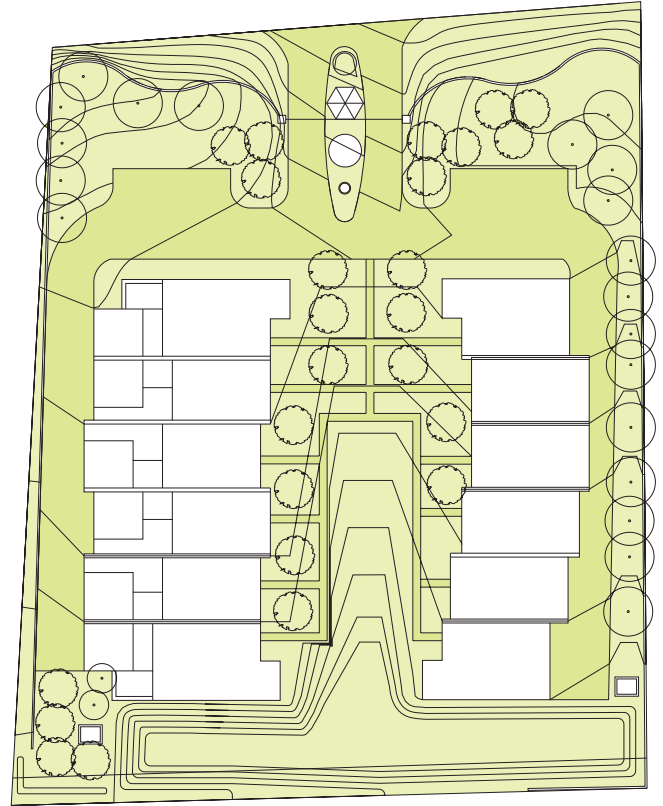
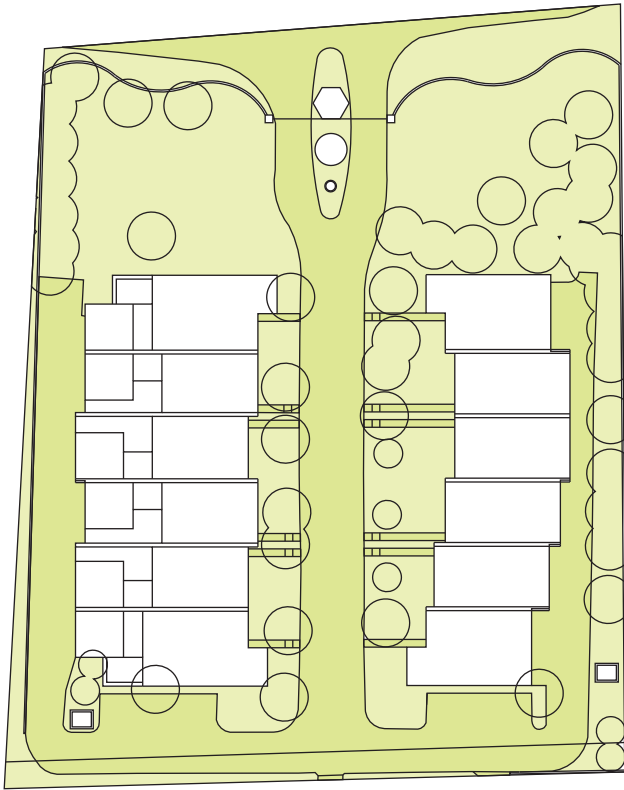


Figure 33: Open Space Vs. Infrastructure Diagrams (Existing)

Existing Condition

~44% open space
~29% infrastructure
(imperivous)

Retrofit Development Condition

~51% open space
~22% infrastructure
(pervious)

Downspout Disconnection

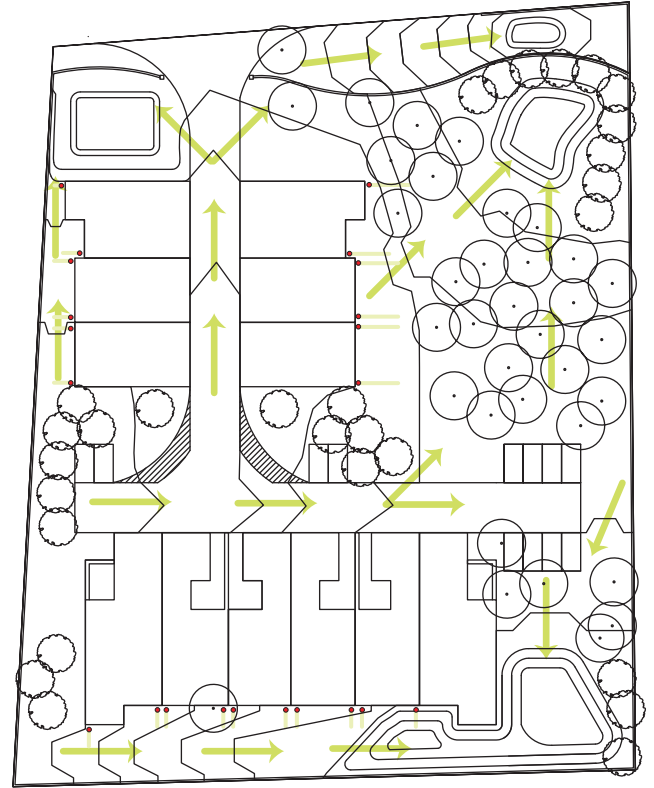
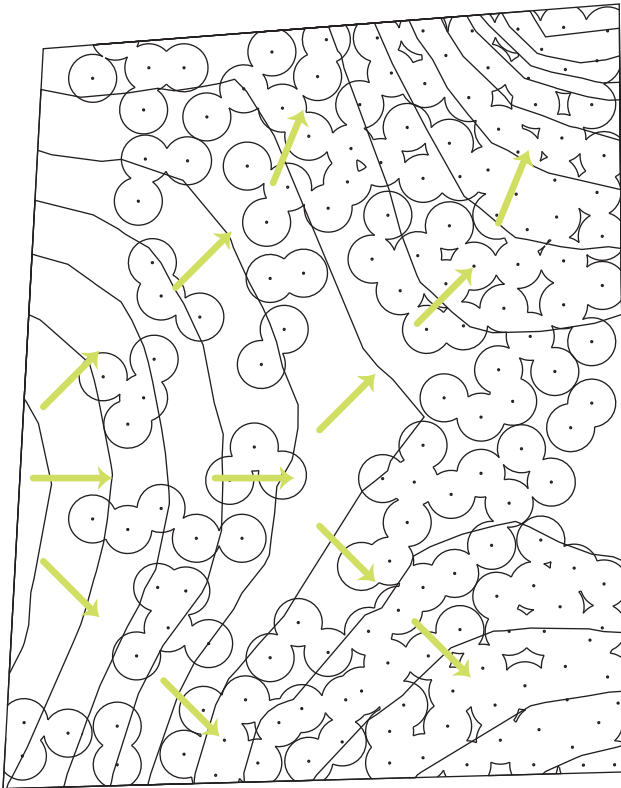


Figure 34: Downspout Disconnection Diagrams (Pre-Existing)

Pre-Existing Condition

no downspouts

New Development Condition

disconnected downspouts

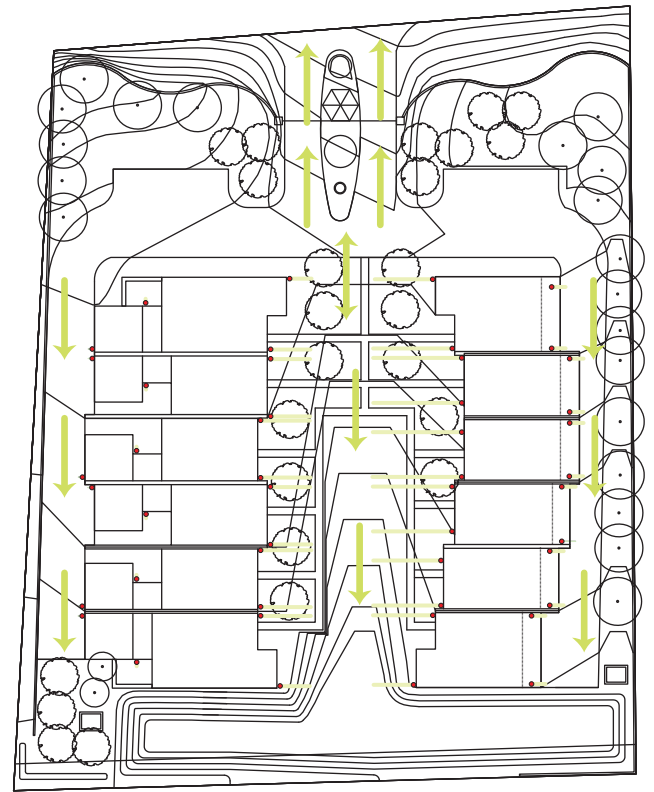
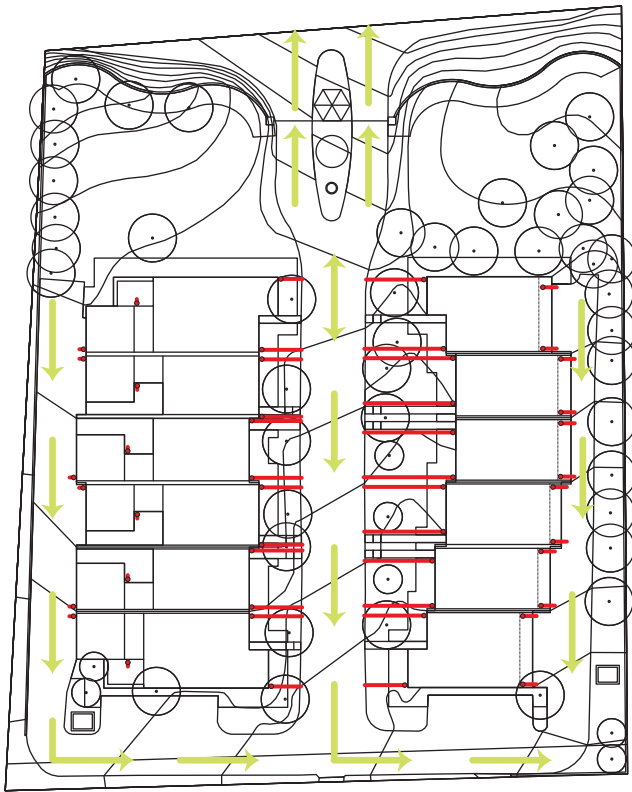


Figure 35: Downspout Disconnection Diagrams (Existing

Existing Condition

Retrofit Development Condition

connected downspouts

disconnected downspouts

Subwatersheds

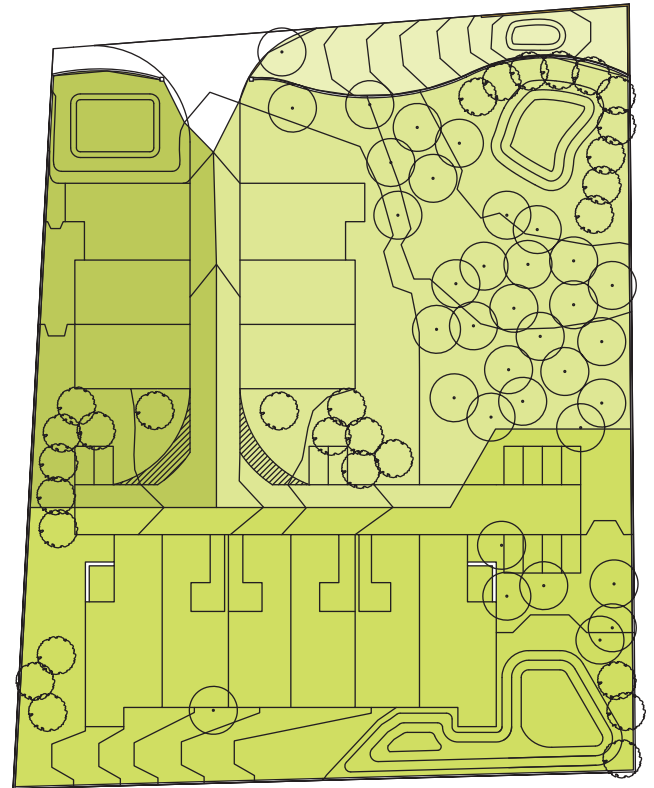
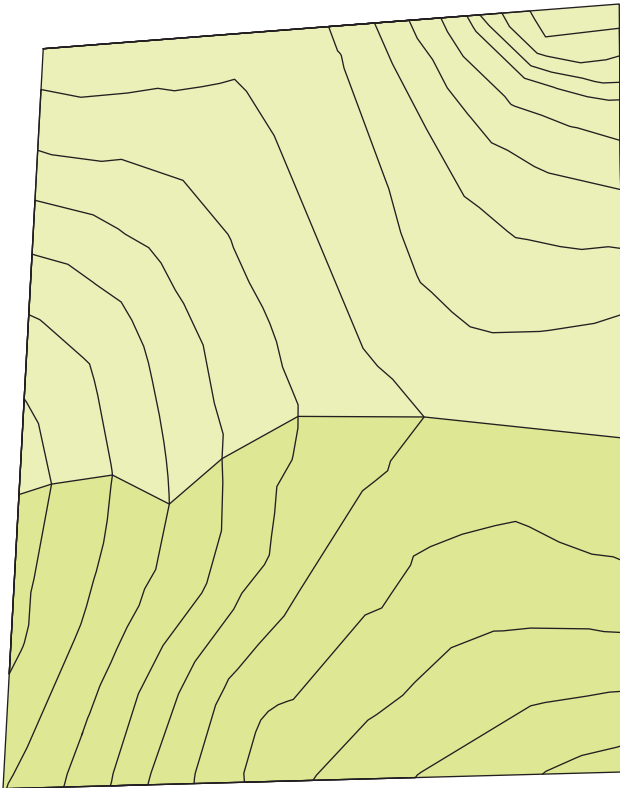


Figure 36: Subwatersheds Diagrams (Pre-Existing)

Pre-Existing Condition

2 subwatersheds

New Development Condition

5 subwatersheds

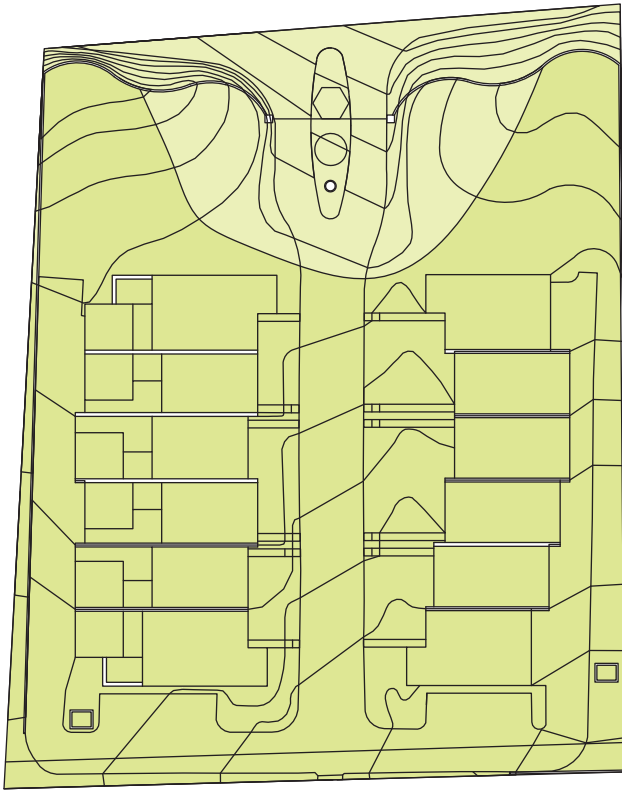
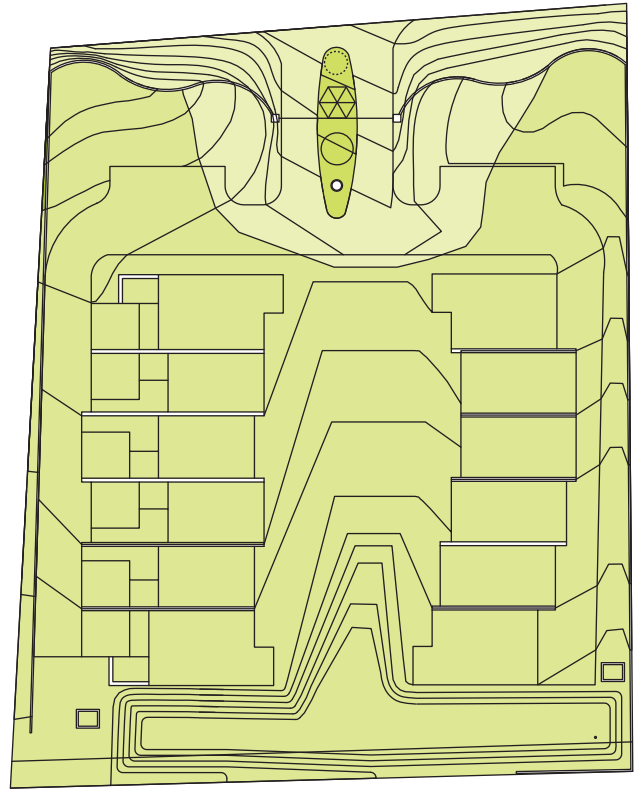


Figure 37: Subwatersheds Diagrams (Existing)

Existing Condition

2 subwatersheds



Retrofit Development Condition

3 subwatersheds

Pervious Vs. Impervious

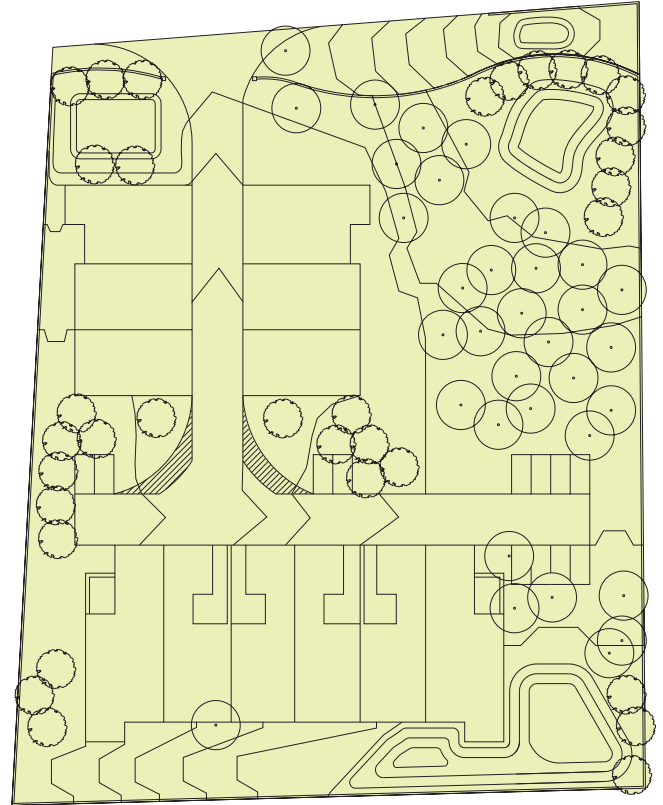
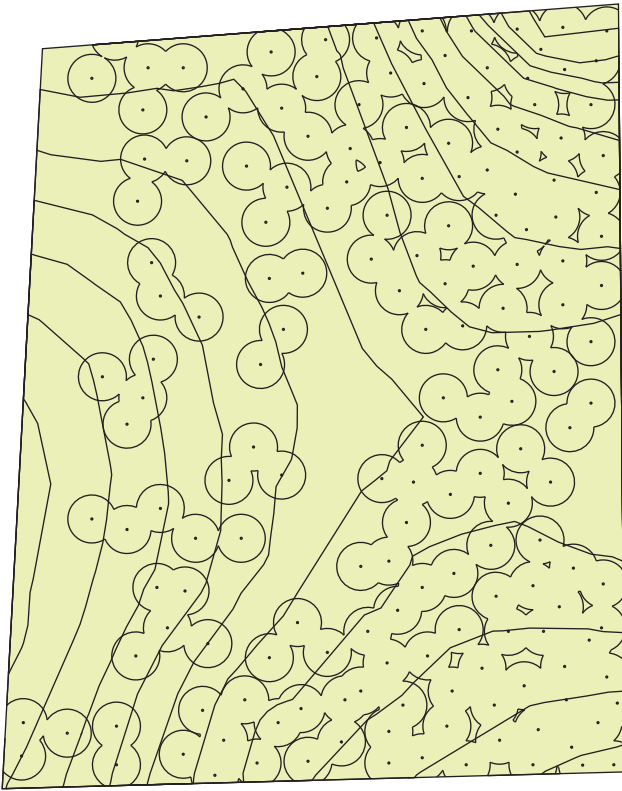


Figure 38: Pervious Vs. Impervious Diagrams (Pre-Existing)

Pre-Existing Condition

~100% pervious

New Development Condition

~99% pervious

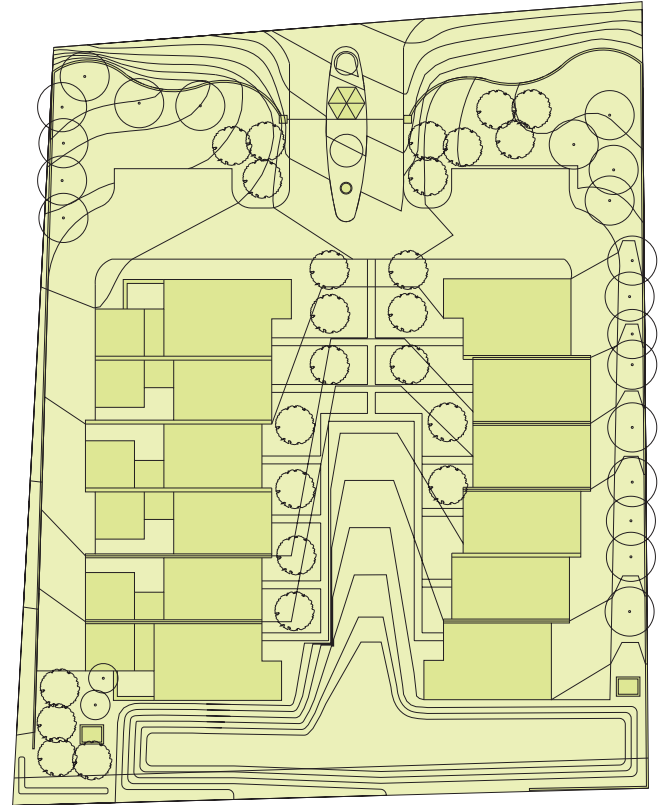
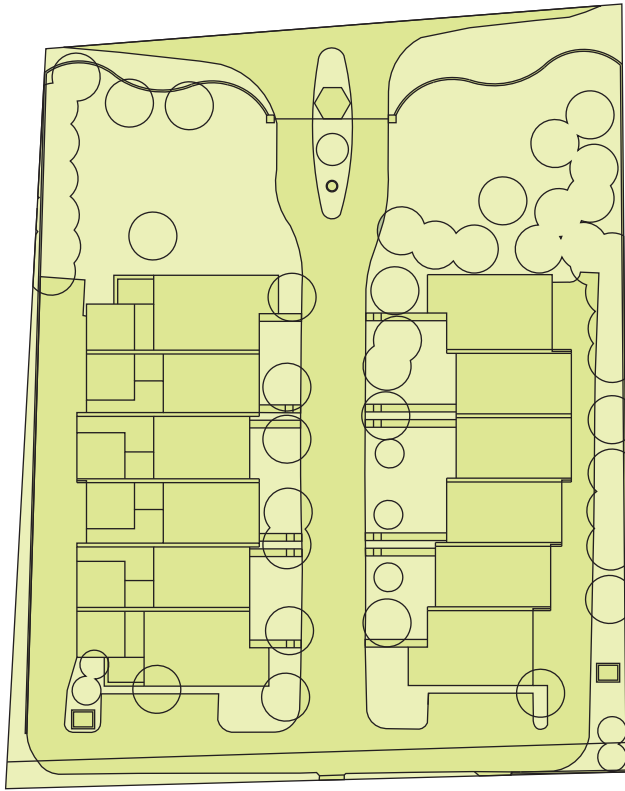


Figure 39: Pervious Vs. Impervious Diagrams (Existing)

Existing Condition

~44% pervious

~56% impervious

Retrofit Development Condition

~74% pervious

~26% impervious

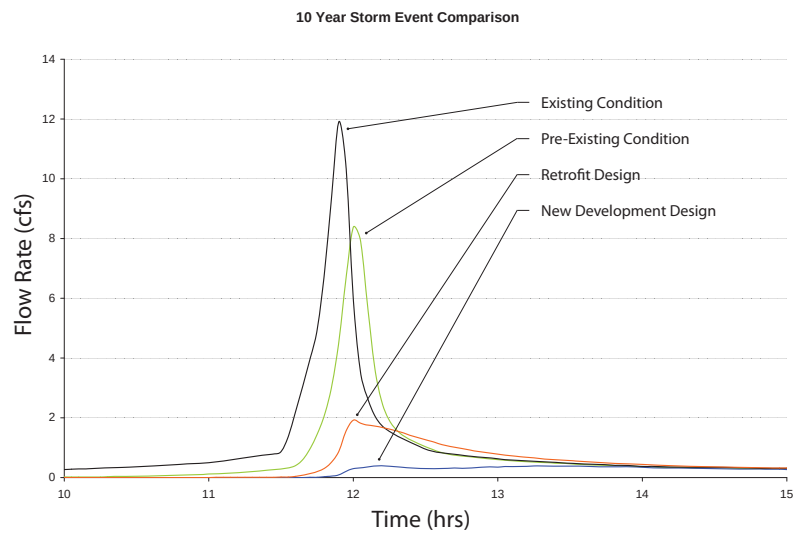
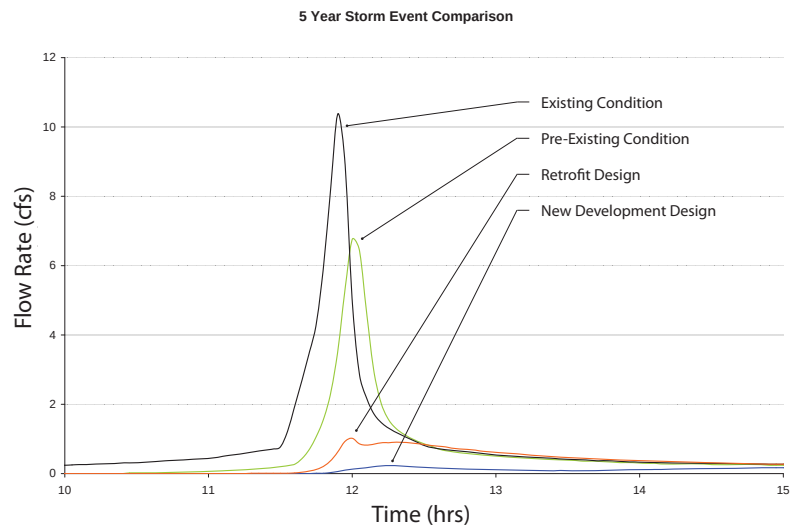
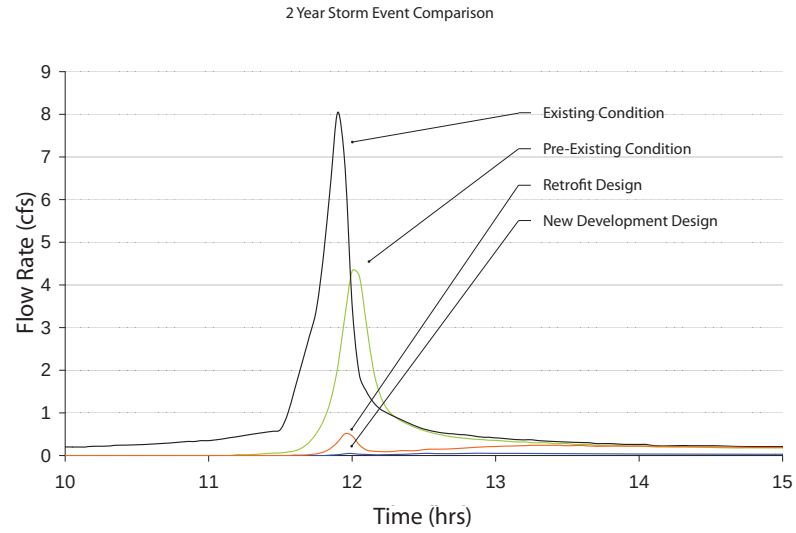


Figure 40: Peak Flow Chart Comparisons (2, 5, 10)

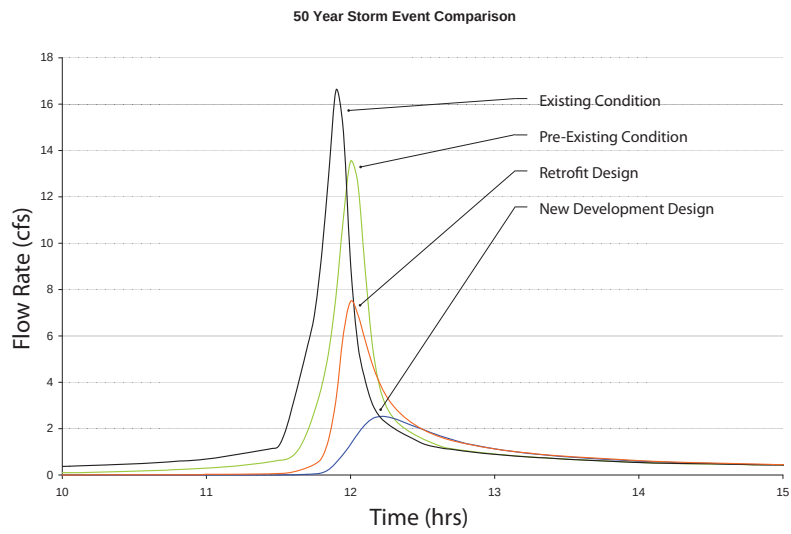
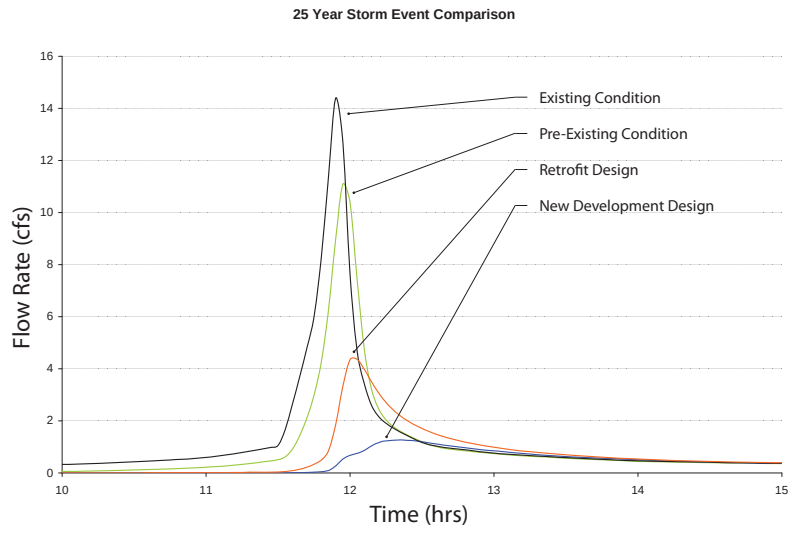


Figure 41: Peak Flow Chart Comparisons(25, 50)

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Vita

Caleb Lillard was born and raised in Franklin, TN, to Jerry and Karen. He is the younger of two siblings: Ashley. For primary school he attended Franklin Elementary School, Freedom Intermediate School, and Freedom Middle School before continuing to Franklin High School. There, he excelled in football and track while graduating with honors. After graduation, he attended The University of Tennessee, Knoxville where he enrolled in the College of Agricultural Sciences and Natural Resources with a major in Landscape Design. He received a Bachelors of Science degree from The University of Tennessee, Knoxville in May of 2008 in Landscape Design. He was then accepted into the inaugural class of the Masters of Landscape Architecture program at The University of Tennessee, Knoxville. Caleb graduated with a Masters of Landscape Architecture degree in May of 2011. His ambition now leads him to become a licensed professional.