ECOLOGICAL STORMWATER SYSTEMS:
A DESIGN PRECEDENT AT CRYSTAL GLEN APARTMENTS IN
ANDERSON, INDIANA
A CREATIVE PROJECT
SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
MASTER OF LANDSCAPE ARCHITECTURE
BY
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1. **Project and Problem Introduction**

The analysis of problems and creative implementation of technology are the foundation upon which a design for an ecological stormwater system is formed. These problems are a result of old methodologies which treat stormwater as a waste to be conveyed off site as fast as possible. This has led to the degradation of ecological systems. Groundwater base flow is lowered which affects stream water levels. Direct surface runoff is heated by impervious cover, loaded with non-point source pollution, and then rushed off site to scour receiving stream banks. Combined sanitary and storm sewers are overloaded with stormwater runoff which is often directly released in our streams. We then use this same water for drinking and recreation purposes.

Low Impact Development (LID) strategies and Split-flow technologies were combined to form an ecological approach to stormwater management. These stormwater techniques can solve water pollution problems and effectively restore natural hydrology. They allow for natural filtration, groundwater recharge, predevelopment direct runoff, and evapotranspiration from soil and plants.

The above mentioned strategies and techniques will be applied to a specific site with unique opportunities and constraints. The design site is the Crystal Glen Apartments in Anderson, Indiana. (see Figure 1-1 and 1-2) This site displays many of the stormwater problems discussed and has a diverse land-use context that is a representative sample of the larger city. The success of such a design will imply viability in many other local landscapes because Anderson, Indiana represents one of one hundred seven Indiana cities.
with similar combined sewer overflow problems.\textsuperscript{1} Indiana has suffered an economic downturn due largely to the loss of manufacturing jobs, thus lacks capital to totally reconstruct stormwater infrastructure. Implementing ecological stormwater systems will reduce the water volumes currently handled by infrastructure and allow for sustainable development without larger investments in stormwater techniques and technologies which have proven themselves unsustainable over time.

\textbf{Figure 1-1: Anderson, IN (B. Krieg)}
1.1 Problem Statement and Sub-Problems

This creative project will identify and design an ecological stormwater system to primarily protect water quality and stabilize water quantity. The design will hypothetically be applied as a retrofit stormwater system at Crystal Glen Apartments in Anderson, IN. The sub-problems are:

1. Examine and design components of an ecological stormwater system.

2. Identify and work with the site implications of the Crystal Glen Apartments.
1.1.1 Sub-problem 1

Examine and design components of an ecological stormwater system: The following outline further breaks down the sub-problem into sections that will be covered in the literature review. The literature review informs the final design program which then informs the final design.

1. Low Impact Development
   a. Integrated Management Approach
      i. Infiltrate water back into the ground.
      ii. Increase evapotranspiration by increasing plant mass.
      iii. Identify a beneficial use for stormwater.
      iv. Filter pollutants out of stormwater.
      v. Select plants that require less irrigation.

2. Split-flow Strategy
   a. No Design Storm/Keep Predevelopment Runoffs
      i. Bioretention filters water before entering infiltration chambers.
      ii. Infiltration chambers accept water from the proportional weirs.
      iii. Proportional weirs split the flow into a bypass pipe or infiltration chamber.
      iv. The bypass pipe carries excess runoff from the site.

3. Ecological Design
   a. Ecological philosophy
      i. Working with nature and staying with natural limits.
ii. Enrichment of the site through complexity and diversity.

iii. Designing for the landscape to evolve with natural processes.

iv. Creativity on site to solve design issues as discovered.

v. Involvement of the users of the site so they own the design.

vi. Minimize energy consumption in the construction and maintenance of the design.²

The aforementioned ecological points were taken into consideration when forming the design goals and objectives which follow this section. Subtle choices in the design are meant to reinforce these ideas even though they aren’t called out as objectives they have made their way into the design. Further, discussion of these finer points can be found in the design program and drawing sections.

1.1.2 Sub-Problem 2

Identify and work with the site characteristics of the Crystal Glen Apartments:

1. What are the average climatic conditions in Anderson, IN?
   a. Temperature
   b. Precipitation

2. What are the existing physical features?
   a. Topography
   b. Geology and soil
   c. Vegetation

3. What is the existing infrastructure?
   a. Storm sewers
   b. Parking and roads
   c. Sidewalks
   d. Buildings

4. What is the site context?
   a. Apartment residents
   b. Neighboring residents
   c. Land use patterns
   d. Transportation availability

1.2 Goals and Objectives

The underlined goals and following objectives were developed for the Crystal Glen site. However, the site is part of a larger system with larger problems that accumulate into macro-scale issues such as combined sewer overflow (CSO), destruction of natural hydrology, and increased infrastructure cost. A greater discussion of the macro-scale issues can be found in the 1.6 significance sections. The goals and objectives will be expanded upon in the design program found in the design recommendations chapter.
1 Reduce stormwater runoff quantity to predevelopment rates and slow time of concentration.

1.1 Increase evapotranspiration through increased plant mass and surface ponding in rain gardens and other landscape features.

1.2 Amend some soils to allow for greater water holding capacity.

1.3 Create below grade void space for water to be reintroduced as base flow through infiltration chambers and stone filled drywells.

1.4 Reduce impervious pavement need or replace with porous materials.

1.5 Slow runoff time of concentration.

2 Improve stormwater runoff quality.

2.1 Filter out suspended solids and litter.

2.2 Filter out and avoid using chemical pollutants such as fertilizers, herbicides, insecticides, oil, grease, and other toxins.

2.3 Reduce erosion wherever possible.

3 Conserve energy and resources at the site scale.

3.1 Exploit rainwater harvesting techniques.

3.2 Create waste to food production.

3.3 Choose/place vegetation for energy and material conservation.

3.4 Encourage use of mass transit and alternate forms of transportation.
Create a landscape which increases quality of life for Crystal Glen and surrounding citizens

4.1 Increase the quality and quantity of connectivity/transportation infrastructure for Crystal Glen and surrounding neighbors.

4.2 Create a sense of place through intentional and artful design where form follows function.

4.3 Include educational and healthy components which foster a greater sense of community.

1.3 Delimitations

This creative project aims to develop a retrofit design using ecological stormwater design principles. Therefore, divergent topics that are justifiably related to the site will be omitted, these delimitations include:

1. Gathering site scale soil data to accurately decide planting plans.

2. Gathering site scale survey information for actual construction.

3. Evaluation of design effectiveness in reducing pollution or runoff volumes.

4. Developing the site design into the level of complete construction documentation.

5. Developing cost estimates or timelines for the design.

6. Developing infrastructure cost savings associated with the design.
1.4 Assumptions

The following assumptions must be accepted in order for the design of the ecological stormwater system to be possible.

1. It will be assumed that Low Impact Development (LID) and Split-Flow techniques are effective at reducing and cleaning stormwater runoff and restoring proper site hydrology.

2. Climatic assumptions based on total historic records such as average annual rainfall and average temperature will be assumed to reflect future conditions.

3. Local regulations will allow or be able to be changed to allow the implementation of the ecological stormwater system.

4. Any changes to bus stop locations would be approved and accepted by the Anderson Transit Authority.

5. The citizens of Crystal Glen Apartments will be willing to participate in the way of life the design requires in order to strengthen the community and maintain the system.

1.5 Significance

Everyone and everything alive needs water to sustain life. Therefore, the quality of water will impact the quality of life. The way in which we shape the land and design stormwater infrastructure will play a critical role in protecting one of our most valuable natural resources—water. The significance of stormwater problems has spurred numerous
regulations. The regulations emphasize the importance of water quality, which in turn is closely linked with water quantity.

The way stormwater infrastructure is built contributes to water pollution. Combined sewer overflows can occur with as little as ¼” of rainfall. This is not only a problem for Anderson, 107 communities in the state have this problem. The cities in Indiana with the largest CSO problems are Ft. Wayne, Indianapolis, and Evansville. Nationally, there are an estimated 772 communities with CSOs. These systems release billions of gallons of polluted water each year.

1.6 Methodology

The methodology applied to this project is a thematic study of the literature on strategies to reduce the quantity of stormwater that enters our rivers, and to improve the quality of stormwater runoff. The High Point residential redevelopment in Seattle, Washington will be the case study used for comparison and as a precedent for Crystal Glen. Emphasis is on identifying problems and designing solutions. The analysis of problems and creative implementation of solutions is the foundation upon which a design for ecological stormwater systems is formed. The majority of the sub-problem questions are answered in the literature review and site inventory and analysis.

This creative project highlights guiding principles set forth in, Cradle to Cradle, considers Environmental Protection Agency (EPA) regulations, and will compare theories from stormwater experts when forming an ecological stormwater theory. The

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3 Anderson Waste Water Treatment Representative, Harbor Day Festival conversation, 2008
case study from High Point Redevelopment in Seattle, WA will be critically analyzed to identify correlations necessary to inform the final design program.

### 1.7 Definition of Terms

i. Ecological Stormwater Design:

1. Ecological: “Relating to ecology, the interrelationships of organisms and their environment”\(^5\)

2. Stormwater: “Water that is not absorbed into soil and rapidly flows downstream, increasing the level of waterways.”\(^6\)

3. Design: “A plan (with more or less detail) for the structure and functions of an artifact, building or system.”\(^7\)

ii. EPA Definition: Non-Point Source Pollution\(^8\)

1. Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;

2. Oil, grease, and toxic chemicals from urban runoff and energy production;

3. Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks;

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4. Salt from irrigation practices and acid drainage from abandoned mines;
5. Bacteria and nutrients from livestock, pet wastes, and faulty septic systems.

iii. EPA Definition: Combined Sewer Overflow (CSO)\(^9\)

Combined sewer systems collect rainwater runoff, domestic sewage, and industrial wastewater together. Usually, this waste water is piped to a waste water treatment plant where it is cleaned and discharged into surface waters. During heavy rain events or when soils are saturated rainwater runoff exceeds the capacity of the waste water treatment plant and the mixtures of wastes are released into surface waters.

iv. Low Impact Development (LID)$^{10}$

“LID is simple and effective. Instead of large investments in complex and costly engineering strategies for stormwater management, LID strategies integrate green space, native landscaping, natural hydrologic functions, and various other techniques to generate less runoff from developed land. LID is different from conventional engineering. While most engineering solutions pipe water to low spots as quickly as possible, LID uses micro-scale techniques to manage precipitation as close to where it hits the ground as possible. This involves strategic placement of linked lot-level controls that are ‘customized’ to address specific pollutant load and stormwater timing, flow rate, and volume issues. One of the primary goals of LID design is to reduce runoff volume by infiltrating rainfall water to groundwater, evaporating rain water back to the atmosphere after a storm, and finding beneficial uses for water rather than exporting it as a waste product down storm sewers. The result is a landscape functionally equivalent to predevelopment hydrologic conditions, which means less surface runoff and less pollution damage to lakes, streams, and coastal waters.”$^{10}$

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v. Split-Flow Strategy

“...a newly developed stormwater management strategy that provides a practical, comprehensive and integrated approach to preserving predevelopment stormwater flow rates, quality, volumes, frequency, and duration. This new strategy is based on site-based systems that treat non-point pollution and split runoff into relative portions based on existing hydrological conditions.”11

2. **Literature Review**

The literature review components combine to form a foundation of knowledge to construct an ecological stormwater system. These fundamentals explore what ecological design means. They also identify water quality and quantity issues which describe the significance of current stormwater problems. Finally, techniques, technologies, and philosophies were examined. The process of accumulating this information influenced the Crystal Glen design.

2.1 **Ecological Design**

Alan Ruff, author of a paper entitled *An Ecological Approach*, lists seven points he feels constitute an ecological landscape. The list is as follows:

1. Working with nature
2. Enrichment through complexity
3. The landscape process
4. Creativity on site
5. Involvement of the users
6. Minimal energy consumption

Working with nature means staying within the natural limits of the site and allowing limits to inform the designer as to what is achievable and appropriate. The design should complement the land, not be forced onto it. For example, some Crystal Glen soils have wetland characteristics, and thus putting infiltration chambers in them
would not be appropriate. These soils are better suited for a naturalized wetland because of the ponding tendencies.

Enrichment through complexity reflects upon nature’s diversity. A natural landscape has variations in physical settings which spur variations in flora and fauna. An ecological landscape has biodiversity, not monocultures and uniformity.

Landscape processes are natural and the design of an ecological landscape should allow for the site to evolve naturally and be flexible to new forces of change. A rigid maintenance schedule to freeze the landscape at one point in time is contrary to the idea of natural succession. Only areas that are to be productive or utilized for continuous human use should be held to such rigid maintenance.

Creativity on site is meant to allow ideas in the construction process to re-inform the design. This means that the designer should be part of the installation process. In the ecological stormwater system it would be beneficial for the residents to be involved in the design and implementation process as well. This would create a sense of ownership, community, and pride in their landscape. This idea carries through to the involvement of the users.

The design should take into account how the construction and landscaping can be performed in an ecologically ethical manner by the local community. Maintenance of the landscape should involve only minimal energy consumption. During the construction of the design, this can be achieved by using local resources. Post-construction maintenance should be minimized by making design decisions that reduce mowing, trimming, fertilization, and irrigation. Planting with native species is one such decision that would achieve this goal.
Minimizing maintenance saves energy, and care should be taken to design the landscape in ways that benefit the micro-climates around buildings and reduce energy needs inside adjacent buildings. Landforms and plantings can screen winter winds and deciduous trees planted on the south facades will shade summer sun and allow solar gain in winter months.

Now that ecological design has been discussed one can look deeper into some environmental issues and how they relate to stormwater systems. Climate change is likely the largest environmental challenge we face in the twenty-first century. Therefore, when considering the creation of an ecological stormwater system it is worth examining the role stormwater could have with climate change issues. The following list is complicated enough to warrant a thesis on each topic. However, this creative project will merely scratch the surface of what future generations might consider of ecological importance.
The 2007 article, *Stormwater Management as Adaptation to Climate Change*, by Laura Funkhouser in The Journal for Surface Water Quality Professionals displays a list of new design goals for stormwater management if climate change becomes a higher priority. The list is:

1. Carbon emission reduction
2. Carbon sequestration
3. Drought effects reduction/water resource protection
4. Energy production
5. Extreme weather/temperature mitigation
6. Runoff hazard reduction
7. Fire hazard reduction
8. Infrastructure repair/mitigation of combined sewer overflows\(^\text{12}\)

The main goals from this list included in the creative project will be to reduce runoff hazards and mitigate combined sewer overflows. Reduction of runoff hazards relate to the quality of stormwater affected by non-point source pollution. The mitigation of combined sewer overflow (CSO) relates to point source pollution and controlling the quantity of stormwater runoff that flows into sanitary sewers. However, an ecological stormwater system could have further positive affects. Increased water supply could help reduce drought and the risk of fire. Increased vegetation from an abundance of water could aid in carbon sequestration. Furthermore, with advances in micro-hydro

\(^{12}\) Laura Funkhouser, “Stormwater Management as Adaptation to Climate Change” *Stormwater: The Journal for Surface Water Quality Professionals*, (July. 2007)
technologies, stormwater could be a renewable energy resource that would aid in reducing greenhouse gas emissions.

Historically, water runoff has been treated as a waste and conveyed off site as soon as possible. The ecological system will restore the natural hydrology of the site by keeping much of the water on the site and treating it as close to where it falls as possible. This allows the rain water to function as the nutrient (food) that it truly is. The natural excess runoff will be conveyed off site only after satisfying the needs of the natural ecosystems.

These principles were instrumental in shaping the design goals, objectives, and program. Subtle choices in the design are meant to reinforce these ideas, and even if not specifically mentioned as objectives, they have made their way into the design. Further, discussion of these finer points can be found in the design drawings section.
2.2 Water Quality

2.2.1 Combined Sewer Overflow (CSO)

Combined sewer systems collect rainwater runoff, domestic sewage, and industrial wastewater together. Usually, this wastewater is piped to a wastewater treatment plant where it is cleaned and discharged into surface waters. During heavy rain events or when soils are saturated rainwater runoff exceeds the capacity of the wastewater treatment plant and the mixtures of wastes are released into surface waters. This occurrence is called combined sewer overflow (CSO). The National CSO Control Policy (US EPA 1994) presents an accurate description of Combined Sewer Overflow (CSO) systems and the consequences of implementing this technology.

“…CSOs often contain high levels of suspended solids, pathogenic microorganisms, toxic pollutants, floatables, nutrients, oxygen-demanding compounds, oil and grease, and other pollutants. CSOs can cause exceedances of water quality standards. Such exceedances may pose risk to human health, threaten aquatic life and its habitat, and impair the use and enjoyment of the Nation’s waterways.”

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The following table clearly shows the pollutants and consequences from CSO’s.

### Table 1. Pollutants of Concern/Consequences of CSOs (US EPA 2001)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Principal Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria (e.g., FC, E. coli, enterococci)</td>
<td>Beach closures</td>
</tr>
<tr>
<td>Viruses</td>
<td>Odors</td>
</tr>
<tr>
<td>Protozoa (e.g., <em>Giardia, Cryptosporidium</em>)</td>
<td>Shellfish bed closures</td>
</tr>
<tr>
<td></td>
<td>Drinking water contamination</td>
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<tr>
<td></td>
<td>Adverse public health effects</td>
</tr>
<tr>
<td>Trash and floatables</td>
<td>Aesthetic impairment</td>
</tr>
<tr>
<td></td>
<td>Devaluation of property</td>
</tr>
<tr>
<td></td>
<td>Odors</td>
</tr>
<tr>
<td></td>
<td>Beach closures</td>
</tr>
<tr>
<td>Organic compounds</td>
<td>Aquatic life impairment</td>
</tr>
<tr>
<td>Metals</td>
<td>Adverse public health effects</td>
</tr>
<tr>
<td>Oil and grease</td>
<td>Fishing and shellfishing restrictions</td>
</tr>
<tr>
<td>Toxic pollutants</td>
<td></td>
</tr>
<tr>
<td>Biochemical oxygen demand (BOD)</td>
<td>Reduced oxygen (O2) levels and fish kills</td>
</tr>
<tr>
<td>Solids deposits (sediments)</td>
<td>Aquatic habitat impairment</td>
</tr>
<tr>
<td></td>
<td>Shellfish bed closures</td>
</tr>
<tr>
<td>Nutrients (e.g., nitrogen (N), phosphorus(P))</td>
<td>Eutrophication, algal blooms</td>
</tr>
<tr>
<td></td>
<td>Aesthetic impairment</td>
</tr>
<tr>
<td>Flow shear stress</td>
<td>Stream erosion</td>
</tr>
</tbody>
</table>

**Figure 2-I: Pollutants of Concern/Consequences of CSO’s (US EPA 2001)**

The ecological restoration of site hydrology will alleviate the problems associated with CSOs only if wastewater treatment plants are designed to handle the predevelopment runoff volumes associated with each site. However, combined sewers require wastewater treatment plants to expend energy by cleaning rainwater that is usually clean when it hits the ground. It is the non-point pollution sources combining with sewage that ruin the quality of rainwater. These non-point pollutants can be dealt with naturally without the need for a wastewater treatment plant. However, monitoring would still need to be done periodically.
2.2.2 Non-point Source Pollution

Non-point source (NPS) pollution comes from any combination of man made or natural things. The pollution is scattered in numerous locations. Precipitation accumulates into runoff and collects the scatter pollution and deposits it into storm drains. Eventually, these pollutants make their way into our water. The EPA lists these pollutants as:

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;
- Oil, grease, and toxic chemicals from urban runoff and energy production;
- Sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks;
- Salt from irrigation practices and acid drainage from abandoned mines;
- Bacteria and nutrients from livestock, pet wastes, and faulty septic systems;

The NPS pollution will be dealt with using Low Impact Development techniques such as bio-retention, bio-swales, infiltration chambers/trenches, and sand filters. It is essential to remove these pollutants if stormwater is to be released directly into surface waters. Further discussion of NPS follows in the Regulations section and the High Point case study examines the implementation of the Low Impact Development techniques.
2.2.3 Water Regulations

The EPA website provides legislation regarding clean water, including the Clean Water Act.

“In 1972 the United States Government passed the Clean Water Act (CWA). Under this act regulations were passed to reduce point source pollution directly into surface waters. Municipalities were given financial aid in constructing waste treatment facilities and surface runoff protection measures. The goal of these measures was to restore the quality of our waters through maintaining chemical, physical, and biological balance. The Clean Water Act originally paid little attention to stormwater runoff as a problem.”\(^\text{14}\)

In 1983, the National Pollution Discharge Elimination System (NPDES) was created to carry out the CWA. The NPDES was a permit program meant to control the water quality problems by regulating the amounts of pollution emitted into our streams from point sources, i.e. pipes or ditches. Individual homeowners do not need a NPDES permit. Only sources that directly input waste to water are required to have a permit. This is usually municipalities or industries. The NPDES system has reduced our water quality problems but we still have impaired waters in our watersheds.\(^\text{15}\)

In 1990, the U.S. Environmental Protection Agency (EPA) realized that more measures were necessary to protect water quality. Just focusing on point source pollution was not solving America’s water problems. Therefore, they initiated Phase I. Phase I required permits for 11 categories of industrial activity, site construction disturbing more


than five acres and pollution control measures on municipal separate storm sewer systems (MS4’s) for municipalities of a certain size. Municipalities of populations greater than 100,000 had to maintain programs to reduce storm drain pollution making its way to streams.¹⁶

Despite all the previous measures taken our streams and water resource qualities are still degrading.

According to the 2000 National Water Quality Inventory, “approximately 40% of surveyed U.S. water bodies are still impaired by pollution and do not meet water quality standards. A leading source of this impairment is polluted runoff. In fact, according to the inventory, 13% of impaired rivers, 18% of impaired lake acres and 32% of impaired estuaries are affected by urban/suburban stormwater runoff.”¹⁷

¹⁷ United States Environmental Protection Agency, Office of Water (4203), Stormwater Phase II Final Rule: An Overview. January 2000 (revised December 2005) EPA 833-F-00-001 Fact Sheet 1.0
The EPA has taken further regulation measures to protect our waters. In December of 1999 the second phase of the NPDES was published in the federal register. This was an extension of Phase I. The new Phase II required that any small MS4 in an urbanized area is required to meet at least the six minimum control measures which are:

1. Public Education and Outreach
2. Public Participation/Involvement
3. Illicit Discharge Detection and Elimination
4. Construction Site Runoff Control
5. Post-Construction Runoff Control
6. Pollution Prevention/Good Housekeeping

The small MS4 designation covers virtually every city in the country that has stormwater systems. There are other details of the Phase II NPDES that would further this discussion, but they will be set aside to allow a focus on how this relates to the thesis problems.

The problem statement identifies the importance of protecting the quality and quantity of stormwater. This is a direct connection to Phase II through the minimum control of post construction runoff. Reviewing the CWA and NPDES phase regulations demonstrates that this study will be useful in meeting some of the regulation.

In the book *Cradle to Cradle* Braungart and McDonough discuss regulations and design. These ideas help shape the overall philosophy used in the design of an ecological stormwater system. They state:

“Regulations force companies to comply under threat of punishment, but they seldom reward commerce for taking initiative. Since regulations often require
one-size-fits all end-of-pipe solutions rather than a deeper design response, they do not directly encourage creative problem-solving… In a world where designs are unintelligent and destructive, regulations can reduce immediate deleterious effects. But ultimately a regulation is a signal of design failure.”

Stormwater systems should be intelligently redesigned using the best technologies we now have available. The redesign of stormwater systems should take the water quality issues being addressed by regulations as the minimum measures to be taken. This would be the foundation of the new stormwater structure.

Braungart and McDonough also state, “The earth’s major nutrients—carbon, hydrogen, oxygen, nitrogen—are cycled and recycled-“Waste equals food.” “Waste equals food” is the primary message of the book and is primary to the logic that will surround the new stormwater structure. H₂O-water-is one of the most important nutrients we need to protect and sustain life on earth. Yet, we treat water as if it were a waste to be disposed of as quickly as possible. The new stormwater system should regard stormwater as a nutrient or “food” for life. The value of water as a nutrient is directly related to the quality of the water. The Low Impact Development (LID) stormwater techniques will cleanse water and restore proper hydrology.

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2.3 Water Quantity

2.3.1 Low Impact Development

The Natural Resource Defense Council (NRDC) published a report on community responses to runoff pollution. Chapter 12 of the report is dedicated to Low Impact Development (LID) and the following benefits are drawn from the introduction. The primary goals of LID are to:

…reduce runoff volume by infiltrating rainfall water to groundwater, evaporating rain water back to the atmosphere after the storm, and finding beneficial uses for water rather than exporting it as a waste product down sewers.10

The result of this Integrated Management Practice (IMP) is reduced runoff volume and pollution. This relates back to the thesis problem of stabilizing runoff quantity and protecting water quality. The vegetation is used in the cleansing of the water, stabilizing soils and water evapotranspiration. Other peripheral benefits are increased aesthetic appeal and habitat revitalization.10
In summary, the LID approach is at the site scale and handles each location according to its opportunities and constraints. Focus is concentrated on trying to handle stormwater as closely to where it falls as possible. This strategy reduces infrastructure costs and allows for more normal hydrologic functioning. Typically, LID has a lower cost than conventional engineered sites. The following table demonstrates the reasons why LID IMP’s are the foundation of the retrofit stormwater system. Of course not all of the techniques will be used; only the ones that fit with the site characteristics.

<table>
<thead>
<tr>
<th>Low-Impact Hydrologic Design and Analysis Components</th>
<th>Flatten slope</th>
<th>Increase flow path</th>
<th>Increase sheet flow</th>
<th>Increase roughness</th>
<th>Minimize disturbance</th>
<th>Flatten slopes on swales</th>
<th>Infiltration swales</th>
<th>Vegetative filter strips</th>
<th>Connected impervious areas</th>
<th>Reduce curb and gutter</th>
<th>Rain barrels</th>
<th>Roof top storage</th>
<th>Bioretention</th>
<th>Vegetation preservation</th>
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<td>Lower Postdevelopment CN</td>
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*Figure 2-2: Low-Impact Development Techniques and Hydrologic Design and Analysis Components (NRDC 2008)*
2.3.2 Split-Flow Stormwater Management Strategies

The Split-Flow strategy is the combination of bio-retention and infiltration techniques to reach predevelopment flow. The new idea behind the Split-Flow is that there is no design storm. There is a drop inlet with two weirs, and as the water flows from the bio-retention basin into the drop inlet, it is proportionally separated into an infiltration chamber and a bypass pipe. This maintains predevelopment runoff rates, reduces first flush non-point pollution, and mimics storm frequency, duration, and volume.\textsuperscript{11}

The original stormwater philosophy was to remove it as quickly as possible from a site to maximize convenience for that individual site. Conveyance to the nearest water body was the solution. Then we moved to detention basins to reduce downstream flooding.\textsuperscript{19} The detention basin was to reduce peak flow rates of a certain design storm. The problem with detention basins is that they fail to mimic natural water balances such as base flows and runoff flows. They hold a design storm and then suddenly overflow once this level is surpassed. This creates erosion downstream and releases the first flush pollutants that the system was intended to stop.

The other theory is to make a system that infiltrates as much of the water as possible. This is recommended by Bruce Ferguson in *Introduction to Stormwater*. Ferguson states: “You should try to infiltrate as much as you can; turn to other approaches only to treat the remaining runoff that cannot be infiltrated. Water belongs in the soil; returning it there is a basic task for urban design.” To a degree he is correct; however, this is yet another system that does not mimic natural site hydrology. In *Introduction to Stormwater* Ferguson placed a figure called Thornthwaite’s water balance concept, which shows the natural water balance. Below you will find a diagram of the water balance concept.

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Figure 2-3: Thornthwaite Water Balance Concept

This concept is similar to the hydrologic cycle but it focuses more on what happens at the ground level. It is based on inflows and outflows of water to reach a balance of soil moisture holding capacity. This capacity varies with soil conditions and seasons. For Ferguson to say that as much water as possible should be infiltrated is misguided, as it would overload the soil moisture and create a state of anoxia. The idea of maximizing infiltration is better than previous stormwater strategies, but again it does not mimic correct site hydrology.

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22 MS Student: Jacob Bauer -- Advisor: Steven Gorelick -- Collaborators: Dr. Eric Reichard (USGS, San Diego) and Dr. Tracy Nishikawa (USGS, San Diego) Regional Groundwater Flow Simulation of Sonoma Valley Including a New Model for Recharge and Three Future Scenarios <http://pangea.stanford.edu/research/groups/hydrogeology/gfx/sonoma_fig5.png> (accessed Spring 2009).
Echols mentions: “The health of preserved uplands vegetation could be adversely affected if their roots are subject to saturation from higher groundwater levels.” He further states, “…natural flash flow frequency would be reduced. These flash flows are an important part of stream hydrology. Many of these flows control changes in stream geomorphology.” The context of the flash flow was in regards to a truncated ten year design storm but it would also apply if all the runoff is infiltrated into the soil.

These discussions about other stormwater methods are to demonstrate why the split-flow method will be used in conjunction with LID techniques. The Split-Flow system lends itself to areas that do not have enough surface area for the various other LID techniques (see Appendix F). However, the site conditions in Anderson will reveal which combination of methods will be best. The theory of needing site runoff is an essential part to maintaining natural hydrology.

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3. **Case Study: High Point Redevelopment: Seattle, WA**

High Point is one of the first redevelopments to combine new drainage technology with urbanism and eco-friendly housing. The natural drainage system combines rain gardens, vegetated infiltration swales with amended soils, and conveyance swales. The hardscape is also designed to better handle drainage with porous concrete sidewalks and the first porous concrete street in Washington State. Water quality was also improved by returning 10% of the Longfellow Creek basin back into pasture conditions.²⁴

Statistics:
- Designer: SvR-Civil Engineering and Landscape Architecture
- Scheduled Completion 2009
- 120 Acres/ 34 Blocks
- 1600 Dwelling Units

Some differences between High Point and Crystal Glen are the topography, the scale of the project, climatic conditions, and the types of housing ownership. The soil likely has different characteristics, but this is only speculation. However, soil amendments were applied to the High Point and will also need to be applied to infiltration zones at Crystal Glen. High Point is a hilly location with greater grade changes than Crystal Glen (see Figure 3-2). This difference has created a need to slow water with check dams in vegetated swales to allow time for infiltration and to reduce erosion (see Figure 3-1). Crystal Glen is extremely flat which creates a situation where

precise grading is important. The soil at Crystal Glen doesn’t allow for quick infiltration and therefore it will be important to make amendments. Two large infiltration chambers will be used to hold the water longer and allow for infiltration to take place.

Figure 3-1: Check dam with weir notch, High Point (B. Krieg)

The scale of Crystal Glen is smaller, but this does not play a factor in the applicability of stormwater design strategies being taken from High Point and applied to Crystal Glen, it merely changes the scale at which components are designed. For example, High Point has a couple acre detention pond to where stormwater is eventually conveyed (see Figure 3-2). Crystal Glen will have a smaller emergent wetland as the low point to which most of the site will drain. This wetland will accommodate most flooding and storm events, though there will also be a raised drop inlet installed, along with an emergency spill way.
The climate in Seattle, Washington is different than that of Anderson, Indiana. In a given year, the temperature averages and precipitation totals of the two locations are similar, but in fact there are stark differences in climate between these cities. The temperature in Anderson is colder in the winters and hotter in the summers. The annual precipitation in Seattle is actually less than Anderson, but Anderson receives larger rain volumes in brief rain events. Seattle has more frequent and prolonged rain events, but with smaller rain volumes. Essentially, it drizzles for extended periods in Seattle and rains intensely for short durations in Anderson.

These climatic differences have a few implications. In Anderson, larger volumes of water require larger stormwater conveyance infrastructure. In Seattle, capturing the first flush of a rain occurs more often but the concentration of pollution is likely less. Whereas, in Anderson, the first flush likely has higher pollution concentration because the duration between rain events is longer, allowing more time for accumulation. The de-
icing agents used in Anderson also create an added pollutant likely not found too often in first flushes in Seattle. The added concentration of pollutants and larger water volumes washing away the pollutants makes slowing and filtering the water even more important.

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**Figure 3-3: Anderson, Indiana Climate**

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**Figure 3-4: Seattle, Washington Climate**

One advantage Anderson has in slowing the rate at which water flows is its flat topography. The soils are not conducive to filtration or infiltration, but again, amendments will be made and added efforts will be made for infiltration and evapotranspiration.

The similarities between the two locations begin with the functionality, programming, and natural stormwater infrastructure of the site. Both are redevelopments of residential locations that need to handle stormwater and create a community for the residents. The first similarity in design will be the use of a community garden (see Figure 3-5 and 3-6). The community garden is a component of the ecological

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stormwater system. It serves a practical use for rainwater gathered in rain barrels and the garden will be the central area for composting. The Crystal Glen stormwater system will utilize compost generated by the garden to improve soil quality and infiltration rates.

*Figure 3-5 and 3-6: Community Garden, High Point (B. Krieg)*
A community garden has numerous benefits - listed in the following outline.27

1. Adds value
   a. Composting reduces landfill and trash handling fees
   b. Less expensive alternative to park space
   c. Increase property values and tax revenue
   d. Gardens are 3-5 times more productive than large scale farming
   e. Local agriculture conserves energy and physical resources by shortening the supply chain
   f. Creates employment opportunities

2. Enhances quality of life
   a. Enhance aesthetics and beauty while reducing stress
   b. Creates recreation and exercise opportunities to improve health
   c. Allows access for low-income families
   d. Creates opportunity for positive socialization and chance encounters across diverse ages, ethnicities, and socioeconomic groups
   e. Creates educational opportunities not commonly found in classrooms
   f. Increase sense of community, ownership, and stewardship
   g. Creates platform for community organization, self-policing, and crime reduction

3. Improves diet
   a. More nutrient rich diet
   b. Local produce reduces negative health affects
   c. Addresses childhood lead poisoning and exposure to chemicals
   d. Access to traditional produce

4. Benefits environment
   a. Increase environmental awareness and appreciation
   b. Protects water quality
   c. Reduces soil erosion and runoff
   d. Restores oxygen to air and reduces air pollution
   e. Reduces urban heat island affect
   f. Sequesters carbon

The second similarity is the installation of a playground. The playground and the community garden were not adjacent in High Point but will be in the Crystal Glen design. The reason for this is to allow young families working in the garden to keep an eye on their children playing in the playground. The close proximity would also allow for more chance encounter between different age groups. Curious children would have an opportunity to learn valuable skills not commonly taught in school settings. The scale and target age of the playground would likely be about the same (see Figure 3-7). The demographic information highlights a substantial population of young children who currently have no play equipment or anything for them outside except open mowed turf.
The third and greatest similarity between High Point and Crystal Glen is the use of natural stormwater infrastructure. As mentioned, the High Point natural drainage system combines rain gardens, vegetated infiltration swales with amended soils, and conveyance swales. The High Point hardscape is designed to better handle drainage with porous concrete sidewalks and curb cuts. While these are not the only parts to the stormwater system, they are the more natural components. Other parts are more technology based; pop-up drains, rain barrels, perforated pipes and check dams (see Figure 3-1 and Appendix: G) are used in conjunction with the natural parts.

The rain garden in figure 3-8 terminates the bio-swale up slope from its position. A similar combination will be used at Crystal Glen between the apartments and adjacent porous hardscapes. Most of the runoff in the Crystal Glen bio-swale/rain garden combinations will come from the apartment rooftops. Whereas, the bio-swale and curb cuts (see Figure 3-9) seen at High Point allow the street water to sheet flow and enter the
curb cut where it then becomes channelized flow. The channelized flow continues down to the rain garden seen in Figure 3-8.

Figure 3-8: Rain Garden, High Point (B. Krieg)

Figure 3-9: Bio-Swale, High Point (B. Krieg)
The rain garden and bio-swale infiltrate small rain events, but when the infiltration rate is surpassed by the volume, a raised drop inlet in the rain garden will accept the excess stormwater. The excess stormwater likely flows through a perforated pipe in a buried infiltration trench until reaching the detention pond (see Figure 3-2). At Crystal Glen, a constructed wetland will be the final destination unless flooding causes the water to spill over into a raised drop inlet. Once in the inlet the water becomes part of the combined sewer system.

The structural components of Crystal Glen which will be similar to High Point are the porous concrete sidewalks (see Figure 3-10). The sidewalks specifications will be discussed more in the design detail section. The parking and drive lanes at Crystal Glen will be impervious concrete sloped toward the center of the drive lane, where a strip of porous concrete will allow runoff to penetrate into a buried infiltration trench that has a perforated pipe. The perforated pipe will lead to the split-flow system at that point.

The High Point porous concrete street has impervious concrete edges (see Figure 3-11). The Crystal Glen streets essentially pull that impervious concrete boarder all the way in until it leaves a four foot strip of porous concrete down the middle.

The areas of the parking and drive lanes that sheet flow runoff towards the edge of the hardscape will be intercepted with an infiltration trench (see Figure 3-12 and 3-13). The infiltration trenches at Crystal Glen will look similar to the ones at High Point, but will likely function differently. Since the trenches will be adjacent to parking, more filtration measures will need to be taken. Sand filters and buffer strips will be used to further clean the water before it reaches the bio-swale. The rocks in the infiltration trench will serve to slow the water, reduce scouring, and serve as vehicle stops. These rock
infiltration trenches will become a common aesthetic throughout Crystal Glen much as they are at High Point. Native rock will be used at different scales throughout Crystal Glen to aid in stormwater management.

Figure 3-10: Porous Concrete Sidewalk, High Point (B. Krieg)

Figure 3-11: Porous Concrete Street, High Point (B. Krieg)
The Crystal Glen ecological stormwater system combines drainage precedents seen in High Point (see Figure 3-1, 3-2, 3-8 thru 3-13) with other LID techniques and
Split-Flow strategies (see Section 1.4) into a complete ecological stormwater system. The Crystal Glen ecological stormwater system goes further than High Point by adding an educational shelter near the constructed wetland, stormwater inspired art near the Broadway bus stop and boardwalk and the central community space which includes the garden, playground, and bus shelter.

The Crystal Glen residents are intended to participate and evolve with the landscape. This would begin by being involved in the design, construction, and maintenance of the landscape. After the major redevelopment is complete residents would be encouraged to assist with the planting of the rain gardens and community gardens. They would be educated about the maintenance of the landscape. A self-led organization would need to be formed to manage the community garden and other happenings around Crystal Glen. These components combine to foster an energized and informed community with a sustainable way of life.
4. **Site Inventory and Analysis**

The site inventory and analysis is meant to orient the client and the designer with the opportunities and constraints of the site. The following categories are included in the inventory and analysis: 1) Demographics, 2) Context and Surrounding Land Uses, 3) Transportation and Circulation, 4) Visual and Perceptual Characteristics, 5) Topography, Soils, and Geology, 6) Watersheds and Hydrology. These categories provide a clear story of the Crystal Glen site. General site information such as an aerial base map can be found in Appendix D.

4.1 **Demographics**

The demographic information found for Crystal Glen is from the Stats Indiana website and based on the 2006 census. Crystal Glen is within a 2006 census block which has a population of 223 people and 95 households. The majority of citizens are white in the census block and only 13 are black and 6 are mixed race. There are no other nationalities within the surveyed area. The dominant gender is female at almost 54%. The median age is 26 years old and 21% of the population is school aged. This is more than 10 years younger than the 37.3 median age noted in the 2006 census information.

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The census block has 95 housing units of which 78 are renter occupied. This high percentage of rented housing is due to the Crystal Glen apartments. The household information also demonstrates a high number of single person households, 30 of the 95. It can be assumed that many of the single person households are apartments within Crystal Glen.

The family information in the census block indicates there are 43 families of which 19 are single parent families, 16 are married families with children and 8 are married with no children. The average family size is 2.89 people. Therefore, the average renters of Crystal Glen can be described as young individuals of around 26 year’s old and young families with school aged or younger children. The needs of the young Crystal Glen residents can be served by redesigning the Crystal Glen site and providing better accessibility to the surrounding land uses and amenities.
4.2 **Context and Surrounding Land Uses**

The Crystal Glen site is the only multi-family residential property in the North Anderson triangle vicinity. The North Anderson triangle, for this thesis/creative project, is spatially enclosed by Cross Street on the south, Scatterfield Road or State Road 9 on the east, and Broadway Avenue or Business State Road 9 on the west (see Figure 4-1).

![North Anderson Triangle](image)

*Figure 4-1: North Anderson Triangle (B.Krieg)*
Crystal Glen is also surrounded by many different types of land uses (see Figure 4-2). Directly to the north are commercial big box stores and fast food restaurants, to the south and east are single family residential lots, and to the west is the Highway 9 business route or Broadway Avenue which leads directly to downtown Anderson. Across the highway are open agriculture fields with some commercial uses along Broadway Ave. Crystal Glen is a transitional land use between single family residential properties and the big box commercial strip. This plays an important role in the transportation and circulation patterns in, through, and around Crystal Glen.
Figure 4-2: Land Use and Building Footprint (B. Krieg)
4.3 Transportation and Circulation

Crystal Glen sits between single family residential lots and commercial amenities (see Figure 4-2). This has made it susceptible to neighboring pedestrians/bicyclists crossing the site as a short cut (see Figure 4-3). Even the residents of Crystal Glen make worn walking paths through the landscape to get to the amenities on the other side of the northern berm. This berm creates both a physical and visual barrier, and in some places the berm is well over 6’ tall and has slopes exceeding 30% (see Figure 4-4). It is possible that some places in the berm could be penetrated to give the residents of Crystal Glen safer access to essential services.

Figure 4-3: Man crossing Crystal Glen on Bicycle (B. Krieg)
The swale and berm on the west edge of Crystal Glen also creates a barrier. The swale moves water off the site to the south where it continues down Broadway Avenue, and the swale sometimes holds water, making it impassable. There is not much reason for the residents of Crystal Glen to get to Broadway Avenue because there is not a sidewalk up there for them to walk on, only a swale with steep sides (see Figure 4-5). If they chose, they could walk down the grass median or on the shoulder of the road, neither of which would be safe. More will be discussed about the berms and swales of Crystal Glen in the visual and perceptual characteristics section following.
Observations of the pedestrian circulation pattern reveals many people walking south down Crystal Street and west on School Street to get back on the Broadway Avenue sidewalk, which then continues south from that point with a sidewalk on each side of the road. Observations of afternoon pedestrian activity showed that the main and only entry/exit to Crystal Glen does not have a sidewalk. School children were walking up the middle of the street. (see Figure 4-6). The topographic information and image show that the center of the street is used to convey water to a drop inlet. This makes access to the site difficult, and of course, unsustainably handles stormwater.

*Figure 4-5: Crystal Glen West Swale (B. Krieg)*
Circulation and transportation corridors through the site could stand to be upgraded. These upgrades would come in the form of increased sidewalks, walking trails, pedestrian bridges over wet areas, and circulation openings through the north berm. Other small circulation adjustments such as accessibility ramps and curb cuts would benefit the site.

Crystal Glen is on a public bus system route. The bus comes from the south up Broadway and enters the K-Mart/Marsh parking lot to the north of Crystal Glen and comes back to a southbound stop on Broadway. However, access to the bus stops for Crystal Glen residents is difficult because of the west swale and north berm, not to mention, having to cross Broadway Avenue diagonally at the entrance of the neighborhood to the south to reach the southbound stop on Broadway.

The stop at K-Mart/Marsh is the furthest north the public transit system comes (see Appendix C Bus Route and Schedule). Therefore, if people wanted to park and ride their cars or ride a bicycle from the surrounding area this stop could be a convenient
location to do it. There is plenty of parking for cars in the K-Mart/Marsh parking lot but nowhere to store bicycles. The Crystal Glen redevelopment should be more accessible, safer, and provide more transit amenities such as bike storage.

4.4 Visual and Perceptual Characteristics

The visual and perceptual characteristics of Crystal Glen are not what most would consider positive. Crystal Glen has some mature trees which add value to the landscape over time. The mature shrubs, however, do not look as nice over time. There is also a lack of landscape features. The site is also lacking in general maintenance, litter is a problem, mud puddles are adjacent to sidewalks in some node locations, and the buildings themselves are deteriorating. The water conveyances system on the site is not adequately designed and water sometimes stands in the parking lot near a dumpster on the east side of the property (see Figure 4-7 and 4-8).

![Figure 4-7: Crystal Glen Flooded Parking Lot and Dumpster Access (B. Krieg)](image_url)
The landforms of the site also have visual and perceptual affects. The north berm creates both a physical and visual barrier from the commercial stores and parking lot to the north (see Figure 4-4). As previously mentioned, some areas in the berm should be removed so the residents of Crystal Glen have safer access to amenities. The landforms on the west edge of Crystal Glen create a barrier to Broadway Avenue. (see Figure 4-5). The landforms create a perceptional experience that feels isolated and for all practical purposes makes getting places difficult, if not sometimes impossible.

The landscaping is a monoculture and clearly meant to be low maintenance. The ground cover is the standard turf grass except for weeds that grow around the drop inlet on the northeast corner of the site (see Figure 4-9).
Figure 4-9: Crystal Glen Littered North East Drop Inlet (B. Krieg)

Living in a place with such conditions would not give a person much reason to spend time outside their apartment. The surroundings of people have some affect on the way they perceive themselves; therefore, the conditions of this landscape would likely create negative thoughts and feeling. Essentially, the Crystal Glen landscape is not a healthy human ecosystem from a visual and perceptual point of view.

4.5 Topography, Soils and Geology

The natural topography of Crystal Glen is flat, with less than 2% slopes on most of the land except for manipulation of the site from construction which has created berms, swales, and positive drainage away from buildings with greater slopes. There are three soil types found on the Crystal Glen site. These soils are Mahalasville, Crosby, and Brookston (See Figure 4-10). About 28% of the site is Mahalasville, 59% Crosby, and 13% Brookston soils.
The Mahalasville soil is a silty clay loam with slopes that normally range from 0 to 2%. Mahalasville is a poorly drained soil with frequent ponding. The water table is 0 to 12 inches deep and the water holding capacity is high at about 10.2 inches.

The Brookston soil is a silty clay loam with slopes in the 0 to 2% range. Brookston is poorly drained with frequent ponding. The water table is 0 to 12 inches deep and the water holding capacity is moderate at about 7.8 inches.

Crosby soils are silty loam with slopes in the 0 to 2% range. Crosby is somewhat poorly drained and without frequent ponding. The water table is about 6 to 24 inches deep and the water holding capacity is moderate at 6.4 inches.

A suitability analysis for septic tank absorption fields shows that none of the site is well suited for infiltration of effluent (see Appendix A). This affects the proposed infiltration designs for the site. Soil amendments will likely need to be made for higher infiltration rates and water holding capacities. Similar suitability criteria such as the
depth of the saturation zone and the speed at which water can move through the soil are important in both situations. The Mahalasville and Brookston are wetland soils with high water tables. This has led to the design decision to excavate a wetland to help contain stormwater from the east basin. The Brookston soils are well suited for the success of a wetland which will hopefully hold water all year. The shape of the wetland was informed by the Brookston soil location along with the topography.

The bedrock geology of Crystal Glen is Silurian, much like most of Madison County. The position of this Silurian bedrock is in the 601 to 800 ft elevation range. Most of the site ground plane is around the 884 ft. elevation, making bedrock 84 to 283 feet below ground. Other geologic features of the site are the Fortville fault which is about five miles away and an unidentified aquifer that is likely within the Silurian bedrock beneath Crystal Glen. None of the bedrock geology seems to play a crucial role in the ecological stormwater system design on Crystal Glen (see Figure 4-11).
An economic geology inventory of the site shows that there are low potentials for sand or gravel resources and there are no petroleum wells on the site (see Figure 4-12).

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Figure 4-11: Crystal Glen Bedrock Geology Map

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Figure 4-12: Crystal Glen Economic Geology Map
4.6 Watersheds and Hydrology

Currently, the Crystal Glen stormwater system is a combination of above ground swales, berms, and an underground separate storm sewer which then enter a combined sewer. Also, the parking lots are used to convey water in the east drainage basin to the east drop inlet.

The site can be divided into an east drainage basin; a west drainage basin and an offsite drainage basin (see Figure 4-13). About 6 acres of the site drain east into the east basin, which leads to a drop inlet that is surrounded by the native vegetation (refer back to Figure 4-9). This inlet goes into a 4 inch pipe roughly 1100 feet long, flows west, and falls 7 inches towards a catch basin. Once reaching the catch basin, it then falls 3.45 feet into a combined sewer that runs south down Broadway Avenue in a 10 inch pipe (see Construction Documents Sheet 2 of 8).

The west drainage basin is about 2 ¾ acres and first flows north into an open grass area, where it is then contained by the western berm and either infiltrates or evaporates. The remaining ¾ acre of the site has been called the off-site basin (see Figure 4-13). Some of the site water falls on the north side of the north berm and makes its way onto the commercial property. Most of the off-site basin precipitation actually falls in the swale on the west side of the property, then flows south with the northern commercial properties runoff.
Identifying the drainage basins was essential to determining the size and location of the new drainage system. The basins at the site scale are essentially the miniature watersheds. Watersheds are an important part to understanding how a site fits into the larger context.

**Crystal Glen Drainage Basins**

![Crystal Glen Drainage Basins](image.png)

*Figure 4-13: Crystal Glen Drainage Basins (B. Krieg)*

Ecological stormwater systems should be examined to see how it affects different watershed scales. Watersheds are areas of land that flow into the same water body. These watersheds can be broken down by scale, and the following maps show the different watersheds and scales of which Crystal Glen is a part. The red star represents Crystal Glen. The largest scale being looked at is the Patoka/White watershed, and from there the watersheds get progressively smaller, all the way down to the Kill Buck/ Shady Run watershed (see Figure 4-14).
One goal of the redevelopment is to attain pre-development runoff rates. Post
development runoff rates for a ten year one hour storm event (for all the basins) equals
8.99 cubic feet per second (cfs), while pre-development rates are 6.06 cfs. The net gain is
2.93 cfs; this amount would need to be dealt with on-site to meet the pre-development
runoff rate design goal. The calculations for runoff rates can be found in the Appendix B.

Figure 4-14: Crystal Glen Watersheds

29
4.7 Summary

The residents of Crystal Glen are young and have young families. They are surrounded by many commercial and transportation amenities but are perceptually and physically cut off by their own landscape. The Crystal Glen site is a barrier to residents of the surrounding neighborhood as well. Quite often people can be found traversing the site out of convenience or safety reasons. Broadway Avenues is treacherous for pedestrians and when it rains the short cuts through Crystal Glen are flooded.

The flat topography and wet soils of Crystal Glen forced the developers to create the swales and berms to control the stormwater. These controls created an impassable, under utilized, ugly landscape which contributes to the degradation of the watersheds that Crystal Glen belongs to. All of the abovementioned conditions create opportunities for improvement or constraints that that need to be worked with when creating an ecological stormwater system. Chapter five will take the opportunities and constraints uncovered in the inventory and analysis chapter and combined them with the High Point case study, and literature review information to form a comprehensive ecological stormwater system. The design criteria will be expanded with other improvements to increase the quality of life for Crystal Glen residents and other peripheral stakeholders.
5. Design Recommendations

This chapter includes the final design program which is based on the original goals and objectives. The conceptual diagrams and original sketches are included in the appendix section to show the design progression. The master plan and accompanying illustrations are meant to create a walk-through of the design along with descriptive narrative tying back to the design program goals. The ecological stormwater system components that are not evident in the illustrations are included in the construction documents. Finally, a comprehensive summary will conclude the chapter five design recommendations.

5.1 Design Program

The design program synthesizes the knowledge gained in the previous chapters into clearly defined program elements which will be illustrated and explained in the following sections.

1. Reduce stormwater runoff quantity to predevelopment rates and slow time of concentration.

   1.1 Increase evapotranspiration through increased plant mass and surface ponding in rain gardens and other landscape features.

   1.1.1 Develop areas of the site with plant matter where the space has limited human activity potential; for example, steep slopes or
marginal areas too narrow for most outdoor activities (see Figure 5-9).

1.1.2 Create depressions throughout the site where water can gather to be infiltrated; for example, rain gardens, bio-swales, or bioretention areas (see Figure 5-2).

1.1.3 Install a check dam at the west end of the site to retain water in the swale and impound it back onto Crystal Glen property. This increases the surface area for evaporation into the air and infiltration into the soil (see Figure 5-5).

1.1.4 Install raised drop inlets in the wetland and the Crystal Glen entrance street to create further water holding capacity before allowing water to enter the combined sewer (see Figure 5-2).

1.2 Amend some soils to allow for greater water holding capacity.

1.2.1 The soil in the rain gardens and bio-swales should be amended. This increases the soil quality for the plants being installed; besides, the soil will be disturbed by grading (see Figure 5-17).

1.2.2 The garden soils in the raised planters will be amended as well (see Figure 5-16).

1.3 Create below grade void space for water to be reintroduced as base flow through infiltration chambers and stone filled drywells.

1.3.1 Installing a porous concrete strip running down the center of the suitable parking areas is intended to allow captured runoff to percolate into infiltration trenches that are backfilled with stone
and void space. Once the infiltration rate of the native soil is exceeded and void air space is filled, the water should find its way to the perforated under drain which then leads to the split-flow diverter and infiltration chambers (see Figure 5-18).

1.3.2 Installation of infiltration chambers underground will be coupled with the split-flow diverter at two locations under the parking surface. The infiltration chambers will have an overflow that ties into the combined sewer along with the split-flow diverter pipe (see Figure 5-17).

1.4 Reduce impervious pavement need or replace with porous materials.

1.4.1 Cropping out unnecessary impervious pavement in turning radii and narrowing drive lanes is one strategy available to reduce impervious pavement (see Figure 5-18).

1.4.2 Reconfiguring parking areas to be double loaded and shortening driving lane distances to increase pavement effectiveness and reduce impervious pavement (see Figure 5-18).

1.4.3 Replacing impervious sidewalks with porous concrete is a way to maintain and increase pedestrian connectivity without compromising the water infiltration goals. Most of the pedestrian connectivity trails added are a combination of pervious materials such as boardwalks and mulch (see Figure 5-2).

1.5 Slow runoff time of concentration.
1.5.1 Disconnecting impervious surface is accomplished using the strips of porous concrete and the pedestrian crossing areas. This goal was not easily achievable in this retro-fit situation (see Figure 5-18).

1.5.2 Increasing the roughness of runoff surfaces will be achieved through the use of mulch, vegetation, and rocks in bio-swales and buffer strips (see Figure 5-13).

1.5.3 Increasing flow distances is another difficult retrofit design goal, however, it is achievable mainly at a miniature scale in the meandering of low water level flows in the bio-swales and the Broadway Avenue Swale (see Figure 5-6).

1.5.4 Maintaining flat slopes is easily achievable due to the inherent flatness of Crystal Glen. The average vegetated slope doesn’t exceed 5% on most of the site and the average hardscape slope barely achieves positive flow of 1% (see Figure 5-12).

1.5.5 Installing a check dam along Broadway Avenue stops most small rain events and slows the concentration of water down slope. The check dam and bio-retention area handles mostly water that does not originate from the Crystal Glen site (see Figure 5-5).

1.5.6 Installing a wetland prevents most of the eastern basin runoff from leaving the site, while the raised drop inlet still slows runoff from leaving the site (see Figure 5-20).
1.5.7 Installing the bio-swale and raised drop inlet along the entrance street of Crystal Glen increases the flow path of the street water and delays water from leaving the site (see Figure 5-2).

2 Improve stormwater runoff quality.

2.1 Filter out suspended solids and litter.

2.1.1 Direct impervious hardscape flow into rain gardens or bio-swales as grading allows (see Figure 5-19).

2.1.2 Create a porous concrete/infiltration system to accept impervious hardscape runoff unable to be directed to rain gardens or bio-swales (see Figure 5-19).

2.1.3 Construct a check dam with a screen along the Broadway Avenue swale (see Figure 5-5).

2.1.3 Build raised and screened drop inlets in the entrance street bio-swale and wetland overflow (see Figure 5-19).

2.2 Filter out and avoid using chemical pollutants such as fertilizers, herbicides, insecticides, oil, grease, and other toxins.

2.2.1 Place turf buffer strips and sand filters adjacent to hardscapes to capture pollutants (see Figure 5-18).

2.2.2 Garden using natural compost for fertilization and safe, natural techniques to reduce disease and insects (see Figure 5-16).

2.2.3 Construction of water quantity controls will aid in pollutant filtering, uptake, and stabilization (see Figure 5-14).

2.3 Reduce erosion wherever possible.
2.3.1 Establish and maintain ground cover and root systems (see Figure 5-8).

2.3.2 Install scouring protection, such as stones or concrete pads on the down slope sides of the check dam and impervious surface runoff areas (see Figure 5-4).

3 Conserve energy and resources at the site scale.

3.1 Exploit rainwater harvesting techniques.

3.1.1 Install a customized rainwater harvesting system on the apartment buildings to be used for grey water needs and irrigation (see Figures 5-6, 5-15, 5-17).

3.2 Create “waste-to-food” production.

3.2.1 Encourage composting of site plant matter and residential consumer waste with the installation of compost bins (see Figures 5-7, 5-13, 5-16).

3.2.3 Develop a community garden for utilization of compost, generation of food, and sharing of resources (see Figures 5-15, 5-16).

3.3 Choose/place vegetation for energy and material conservation.

3.3.1 Position groups of coniferous trees on berms to create a wind block from cold northwesterly winter winds for the apartment (see Figure 5-7).
3.3.2 Plant deciduous trees on the south and southwesterly sides of apartments to shade summer sun. The deciduous trees then will lose their leaves to allow winter sun to reach the apartments (see Figure 5-3).

3.3.3 Place trees to shade hardscape, reducing urban heat island effect and the need for microclimate control measures (see Figure 5-24).

3.3.4 Shade as many air conditioning units as possible to allow better energy efficiency (see Figure 5-24).

3.3.5 Choose native plants to reduce irrigation needs (see Figure 5-14).

3.3.6 Reduce mowed turf area to conserve materials and energy (see Figures 5-13, 5-20).

3.4 Encourage use of mass transit and alternate forms of transportation

3.4.1 Create attractive mass transit nodes which are safe, convenient and easily identified along Broadway Avenue and the north berm (see Figures 5-3, 5-8).

3.4.2 Provide amenities to encourage and ease the use of multi-modal transportation systems (see Figures 5-3, 5-12, 5-20, 5-21).

4 Create a landscape which increases quality of life for Crystal Glen and surrounding citizens

4.1 Increase the quality and quantity connectivity/transportation infrastructure for Crystal Glen and surrounding neighbors.
4.1.1 Increase pedestrian and bicyclist connections through Crystal Glen for neighboring citizens (see Figures 5-9, 5-10).

4.1.2 Create attractive mass transit nodes which are safe, convenient and easily identified along Broadway Avenue and the north berm (see Figure 5-8).

4.1.3 Provide amenities such as: covered bike storage, water fountains, shelter, seating, and information. This will encourage and ease the use of multi-modal transportation systems (see Figures 5-10, 5-11).

4.1.4 Create a boardwalk along Broadway Avenue for people wanting to traverse the site safely from the southern neighborhood to the community amenities north of Crystal Glen (see Figure 5-4).

4.1.5 Create a crosswalk from the Crystal Glen boardwalk to the bus stop on the west side of Broadway Avenue (see Figure 5-6).

4.2 Create a sense of place through intentional and artful design where form follows function.

4.2.1 Create an artistic and unique form representing Crystal Glen, which serves to function of a gateway, landmark for way finding, and also adds aesthetic appeal (see Figures 5-4, 5-9, 5-11, 5-23, 5-24).

4.2.2 Create an artistic, unique, and highly visible form which aims at inspiring thought about combining the use of functional stormwater infrastructure and the production of renewable energy in a sustainable way (see Figure 5-5).
4.3 Include educational and healthy components which foster a greater sense of community.

4.3.1 Promote the healthy use of the community garden, playground, circulation/transportation amenities, and the woodland shelter throughout Crystal Glen and the adjacent neighborhood (see Figures 5-7, 5-12, 5-11, 5-21, 5-22).

4.3.2 Provide signage to inform people about the redesign of Crystal Glen and its social, economic, and environmental benefits (see Figure 5-10).

5.2 Design Drawings

Section 5.2 first looks at the master plan but then moves forward through a sequence of perspectives displaying the improvements which meet the design program. The following illustrations were created using a one-foot contour interval. The contours seen throughout the landscape are not meant to communicate actual steps like the ones seen at the entrances of the apartment buildings. They indicate the slope of topography. Furthermore, the plantings seen are a combination of existing vegetation and added vegetation and do not totally represent the exhaustive planting plan which would actually accompany the implementation of the design.

In the master plan (see next page) one can clearly see the first goal of reducing stormwater runoff in effect. The wetland in the east basin holds most stormwater events until reaching the spill over elevation of 882 feet as shown in this view. The soil excavated to make the wetland was then placed in the south east of the site to create the
mound upon which the upland trees were planted. The bio-retention on the west side of the site along Broadway Avenue was created using a check dam which will be discussed later in more detail. Other design program elements which work to reduce stormwater runoff were the increased plant mass everywhere and the rain garden/bio-swale systems. These water runoff controls will also simultaneously improving the quality of stormwater runoff.

The third design goal to conserve energy and resources at the site scale can be seen in latter illustrations of the community garden, wind blocks, shade trees, rain harvesting system, and better mass transit amenities. The fourth design goal to create a landscape which increases quality of life for Crystal Glen and surrounding citizens will be better illustrated in the following perspectives.
Crystal Glen Apartments Master Plan

Legend:
1. Bio-Retention
2. Bio-Swale
3. Broadway Boardwalk
4. Central Sidewalk
5. Check Dam
6. Cistern
7. Community Garden
8. Garden Path
9. Gateway Arch
10. North Trail
11. Pine Grid
12. Playground
13. Porous Infiltration Trench
14. Rain Garden
15. South Bound Bus Stop
16. South Trail
17. Transit Shelter
18. Wetland
19. Wetland Boardwalk
20. Woodland
21. Woodland Shelter
22. Woodland Trail

Figure 5-1: Master Plan (B. Krieg)
Figure 5-2: Perspective #1- view of entrance road from the south (B. Krieg)

Goal 1.1.2 – Rain garden & bio-swale/ increase evapotranspiration
Goal 1.1.4 & 1.5.7 – Raised drop inlet/ increases surface ponding, slows runoff time of concentration
Goal 1.4.3 – Porous concrete sidewalk/ replace impervious cover

This view of the entrance shows the new porous concrete sidewalk on the east side of the street. The drive entrance was narrowed to 18’ to reduce imperviousness and slow traffic. The street slopes towards the bio-swale which filters and slows the water. The water flows to the south and ends in the round rain garden where a raised drop inlet was located in case the infiltration rate of the system was exceeded.
In Figure 5-3 one can see through the west commons towards the Broadway boardwalk and the Crystal Glen gateway landmark. This is the scene pedestrians will see when passing through the west commons on their way to the south bound bus stop seen in the background across Broadway Avenue. In the middle ground is a locust tree which shades the apartment in the summer and allows sunlight to warm the building in the winter.
In the foreground of Figure 5-4 one can see the Crystal Glen gateway. The gateway is intended to be an artistic and unique form representing Crystal Glen. The gateway is a landmark for way finding and adds aesthetic appeal. The boardwalk itself is a key circulation feature that safely links people to the commercial, service, and transportation amenities no matter the weather conditions.
The check dam in Figure 5-5 and 5-6 is meant to be an artistic, unique, and highly visible form which aims at inspiring thought about combining the use of functional stormwater infrastructure and the production of renewable energy in a sustainable way. The functional part of the check dam serves to slow and filter stormwater before eventually allowing it to travel down the Broadway swale. The check dam holds stormwater from the northern commercial land uses in a bio-retention area that occupies the northwest portion of the site. This action displays a greater sense of community responsibility for the environment that hopefully will inspire similar acts of environmental consciousness.
Figure 5-6: Perspective #5- Broadway Avenue and Crystal Glen transition (B. Krieg)  
Goal 1.5.3 – Meandering swale bottom/ increase flow distance  
Goal 3.1.1 – Cistern/ rain harvesting for grey water and irrigation  
Goal 4.1.5 – Broadway cross walk/ connectivity, safety  

Figure 5-6 zooms out to display perspective 2, 3, and 4 in relation to each other. Together the gateway, boardwalk, and check dam increase the quality of life for Crystal Glen and surrounding residents. The pedestrian bridge safely connects people to the south bound bus stop and the gateway creates and identifiable landmark for travelers. One can also see the rain cistern on the west side of the closest apartment and the groupings of spruce trees to the northwest of the apartments meant to save energy by blocking winter winds. Together these elements would create a positive identity and sense of place for Crystal Glen that is highly visible from Broadway Avenue.
The north trail seen in Figure 5-7 follows the ridge of the north berm. The north trail is meant to create connectivity from the east wetland to the west boardwalk. Between these two points the north trail has a pedestrian bridge which creates the roof of the bus shelter seen in Figure 5-8. The north trail is part of the trail system that loops around Crystal Glen. Residents can use the trails for exercise or to simply get from one place to another. The trails are made out of wood chips and other compostable materials created on site.
Figure 5-8: Perspective #7- view of north trail pedestrian bridge (B. Krieg).
Goal 2.3.1 – Plant root systems/ reduce erosion on steep grade
Goal 3.4.1 – Transit shelter/ encourage mass transit
Goal 4.1.2 – Transit node/ improve quality of life, safe, convenient, and easily identified
Figure 5-9: Perspective #8-view of bus shelter and gateway (B. Krieg).
Goal 1.1.1 – Decorative plantings/increase evapotranspiration on marginal land
Goal 4.1.1 – At grade access through north berm/increased connectivity
Goal 4.2.1 – Gateway arch/unique lighting features safety and aesthetics

The gateway seen in the bus shelter perspectives is scaled down from the one first seen along Broadway Avenue. These perspectives clearly display the transparent underside of the arch. The purpose of this is to allow light to bounce off the inside of the arch when it is lit from inside the column at night. The light source emitting up from the columns would fade in intensity. As your eye went to the center of the arch it may appear that the keystone were missing at night, thus causing a sense of mystery and intrigue.
Figure 5-10: Perspective #9 - view of bus shelter and central space (B. Krieg).

Goal 4.1.1 - At grade access through north berm/ increased connectivity
Goal 4.1.3 – Transit amenities/ bike storage, shelter, seating, and information
Goal 4.3.2 – Educational signage about ecological stormwater management at Crystal Glen/ promote social, economic, and environmental benefits

The bus shelter seen in Figure 5-9, 5-10, and 5-11 supplies the amenities necessary for comfortable use of the transit system. The shelter is located in the north berm for protection against wind and to create a crossing between Crystal Glen and the services to the north of the berm. Furthermore, it is a meeting place between local residents and people that might come to the stop to access the local shopping. The shelter will allow for chance encounters which lead to better socialization and thus a better sense of community. This shelter will be fitted with information about the design at Crystal Glen and the change it will bring to Anderson.
Figure 5-11: Perspective #10- view of central axis from bus shelter (B. Krieg).
Goal 4.1.3 – Water fountain, shelter, & seating/ improve quality of life
Goal 4.2.1 – Gateway arch/ landmark
Goal 4.3.1 – Public access to community garden and playground/ fosters sense of community

Figure 5-11 shows the central north south axis established by the central sidewalk.

The central sidewalk has the community garden and the playground flanking its sides and the bus shelter as its north terminus. The southern end of the axis is an open flat and dry flex-space for playing or whatever needs arise.
Figure 5-12: Perspective #11—view of playground from central sidewalk (B. Krieg).  
Goal 1.5.4 – Maintain flat slopes/ slows runoff time of concentration  
Goal 3.4.2 – Central sidewalk/ increases access to transit and off-site amenities  
Goal 4.3.1 – Playground/ improves quality of life

The demographic data for Crystal Glen confirmed an unusually large number of young children and young families. However, there are no recreational amenities on the Crystal glen site for these citizens. This playground in Figure 5-12 fulfills this need while simultaneously creating a place to build community interaction.
Goal 1.5.2 – Mulch, plants, & rocks in bio-swale/ slows runoff time of concentration
Goal 3.2.1 – Compost amended mulch/ material conservation and re-use
Goal 3.3.6 – Mulch/ reduces mowed turf, conserves energy

The bio-swale seen in Figure 5-13 and 5-14 functions to filter surface runoff from the central lawn area and infiltrate excess water released from the rain harvesting system. The rain gardens throughout the bio-swale are meant to add a certain aesthetic to Crystal Glen along with the functional uses. The rain gardens and bio-swales have amended soils with locally produced materials such as mulch and compost. Sand and aggregate amendments will be brought from sources within the community.
Figure 5-14: Perspective #13- view of community garden, playground, and bus shelter (B. Krieg).

Goal 2.2.3 – Bio-swale/ filters out pollutants
Goal 3.3.5 - Native plants/ reduces irrigation, energy, and resources
The community garden in Figure 5-15 and 5-16 plays an important role at Crystal Glen. It achieves many objectives towards the goal of energy and resource conservation at the site scale. The community garden is irrigated with water harvested on site. The compost bins in the garden reduce waste streams and re-uses resources that would have otherwise been hauled away and placed in a landfill, thus saving energy and land resources. These water and soil nutrients are normally wasted. However, now they are utilized to grow food for Crystal Glen residents. Producing your own foods in a garden reduces the embodied energy it takes for you to live. Now one doesn’t need to buy vegetables from the grocery that are trucked in from a thousand miles away.

The community garden also serves a social function. It gives people a reason to get outside and do something together. The garden and the playground were purposely placed adjacent to one another so parents could work in the garden and keep an eye on
their children playing. This central space is also energized with human activity. People watching would be easily accomplished in this space. People in their apartments could look outside and watch people and people within the space could observe each other. The garden would save energy and materials while simultaneously improving the quality of life for Crystal Glen and surrounding residents with an increased appreciation for nature and themselves.

Figure 5-16: Perspective #15- view of community garden and bio-swale (B. Krieg).

Goal 1.2.2 – Compost amended planter soil/ adds water holding capacity
Goal 2.2.2 – Compost as fertilizer/ avoids chemical pollutants
Goal 3.2.1 – Compost bins/ reduces residential waste streams
Goal 1.2.1 – Amended bio-swale and rain garden soil/ increases water holding capacity

Goal 1.3.2 – Cistern overflows into drywell/ below grade void space for infiltration

Goal 3.1.1 – Cistern and rain harvesting gutters/ conserve water resources, reduce runoff

Figure 5-17 displays the rain harvesting system. The rain would fall on the roof and be captured by the oversized gutters that would bring the water to the central cistern. A clear tube from the gutter to the cistern would allow residents to watch the water enter and monitor it for any problems. Debris would be filtered out of the rain water for composting while water would be stored in the cistern for later use.

Underground pipes would lead to the grey water system installed in the apartments. Other pipes could lead to an irrigation system. A valve would be attached to the outside of the cistern for any other uses that people might have, such as washing their car.
An overflow pipe would be installed to run the water underground into a drywell located in the bio-swale. If the drywell was saturated the overflow valve on the dry well would allow water to spill onto the surface of the bio-swale where it would make its way into one of the rain gardens. The water would proceed from rain garden to rain garden along the bio-swale until it either is infiltrated or makes its way to the wetland. Once in the wetland it would either be held or eventually raise the level of the wetland to the 882 elevation at which time the wetland would spill into the raised drop inlet.

Figure 5-18: Perspective #17- central view of Crystal Glen from the north (B. Krieg).

Goal 1.3.1 & 1.5.1 – Porous concrete infiltration trench/ underground void space for infiltration, disconnecting impervious surfaces

Goal 1.4.1 – Defined turning radii & narrow drive lanes/ reduces impervious surfaces

Goal 1.4.2 – Double loaded & shorter drive lanes/ reduces impervious surfaces

Goal 2.2.1 – Turf buffers & sand filters adjacent to parking sheet flow/ filters oils, greases, and road salts

This central overview of Crystal Glen in Figure 5-18 presents the community garden, playground, and bus shelter in relation to the broader context of the site including
the parking areas, and the bio-swales and the parking system which include the porous concrete infiltration trenches.

Figure 5-19 shows the wetland system from the north. The water is at its highest level before spilling into the raised drop inlet. The majority of the time wetland would be separated into two sections, the smaller south pool and the larger north pool. The wetland would serve to retain and cleans stormwater as well as create habitat for animals. This part of Crystal Glen would be allowed to evolve naturally over time.
Figure 5-20: Perspective #19- view across wetland to the woodland (B. Krieg).
Goal 1.5.6 – Wetland/ stops most eastern drainage basin runoff
Goal 3.3.6 – Natural succession/ reduces mowed turf, saves resources and energy
Goal 3.4.2 – Wetland boardwalk/ provides connectivity for multiple modes of transit

This view in Figure 5-20 is the fork in the trail around the wetland. One could go right on the trail to reach the apartments or left across the boardwalk to reach the Indian Meadows neighborhood. The wetland and woodland will substantially reduce the amount of mowed turf on the site and reduce resource consumption. The wetland also serves as the last line of defense in the eastern drainage basin before allowing the stormwater runoff from leaving the site in a combined sewer. This boardwalk in Figure 5-20 connects pedestrians from the Indian Meadows neighborhood to the east with the commercial services north of Crystal Glen. One can imagine the man in Figure 4-3 riding his bike across this boardwalk and enjoying the sights and sounds of landscape. The boardwalk also leads the woodland trail created on the mound built out of the soil from the wetland excavation.
Figure 5-21: Perspective #20- view of woodland trail (B. Krieg).

Goal 4.3.1 – Woodland Trail/ provides exercise and relaxation opportunities

The woodland trail in Figure 5-21 is on higher ground and would be a great shady spot to enjoy a hot summer day. The woodland increases shelter for native animals and increase the plant mass. This is would be another destination and change of scenery along the trail system that would increase the quality of life within Crystal Glen.
The woodland shelter in Figure 5-22 is a more private space than other locations around the site. This is where people throughout Crystal Glen and the surrounding neighborhood can meet for a cookout or just relax when using the south trail.
Figure 5-23: Perspective #22- view of pine grid from the south trail (B. Krieg).  
*Goal 4.2.1 – Pine grid/ unique form, landmark adding aesthetic appeal*

Figure 5-23 shows the existing pine grid with the south trail running along the southern edge. The pine grid represents a transition back into a more formal and controlled landscape. In contrast to the wetland and woodland area from which one would have just left.
Figure 5-24: Perspective #23- central view of the entrance (B. Krieg)

Goal 3.3.3 – Trees shading hardscape/ reduce urban heat island
Goal 3.3.4 – Shade air conditioning units/ reduce energy consumption
Goal 4.2.1 – Gateway arch/ sense of place, entrance marker

Figure 5-24 brings us back to the entrance of Crystal Glen. One can see the gateway being displayed for a third time at this point. The porous concrete infiltration strips are also noticeable in this view. The driving lanes and turning radii are narrower and more defined with the porous sidewalks. This has led to a decrease in impervious surfaces. Some trees in this scene also shade impervious cover and air conditioning units. This reduces the urban heat island effect and the energy consumed to combat it.
5.3 **Construction Documents**

The construction documents show the grading plan, existing site conditions, hardscape and drainage details, and the Triton infiltration system details. These documents were provided to illustrate the existing conditions manipulated to allow the ecological stormwater retrofit. The grading plan will illustrate the level of detail required to allow this very flat site to function. Furthermore, the design elements sheet highlights where the remaining details can be found within the design. The hardscape and drainage detail sheet along with the Triton infiltration details are numbered to correspond with the design element sheet.
Typical Main Header Row Assembly

Design Engineer is Responsible for Ensuring Suitability of Subgrade Soils.

Installation Diagram:
- 18" Min. Cover Depth
- 6" Min. Cap
- 36" Min. Typical
- 7.5" Min. Non-Woven Geotextile
- 12" Min. TYP.
- 6" Min. Cap
- 3424 Washed Crushed Angular Stone
- Drainage Well Gravel and Soil/Cement Mixtures
- Ballast Well Gravel and Soil/Cement Mixtures
- 2-36.5x68 or 5x72 SS.17 Chambers
- Standard End Cap

NOTE: The ASD Line of Chambers is 15% Field compacted in 6" lift to 85% Proctor Density. See Table of Acceptable Fill Materials.
5.4 Conclusion

The design of Crystal Glen Apartments illustrates an ecological stormwater system by mimicking natural hydrology while providing a diversity of habitats for wildlife. The wetland and woodland areas are low maintenance and allow natural plant succession. While the garden and playground is maintained for people to utilize.

Creative design lead to artistic forms such as the entrance marker and the check dam that function within the context. Furthermore, the involvement of the users would hypothetically take place if this design were to be installed. The garden is one area where involvement would be high.

Additionally, the ecological design has aimed to minimize energy consumption and material use. The garden and composting reduces the embodied energy of food and the energy lost in waste streams. Water harvesting utilizes stormwater for grey water uses and irrigation. This reduces energy spent on cleaning runoff water that the waste treatment plant needlessly filters and saves infrastructure cost for the city.

The protection of water quality is another goal met within the project. Secondary research shows low impact development techniques filter out and prevent the spread of pollution. The second stormwater goal to reduce site runoff to pre-development runoff rate for a ten year, one hour storm event can be quantified. The stabilized runoff volumes demonstrate downstream pollution such as combined sewer overflow will not be a result of Crystal Glen runoff (see Appendix B). Therefore, the ecological stormwater system is successful at handling most rain events.
Improving the quality of life for the residents of Crystal Glen and surrounding neighbors is the final goal, but it can not easily be quantified like the stormwater volumes. However, creating the new connections to the various transit or service amenities will improve quality of life. The new identity and sense of place that the stormwater system, gateways, and central space create is a positive, healthy, and educational benefit for quality of life.

Finally, the successful design of the ecological stormwater system for Crystal Glen Apartments is a model for solving similar site design and stormwater management problems. Landscape architects must educate clients and the public about responsible stormwater management decisions and the potential for it to affect our social, economic, and environmental well being.
Appendix A: Septic Tank Suitability Map

Web Soil Survey 2.0 National Cooperative Soil Survey
## Appendix B: Stormwater Runoff Calculations

### Crystal Glen Stormwater Runoff Pre-Design

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<td>256427 0.580</td>
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<td>97236 2.232</td>
<td>51742 1.188</td>
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<td>2.31 1.89 0.14 4.34</td>
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<td>419215 9.024</td>
<td>256431 5.09</td>
<td>1.59 1.27 0.10 2.93</td>
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### Basin Cubic Feet per Second Net Gain Volumes

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<td>419215 9.024</td>
<td>256431 5.09</td>
<td>1.59 1.27 0.10 2.93</td>
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## Crystal Glen Post Ecological Stormwater Retrofit

### Crystal Glen Surface Areas

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<th>x</th>
<th>T (min)</th>
<th>P (ip)</th>
<th>A (acre)</th>
<th>q (cfs)</th>
<th>Basin Cubic Feet per Second Volumes</th>
</tr>
</thead>
<tbody>
<tr>
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<td>419215.9624</td>
<td>205431.909</td>
<td>121489.279</td>
<td>32265.741</td>
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### Crystal Glen Basin Areas

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<thead>
<tr>
<th>Surface Type</th>
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<th>T (min)</th>
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</thead>
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<td>32265.741</td>
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### 10 Year Storm Event - Post Development

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<th>T (min)</th>
<th>P (ip)</th>
<th>A (acre)</th>
<th>q (cfs)</th>
<th>Basin Cubic Feet per Second Volumes</th>
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<td>121489.279</td>
<td>32265.741</td>
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### Basin Cubic Feet per Second Volumes

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>a (acres)</th>
<th>x</th>
<th>T (min)</th>
<th>P (ip)</th>
<th>A (acre)</th>
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<td>121489.279</td>
<td>32265.741</td>
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### Buildings

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<th>T (min)</th>
<th>P (ip)</th>
<th>A (acre)</th>
<th>q (cfs)</th>
<th>Basin Cubic Feet per Second Volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>North 1</td>
<td>3050.805</td>
<td>0.042</td>
<td>1843.042</td>
<td>0</td>
<td>0.000</td>
<td>0</td>
<td>0.000</td>
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<tr>
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<td>0.042</td>
<td>1843.042</td>
<td>0</td>
<td>0.000</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>North 3</td>
<td>3050.805</td>
<td>0.042</td>
<td>1843.042</td>
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<td>0.000</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
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<td>4040.063</td>
<td>0.042</td>
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<td>0.000</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>East 2</td>
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<td>1843.042</td>
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<td>0</td>
<td>0.000</td>
</tr>
<tr>
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<tr>
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<td>1843.042</td>
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<tr>
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<td>1843.042</td>
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<td>0.000</td>
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<td>0.000</td>
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<tr>
<td>Office</td>
<td>1133.026</td>
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<td>1843.042</td>
<td>0</td>
<td>0.000</td>
<td>0</td>
<td>0.000</td>
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</table>

### Total Asphalt Rooftops

| Total Asphalt | 49984.1154 | 21381.481 | 32265.741 | 0 | 0.030 | 0 | 0.000 |

### Parking Lots

| Parking Lot | 23568.3400 | 21381.481 | 32265.741 | 0 | 0.099 | 0 | 0.000 |

### Porous Concrete

| Porous Concrete | 0.1 | 7.21 | 0.01 | 0.00 | 0.00 |

### Ignored Impervious Reduction

| Ignored Impervious Reduction | 11424 | 75766 | 1.740 | 46409 | 1.032 | 3095 | 0.898 | 3215 | 0.074 | 0.03 | 0.02 |

### Total Impervious

| Total Impervious | 43429 | 7.584 | 220492 | 5.062 | 82443 | 1.893 | 29080 | 0.668 |

### Total Basin Area

| Total Basin Area | 419215.9624 | 205431.909 | 121489.279 | 32265.741 |

### Crystal Glen Surface Areas

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>a (acres)</th>
<th>x</th>
<th>T (min)</th>
<th>P (ip)</th>
<th>A (acre)</th>
<th>q (cfs)</th>
<th>Basin Cubic Feet per Second Volumes</th>
</tr>
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<tr>
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<td>419215.9624</td>
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### Crystal Glen Basin Areas

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<th>Surface Type</th>
<th>a (acres)</th>
<th>x</th>
<th>T (min)</th>
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<th>A (acre)</th>
<th>q (cfs)</th>
<th>Basin Cubic Feet per Second Volumes</th>
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<tr>
<td>Total Basin</td>
<td>419215.9624</td>
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<td>121489.279</td>
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### 10 Year Storm Event - Pre-Development

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<th>A (acre)</th>
<th>q (cfs)</th>
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<td>Total Basin</td>
<td>419215.9624</td>
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<td>121489.279</td>
<td>32265.741</td>
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### Basin Cubic Feet per Second Net Gain Volumes

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<td>121489.279</td>
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Ecological Stormwater System Runoff Reduction Calculations for a 10 Year 1 Hour Storm Event

- Alterations to the net runoff gain:
  - Change impervious concrete sidewalks to porous concrete sidewalks.
  - Narrowing and reduction of impervious parking surfaces square footage. = 11424

### Conversions:

<table>
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<th>Cubic Feet Per Second Conversion to Cubic Feet Per Hour</th>
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<td>Hour x Minutes x Seconds = Seconds per hour</td>
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<tr>
<td>1 x 60 x 60 x 3600 =</td>
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<tr>
<td>Cubic Feet to Gallons</td>
</tr>
<tr>
<td>Cubic Foot = Gallon</td>
</tr>
<tr>
<td>1 = 7.48</td>
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### Volumes:

- Crystal Glen net cubic feet per second: 2.28
- Crystal Glen net cubic feet per hour: 8221
- Crystal Glen net gallons per hour: 61494

### Cistern Volume:

<table>
<thead>
<tr>
<th>Area of Base</th>
<th>Cubic Foot</th>
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<tr>
<td>Pi x Radius Foot squared x Foot Height = Volume</td>
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<tr>
<td>3.14 x 2.25 x 10.00 = 70.69</td>
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</tbody>
</table>

| Number of Cisterns x Cubic Foot Volume = Total Cubic Foot Total Gallons |
|--------------------------|-----------------------------|
| 18 x 70.69 = 1272 | 9518 |

### Rain Gardens Volume:

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Ft.Sq</th>
<th>Height</th>
<th>Volume Cubic Ft</th>
<th>Gallons</th>
<th>Quantity</th>
<th>Total Gallons</th>
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<td>423</td>
<td>7</td>
<td>2959</td>
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<tr>
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<td>692</td>
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### Triton System Volume:

<table>
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<th>Cubic Ft per Lineal Ft</th>
<th>Gallons per Foot</th>
<th>Length</th>
<th>Gallons</th>
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<td>14.71</td>
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<td>110</td>
<td>226</td>
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<td>24369</td>
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### Total Storage Volume Summary:

- Cisterns + Rain Gardens + Triton System = Total Storage Volume in Gallons
  - 9518 + 28299 + 24369 = 62685
- Total Storage Volume in Gallons Needed: 61494
- The total volume storage for a 10 year 1 hour storm is exceeded by nearly 1200 gallons.
Appendix C: North Anderson Transit Map and Schedule
# Route 1 - North Anderson

## Monday through Friday

<table>
<thead>
<tr>
<th>Depart Terminal</th>
<th>Broadway &amp; Vineyard</th>
<th>Community Hospital</th>
<th>Woodbine &amp; Ashborne</th>
<th>Cross St. Market</th>
<th>Highland H.S.</th>
<th>Cross &amp; Alexandria Pike</th>
<th>K-Mart Marsh</th>
<th>Broadway &amp; Grand</th>
<th>Arrive Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00</td>
<td>7:07</td>
<td>7:10</td>
<td>7:16</td>
<td>7:21</td>
<td>XXXX</td>
<td>7:30</td>
<td>7:35</td>
<td>7:45</td>
<td>7:46</td>
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<tr>
<td>8:00</td>
<td>8:07</td>
<td>8:10</td>
<td>8:16</td>
<td>8:21</td>
<td>8:25</td>
<td>8:30</td>
<td>8:35</td>
<td>8:45</td>
<td>8:46</td>
</tr>
<tr>
<td>1:10</td>
<td>1:17</td>
<td>1:20</td>
<td>1:26</td>
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<tr>
<td>6:10</td>
<td>6:17</td>
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<td>6:26</td>
<td>6:31</td>
<td>---------------</td>
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## Saturday Service

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</thead>
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<tr>
<td>1:00</td>
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<td>1:10</td>
<td>1:16</td>
<td>1:21</td>
<td>1:25</td>
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<td>2:25</td>
<td>2:30</td>
<td>2:35</td>
<td>2:45</td>
<td>2:46</td>
</tr>
<tr>
<td>3:00</td>
<td>3:07</td>
<td>3:10</td>
<td>3:16</td>
<td>3:21</td>
<td>---------------</td>
<td>Out of Service</td>
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</tbody>
</table>

Monday through Friday Service provided to Highland High School with the exception of the 7am and the 2:10pm run, service is suspended due to traffic congestion.
Saturday service to Highland High School on all runs.
Appendix D: Crystal Glen Aerial Base Map
Appendix E: Split-Flow Plan/Diversion Weirs/ Section of Split-Flow System

Fig. 3-15—Plastic Inlet with Weirs
Appendix F: High Point Drainage System Illustration
Crystal Glen Circulation Plan
Crystal Glen Circulation Plan Sections
Crystal Glen Grading Plan
Crystal Glen Water Diagram
Crystal Glen Slope Diagram
Works Cited


Funkhouser, Laura et al., “Stormwater Management as Adaptation to Climate Change”, *Stormwater: The Journal for Surface Water*


MS Student: Jacob Bauer -- Advisor: Steven Gorelick -- Collaborators: Dr. Eric Reichard (USGS, San Diego) and Dr. Tracy Nishikawa (USGS, San Diego) *Regional Groundwater Flow Simulation of Sonoma Valley Including a New Model for Recharge and Three Future Scenarios* <http://pangea.stanford.edu/research/groups/hydrogeology/gfx/sonoma_fig5.png> (accessed Spring 2009).


