Integrated Infrastructure:
A Neighborshed Approach to Stormwater Management

by

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Abstract

This thesis describes an integrated approach to infrastructure planning, watershed management and neighborhood livability for an urban basin in Portland, Oregon. After an examination of existing integrated approaches used in Oregon and British Columbia, this project outlines a framework for the analysis and planning of green infrastructure in the Oak Basin. After analyzing the conditions of the three systems that affect and are affected by green infrastructure (infrastructure – watershed – neighborhood), a green infrastructure plan was developed to meet systems needs. Additionally, site level designs reflect green infrastructure plan goals and targets as well as illustrating how these spaces can contribute to neighborhood livability.

Table of Contents

List of Tables

List of Figures

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<u>Committee members</u>

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1. Introduction

Typically, stormwater infrastructure is a hidden part of the city, collecting the rainwater shed from impervious surfaces and conveying it through a system of underground pipes before it discharges to a body of water. As a system designed only to protect private property from the danger of flooding or other water damage, it necessarily overlooks other roles of water in the urban landscape. The unintended consequences of this singularity of purpose include the disruption of the hydrological cycle and also the separation of urban residents from the opportunity to learn about and enjoy water in their everyday landscape. Furthermore, this invisible and centralized system of stormwater management has proven to be an expensive budget item for governmental jurisdictions. Recognizing the limitations and problems associated with conventional stormwater management systems, new approaches are emerging to manage stormwater more holistically.

Increasingly, infrastructure and stormwater planning efforts are using a watershed approach to resolve the issues brought about by conventional stormwater systems and to improve watershed health. The watershed has been identified as an ideal planning unit for many purposes (McHarg, 1992; Lyle, 1999; Marsh, 1998; Aberley, 1994, Hough, 1994; Spirn, 1984), not the least of which is developing stormwater management plans. In addition to linking stormwater to watershed, theorists and practitioners in these fields have identified the need to link watershed-scale efforts to site design. To be successful, integrated design work must reflect the natural processes at work in a larger context, as the regional scale informs the activities of site-scale design. Pieces of an integrated approach are emerging through exemplary planning efforts and award-winning site designs, but the picture on how to link the efforts of one scale, the watershed, to another, the site, is still incomplete.

This project forwards a model for integrating not only the objectives of infrastructure planning, watershed management and neighborhood livability, but also a means to connect these watershed-scale objectives to the level of site design. This integration can occur by applying a "neighborshed" concept, which is based on the ecological unit of the watershed and the scale of the neighborhood. The idea of watersheds relies of the use natural boundaries to delineate areas rather than political means. This provides a basic framework for dividing areas into manageable and interconnected units. Neighborhoods, by using local knowledge and involvement, and by providing a reasonable size for planning and decision-making, allow residents a direct link to the process and urban form of their local area.

The result of using an integrated planning process is a visible and integrated infrastructure system, layering stormwater, recreation and transportation needs into one synthesized design. By transforming the notion of "infrastructure" into "landscape," design solutions not previously imagined become possible, allowing ecological processes to be recovered and revealed, and enriching the experience of place within urban neighborhoods.

1.1. Purpose

The primary aim of this project is not only to better integrate hydrologic watershed health objectives with infrastructure planning, but also to demonstrate that additional livability benefits can be derived from stormwater facilities that are well-designed. Portland, Oregon is leading the way for innovative integrated approaches through its watershed and stormwater management strategies. Some of these plans and practices are discussed in further detail under chapter 3.1. This thesis builds upon this pioneering work, while providing a model of how to better integrate neighborhood concerns with watershed and infrastructure objectives. The aim of this project is to provide impetus to coordinate planning efforts to enable greater synergies to occur, in Portland and other jurisdictions in the Portland metropolitan region.

This project does not duplicate the efforts of existing agencies, but seeks to further existing goals and planning efforts. As an academic exercise, this project takes greater license to push a stormwater management agenda further than might be reasonably expected for an urban neighborhood. This project seeks to complement the existing work of the City of Portland's Bureau of Environmental Services (BES) by:

- Designing to more aggressive stormwater targets
- Better integrating livability objectives
- Illustrating how stormwater facilities can enhance public space and build community identity
- Describing the benefits of a multi-objective system

A secondary aim of this proposal is to test designs for stormwater facilities in very urban situations. Improving watersheds in an urbanized setting requires a different set of strategies than less developed watersheds. A watershed is an ecological unit where water drains from a landscape to a common point of discharge. In urbanized situations, such as the site chosen for this thesis, the sewerage basin - the pipeshed - essentially is the watershed. Pre-development drainage networks have been eliminated by the urban footprint, with surface runoff shedding quickly to underground conveyance. Until surface runoff makes its way to the piped system, much of this stormwater can be found in the streetscape: city streets are the new urban rivers.

Typical watershed restoration interventions might protect watershed health in rural areas; however, these interventions are only partial solutions for urban areas and in fact, may not apply at all. This thesis provides an opportunity to re-imagine what watershed restoration might look like in an urban context – enhancing the health of the watershed and the character of the city simultaneously.

1.2. Methodology

Theoretical Position

This thesis begins by establishing the theoretical foundation upon which the analysis, goals and design strategies rest (chapter 2).

Case Studies

An examination of existing integrated approaches to stormwater management helps to determine where the "bar" is set for stormwater planning and design. The lessons drawn from these approaches were used to define the framework for analysis (chapter 4).

Basin Analysis

Each system was analyzed to identify limitations and opportunities for improvement (chapter 5). Some of the issues under consideration include:

- Current and historic watershed conditions
- Infrastructure conditions, as described by CH2MHill in the Beech/Essex and Oak Predesign Report
- Neighborhood conditions as they relate to City goals and objectives

Principles, Goals, and Targets

Based on the information from the analysis, a set of principles were developed to frame the goal-setting. Specific goals and targets were set to meet the needs of the watershed, infrastructure, and neighborhood systems (chapter 6).

Synthesis

The green infrastructure plan is a set of strategies developed to meet the principles and goals at the neighborshed level (chapter 7).

Site Design

A design for a City Bikeway illustrates how green infrastructure would look on the ground (chapter 8).

Conclusion

In the conclusion, thesis findings are summarized and the limitations to the project are described. The conclusion described what worked, what didn't work, and where there is room for additional research (chapter 9).

2. Position

2.1. Integrated Approach

Planning and design practices are increasingly recognizing the role of water in urban landscapes. Generally, infrastructure planning occurs within discrete disciplines of study (e.g. land use, transportation, water supply, sewer systems) without a significant amount of inter-relationship. However, stormwater systems are beginning to be integrated into cities' watershed, infrastructure and land use plans. These frameworks tend to examine stormwater in the context of the larger watershed and/or develop plans at a watershed level. Municipalities are introducing Integrated Stormwater Management Plans, Low Impact Development (LID), and Stormwater Best Management Practices (BMPs) as part of their policy mandate.

Researchers have noticed that the nature of water management is changing from a technical/engineered approach to one that is more multi-functional:

> "Traditional water management projects, including fresh water supply, water treatment systems, waste water management, flood mitigation measures, irrigation, and drainage, are mainly addressed from a technical civil engineering perspective. Such projects have increasing economic, environmental, and societal implications, and this is causing a change in focus of water management projects. The traditional focus on technological optimization is being switched to include concerns for ecological sustainability, economic balance, technical endurance, and societal acceptance" (Bernhardi *et al*, 2000).

Alternative and multi-functional infrastructure systems have been coined as the "green infrastructure" of the city. Broadly speaking, green infrastructure is the ecological network that provides vital services to a community. An example of green infrastructure would be street trees which evapotranspirate stormwater, absorb pollutants, and provide cover for pedestrians. Green infrastructure can also mean the absorptive landscapes which allow water to infiltrate into the ground, reducing stormwater runoff and recharging groundwater supplies. As a system, green infrastructure is an integrated network of streets, forests, greenways, and bikeways that are designed to enhance their ecological function. In addition to providing these ecosystem services - a multifunctional infrastructure system – green infrastructure contributes to the livability of the urban environment and can potentially reduce costs of delivering these myriad services through integrated design (American Forests, 2006a; Condon & Isaac, 2003a).

The degree of integration pursued in any planning or design process depends on the broadness of the problem definition and who is invited to solve the problem. Scientists and engineers might integrate stormwater management objectives with infrastructure plans without considering broader livability concerns. For example, the guidebook, *Low Impact Development Design Strategies*, has been very successful in redefining stormwater management by advocating a watershed-based approach (Prince George's County, 1999). However, some recommendations conflict with other accepted principles of sustainability, such as higher-density development that supports transit use. These contradictions can be expected in the evolution of the framework for integrated planning, but it serves as a reminder that integrated work benefits from diverse stakeholder involvement.

Proper integrated stormwater management requires understanding of the interrelationship of all parts of the system. A local action on a particular piece of property has a direct impact on that property, as well as a cumulative impact on the greater watershed context. Therefore, not only does this work require integrative efforts at a disciplinary level, but also connections between scales. Watersheds can be an organizing principle of the landscape that defines a region or place. As a physical landscape unit, its boundaries can be easily identified. Another benefit of watersheds as an organizing unit is that they are adaptable to a variety of scales. The growth and success of watershed councils suggests that the watershed is a useful and manageable scale in which to operate (Aberley, 1994).

However, it is also important to acknowledge the role of human activity and organization within the watershed. In urban areas, neighborhoods have served as important planning units for infrastructure, within which resident needs and commercial and public services are organized. This organizational structure and activity creates neighborhood identity and a sense of place for residents.

This approach suggests that using the ecological unit of the watershed and the scale of the neighborhood serves as an appropriate planning unit for green infrastructure development and pursuing stormwater management strategies. This idea of neighborhood watersheds, or "neighborsheds", allows us to plan at a scale that is both accessible and based on natural boundaries. Combining the scale of the neighborhood with the ecology of the watershed creates a useful framework for interdisciplinary planning. Furthermore, recognizing the ecological context of a neighborhood generates richer possibilities for place-making.

2.2. Reveal Infrastructure

"Infrastructure systems, by virtue of their scale, ubiquity, and inability to be hidden, are an essential visual component of urban settlements."

Gary Strang, Infrastructure as Landscape (2002, p. 220).

A second position that guides this project is the notion of revealing infrastructure in the landscape. While just as essential to the urban landscape as buildings or parks, infrastructure systems have not been given the same level of design attention as other pieces of city-building. Generally, infrastructure is an engineered response to a narrowly defined problem. The design results are not always sympathetic to community vitality or aesthetically pleasing, and as a result, the tendency is to try and shield infrastructure from public view. Since the planning and design work have been compartmentalized, the resulting infrastructure system delivers upon its singular purpose while neglecting other factors – such as neighborhood compatibility and environmental impact. Like other elements of urban design, infrastructure should be subject to the same questions of what makes a good city (Strang, 2002).

A downside to hiding away infrastructure systems is the lost opportunity to understand how they function and their impact on sustainability. Robert Thayer emphasizes that "an *acceptance of sustainable techniques and technologies into our concept of nature and human nature* is an essential part of the process toward remaking global institutions..." (original italics, Thayer, 2002, p. 189). "Sustainable technologies and landscape features like natural storm drainage... symbolize "conspicuous nonconsumption" and are essential markers along the road to a more sustainable world..." (Thayer, 2002, p. 192).

Figure 2.1. Oregon Convention Center

This project seeks to reconceptualize infrastructure as a means to organize the landscape. William Morrish redefines the role of infrastructure: "Beautiful infrastructure, which responds to the physical and topographical features of the locale, is primary to creating community identity and a personal sense of orientation" (Morrish, 1996, p. 97). By combining landscape ecology principles with the landscape vocabulary of Kevin Lynch, Morrish describes how infrastructure networks can provide greater spatial definition to landscapes, with multidimensional benefits (Morrish, 1996).

A driving feature of this redefined sense of infrastructure is the water system, as Strang indicates: "A place's hydrology should be part of the basic armature of urban form" (Strang, 2002, p. 223). Portland has been relatively successful in this regard, having several award-winning designs that expressly reveal the function of water within its particular urban environment. The Oregon Convention Center and the City of Portland's Water Pollution Control Laboratory, designed respectively by Murase Associates and Mayer/Reed (see figures 2.1 and 2.2), are two examples of these kinds of projects. More recently, Tanner Springs Park in the Pearl District of Portland, designed by Atelier Dreiseitl and Greenworks, is a more contentious example of an urban "wetland" (for discussion, see the editorials and letters to the editor in April and May 2006 issues of Landscape Architecture Magazine).

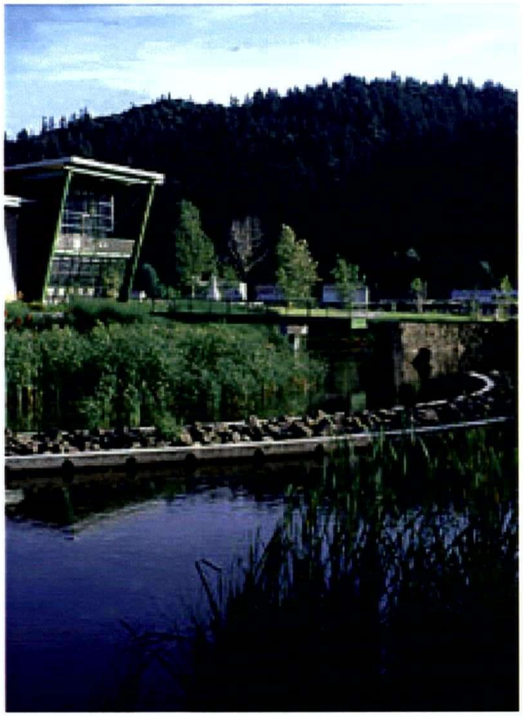


Figure 2.2. Water Pollution Control Laboratory

2.3. Didactic Design

Several researchers have suggested that people have a critical connection to the landscape. Yi-Fu Tuan coined "topophilia" as "the affective bond between people and place or setting" (Tuan, 1974). Michael Hough describes sense of place as the evolution of a collective response to a particular place (2002).

Randolph Hester (1995) notes that modern living has divorced us from the understanding our local environment and community, creating a loss of place. In order to maintain a sustainable quality of life, we must create conscious connections to them:

> "From the root *anomia*, meaning lawlessness, anomie in this case refers to the state of confusion individuals and society feel about how to act toward their community and landscape. Seemingly freed from dependence on our community and the environment, we must choose new relationships with both."

Landscape architects are often called upon to create a sense of place through design, in part to remedy this perceived loss. "Eco-revelatory Design" has been coined to describe work that expressly reveals the ecological conditions on-site. Additional value comes from being able to reveal previously unseen processes, reinforcing the idea that the built environment "...can be redesigned so that people are richly informed about their place and the ecological processes endemic to it (Van der Ryn & Cowan, 1996, p. 162)."

Similarly, Marc Treib (2002) offers the didactic approach to landscape architecture in which "forms should tell us, in fact instruct us, about the natural workings or history of the place" (p. 95). However, didactic design does not imply a reproduction of historical or ecological forms that once occupied the site. Alexandre Chemetoff's bamboo garden at the Parc de la Villette exemplifies didactic design wherein the existing infrastructure remained as part of the design (Treib, 2002). In fact, Chemetoff made a conscious decision to lower the garden level below the park so that the hydrological features are "not only revealed, but become the subject of the garden" (Berrizbeitia and Pollak, 1999, p. 64).

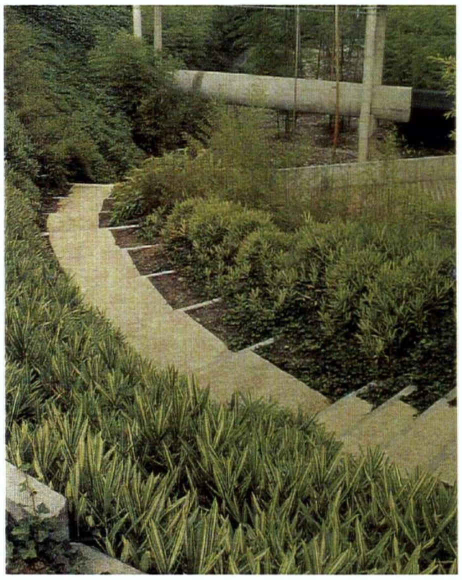


Figure 2.4. Chemetoff's Bamboo Garden

Treib distinguishes didactic design from the "Genius of the Place," an approach that evolved from the philosophy of Alexander Pope. Reliance on this approach becomes especially problematic when designers wish to restore a site to original conditions. Treib notes that the genius of place is often tokenized, particularly in urban environments where layers of human alteration on the site make it difficult to read the genius of the place (Treib, 2002). As Joan Nassauer (2002) aptly noted: "Landscape architects may consult the genius of the place, but they do not expect the genius of the place to design it" (p. 196).

The aim of this proposal is to create a living and dynamic sense of place, based on the layers of history in the landscape. Designing for a sense of place should integrate new design with the local character of place honestly and without nostalgia. Otherwise, without this understanding of the processes and historical evolution of a place, place-making efforts may result in a museumified version of place (Relph in Swafford, 2002, p. 102-3). Creating stormwater facilities can help inform residents of the watershed workings of place, one that is actively operating and integrated into the urban fabric.

2.4. Public Acceptance

Using transparent, revelatory design to create a living sense of place and provide an opportunity for environmental education has limitations. Contrary to Thayer's demand for transparency, Nassauer (2002) argues that simply exposing ecological systems does not solve the problem: "the common popular delusion [is] that nature will speak for itself – if only human beings would quit interrupting. A belief that nature needs no presentation... leaves ecosystems highly susceptible to misunderstanding" (p. 197). Nassauer suggests that "we must design to frame ecological function within a recognizable system of form" (p. 198).

Sometimes people's aesthetic notions of stewardship are actually not environmentally sound. Nassauer (2002) acknowledges that this type of landscape aesthetic can be environmentally problematic when "our strong cultural conventions....has led to a contrived and frequently misleading nature" (p. 68). Emerging are ideas that "aesthetic appreciation should be informed by ecological knowledge, so that what is good ecologically also looks good to us ...[u]nder this theory, knowledge of ecological function and processes can overcome what are presumably cultural biases against so-called *messy* ecosystems: those which lack the orderly look of more conventionally managed landscapes" (Sheppard, 2001).

In her research on visual preference and stormwater management, Cecilia Achiam found a disconnect between visual preference and sustainable stormwater design. Although people indicated they valued the ecological systems, they found those systems to be less visually attractive. Achiam suggested that designing stormwater treatment systems using conventional aesthetics may make them more visually acceptable (Achiam, 2002).

Nassauer suggests that "[w]e can align aesthetics and ecology by design. Bringing aesthetic expectations into play in a way that benefits landscape ecology requires designing strategies, landscapes, and policy with an awareness of what people enjoy and value in the appearance of the landscape now" (1997, p. 77). Nassuauer indicates that revealing ecological function is one component of the design strategy and observes that "*[c]ultural expectations can change when familiar aesthetic conventions are used to frame the novel appearance of ecological function*" (1997, p. 78).

In addition to using conventional aesthetics, Achiam suggests other strategies to increase acceptance of green infrastructure (2002):

- Incorporate other public amenities (making them more multi-functional)

- Promote alternative management as a means to incorporate the community's values in a public way
- Ensure that community features are identified and protected through watershed management plans
- Use collaborative design practices to build acceptance and incorporate local knowledge

2.5. Conclusion

The synergistic planning of the interconnected systems – watershed, infrastructure, and neighborhood – at the manageable scale of the "neighborshed" is the basis for the integrated approach described here. By integrating this multi-faceted infrastructure system into the landscape, the ecological, cultural and technological layers of the city can be artfully exposed. The functionality of the city becomes more transparent, providing an opportunity to understand the complex interrelationships of the systems. A dynamic and living sense of place can be created with this understanding; a green infrastructure system that is transparent and legible; multifunctional and acceptable; orderly and beautiful.

3. Context

3.1. Issues and Trends in Stormwater Management

Stormwater management was conceived in its earliest stages as simply a means to remove water from the urban landscape as fast as possible for human safety, sanitation, and comfort. The basic method of stormwater removal – a system of underground pipes conveying runoff to a receiving body of water – has remained essentially unchanged for the past century in North America. The impacts of this infrastructure system are now known to create erosion problems in streambeds, disrupt the flow regime of streams, and increase temperature and pollution levels in receiving waters.

In urban areas, rainfall normally intercepted by vegetation and infiltrated slowly into the ground falls instead onto impervious surfaces, such as roofs and streets, and is shunted quickly to a stormwater conveyance system. The infiltration of water to groundwater reserves (groundwater recharge) is significantly reduced by these impervious surfaces and the conveyance system. Water that does infiltrate to the groundwater table provides streams with consistent baseflow. Without the recharge of groundwater, streams have lower baseflow in dry conditions and then surge in wet conditions. During storm events, rainfall becomes fast-moving surface runoff impacting receiving bodies of water by increasing the total volume of water and the peak volume of water. This peak flow of water may impact receiving streams by eroding streambanks or creating "flashy" conditions of stream flow.

Additionally, these peak flows of water tend to have higher temperatures than pre-development conditions, as the water travels over heated surfaces (e.g. parking lots) rather than infiltrating into the ground. This runoff also collects pollutants from the land and streets, including fertilizers and petroleum products. Temperature, sedimentation, and pollution are common problems for urban streams. Called non-point source pollution, these parameters are now regulated by the Clean Water Act (see chapter 3.2.1).

Another part of the hydrological cycle interrupted by urbanization is groundwater recharge. Girling and Kellett (2005, p. 119) note:

> *"Rushing the stormwater out of cities also depletes the groundwater within urban areas. Although rainfall volumes vary dramatically from landscape to landscape and from season to season, groundwater is a ubiquitous, crucial component of*

the hydrologic cycle. A far more stable resource than surface water, groundwater typically remains a consistent temperature and its levels (relative to the ground plane) vary slowly from rainstorm to rainstorm and season to season. It is a crucial source of water for trees and other large woody vegetation, and it provides a stable source of water for lakes, streams, and rivers [Ferguson 1994]. By capturing stormwater from impervious surfaces and piping it to streams, rivers, and lakes, cities that utilize these conventional stormwater management systems deplete their groundwater resources."

Additionally, in many older cities, sewerage and stormwater conveyance are handled in one combined pipe. Stormwater runoff flows through the same pipes as sewage headed to the sewage treatment facilities. With large storm events, peak flows of stormwater overwhelm the capacity of these combined sewers, creating overflow situations. In many cases, this excess stormwater and sewage then overflow to outfalls in receiving waters (i.e., streams, rivers and oceans).

One common strategy used in ameliorating the peak flow conditions resulting from impervious surfaces is to build reservoirs or detention basins to hold the water and release it more slowly so as not to overwhelm the infrastructure system. While addressing concerns about volume, the "pipe-and-pond" approach does not address water quality issues nor more importantly, does it begin to think about repairing the hydrological cycle. For example, Ferguson notes, "...the volume of water stored in soil layers in most natural watersheds exceeds the quantities that could be stored in dammed reservoirs or the typical detention basins that many cities require (Ferguson, 1998, in Girling & Kellett, 2005, p. 122)."

With growing awareness of the environmental impact of these conditions, municipalities have taken steps to remedy the situation. For many jurisdictions, this means upgrading the capacity of existing pipes or separating storm and sewer pipes to eliminate combined sewer overflows (CSOs). New approaches are emerging that consider these peak flow concerns within the larger system. Their aim is to protect watershed health and solve for multiple objectives at once. As indicated above, the City of Portland has already begun to take a more holistic approach and this project seeks to take it further.

3.1.1. Other considerations

The environmental impacts of imperviousness extend beyond watershed health. The increased amount of impervious surfaces alters the local climate through the Urban Heat Island Effect.

Ambient city temperatures rise as a result of the reflective heat from impervious surfaces and the lack of vegetation limits the cooling effect of evapotranspiration. The cooling effect of trees is not limited to evapotranspiration; any pedestrian recognizes the shady relief of street trees on a hot summer day.

The reliability and quality of water resources is also threatened by global warming. Changes in location, time of year, and form of precipitation are some of the consequences of increased greenhouse gas production. A green infrastructure system that attempts to restore the hydrological cycle and increase vegetation will help offset some of the impacts of global warming. Increased infiltration not only relieves the capacity of the pipe system in the case of stronger rain events but also provides higher levels of groundwater recharge and water availability for potential increases in length or severity of summer droughts. Improving urban forestry captures carbon dioxide and is another strategy in combating global warming, listed in the City of Portland and Multnomah County's Local Action Plan on Global Warming (City of Portland & Multnomah County, 2001).

3.2. City of Portland Context

3.2.1. Clean Water Act

The 1972 Clean Water Act was drafted initially to regulate users that delivered large amounts of "point" source pollution, such as factories. However, the Clean Water Act was amended in 1987 to manage polluted runoff from urban areas in the form of "non-point source" pollution (Girling & Kellett, 2005). Non-point source pollution includes the stormwater collected from the landscape and discharged into streams and rivers. The Clean Water Act requires the City of Portland to meet the requirements of the National Pollution Discharge Elimination System (NPDES) for its stormwater and wastewater. This federal program is locally administered by the Oregon Department of Environmental Quality (DEQ). Another relevant component of the Clean Water Act is the water quality standards set by Total Daily Maximum Load (TDML) programs. (Bureau of Environmental Services, 2005b)

3.2.2. Endangered Species Act

In 1999, populations of steelhead trout and Chinook salmon that use Portland's waterways were listed as threatened under the federal Endangered Species Act (ESA). This listing requires that no fish habitat be damaged. The City of Portland responded with a council resolution to assist with the recovery of these species (Bureau of Environmental Services, 2005b).

3.2.3. Combined Sewer Overflows

Portland is currently implementing the largest public works project in the city's history, the Eastside Combined Sewer Overflow Interceptor Project, popularly referred to as the 'Big Pipe' Project. The project is driven by the EPA mandate to improve water quality a direct result of increased urbanization coupled with an outdated combined sewer system design. In order to meet the Amended Stipulation and Final Order (ASFO), the City of Portland must:

"... eliminate all untreated CSO discharges from May 1 to October 31 except during storms greater than or equal to a storm with a three year return frequency..."

The Big Pipe will reduce the impact of stormwater and sewage from being directly discharged into rivers during combined sewer overflows (CSOs) and meet water quality goals. This end-of-the-pipe scenario is the final part in a multiple-phase project including the Westside Big Pipe, other smaller pump stations, and other infrastructure elements.

3.2.4. Stormwater Management Manual

Portland's Bureau of Environmental Services (BES) has developed a Stormwater Management Manual (Manual) which governs stormwater management requirements for new development or redevelopment that results in 500 square feet of new impervious surfaces. The intent of the Manual is to encourage the management of stormwater at the source, rather than relying solely on conventional and centralized engineered infrastructure systems.

As part of the Manual, BES has created a Stormwater Destination/Disposal Hierarchy to determine the disposal point of stormwater. The first choice is to infiltrate stormwater on-site whenever possible, with the last option in the hierarchy to connect stormwater to a combined sewer system. Also, the Manual contains specifications on how to construct stormwater facilities and which application each facility is suitable for.

In addition to providing engineering methodologies for sizing stormwater facilities, BES has also created a "Simplified Approach" to assist property owners to size stormwater facilities. This approach involves filling out a form to size facilities based on the amount of impervious surface to be managed. BES has developed sizing factors which are used as multipliers in this simplified calculation. The calculation embedded in the sizing factor assumes a 25-year storm event.

3.3. Context as Information

These contextual issues drive the need for developing a green infrastructure plan as an alternative to conventional stormwater systems which do not adequately address these concerns. Conventional systems may resolve some of the issues, such as peak flows, but at a burdensome cost. Portland's Stormwater Management Manual is a starting point for responding to these concerns by requiring stormwater management to be better integrated into the landscape.

Green infrastructure systems have the potential to not only resolve these concerns, but provide additional benefits such as an improved pedestrian environment, reduced ambient air temperature, or increased habitat value. This thesis attempts to illustrate how critical stormwater concerns can be met through a green infrastructure plan while illustrating how additional benefits can be derived from the system.

4. Integrated Approaches

Integrated approaches that operate at a watershed scale have been called Low-Impact Development, Integrated Stormwater Management Planning, or more generally, a watershed-based approach to stormwater management. The Greater Vancouver Regional District, Metro Regional Government (Portland) and the City of Portland all employ these kinds of approaches. In general, these plans aim to provide a comprehensive approach to restoring watershed health by addressing the root causes of watershed problems, rather than solving for the symptoms. Additionally, these approaches tend to solve for multiple objectives, layering infrastructure, watershed and livability concerns through integrated solutions.

A second approach is through integrated site design that reduces impervious surfaces and collects, re-uses, cleans and/or infiltrates stormwater. Called Integrated Management Practices, Stormwater Source Controls, Stormwater Best Management Practices or green infrastructure, these designs collect and often clean stormwater in order to remove it from an overburdened infrastructure system and return it to the groundwater table. Advantages of these systems include potential cost savings from reduced infrastructure, an ability to adapt to specific site conditions, and an ability to mimic pre-development groundwater recharge. In addition, other objectives for watershed and neighborhood health can be incorporated into these site-specific designs.

The following case studies are examples of integrated approaches as practiced in Portland, Oregon and British Columbia. They range in terms of scale, areas of integration and degree of comprehensiveness. Learning from these approaches allow for the development of an approach that can bridge the integrated work at the watershed scale and the site scale.

4.1. City of Portland

4.1.1. 2005 Portland Watershed Management Plan: Actions for Watershed Health

"In Portland, land and water are elemental, the very icons of the city. The rain, our region's rivers, and our land - the watersheds that gather, feed, and protect them - are our identity, the essence of who we are and where we've come from."

Chet Orloff, Introduction to the 2005 Portland Watershed Management Plan

The *2005 Portland Watershed Management Plan: Actions for Watershed Health* (Portland Watershed Plan) is the City of Portland's comprehensive plan for sustainably managing Portland's watersheds. It describes the goals, objectives, strategies, and actions for improving the city's watersheds. The Portland Watershed Plan was built upon a framework document, *Portland's Framework for Integrated Management of Watershed Health* (Framework), which defines the integrated approach and establishes the scientific understanding that directs the goals and objectives. The Framework indicates that an integrated approach is valuable because it affords an opportunity to coordinate City responses to federal, state and regional laws and regulations (Bureau of Environmental Services, 2005b).

The Bureau of Environmental Services, the department in charge of the Portland Watershed Plan, identified the causes of environmental problems and sought to develop an integrated plan that meets the multiple objectives embedded in the plan. The strategies outlined in the Portland Watershed Plan require the coordination of multiple bureaus to ensure the health of watersheds is improved (Bureau of Environmental Services, 2005a). Watershed health was defined through the Framework and is principle from which the Portland Watershed Plan's (2005a) goals are derived:

> "A healthy urban watershed has hydrologic, habitat, and water quality conditions suitable to protect human health and maintain viable ecological functions and processes, including self-sustaining populations of native fish and wildlife species whose natural ranges include the Portland area" (p. 9, 38).

This comprehensive approach identifies four goals that comprise the ideal conditions for watershed health (Bureau of Environmental Services, 2005a p. 39):
Hydrology: *Move toward normative flow conditions to protect and improve watershed and stream health, channel functions, and public health and safety.*

Physical Habitat: *Protect, enhance and restore aquatic and terrestrial habitat conditions to support key ecological functions and improved productivity, diversity, capacity and distribution of native fish and wildlife populations and biological communities.*

Water Quality: *Protect and improve surface water and groundwater quality to protect public health and support native fish and wildlife populations and biological communities.*

Biological Communities: *Protect, enhance and restore native aquatic and terrestrial species and biological communities to improve and maintain biodiversity in Portland's watersheds.*

Finally, actions in the following areas are intended to move the city to meeting the watershed goals above (Bureau of Environmental Services, 2005a):

- Stormwater Management
- Revegetation
- Aquatic and Terrestrial Enhancement
- Protection and Policy
- Operations and Maintenance
- Education, Involvement, and Stewardship

The 2005 Portland Watershed Management Plan offers a comprehensive framework for addressing a range of watershed health goals. The definition of watershed health acknowledges the limitations of an urban environment while still supporting ecological systems. This watershed-based approach recognizes the interrelationships between land use and the watershed and identifies a range of strategies that require the support of other departments and agencies. To an extent, neighborhood considerations (which are outside of BES' jurisdiction) are acknowledged but a process for further integrating them is not provided.

4.1.2. Integrated Taggart D Pre-design

Traditionally, "pre-design" projects are engineered analyses and plans that identify solutions to infrastructure problems in a sewerage basin. However, a new approach is being taken with the Integrated Taggart D Pre-Design where alternatives to piped solutions are examined, with the larger aim of finding ways to improve watershed health as well as solve infrastructure problems. Joint objectives include:

- Eliminating basement flooding
- Replacing/repairing existing infrastructure
- Finding most cost-effective solution
- Improving surface and groundwater hydrology
- Improving water quality
- Reducing CSO volume and peak discharges from the basin
- Improving sustainability and community livability

For each objective, a performance indicator has been described which is specific to the Taggart D basin. For example, two indicators for "Improve surface and groundwater hydrology" include increased infiltration, where appropriate, and reduced effective impervious area. Water quality objectives are driven by Federal regulatory compliance (e.g. Total Maximum Daily Loads) and existing City policies.

The Integrated Taggart D Pre-design is an excellent example of developing joint objectives for an integrated watershed and infrastructure planning process. The indicators for evaluation are an especially important contribution for monitoring how these plans work and evolve over time. The Bureau of Environmental Services' potential to integrate watershed health concerns with infrastructure objectives is quite high because both fall within the mandate of their work. However, as identified above, their ability to address livability concerns is limited as land use decisions fall outside their scope of responsibility.

4.1.3. Sandy Boulevard Resurfacing and Streetscape Project Plan

Sandy Boulevard's transfer in jurisdiction from the Oregon Department of Transportation to the City of Portland required an upgrade to City street standards. The Sandy Boulevard Resurfacing and Streetscape Project Plan's (Sandy Boulevard Plan) primary objective was roadway surface improvement, although other objectives were folded into the scope of work. The Bureau of Environmental Services identified the Sandy Boulevard Plan as an opportunity to develop stormwater test pilot sites and reduce stormwater volume to the sewer system. The criteria developed for stormwater facility sizing was to meet the Department of Environmental Quality's Amended Stipulated Final Order (ASFO) requirement of 1.41 inches of rainfall capture and also to use BES simplified approach. The AFSO is the federal regulatory mechanism for reducing combined sewer overflows into the Willamette River.

The Sandy Boulevard Plan's goals and objectives are driven by livability concerns (Office of Transportation, 2005, p. 4-5):

- Improve pedestrian safety and convenience
- Provide good connections between neighborhoods
- Improve drivers' safety and convenience
- Support access to business and residential neighborhoods
- Improve bicycle safety and convenience
- Increase safety and convenience for transit users
- Support the community identity

The Sandy Boulevard Plan provides a different approach toward integrating stormwater into the landscape. Rather than an approach grounded in watershed health improvement, BES found an opportunity to test stormwater design into a plan to improve neighborhood livability. As an opportunistic aspect of the project, the stormwater facility designs are not connected to the infrastructure or watershed plan.

4.1.4. Portland Central Eastside Industrial District Study

An unpublished report from the City of Portland, *Optimizing Ecoroof Benefits in the City* (Ecoroof Study), approaches green infrastructure from a cost-benefit analysis. In order to determine the value of ecoroofs, the City facilitated a study where ecoroofs were applied to buildings in Portland's 670-acre Central Eastside Industrial District (CEID). Additionally, the Ecoroof Study describes the benefits of green roofs and how they align with City of Portland goals and objectives. The City calculated stormwater runoff, building energy consumption and the urban heat island effort as a result of placing ecoroofs on these buildings. The City (Office of Sustainable Development *et al*, 2005) found these results:

- 207 million gallon reduction in stormwater runoff (32% overall reduction in the district)
- $607,000 reduction in future annual private stormwater fees
- 34,700,000,000 Btu reduction in heating-/cooling-related building energy consumption
- $600,000 reduction in heating/cooling-related private electric utility costs
- 0.5-0.9 F reduction in summertime ambient air temperature in the CEID's core area.
- 0.4 F reduction in summertime ambient air temperature a mile downwind from core area.

The value of a green infrastructure system is that it yields multi-dimensional benefits, from improved watershed health to potential savings in infrastructure costs. The Ecoroof Study illustrates how this green infrastructure strategy impacts the health of the environment, the infrastructure system and its contribution to livability. Although beyond the scope of this thesis project, quantifying the benefits of an integrated 'neighborshed' plan would make an even stronger case for pursuing green infrastructure in the Oak Basin.

4.1.5. Lloyd Crossing Sustainable Urban Design Plan and Catalyst Project

Sponsored by the Portland Development Commission, the Lloyd Crossing Sustainable Urban Design Plan and Catalyst Project (Lloyd Crossing) aims to design the Lloyd District as an urban ecosystem with high economic development potential. The redevelopment potential of the Lloyd District is significant, with its proximity to downtown, high number of transit lines and large parcels of undeveloped or underdeveloped land. The goals for Lloyd Crossing (Portland Development Commission, 2005, p. 6) are to:

- Reduce environmental impact to pre-development levels
- Restore pre-development habitat metrics
- Live within the site's rainfall budget
- Live within the site's solar budget
- Achieve carbon balance
- Preserve urban density

The environmental performance of pre-development conditions formed the basis for the plan's targets. As indicated above, environmental dimensions beyond hydrology (such as habitat and energy) were included in the plan. In addition to environmental metrics, place-making is specifically addressed through a "vibrancy" index. This urban design study addresses resource strategies not only in the landscape but also through the new architecture envisioned in the area.

Simple and radical, the punchy principles of Lloyd Crossing are a strong starting point for the development of a green infrastructure plan. Furthermore, the comprehensive examination of environmental and livability issues make a good model for integrating these two systems. The use of pre-development conditions as a proxy for appropriate levels of water runoff or vegetation strategy is also valuable. This thesis project is slightly different in approach as it is focused on strategies in the landscape, whereas Lloyd Crossing speculates about the reuse and conservation of resources in the architecture as well.

4.2. British Columbia

4.2.1. Stormwater Planning: A Guidebook for British Columbia

The government of British Columbia requires that jurisdictions complete Liquid Waste Management Plans, which must include a stormwater component. Developing an Official Community Plan (OCP) can provide the basis for developing a Liquid Waste Management Plan (LWMP). The Guidebook notes that the two processes (OCPs and LWMPs) have not been well integrated in the past, but the opportunity to create more integrated stormwater management planning is there.

The Guidebook's ISMP process begins with prioritizing watersheds for action, developing watershed performance targets based on site-specific data, and translating these targets into design guidelines. The acronym, ADAPT, summarize the principles of stormwater management:

A **Agree** that stormwater is a resource

D **Design** for the complete spectrum of rainfall events

A **Act** on a priority basins in at-risk catchments

P **Plan** at four scales – regional, watershed, neighbourhood and site

T **Test** solutions and reduce costs by adaptive management

With regard to second principle, integrated solutions provide (Stephens *et al*, 2002, p. ES-4):

- Rainfall capture for small storms (runoff volume reduction and water quality control).
  Capture the small frequently occurring rainfall events at the source for infiltration and reuse.
- Runoff control for large storms (runoff rate reduction).
  Store the runoff from the infrequent large storms and release it at a rate that approximates the natural forested condition.
- Flood risk management for the extreme storms (peak flow conveyance).
  Ensure that the drainage system can safely convey extreme storms.

The Stormwater Guidebook not only suggests mimicking pre-development conditions as a strategy for restoring watershed health, but also provides a clear direction for how to do so. The Stormwater Planning Guidebook provides explicit strategies for returning to more normative hydrological conditions; for example, in their principles "Design for the complete spectrum of rainfall events" and "Act on a priority basis in at-risk catchments." The Guidebook develops general principles and uses site-specific data to derive solutions for infrastructure and watershed needs. Another valuable component of the Guidebook is that it describes the value of integrating stormwater planning with land use planning and indicates how that might be accomplished through Official Community Planning processes. As a guidebook dedicated to stormwater, however, it lacks the full integration of other watershed health concerns, such as upland habitat.

4.2.2. Integrated Stormwater Management Planning

Recognizing the impacts of land-development pressures on the environment, the Greater Vancouver Regional District (GVRD) is undertaking Integrated Stormwater Management Planning (ISMP) on a watershed scale in the Greater Vancouver region. The GVRD's *Liquid Waste Management Plan* indicates that ISMPs will be developed for all urban watersheds by 2014. The ISMP process is governed by a no-net-loss system, which allows trade-offs within the watershed. The Terms of Reference Template frames an ISMP process that integrates science and engineering with land use planning and community values. The template outlines a process on three levels: engineering, planning, and environmental.

Performance indicators for watershed health are effective impervious area, riparian forest integrity, and benthic macro-invertebrates (measured through the Benthic Index of Biotic Integrity, B-IBI). As the BC Guidebook recommends, and as BES has done through its 2005 Portland Watershed Management Plan, the ISMP template classifies and prioritizes watersheds. For example, high priority watersheds would include those with small to medium-sized creek systems (Kerr, Wood, Leidel Consulting Engineers, 2002).

The ISMP process is a comprehensive approach to integrated stormwater with watershed health, with a strong emphasis on the impacts of land use to watershed health. The systems of engineering, environmental, and land use parallel the systems described by this thesis of infrastructure, watershed, and neighborhood. The GVRD's Template for Integrated Stormwater Management uses both hydrological and biological indicators, which indicates a concern beyond strict stormwater management to watershed health.

4.3.3. Effectiveness of Source Controls Report

Using the BC Water Balance Model, a tool for calculating stormwater facility performance, this report determines how each facility performs under different land use conditions (particularly in regard to the amount of impervious surfaces covering the site). This report indicates which facility is most appropriate for which land use given certain hydrologic indicators. Total runoff volume and the number of times that natural mean annual flood is exceeded are two of those indicators. This report suggests limiting runoff to 10% of annual rainfall volume, and returning the remaining 90% to natural hydrological pathways (i.e. infiltration and evapotranspiration). Decisions about selecting a stormwater facility involves the larger context as well: the report indicates it is necessary to plan at the scale of the watershed, the neighborhood and the site (CH2MHill, 2002).

4.2.4. The Headwaters Project and the East Clayton Neighborhood

In September of 1995, the James Taylor Chair in Landscape and Liveable Environments organized a design charrette for a 400-acre site in the City of Surrey. The results of the design charrette led stakeholders to forward a demonstration project in the City of Surrey, which evolved into the Headwaters Project and the neighborhood of East Clayton.

Ecological performance objectives were identified. In addition to requirements limiting impervious surfaces and percent vegetation, each building site was to capture 24 mm (0.9 inches) of rain times the total area of the parcel. The same rainfall capture standard applied to streets. Also, street right-of-ways were required to be no more than 50% impervious, with the remaining area to absorb the runoff. Urban forestry objectives include planting trees that will grow to 40 feet in height and breadth, such that canopy coverage reaches 60%. School and park sites were designed to capture rainfall at a rate of 1.41 inches a day. A wet detention pond was planned to handle 5-yr storm events and the school field would flood during the 100-year storm (Condon & Isaac, 2003b).

The James Taylor Chair in Landscape and Liveable Environments' (JTC) approach to neighborhood design includes mimicking pre-development conditions. The JTC benchmark for stormwater management is infiltrating 90% of a site's annual rainfall volume, which translates to capturing the about the first inch of rainfall for Surrey, B.C. The 90% target is also important because studies have shown that when effective impervious area exceeds 10%, then stream health is severely degraded (Booth & Jackson, 1997). As an independent research and design center, the James Taylor Chair in Landscape and Liveable Environments has the liberty to make recommendations of land use and stormwater through dialogue with responsible agencies. Integration of all objectives is part of the work in drafting the design guidelines.

4.3 Findings

This review of existing integrated approaches helps determine where the "bar" is set for urban watershed planning and design. The approaches undertaken in Oregon and British Columbia begin to frame a sustainable process for watershed health and neighborhood livability. The key concepts learned from this review are further described below.

The link between hydrology and watershed health appears primary in urban watershed and infrastructure plans and is also a driving assumption in this thesis. Combining watershed hydrology with infrastructure demands is a common thread among the integrated approaches reviewed, such as the approaches suggested by the BC Stormwater Planning Guidebook and the City of Portland's Taggart Predesign. Furthermore, the Lloyd Crossing Study and the BC Stormwater Planning Guidebook suggest that restoring hydrological systems closer to pre-development conditions is the best way to improve watershed health. The concept of returning to functionally returning to pre-development conditions is a theme picked up in this thesis.

How to actually restore hydrology to pre-development conditions is explained by the BC Stormwater Planning Guidebook in its dictum: "Design for the complete spectrum of rainfall events." A common hydrological target is limiting rainfall runoff to 10% of annual rainfall volume and infiltrating and evapo-transpirating the remaining 90%, which is cited both in the Effectiveness of Source Controls Report and in the work of the James Taylor Chair in Landscape and Liveable Environments. This target is also used in this thesis, as will be described under chapter six.

While these studies tend to emphasize the connections between watershed health and infrastructure system, they tend not to describe the potential benefits to neighborhood livability. Generally, this level of integration requires exploration into other bureaus and agencies beyond those concerned with stormwater. However, both the Portland Watershed Plan and the GVRD's Integrated Stormwater Management Plans acknowledge the need to address land use issues. The Sandy Boulevard Plan is an example of one project that does address stormwater facility design as part of place-making. This thesis attempts to provide a stronger framework for watershed planning that incorporates these neighborhood livability concerns.

A holistic planning effort for watershed health, infrastructure and place-making is best illustrated through the Surrey and Headwaters design charrettes, which led to the East Clayton Neighborhood Concept Plan. This thesis framework bears a stronger resemblance to the processes used in the James Taylor Chair in Landscape and Liveable Environments.

5. Analysis

5.1. Watershed

Portland is located in the Willamette River Basin. Within the city limits of Portland are five watersheds, including a portion of the Willamette River Basin. The Willamette Watershed has been divided into 27 subwatersheds by the Bureau of Environmental Services (BES). The Oak-Alder-Division subwatershed is one of those subwatersheds, located in the central eastside of Portland. This study area is the Oak Basin, the northernmost sewage basin of the Oak-Alder-Division subwatershed.

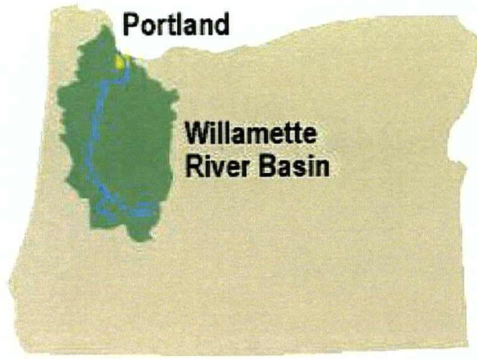


Figure 5.1. Willamette River Basin

The basis for the watershed analysis of the Oak Basin is based on the Oak-Alder-Division subwatershed characterization performed by the Bureau of Environmental Services. Characterization studies have been undertaken for the 27 subwatersheds within the Willamette Watershed. Since the Oak Basin is located in the northern portion of the Oak-Alder-Division subwatershed, some characteristics of the Oak-Alder-Division subwatershed may not apply to the Oak Basin portion.

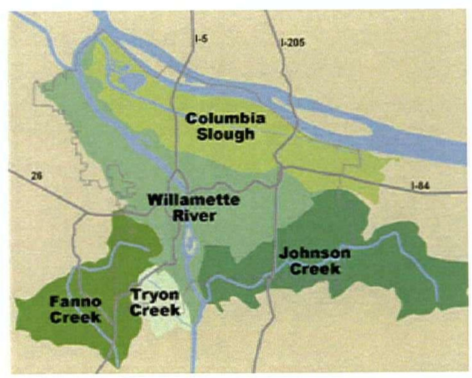


Figure 5.2. Portland Watersheds

Figure 5.3. Oak-Alder-Division
Sources: BES, City of Portland

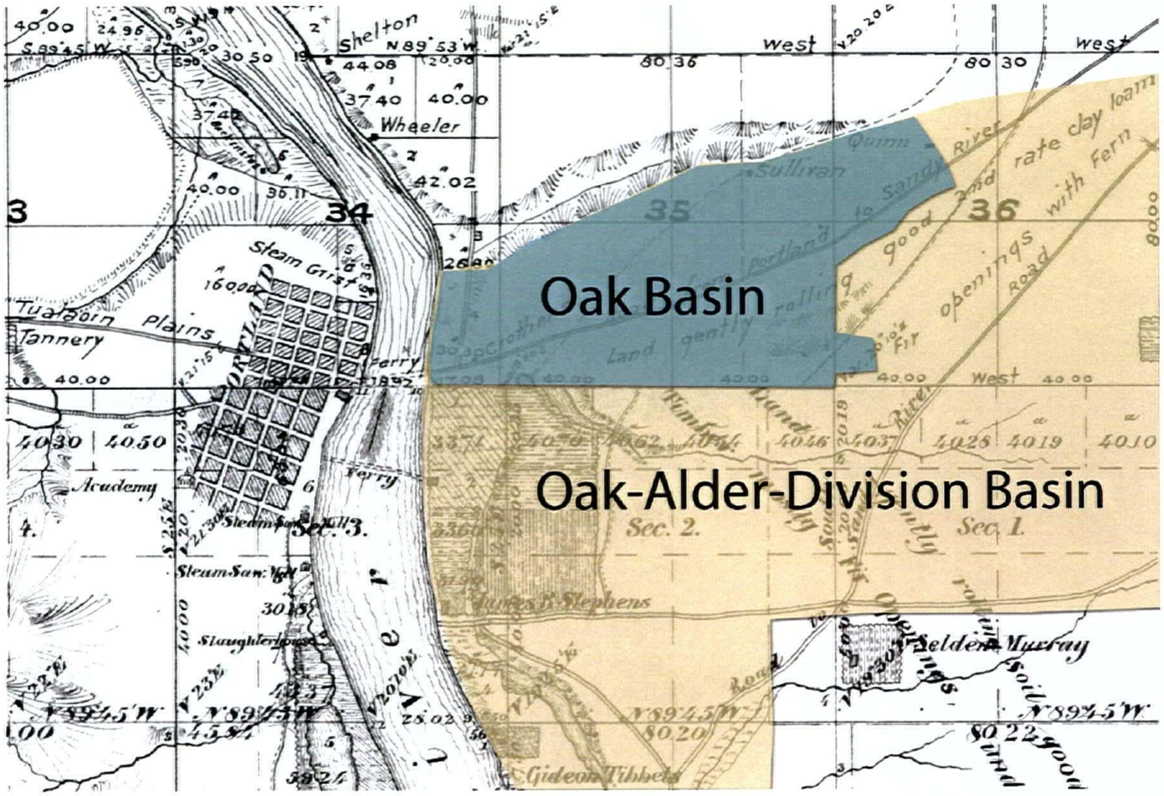


Figure 5.4. Oak Basin in the Oak-Alder-Division subwatershed

5.1.1. Soils

Soils are primarily Willamette Silts (CH2MHill, 2004), specifically classified as Multnomah and Latourell soils, some of which has been covered by fill or removed by cutting and grading. Multnomah soils are a silt loam with subsoils that are gravelly silt loam over very gravelly sand. Latourell soils are loamy with subsoils of loam and sand. These soils are classified as Type B hydrologic soils, which has a moderate to high infiltration rate of 0.15 -0.30 inches per hour (Bureau of Environmental Services, 1999; Metro, 2000).

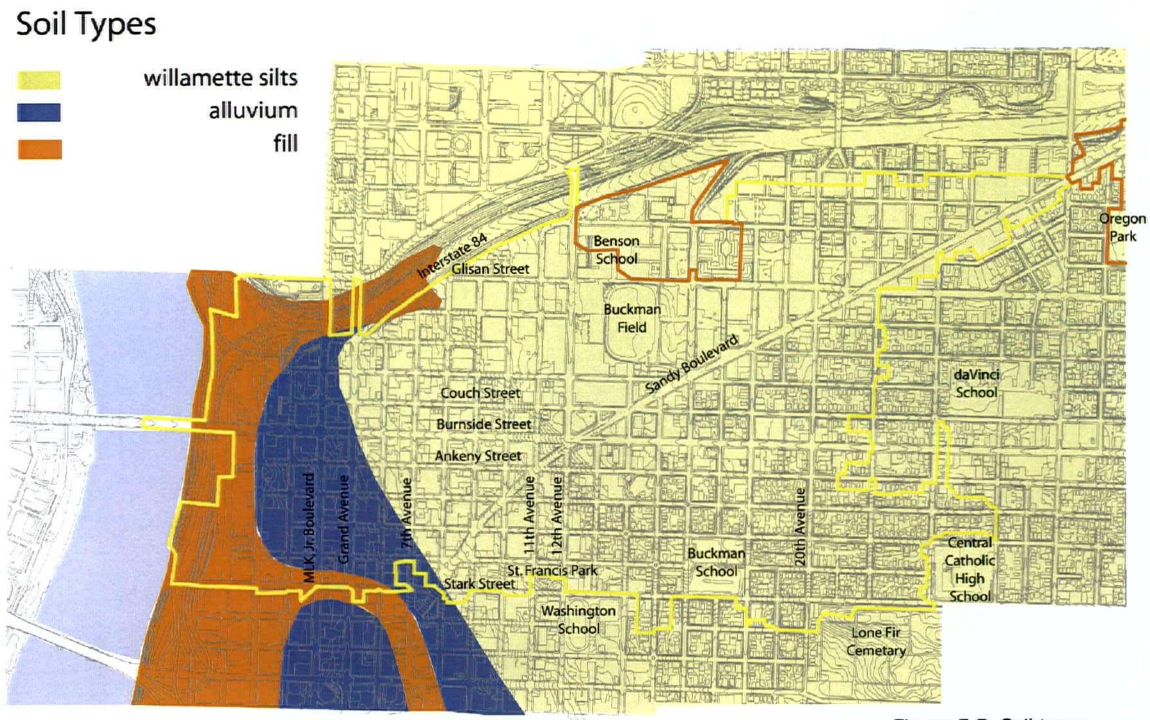


Figure 5.5. Soil types

5.1.2. Water

According to BES HYRDO data, the average annual rainfall in the area of the basin is 37.3 inches (Bureau of Environmental Services, 2006). Portland has Type IIB rainfall pattern, which means that is has long duration, low intensity rainfall. The majority of this annual rainfall occurs between October and May.

The depth to groundwater in the western portion of the watershed is less than 30 feet and in the eastern two-thirds the depth to groundwater ranges from 30 to 90 feet (Bureau of Environmental Services, 2006).

5.1.3. Vegetation

The Oak-Alder-Division subwatershed currently only contains 5% of vegetative cover, with 95% of the subwatershed in industrial, commercial, and residential development. The largest amount of vegetative cover is located in the Lone Fir Cemetery, outside the boundaries of the Oak Basin (Bureau of Environmental Services, 2006). Therefore, the vegetative cover for the Oak Basin is probably lower than 5%.

Pre-development conditions consisted of a range of ecosystem types, although dominated by Douglas fir woodlands, with varying degrees of openness. The most dominant type is savanna, which contained scattered Douglas fir and some oak. The next dominant type of ecosystem, the mixed fir/oak woodland, contained the same species but with some bigleaf maple and an emergent understory of young trees and shrubs. BES' subwatershed characterization study describes the conditions:

> "According to reconstructions of land survey records, vegetation cover types circa 1850 in the Oak-Alder-Division subwatershed consisted of scrub-shrub wetland (5% coverage), savanna (50% coverage), mixed fir/oak woodland (20% coverage), Douglas fir woodland (15% coverage), burned Douglas fir woodland (5% coverage), emergent wetland (1% coverage), open water (2% coverage), and a seasonally flooded area (2% coverage)." (Christy *et al.*, 2000, in Bureau of Environmental Services, 2006).

5.1.4. Riparian

The riparian area of the Willamette River in this subwatershed consisted of a mix of open woodland, willow swamp, emergent wetland, and seasonally flooded lakes (Hulse *et al.*, 2002, in Bureau of Environmental Services, 2006). Currently the riparian area of the Willamette in this basin has been completely urbanized. Furthermore, no streams exist within the Oak-Alder-Division subwatershed and it appears from an 1850 historic survey that no streams ever existed within the portion that currently is the area of the Oak Basin.

5.2. Infrastructure

The basis for the analysis of the stormwater infrastructure for the Oak Basin is the Beech/Essex and Oak Basin Predesign Report, produced by CH2MHill for the City of Portland. The aim of this study was to identify the means to correct system deficiencies in the basin. The primary drivers behind the study were structurally defective pipes and relieving basement surcharging. In the Oak Basin, 80% of pipes surcharge during the 25-year storm event and two-thirds of manholes are also prone to surcharging (Bureau of Environmental Services, 2006). An additional context for the report was to repair the system such that it would meet the Department of Environmental Quality's (DEQ) Amended Stipulated and Final Order (ASFO) for reducing combined sewer overflows into the Willamette River (CH2MHill, 2004).

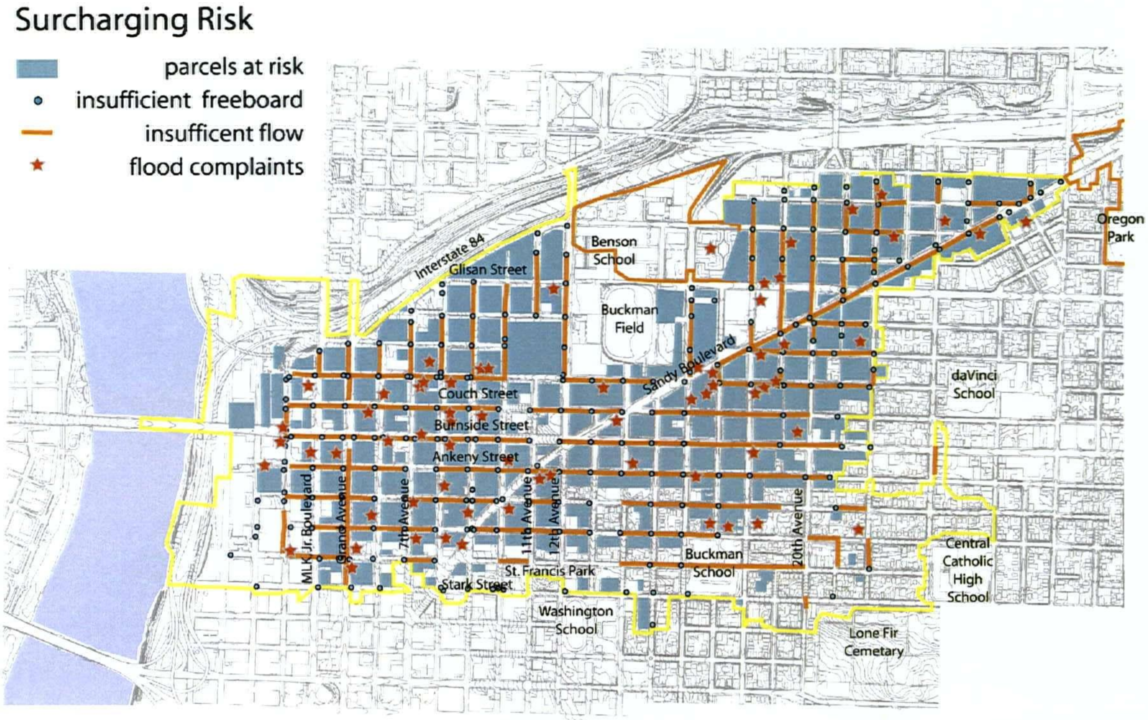


Figure 5.6. Surcharging risk

This basin handles sewage and stormwater in combined pipes, most of which are constructed of vitrified clay, with larger pipes constructed of brick and stone. The collection system is composed of seven parallel systems of relatively small diameter pipes. The seven systems drain to the Southeast Interceptor (SEI) on Grand Avenue. Most of the flows are diverted to an outfall via a diversion structure on SE 3rd Avenue between SE Ash Street and SE Pine Street. During storm events, combined sewage that exceeds the capacity of the diversion structures is discharged into the Willamette River through this outfall (CH2MHill, 2004).

5.2.1. Land Use and Imperviousness

The highly urbanized Oak Basin is 74% impervious, and is anticipated to be 79% for future conditions. The scenario for future conditions is based on 1999 City of Portland Comprehensive Plan Zoning. Impervious surfaces are an important measure of stormwater contributions to the infrastructure system as the area of impervious surface generates the bulk of flow during the design storm. Table 5.1 describes the amount and type of impervious surfaces in the basin.

Impervious Surfaces in the Oak Basin

Impervious Type	Percent of Subwatershed
Building	26.9
Parking	9.4
Street	37.7
	74%

Table 5.1 (after CH2MHill, 2004)

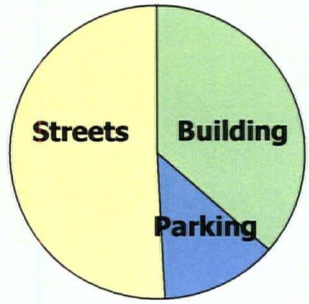


Figure 5.7. Impervious Types

Of the 74% impervious surfaces in the basin, 51% of those surfaces are streets. Tables 5.2 and 5.3 below describe the types of land uses in the Oak Basin. Currently, nearly half of the basin is comprised of industrial lands. The amount of industrial land is expected to increase with the greatest loss of land being in multi-dwelling units.

Existing Land Use

Land Use Category	Number of Acres	Percentage of Basin
Oak Basin		
Commercial	50	12
Industrial	209	49
Multi-Family	78	19
Open Space	27	6
Residential	60	14
Total	424	100

Table 5.2 (Beech/Essex and Oak Basin Pre-Designs, CH2MHill, p. 2-13.)

Future Land Use

Land Use Category	Number of Acres	Percentage of Basin
Oak Basin		
Commercial	50	13
Industrial	209	56
Multi-Family	37	10
Open Space	17	5
Residential	60	16
Total	424	100

Table 5.3. (Beech/Essex and Oak Basin Pre-Designs, CH2MHill, p. 2-13.)

5.2.3. Infrastructure Plan

Through the Oak Basin Predesign Report, different scenarios were developed to determine the most cost-effective means to meet the goals of the plan. The final recommendation was to improve the capacity and condition of pipes, rather than separate the combined sewers, due in part to the extra capacity created by connecting to the Southeast Relieving Interceptor (SERI) and the "Big Pipe" project. New CSO pipes must be sized to carry the 25-year, 6-hour design storm, which will relieve surcharging risk (CH2MHill, 2004). A significant portion of the basin needs pipe replacement, due to the current condition and capacity of the pipes (see figure 5.8).

Inflow control locations, which may be surface stormwater facilities, were considered as part of the alternatives. The primary evaluative criteria for inflow controls, aside from technical feasibility, was cost mostly through cost-savings of reduced pipes downstream (CH2MHill, 2004). However, because the assumptions about future land use changed during the course of the Predesign Report, a re-evaluation of inflow control opportunities should be undertaken. Additionally, the Predesign Report indicates that integrating additional analysis of all the benefits of inflow controls might suggest a different alternative than the recommended plan produced for the basin (CH2MHill, 2004).

Even though highly altered through urbanization, the modified local basin "pipesheds" generally reflect watershed drainage patterns. However, the CSO system of pipes redraws the pipeshed boundaries such that they bear little resemblance to the actual watershed. This system encourages the City to think in terms of limited hydrological functions – the imperative to remove total and peak volumes from the system to reduce CSO overflows. The incentive to plan for watershed health through localized infrastructure plans is lost. Therefore, reliance on the centralized "Big Pipe" is necessarily opposed to the concept of the neighborshed.

This thesis does acknowledge that the Big Pipe is under construction and is a reality that must be addressed in the proposed green infrastructure plan. However, this thesis encourages the City to consider other hydrological concerns than large storm events and use local watersheds as the basis for developing more sensitive infrastructure plans.

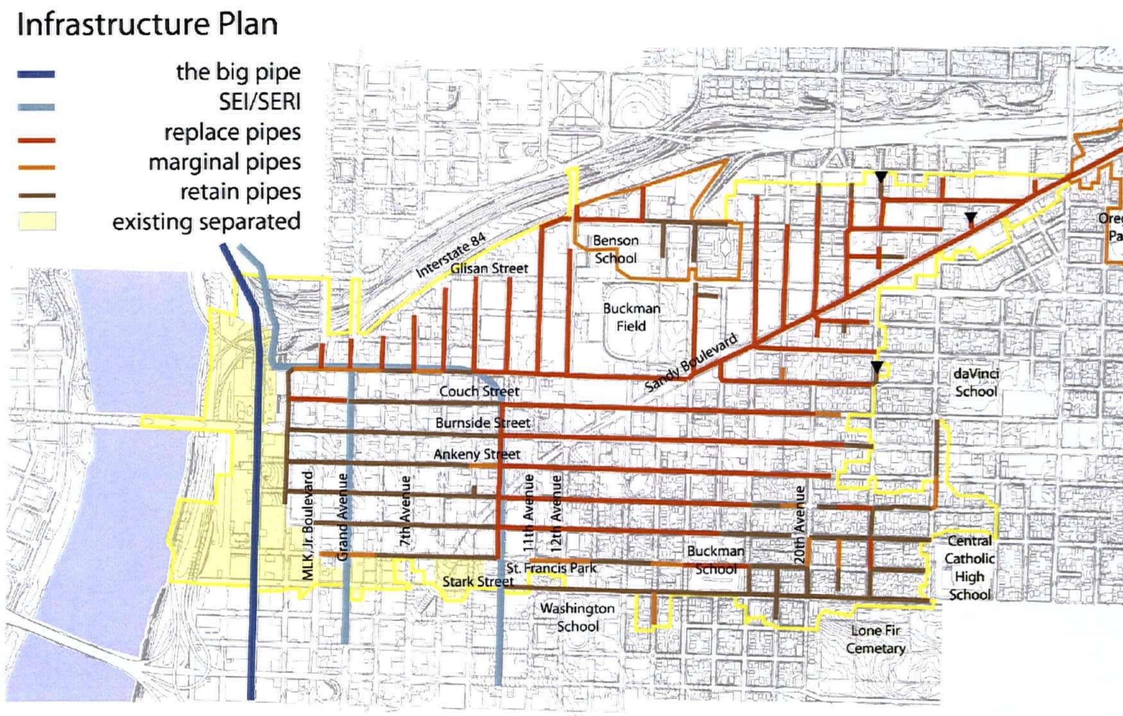


Figure 5.8. Recommended infrastructure plan

5.3. Neighborhood

5.3.1. Land Use

The Oak Basin is located among two neighborhood associations, a business district and a historic district (see figure 5.9). The Kerns Neighborhood is located in the northern portion of the Oak Basin, from Interstate 84 (located in Sullivan's Gulch) to the North, 32nd Avenue to the East, and East Burnside to the South, except at 28th Avenue, which then extends south to Stark Street. The Buckman Neighborhood, whose full boundaries run from the Willamette River east to SE 28th Avenue, from East Burnside Street at its northern boundary and south to SE Hawthorne Boulevard. The Oak Basin's eastern boundary runs crookedly along East 24th Avenue, follows

Sandy Boulevard to the northeast and just touches 28th Avenue. The Oak Basin also does not extend as far south as the Buckman boundary; it ends at SE Stark Street.

Neighborhood Boundaries

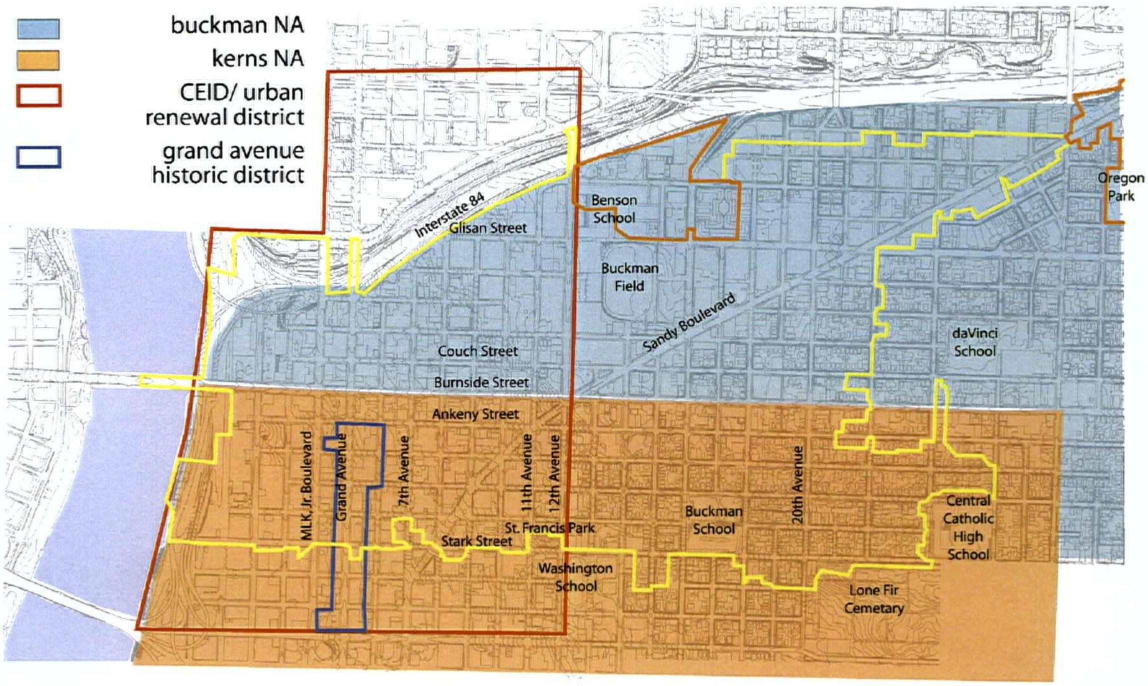


Figure 5.9. Neighborhood boundaries

The area of the Buckman Neighborhood was founded in 1870 as a separate city; about one hundred years later it formed as the Buckman Neighborhood Association (Buckman, 1991). The neighborhood is laid out generally on 200 foot by 200 foot blocks, on flat terrain with 60-foot-wide right-of-ways. Institutional or public uses often have larger block sizes (i.e. Lone Fir cemetery). Although the street pattern is an interconnected grid, some streets do not run straight through, subtly dividing the neighborhood into mini-neighborhoods (Buckman, 1991).

According to the Buckman Neighborhood Plan, adopted by City Council in 1991, the characteristics of Buckman include older houses, apartment buildings, and commercial storefronts; nearness to downtown Portland; a centrally located school and parks; local shops and serves that are accessible to the residents of Buckman; nearness to the Willamette River; and quiet, tree-lined streets that encourage walking and bicycling. Residents appreciate the human scale of the buildings and a sense of neighborliness. They wish to avoid high density residential development with surface parking and rather achieve density through mixed use development in proximity to transit (Buckman, 1991).

A substantial portion of the Kerns Neighborhood is comprised of industrial and commercial land uses (see figure 5.10). The Kerns Neighborhood Action Plan (1987) expresses a concern for commercial encroachment through the neighborhood. Like the Buckman Neighborhood, it enjoys a central location and good transit services, which residents wish to capitalize upon by promoting the development of pedestrian, bicycle and transit amenities (Kerns, 1987). The Kerns Neighborhood contains only 3% open space with Oregon Park as the only neighborhood park, which lies just outside the boundaries of Oak Basin.

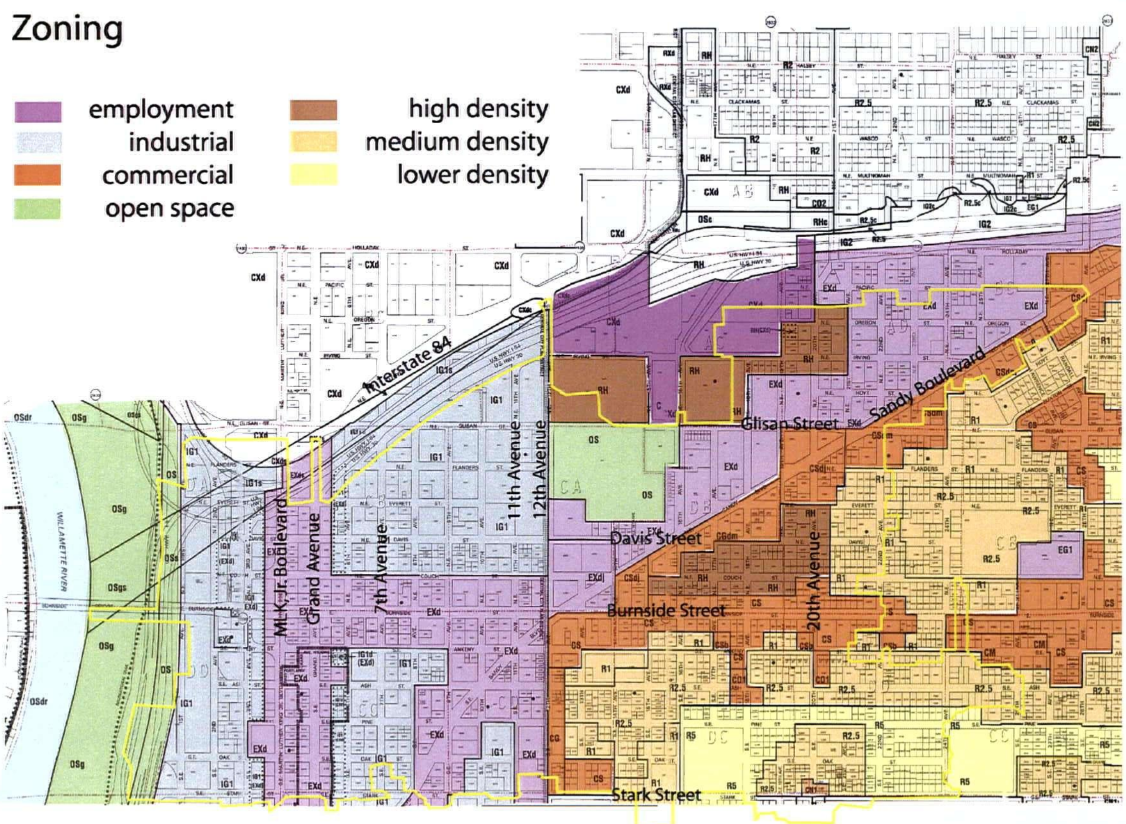


Figure 5.10. Zoning

The Central Eastside Industrial District (CEID) crosses the borders of Buckman and Kerns Neighborhoods. The CEID is characterized by old warehouses and industry. It is an area that grew up around rail and shipping systems, and now including highway access via I-5 (Buckman, 1991). Designated as an Urban Renewal District, it is eligible for monies from the Portland Development Commission. Recent trends have seen the emergence of this area as a "creative" district, with design businesses, restaurants, and coffee shops currently co-existing with the produce distribution industries and furniture warehouses.

Along Martin Luther King, Jr. and Grand Avenues is the East Portland/Grand Avenue Historic District.

5.2.2. Streets

The Oak Basin is crossed east-west by major arterials E. Burnside Street and SE Stark Street. In a north-south direction are traffic couplets Martin Luther King, Jr. Boulevard and Grand Ave and 11^{th} and 12^{th} Avenues. NE Sandy Boulevard, originally a Native American trail (Office of Transportation, 2005), runs diagonally through the neighborhood. With the exception of 11^{th} and 12^{th} Avenues, the above streets above are also served by transit. City Bikeways are also well-distributed through the basin (see figure 5.11).

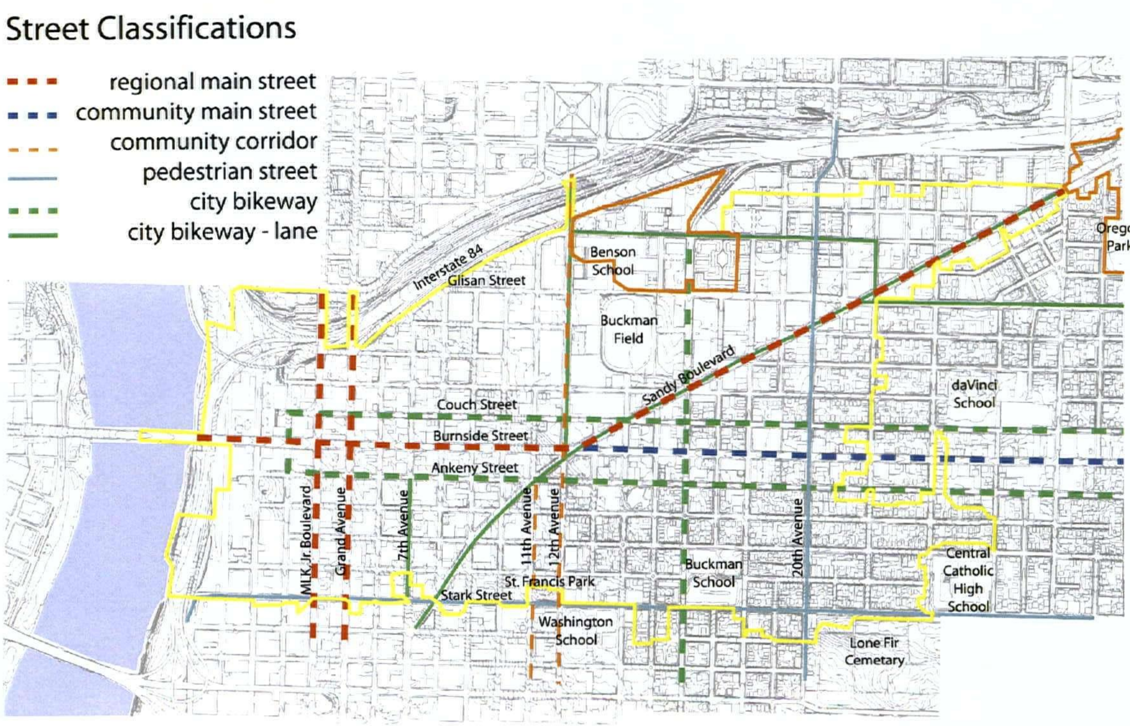


Figure 5.11. Street classifications

The Oak Basin's central location is considered an advantage to the neighborhood associations; however, its proximity to downtown also means that commuter traffic impacts the neighborhood (Buckman, 1991; Kerns, 1987). In addition to concerns about speeding through the neighborhood, parking is also difficult (Buckman, 1991). In order to reduce traffic problems, the Buckman Neighborhood Plan specifically recommends that the City provide more amenities at bus stops, establish trolley service, create traffic diverters that allow bicyclists to cross streets safely and paint stop lines at stop signs (Buckman, 1991).

The City of Portland's Comprehensive Plan has a series of street classifications to determine the emphasis of transportation modality for that street and the appropriate level of street improvements, including appropriate land uses, important connections to other streets, and parking requirements (Bureau of Planning, 1980/2004). For this part of city, the primary transportation objective is to protect "residential areas and industrial sanctuaries from non-local traffic, while maintaining access to established commercial areas" (Bureau of Planning, 1980/2004, p. 96). Comprehensive Plan designations are organized into the categories of Traffic, Transit, Bicycle, Pedestrian, Freight, Emergency Response, and Street Design. Some of the relevant classifications that apply in the Oak Basin are listed below, with the streets in the basin that fall into that category (Bureau of Planning, 1980/2004, pp. 47-57):

Traffic

- **Major City Traffic Streets** are intended to serve as the principal routes for traffic that has at least one trip end within a transportation district: *Grand Avenue, Martin Luther King, Jr. Boulevard, Sandy Boulevard.*
- **District Collectors** are intended to serve as distributors of traffic from Major City Traffic Streets to streets of the same or lower classification. District Collectors serve trips that both start and end within a district: *Burnside Street.*
- **Neighborhood Collectors** are intended to serve as distributors of traffic from Major City Traffic Streets or District Collectors to Local Service Streets and to serve trips that both start and end within areas bounded by Major City Traffic Streets and District Collectors: *Stark Street, Glisan Street, 20th Avenue.*

Transit

- **Major Transit Priority Streets** are intended to provide for high-quality transit service that connects the Central City and other regional and town centers and main streets: *Grand Avenue, Martin Luther King, Jr. Boulevard, Burnside Street, Sandy Boulevard.*
- **Transit Access Streets** are intended for district-oriented transit service serving main streets, neighborhoods, and commercial, industrial, and employment areas: *Glisan Street, 20th Avenue.*

Freight

- **Freight Districts** are intended to provide for safe and convenient truck movement in areas serving large numbers of truck trip ends and to accommodate the needs of intermodal facilities: *Central Eastside Industrial District.*
- **Major Truck Streets** are intended to serve truck trips with one or both trip ends in a Transportation District: *11th Avenue, 12th Avenue.*
- **Minor Truck Streets** are intended to serve truck trips with both trip ends in a transportation district: *Burnside Street, Sandy Boulevard.*

Bicycle

- **City Bikeways** are intended to serve the Central City, regional and town centers, 53 station communities, and other employment, commercial, institutional, and recreational destinations: *Grand Avenue, Martin Luther King, Jr. Boulevard, Irving Street, Glisan Street, Couch Street, Ankeny Street, 7th Avenue, 11th Avenue, 12th Avenue, 16th Avenue, Sandy Boulevard.*

Pedestrian

- **City Walkways** are intended to provide safe, convenient, and attractive pedestrian access to activities along major streets and to recreation and institutions; provide connections between neighborhoods; and provide access to transit: *Grand Avenue, Martin Luther King Jr. Boulevard, Burnside Street, Stark Street, Sandy Boulevard, 20th Avenue.*

Street Design

- **Regional Main Streets** are designed to accommodate motor vehicle traffic, with features that facilitate public transportation, bicycles, and pedestrians: *Martin Luther King, Jr. Boulevard, Grand Avenue, Sandy Boulevard, Burnside Street.*
- *Community Main Streets* are designed to accommodate motor vehicle traffic, with special features to facilitate public transportation, bicycles, and pedestrians: *Burnside Street.*
- *Community Corridors* are designed to include special amenities to balance motor vehicle traffic with public transportation, bicycle travel, and pedestrian travel: *11th Avenue, 12th Avenue.*

For the purposes of this thesis, the most significant classification category is Street Design, which identifies "the preferred modal emphasis and design treatments for regionally significant streets and special design treatments for locally significant streets" (Bureau of Planning 1980/2004, p. 58). This category prioritizes among the multiple categories of street designations and determines the preferred design treatment of a particular street. Street Design designations by definition have transit, bicycle and pedestrian elements. Transit Streets, City Bikeways and

Pedestrian Streets not included in the Street Design designation are also important streets relative to the goals established for this project. The above map (figure 5.11) describes these various designations. Note that City Bikeways may share the road with vehicular traffic or they may have a striped lane. Additionally, all other streets are considered Local Service Bikeways, with the exception of regional throughways.

5.3.3. Heritage Trees

City of Portland Parks and Recreation has a Heritage Tree program. Two heritage trees are located within the Oak Basin. Located on private property, a 50-foot high shellbark hickory (*Carya laciniosa*) is located at 143 SE 32nd Ave. An 80-foot high Wych elm (*Ulmus glabra*) is located at 216 SE 17th in the public realm – the planting strip.

5.3.4 Park Types

Another layer in the framework is the open space hierarchy for the neighborhood. An important consideration for neighborhood livability is the amount and type of open space and recreation opportunities that are available. A common framework used for open space and recreation planning is the Recreation Opportunity Spectrum (ROS), which marks a shift from a numeric based system of providing open space (i.e., one park per 5,000 inhabitants) to one that addresses the specific recreation and open space needs of the community. This kind of needs-based approach recognizes a community's socio-economic characteristics, the existing level of open space provision and the environmental attributes of the area.

Open space and recreation needs can be categorized is several ways, including scale of facility, population served, levels of social interaction encouraged, or the degree of natural protection. Adequate access to open space and recreation is also important, and the definition of adequate often varies based on the type of facility. For an urban neighborhood like the Oak Basin, these types of open spaces are appropriate:

Interstitial: green spaces along corridors and between buildings provide a level of visual relief from the built environment, and may provide passive recreation or even some level of urban habitat. This may include street trees or greenways.

Pocket park: small parks that serve a very local neighborhood population, which provides passive recreation or children's play space.

Neighborhood Park: neighborhood-scale parks, located within an easy walking distance of residents, that provide active recreational space and children's play space. School grounds often serve this function.

Community or District Park: a larger neighborhood park that provides a greater range of activities and serves a more diverse age population than a neighborhood park. It may include areas of natural habitat and associated recreational opportunities.

Regional Park: a larger park that may provide active recreation or access to natural areas of significant interest to the population.

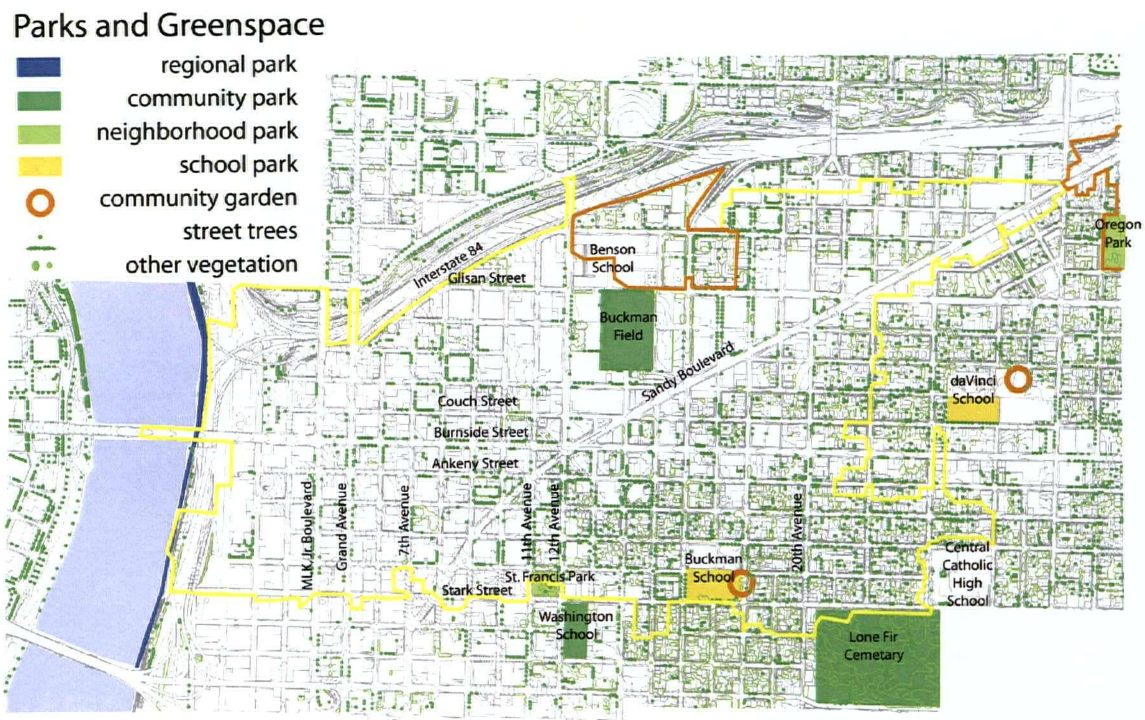


Figure 5.12. Parks and greenspace

5.3.5. Park Access

The amount, type and quality of urban parks and greenspaces are significant factors contributing to urban livability. As Portland Parks and Recreation points out in its vision document, Parks 2020 Vision, Portland's parks and recreation system is one of the factors that contributed to ranking Portland as America's most livable city in 2000. However, as Portland Parks also points out, some aspects of the park system need improvement (Portland Parks, 2000). The vision, goals and objectives of Portland parks provides another level of evaluative criteria for this design.

One goal in the Portland 2020 Vision is to increase the urban forest on streets and parks; the objective is to expand the urban forest from 60% to 80% on city streets and from 80% to 90% in city parks (Portland Parks, 2000). Another pertinent goal is to increase "green connections" along each designated main street in the city (Portland Parks, 2000, p. 3). The city's objectives for providing a variety of recreation opportunities and experiences include the provision of neighborhood parks within a 10-15 minute walk of residents and a Community Park within one mile of residents (Portland Parks, 2000). However, this thesis project uses a 5-minute walking radius to neighborhood parks as a measure for parks access, which is especially important for neighborhood parks. Residents are more likely to use neighborhood parks, which often have play facilities for children, if they are located within a 5-minute walk.

Access to parks is fair in Oak Basin. The portion of the basin which does not have a neighborhood or pocket park within a 5-minute walk is the Central Eastside Industrial District and the employment and industrial zones north of Sandy Boulevard. However, these areas do have access to a community or regional park within a 10-minute walk. Figure 5.13 illustrates a 5-minute walk to all facilities.

Park Access

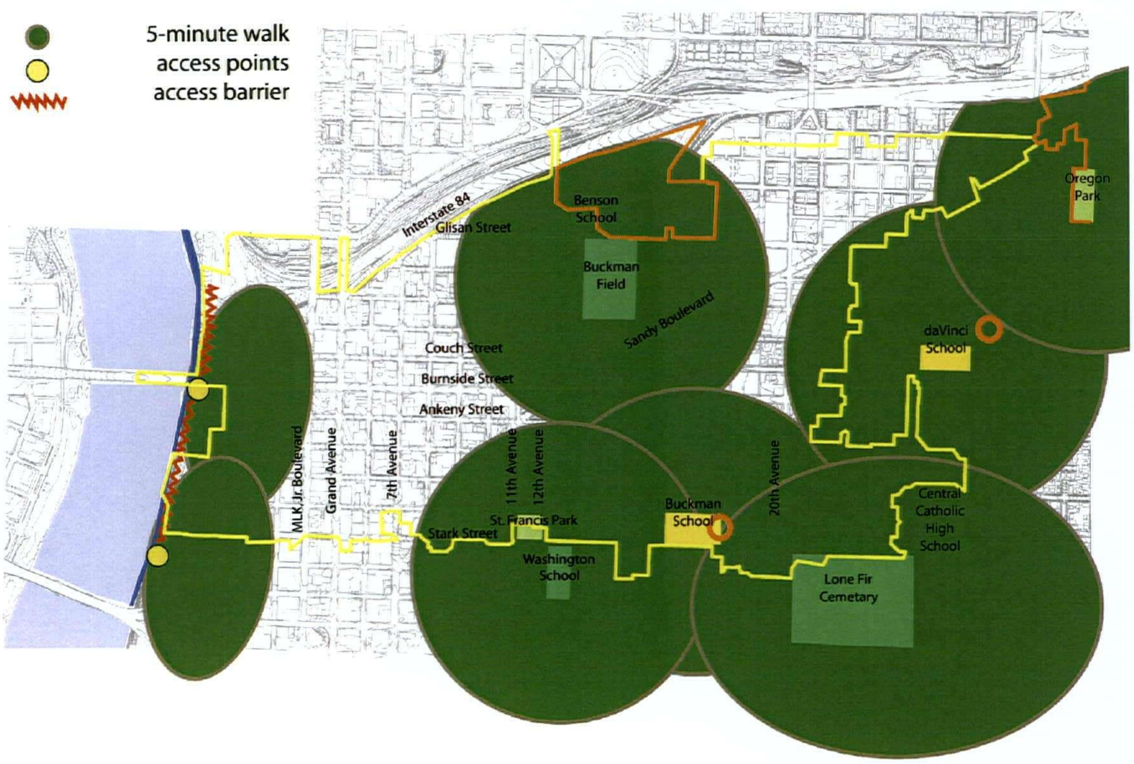


Figure 5.13. Park access

5.4. Findings

5.4.1. Watershed

Current hydrological conditions of the Oak Basin are nearly the reverse of historical patterns. The pre-development conditions of open woodland and savannah suggest 10-20% surface runoff, with a large amount being infiltrated and evapotranspirated. Today the amount of imperviousness and low vegetative cover in the basin results in high runoff volumes and little infiltration. It is currently 74% impervious and is expected to become nearly 80% impervious with continued redevelopment. As an urbanized basin, there is no intact habitat and little open space.

The combined sewer and stormwater system in the basin sends runoff to a stormwater treatment facility, thereby negating the need to clean water via filtration facilities. However, runoff volumes remain a concern and implementing source controls, particularly at the top of the 'pipeshed,' will relieve infrastructure system capacity. Water quality becomes a concern if untreated stormwater overflows into the Willamette River by volumes that exceed the capacity of the piped system.

The primary ecological driver for the watershed is to minimize its contribution to Combined Sewer Overflows. Groundwater recharge is valuable for the health of vegetation, but is not necessary to provide baseflow to streams, which is often the concern of urbanization's impact on stream health. While infiltrating stormwater for water quality purposes is not a significant consideration, some level of infiltration for groundwater recharge is desirable to provide water for vegetation. Also, vegetated facilities – particularly with trees - are important for mitigating the urban heat island effect (bicycling down Ankeny Street on a summer day provides one with a poignant experience of the urban heat island effect).

With streets comprising 51% of impervious surfaces in the basin, they are a target for stormwater interception and infiltration. Green street designs, already emerging in popularity in the city, are one way of handling this runoff. Interception through street trees would also help relieve the stormwater burden on the infrastructure system.

5.4.2. Infrastructure

The Oak Basin Predesign Report found that the 80+yr old system suffers from poor condition and capacity of pipes. It was determined that upgrading the capacity and condition of pipes was the most appropriate route, not separating the sewer and stormwater systems. The Predesign Report also recommended implementing three source controls (surface stormwater management facilities) to remove runoff from the systems in key locations. To relieve surcharging problems in the basin, pipes must be sized to handle the 25-year, 6-hour storm event, which is a total of 1.89 inches of rainfall.

Although the most of the CSO pipes in the basin will be replaced and upsized, some incentive remains to remove some water from the system. As the basin continues to urbanize, increased impervious surfaces will increase the demand on the CSO system. This runoff travels to the water treatment plant via the "Big Pipe." The multiplication of increased urbanism throughout the city will strain the capacity of the Big Pipe in the near future – the City estimates that it will be at capacity soon after its completion in 2011 (Office of Sustainable Development *et al*, 2005). Stormwater source controls are a necessary part of an infrastructure plan to reduce combined sewer overflows.

5.4.3. Neighborhood

Nearly half the basin contains commercial and industrial uses and the other half is residential. As historic streetcar suburbs, the basic organization of the area is generally conducive to transit-oriented development, walkability, and is bicycle-friendly. However, land uses are not being used to their greatest capacity; for example, a number of surface parking lots exist. Portions of the neighborhood have recently undergone redevelopment that is generally new mixed use development consistent with the goals of the City and the Neighborhoods.

Busy streets – Sandy Boulevard and Burnside Street – are not especially pedestrian friendly. Several bicycle ways exist in the area, with minimal design interventions to support their function as bicycle ways. Neighborhood Parks are well-distributed within the area, and a new community center will also serve the neighborhood (Washington School). While new neighborhood parks are not needed, increased green space is. Increasing the urban forest would improve the character of the neighborhood, and is consistent with the desire of residents, as expressed in the area's neighborhood plans. Increased green space provides for certain kinds of green space in the hierarchy of park spaces (i.e. interstitial spaces and pocket parks). The green network does not need new "patches" as much as stronger corridors to make a complete system. However, creating new pocket parks to serve very local populations that do not have a park facility within a 5-minute walk is another option that should be examined.

6. Principles, Goals, and Targets

This chapter establishes the framework for creating a integrated green infrastructure plan. The review of existing integrated approaches employed in Oregon and British Columbia provide a general understanding of how to meet the multiple interests that jurisdictions face with watershed health, infrastructure planning, and neighborhood livability issues. The analysis in the previous chapter identified the particular concerns and opportunities in the Oak Basin with regard to these three systems. The findings of the case studies and the information from the Oak Basin provided the beginning of a framework for understanding how to plan for these systems in a comprehensive and holistic way. This chapter elaborates on this understanding by providing a set of principles, goals and targets for the Oak Basin.

6.1. Principle: Mimic Natural Conditions

Many of the integrated approaches examined in chapter 4 express the idea of mimicking pre-development conditions in order to improve watershed health. While it is often not possible to restore watershed features such as stream corridors in highly urban areas, it is possible to re-design cities to perform certain hydrological functions. This can be accomplished by identifying key environmental factors that can be improved, determining their functional requirements, and adapting them to an urban environment. The principle *Mimic Natural Conditions* can be used to help guide decisions for re-ordering the urban structure for greater sensitivity to watershed health.

6.1.1. Goal: Reduce volume of runoff

Based on pre-development conditions, the principle of mimicking natural conditions means limiting runoff to 10% of the annual rainfall in this basin. Additionally, research has shown that 10% effective impervious areas are a critical threshold for stream health (Booth & Jackson, 1997). In this basin, infiltrating 90% of annual rainfall translates to capturing the first inch of rainfall every 24 hours. The best way to do this is to provide a distributed network of infiltration facilities throughout the basin. This better reflects pre-development hydrology; additionally, it creates a dispersed network of greenspace in a basin that lacks interstitial greenspace. Therefore, one target for the green infrastructure plan is to:

- Infiltrate at least 1"/24 hours on each parcel and street. This will provide flow control and pollution reduction for 90% of annual stormwater volume, as well as recharging groundwater supplies.

6.1.2. Goal: Reduce rate of runoff

As the Stormwater Planning Guidebook indicates, mimicking natural conditions also means that runoff from the infrequent large storms should be stored and then released it at a rate that approximates the natural forested condition. This next tier of rainfall events occur 10% of the time. In conventional systems, this excess capacity is often managed through single-purpose detention basins. As the BC Stormwater Planning guide suggests, managing the capacity of the second tier of rainfall events could be in the form of detention facilities or infiltration facilities (Stephens *et al*, 2002).

Conventional single-purpose detention basins also imply a need to secure a large piece of land that is publicly-owned but generally not for public access. However, it is possible to create smaller facilities and to build multiple functions into them. Single-purpose landscapes do not make sense in constrained urban areas where competition for space is high. For example, Metro's guidebook, *Green Streets*, suggests an alternative strategy for managing peak flow through linear infiltration or detention strips (2002). Therefore, one strategy for the green infrastructure plan is to:

- Create multifunctional community-scale facilities to detain larger storms to assist in runoff rate reduction.

6.1.3. Goal: Increase vegetation

Indicators commonly used in other watershed plans, such as riparian forest cover, are not especially relevant in an urbanized basin like the Oak Basin. However, there are certainly benefits to increased vegetation in an urban environment, particularly for stormwater. The combination of tree canopy interception and evapotranspiration in a natural rainforest can approach 40% of annual rainfall (Stephens *et al.*, 2002 in Interim Report, 2004). Additionally, as an urban forest evapotranspirates rainwater it reduces the stormwater burden while moderating the ambient temperature through the consumption of heat energy (Spirn, 1984, in Girling & Kellett, 2005). Trees also moderate the urban heat island effect through blocking the sun's radiation. From a livability perspective, trees provide cover for pedestrians and are a source of visual relief from the hardness of the built environment (Girling & Kellett, 2005). Therefore, another appropriate goal for this watershed is to increase the amount of its vegetative cover.

Pre-development vegetation levels suggest a higher level of vegetative coverage than the current coverage of 5%. The Oak Basin was not entirely forested but rather was covered in a large amount of savannah and open woodland ecotypes. Some studies suggest that tree cover of an area should be at least 40%, which is difficult to reach in urban areas (Benedict & McMahon, 2006). American Forests recommends an average 25% tree canopy for urban neighborhoods, east of the Mississippi and in the Pacific Northwest. Therefore, the strategy suggested for meeting the goal of increased vegetation is to:

- Increase total basin vegetative coverage to at least 25%, primarily through increasing the urban forest via street trees and increased tree planting in parks.

6.2. Principle: Healthy, visible, and green infrastructure

The transparency of an infrastructure system is critical to understanding its function and contribution to sustainable design. As Thayer observes: "If the perceptual function of a technology is to convince us the world is a better place to live, while the practical dimensions of the technology contribute to making the world worse, something is critically out of balance" (Thayer, 2002, p. 189). Currently, the Oak Basin's infrastructure system is primarily an underground system of pipes that interrupts the hydrological cycle. Furthermore, this system contributes to Combined Sewer Overflows (CSOs), which is the primary environmental impact of the Oak Basin. In addition to developing a more legible and transparent stormwater infrastructure system, this system should also eliminate the Oak Basin's contribution to CSOs.

Also, the original purpose of a stormwater infrastructure system is to protect human health and provide for human comfort. This primarily means ensuring that private property, public land and streets are protected from flooding. Conventional infrastructure systems are engineered to meet this objective, but in their singleness of purpose, overlook other factors like watershed health. A green infrastructure system that mimics natural conditions integrates these concerns by ensuring public and watershed health is maximized.

6.2.1. Goal: Reveal infrastructure

Rather than piping stormwater underground, making infrastructure visible suggests that surface stormwater facilities should be the first kind of strategy pursued for stormwater management. The Bureau of Environmental Services has developed a "Stormwater Hierarchy" in its Stormwater Management Manual (2004) for stormwater management measures. Once a site is developed or redeveloped (with 500 square feet or greater), regulations in the Manual are triggered. The first requirement is to infiltrate stormwater on site, although the BES hierarchy does not specify which kind of on-site facilities. This strategy builds upon the BES hierarchy, requiring on-site facilities but also:

- In developing stormwater management strategies for a site, consider surface facilities first.

6.2.2. Goal: Provide for public health and safety

While the strength of a green infrastructure system rests on its ability to provide multi-dimensional benefits to the landscape, it still must provide this essential service of protecting public health and safety. Basement surcharging is a significant infrastructure concern in this basin. In the Predesign Report's Recommended Plan, pipes have been sized to meet the 25-yr/6-hour storm in order to meet objectives for reducing basement flooding. Therefore, this thesis recommends that the public infrastructure system be designed to meet this storm event: all streets and park sites within the basin should be able to infiltrate a total of 1.89 inches.

- Provide basement flooding relief at the level of the 25-yr/6-hour storm (1.89") by combining sewer pipe size with 1" infiltration facilities.

6.2.3. Goal: Eliminate Oak Basin's contribution to CSO overflows

Eliminating CSO overflows into the Willamette River requires greater detention of peak flows from large storm events. In order to meet DEQ standards for CSO overflow compliance, the public infrastructure system is required handle at least the 3-yr summer storm. This storm's total depth is 1.41 inches. This standard prevents many CSOs but does not eliminate them entirely. If we want to be more aggressive, and design a green infrastructure system with no overflows to the Willamette River, then a higher standard is in order.

Combining the capacity of the existing pipe system with a green infrastructure system provides a higher level of protection, as meeting the goals of mimicking natural systems (providing 90% infiltration) and a reduced reliance on conventional infrastructure systems. While facilities designed to capture the first inch of rain suffices for 90% of all events, larger storm events must be considered. Community detention facilities to slow the rate of runoff will help with reducing the demands of the CSOs and minimize overflows to the Willamette River.

- Eliminate CSO overflows by combining sewer pipe size with 1" infiltration facilities to manage the 25-yr/6-hour storm (1.89").
- Create community-scale facilities that infiltrate 1.89" of rainfall.

6.3. Principle: Foster Sustainable Urbanism

Green infrastructure is not an isolated component of the city structure, but operates contextually with other facets of urbanism. The principle Fostering Sustainable Urbanism addresses the range of sustainable planning and design strategies that enable full expression of green infrastructure's potential. Without addressing all these needs, green infrastructure is at risk of perpetrating the same problem of conventional infrastructure systems – single-purpose design at the expense of other environmental factors or livability.

What is most important and long-lasting for city functionality is its urban footprint – the streets, the blocks, the parks and open spaces that shape the city. These generate the patterns for human habitation and mobility which comprise a large amount of material and energy consumption. Sustainable urban design creates a framework for reducing greenhouse gas emissions and preventing development from sprawling over farm and forestland. In addition to promoting pedestrian movement and transit activity, compact development also reduces per capita stormwater impacts - up to 75%, according to some studies (CH2MHill, 2002, p. 8).

While this thesis does not directly address these urban patterns, it is important to understand that the strategies suggested are compatible with and, in fact, necessary for the success of a sustainable city. The concept of sustainable urbanism recognizes that a return to pre-development structural conditions is not feasible, acknowledging the layered history of human endeavor and creativity on the shape of the landscape. Urbanism is an essential component of sustainable design. Developing watershed-friendly stormwater strategies is another facet of sustainable development, where stormwater infiltration does not come at the expense of urban density or street connectivity. This is because urban areas must also grapple with issues such as air quality and land consumption due to sprawl as well as hydrological concerns. In this proposal, these other goals for sustainability are met within this framework.

The goals for the neighborhood layer have been drawn, in large part, from existing city policies and augmented by additional research on what constitutes sustainable urbanism. City of Portland planning documents generally reflect New Urbanism principles, coupled with a more explicit concern for the environment as expressed through its environmental overlay zones and other elements. The mechanism that directs land use decisions in Portland is the Comprehensive Plan, administered by the Bureau of Planning. Among the goals listed in the Comprehensive Plan, and particularly relevant for this project, are those for Urban Development, Transportation, and Environment.

Among the goals listed under Urban Development in Portland's Comprehensive Plan are those for open space and mixed uses along transit streets, including densities that support transit use. Transportation goals include policies that encourage walking and bicycling through design interventions. Environmental goals encourage the protection of land, air, and water resources through such activities as bicycling and walking, protection of drainage ways, and improving water quality through stormwater facility designs (Bureau of Planning, 1980/2004).

6.3.1. Goal: Encourage bicycle and pedestrian activity

The Comprehensive Plan and neighborhood plans express a desire for greater bicycle and pedestrian activity. Green infrastructure systems can be designed to assist in promoting bicycle and pedestrian activity. Therefore, the green infrastructure plan should examine opportunities to:

- Improve safety and convenience (e.g. shade, water, resting places) of bicycle and pedestrian streets (i.e. Main Streets)

6.3.2. Goal: Foster Community Identity

Chapter 5 described the human-scale neighborhoods with strong local identity in the Oak Basin, valued by the residents in the community. Green infrastructure systems can help in this development, including generating a sense of place with stronger connections to the watershed and hydrological processes. Therefore, the green infrastructure plan should:

- Ensure new development promotes human-scale development, enhances local character, and generates a sense of place.

6.3.3. Goal: Adequate and accessible greenspace

The idea of providing a wide range of recreation opportunities and experiences is a key planning factor for parks development. Beyond the issue of adequate access, this concept ensures that different kinds of experiences are available for the urban dweller – recreation, relaxation, visual relief. It also suggests that a "park" might take different shapes and sizes in order to meet the needs of a neighborhood. The findings from the analysis show that access to neighborhood parks is fair, although the overall amount of vegetation and interstitial greenspace is low. Two strategies will assist with meeting this goal:

- Increase interstitial greenspace via urban forestry improvements to reach 25% coverage of the basin
- Secure pocket parks in areas low in public space or green space

7. Green Infrastructure Plan

Green infrastructure is the ecological network that provides vital services to a community. It is a concept that can be applied at many scales and systems. For example, it can be applied at a landscape level as a means to conserve ecological, cultural or working lands. In this thesis, green infrastructure is described as a multi-dimensional urban system, meeting not only infrastructure objectives but also providing visual, recreational, and hydrological services. Green infrastructure planning is an approach for integrating multi-faceted urban systems into a cohesive plan for improved neighborshed livability.

Developing a green infrastructure plan requires examining watershed, infrastructure and neighborhood systems simultaneously. In doing so, stormwater facilities can meet multiple infrastructure and neighborhood objectives. One example employed currently by the City of Portland is traffic-calming curb bulbs that also function as stormwater infiltration facilities.

The following maps describe how the green infrastructure principles, goals and strategies manifest in physical form throughout the Oak Basin. The green infrastructure plan has several components, each of which is described in its own map. The comprehensive plan is summarized below.

7.1. Comprehensive Green Infrastructure Plan

Reducing the volume and rates of runoff and increasing vegetative cover are ways to mimic natural conditions. Specifying that every street and parcel infiltrates one inch of rainfall every 24 hours approximates the pre-development conditions of the watershed. Different types of stormwater facilities are more appropriate for certain land use types, and surface facilities are given highest priority in order to increase the legibility of the green infrastructure system. Increasing tree canopy coverage to 25% also assists with runoff volume and rate reduction, as well as providing more green space throughout the basin. Certain streets and open spaces have been designated as community-scale infiltration facilities to assist with peak runoff rates. All the infiltration targets have been set to mimic natural conditions and to ensure that the infrastructure system resolves problems with combined sewer overflows and basement surcharging.

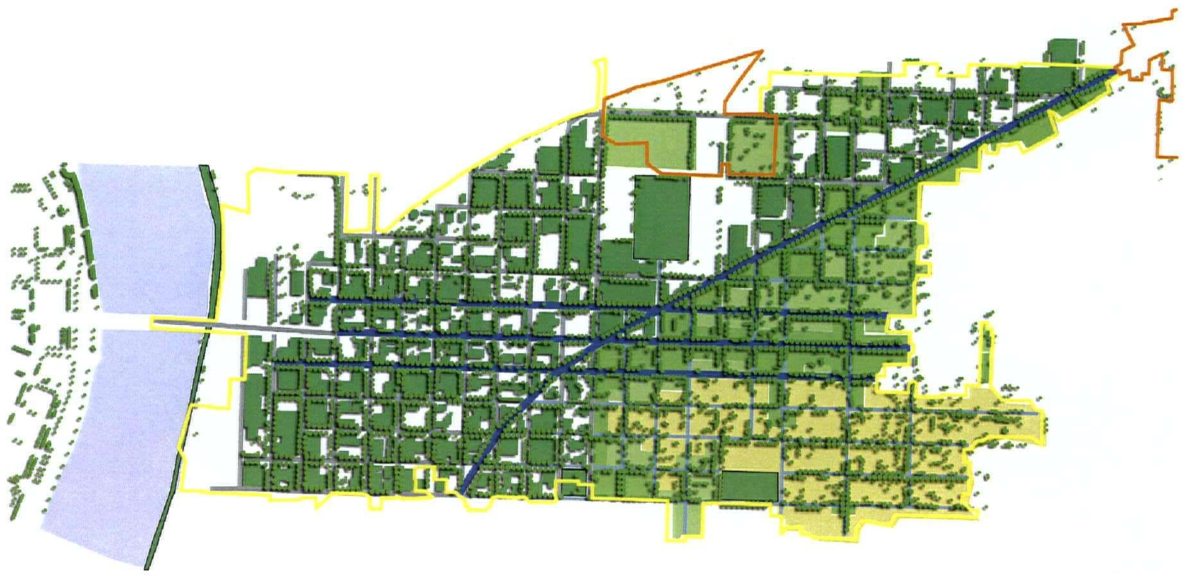


Figure 7.1. Comprehensive green infrastructure plan

7.2. Land Use Strategies

Every parcel should infiltrate one inch of rainfall in order to meet targets. Strategies to meet this target will vary depending on the type of land use and space available:

- Residential areas may use absorbent landscaping, swales, or rain gardens
- Commercial and multi-dwelling may use rain gardens or stormwater planters
- Industrial and employment zones may use stormwater planters or green roofs

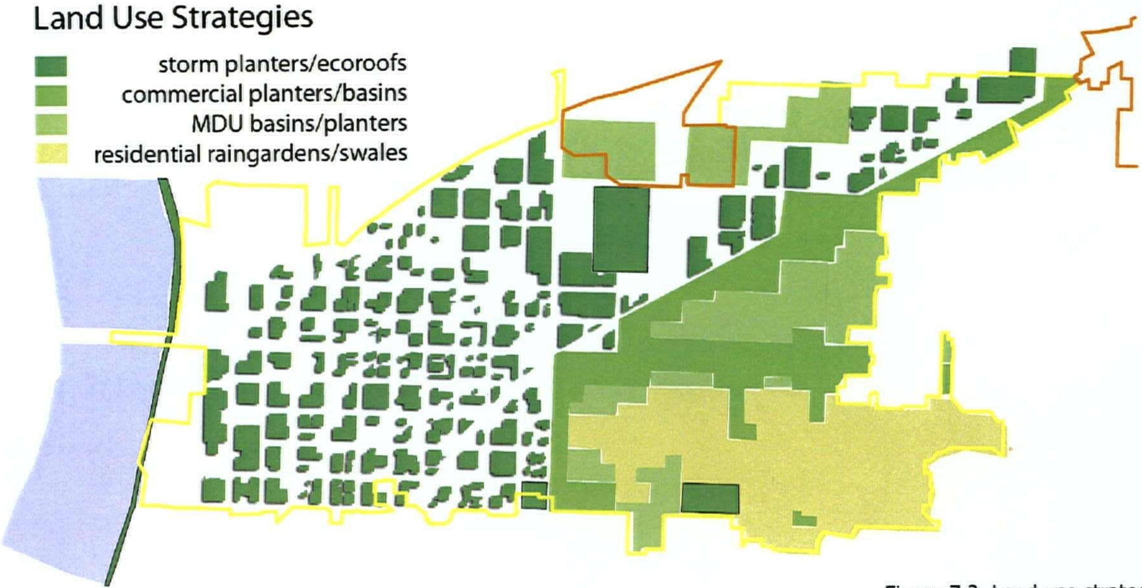


Figure 7.2. Land use strategies

Figure 7.3. Downspout disconnect
Source: LCREP

In addition to soil conditions, different stormwater facilities are appropriate for land use types based on the amount of impervious surfaces the site has. *The Effectiveness of Stormwater Source Control* report describes single-dwelling residential landscapes as having 30 - 60% impervious surfaces. This report shows that an additional 300 mm (12 inches) of soil added to residential landscapes ("absorbent landscaping") is sufficient for mitigation of pervious surface runoff, even over soils with poor hydraulic conductivity. The report also indicates that this type of absorbent landscaping is particularly effective in reducing peak runoff rates. To mitigate runoff from areas of impervious surfaces, additional facilities are required to convey and infiltrate the water, although absorbent landscaping may handle a significant portion of it. Subsurface and bioretention facilities (e.g. rain gardens) both work well in a residential landscape. Gravel improves the performance of facilities. Infiltration facilities provide additional storage with additional depth, although the benefits diminish beyond a threshold of 500 mm (1.6 feet). These performance measures assumed 50% imperviousness (CH2MHill, 2002).

Figure 7.4. Maplewood, MN rain garden
Source: Ohio Watershed Network

Medium to high density residential landscapes have impervious areas ranging from 60% - 100%. Commercial landscapes are similar, with impervious surfaces ranging from 80%-100%. Surface infiltration facilities can be used in some situations, although it becomes more difficult to mitigate the runoff as impervious areas increase. An example of multi-dwelling residential development using an infiltration basin is Buckman Heights, which is located within the Oak Basin. Built in 1998, the 4-story, 150-unit residential development contains two infiltration basins (1,600 square feet in total) in the entry courtyard that infiltrates all stormwater from the site up to ten-year storm events (figure 7.5).

Figure 7.5. Buckman Heights infiltration basin
Photo: Bureau of Environmental Services

For a site with 70% impervious surfaces and with soils of medium to high conductivity, using just under 10% of the lot for infiltration facilities can reduce the volume of runoff to 10% of annual rainfall. Once lot coverages reach 80% impervious surfaces, however, infiltration facilities become more difficult to implement, expensive to create, and do not perform as effectively (CH2MHill, 2002).

Figure 7.6. Epler Hall infiltration planter

For sites with extremely high impervious surface areas – some commercial sites and most industrial and employment-zoned sites – other strategies need to be employed to reduce runoff volumes. Vegetated stormwater planters are one strategy for infiltration or treating stormwater runoff. Figure 7.6 shows such an infiltration planter at Portland State University's Epler Hall, located adjacent to a student residence and associated plaza.

Figure 7.7. Ecotrust ecoroof

Extensive green roofs can reduce volumes to approximately 60%, with a reduction up to 35% with increased absorbent soils (intensive green roofs). Volume reduction depends significantly on the wetness or dryness of the climate. Green roofs work best during dry months where short storms can be detained and evapotranspirated through the vegetation. In the winter months, green roofs often perform more effectively for peak runoff rate reduction rather than significantly reducing volume. Sites with high building coverage should examine strategies that include re-use of water in the building (e.g. flushing toilets). In this climate, large cisterns are required to make it through the dry summer months, adding to the cost of the facilities (CH2MHill, 2002).

7.3. Street Strategy

Each street should infiltrate one inch of rainfall every 24 hours:

- Residential streets through green streets
- Industrial streets through catchment basins
- Additional infiltration on Sandy Boulevard, Burnside, Ankeny and Couch Streets

Figure 7.8. Street strategies

Since streets comprise 51% of the basin's impervious surfaces, generating design strategies for them is very important. In this proposal, we suggest retrofitting all streets to handle 1" of rainfall every 24 hours, with the exception of community-scale facilities, discussed below. The *Effectiveness of Stormwater Source Control* report indicates that 90% infiltration can be achieved on local roads with stormwater facilities 1 -2 meters (3.2-6.5 feet) in width (assuming medium to high infiltration capacity). On collector roads (11 meter or 36 foot-wide roadways), stormwater facilities perform similarly with the same width of facility (CH2MHill, 2002).

This renovation work can be accomplished in several ways, depending on the type of street. In the course of working on the Ankeny Street design, four design possibilities emerged as a means to integrate stormwater into the streetscape. These strategies are useful ways of thinking how to integrate stormwater design into other streets in the neighborshed. They are diagrammatically described below.

7.3.1. Insertion

In areas where mature trees exist in the planting strip, retrofitting the entire planting strip for a stormwater facility is not desirable because it would alter the trees' hydrological environment. However, in some cases, sections of the planting strip do not have trees and so provides an opportunity to *insert* a stormwater facility into the strip.

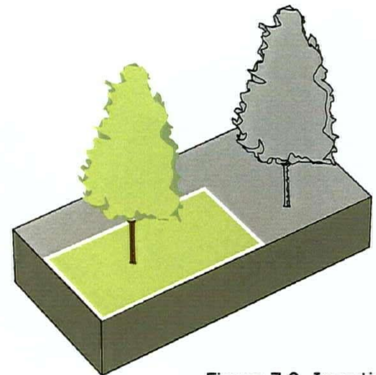


Figure 7.9. Insertion

7.3.2. Addition

Many planting strips in old Portland neighborhoods are too narrow to support stormwater infiltration functions. On local streets in particular, it may be appropriate to *add* a stormwater facility onto the street side of the planting strip. Where mature trees are present, retaining the existing curb will prevent disruption to tree roots and reduce costs of the project. A precedent for adding stormwater facilities to the side of street can be found in Portland's Siskiyou Green Street pilot project.

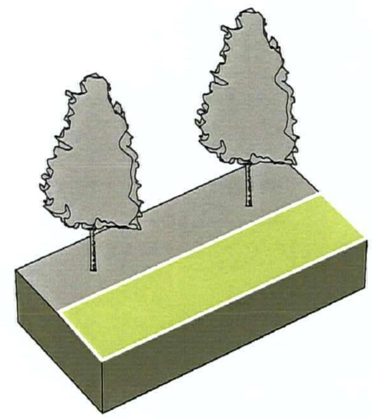


Figure 7.10. Addition

7.3.4. Reconstruction

Where no trees exist and where the planting strip is too narrow to support a stormwater facility, it may be appropriate to *reconstruct* the streetscape to accommodate stormwater facilities. Street dimensions can be altered to reduce the amount of roadway and increase the width of the planting strip. This makes the most sense on streets that require resurfacing and other street improvements.

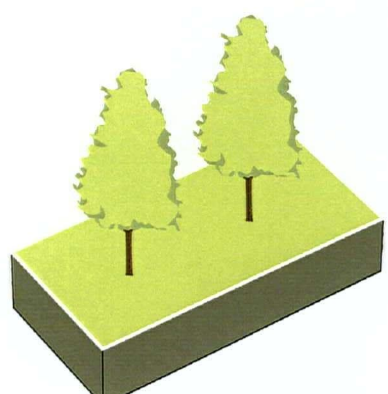


Figure 7.11. Reconstruction

7.3.5. Redevelopment

Public and private *redevelopment* projects offer more flexibility in redesigning streetscapes. In these projects, the scope of work is large enough to allow for more experimentation than the above strategies, which are most simple retrofits. An example of a redevelopment strategy is the Sandy Boulevard streetscape project, which provided an opportunity to integrate stormwater designs creatively into streetscapes and plazas.

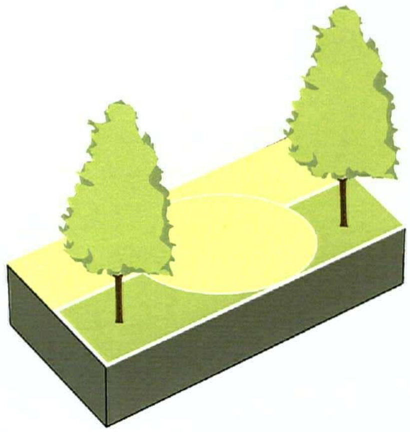


Figure 7.12. Redevelopment

Figure 7.13 is an example of an *addition* renovation from a BES project on Ankeny street. Also at right, figure 7.14, is an example of an *insertion* strategy on a downtown street in Portland.

Figure 7.13. Ankeny: Addition

Figure 7.14. PSU: Insertion

Industrial streets may not have the same space and greater probability of traffic impact to these facilities, requiring a different strategy. In these situations, catch basins may be the most appropriate facility for capturing stormwater. Catch basins can be adapted to provide infiltration by having holes in the bottom. Although all facilities need regular maintenance, it is especially important that these catch basins are cleaned at least once or twice a year to ensure the facility does not get clogged (Stormwater Manager's Resource Center, 2006).

7.4. Community-Scale Facilities

Community-scale facilities manage larger storm events to ensure that peak runoff rates are reduced and do not contribute to combined sewer overflows. Facilities are designed to infiltrate 1.89" of rainfall.

- Buckman Field
- Buckman Elementary School
- Main Streets: Sandy Boulevard and Burnside Street
- Bikeways: Ankeny Street and Couch Street

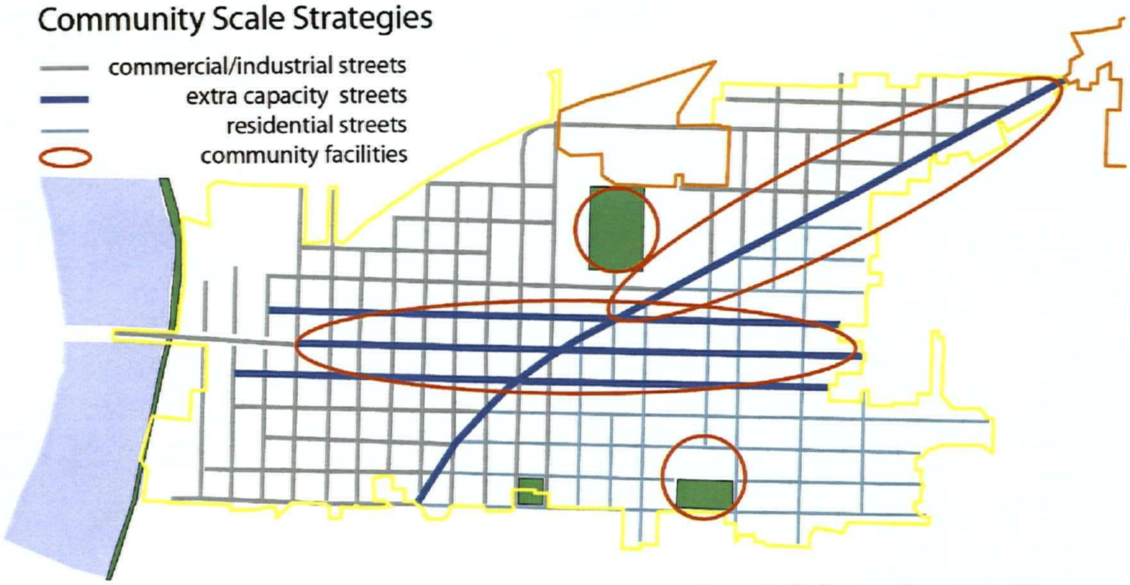


Figure 7.15. Community scale facilities

The location of community-scale facilities was based on their ability to meet multiple objectives. Their position in the watershed is such that they are able to capture "upstream" water sources, thus reducing the demand on the infrastructure system downstream. Buckman Field and the Buckman Elementary School field also provide two of the largest public spaces in the basin, with the singular purpose of providing active recreation. These spaces can be redesigned to incorporate stormwater infiltration as well. Designing green infrastructure systems along Main Streets and Bicycle Ways meet neighborhood objectives of improving the pedestrian and bicycle environment.

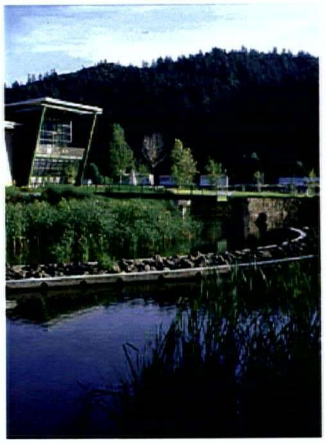


Figure 7.16. Water Pollution Control Laboratory

The Bureau of Environmental Service's (BES) Water Pollution Control Laboratory demonstrates how a community-scale facility can also be a neighborhood amenity.

The Sandy Boulevard Resurfacing and Streetscape Project Plan is an example of redesigning a streetscape to incorporate infiltration facilities. Instead of 1.89" of infiltration capacity, the Sandy Boulevard Plan has used 1.41" for infiltration targets, which is derived from the AFSO from the Oregon Department of Environmental Quality. As indicated in chapter 4, the current Sandy Plan provided an opportunity for BES to test stormwater facilities and the target numbers set are not related to watershed-scale plans or targets. Aside from testing stormwater facilities, a primary purpose of the stormwater designs is to improve the quality of the streetscape (Office of Transportation, 2005).

Other stormwater facilities could be strategically designed as pocket parks; strategic for both their placement in the neighborhood where parks are lacking and strategic in their placement in the watershed for greatest environmental benefit. The industrial district north of Sandy is likely the best location for such a facility. In addition to lacking a neighborhood park within a 5-minute walk, the area is located "upstream" in the pipeshed and any reduction of stormwater into the conventional piped system could result in downsized pipe size downstream. *The Beech/Essex and Oak Basins Predesign Report* suggested that the most beneficial location for source control locations were in this area.

7.5. Street Tree Strategy

Street trees play an important role in the green infrastructure plan by increasing vegetation, providing evapotranspiration services, and improving the livability of the neighborhood. Therefore, this plan recommends:

- Planting wide-canopy street trees to intercept and evapotranspirate rainwater, reduce the urban heat island effect, and provide cover to pedestrians
- Limbing up trees to 13 feet in industrial areas or other areas with space constraints

Existing Street Trees

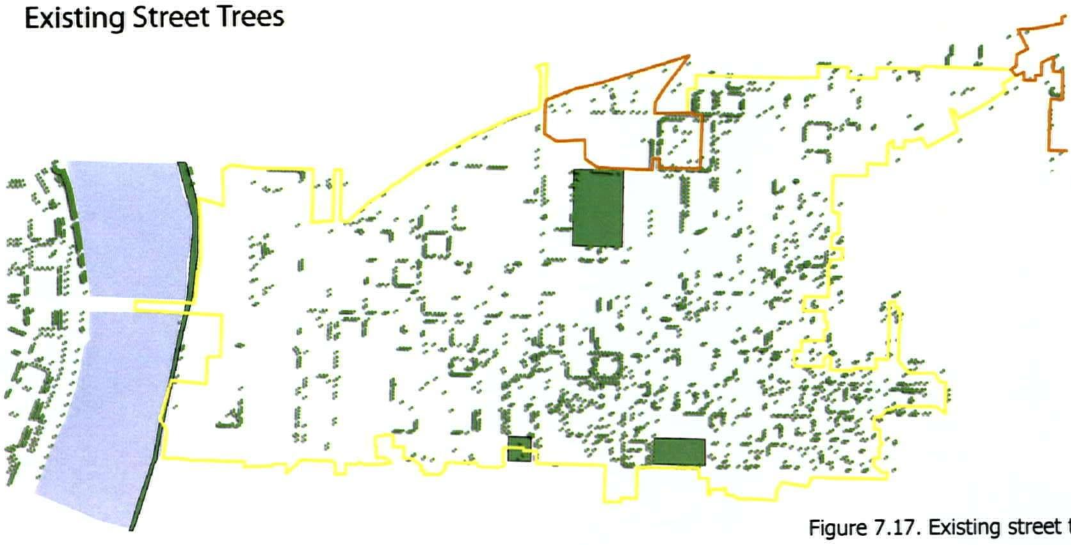


Figure 7.17. Existing street trees

The existing vegetative cover in the Oak Basin is quite low, at less than 5%. Figure 7.17 shows the existing distribution of street trees. With streets comprising approximately 38% of land area in the Oak Basin, planting street trees to reach 60% canopy coverage at maturity results in a basin-wide canopy cover of 22% (see figure 7.18). By increasing the planting of trees at Buckman Field, the Buckman Elementary School field, and encouraging tree planting on private property, the goal of 25% canopy coverage can be achieved. This level of vegetative cover would provide numerous benefits to the urban environment, from interception of rainfall and evapotranspiration to increased shade for pedestrians and visual relief to the built environment.

Proposed Street Trees

Figure 7.18. Proposed street trees

7.6 Conclusion

This green infrastructure plan is the result of applying the urban sustainability framework to the specific site conditions in the Oak Basin. It yields a basin-wide plan that meets the stormwater targets of infiltrating 90% of annual rainfall volumes through implementing various strategies appropriate to different land use types, creating community-scale detention facilities, and planting a significant amount of street trees. Removing 90% of the annual volume of stormwater as well as providing community-scale infiltration relieves the infrastructure system of handling all stormwater volumes unnecessarily. The creation of additional greenspace provides visual relief to the urban environment and makes watershed processes more visible. Securing a pocket park in the industrial area northeast of Sandy Boulevard would also benefit the basin, both from the ability to infiltrate more water and create a place of rest and relaxation for workers.

The green infrastructure plan has short-comings in two areas. First, the strategy for using large public spaces and certain streets for community-scale detention facilities is theoretically sound; however, this area was not given the time it deserved to delineate catchments and examining stormwater flows to see how these facilities would work on-the-ground. These facilities will work for community-scale detention, although they may not be most strategically sited for the benefit of the entire basin. Secondly, without knowing the impact of the removal of 90% of annual flows from the conventional infrastructure system, it is difficult to estimate how well the green infrastructure plan meets its infrastructure target.

8. Site Design

The next level of this thesis project is to illustrate how the green infrastructure plan operates at a site scale. The site area of Ankeny Street, a City Bikeway in the Oak Basin, is used to show how the principles for the green infrastructure plan are met at a site level. Site designs should illustrate how to mimic natural conditions by capturing 90% of annual volume, providing community-scale detention facilities and increasing vegetation. They should also help create a healthy, visible, and green infrastructure system. Also, moving from a basin-wide scale to a site design provides an opportunity to visualize how integrating stormwater into the landscape can improve neighborhood livability and foster sustainable urbanism.

8.1. Site Description

Ankeny Street is a City Bikeway that runs south of Burnside Street (see figure 8.1). Its function as a City Bikeway is not strongly supported by design; it is essentially an ordinary local neighborhood street.

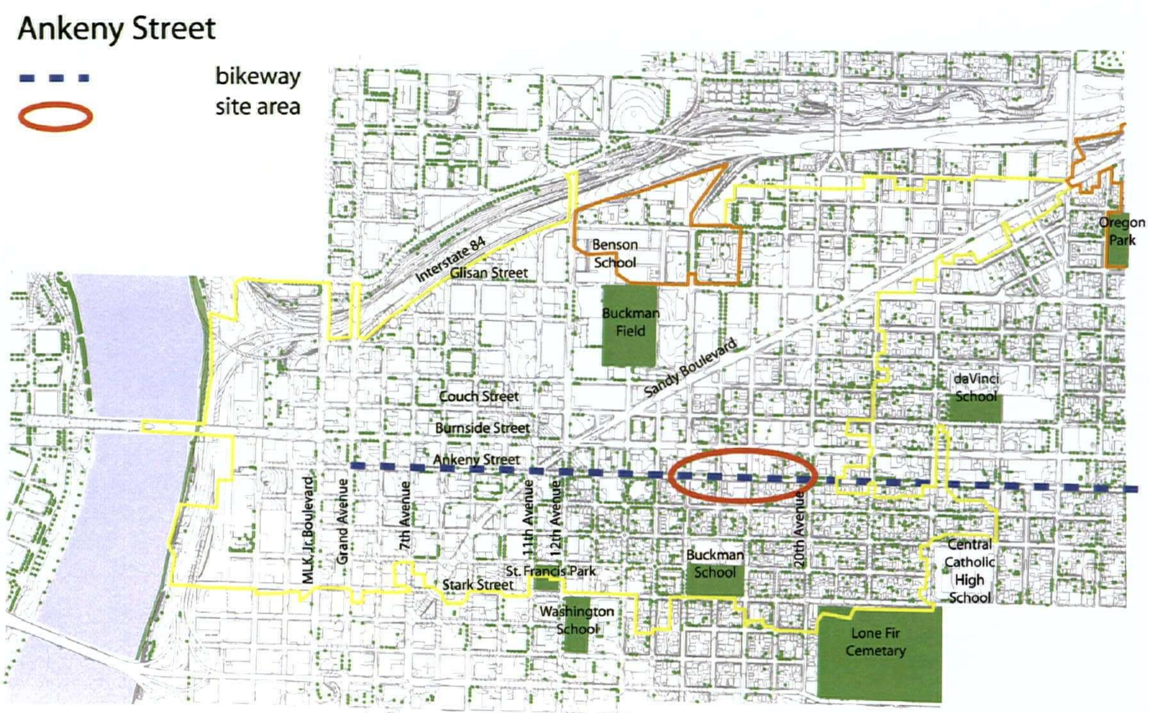


Figure 8.1. Ankeny Street context

As a bikeway, Ankeny Street traverses through the Central Eastside Industrial District through the Buckman Neighborhood, continuing beyond the boundaries of the Oak Basin into the Laurelhurst Neighborhood. Land uses adjacent to Ankeny Street change from industrial to mixed commercial and residential to strictly residential, once it crosses into Laurelhurst Neighborhood. Ankeny

Street has been designated as a community-scale facility in part due to its location in the watershed and in part because it is a City Bikeway, which would benefit from additional design work to improve its character and function as a Bikeway.

The site chosen for this exercise is SE Ankeny Street between 16th and 20th Avenues, which contains a mix of commercial and residential uses. Buildings are located close to the right-of-way; commercial uses may be on the property line or only a couple feet from the property line. The front yards of residential dwellings are generally five to ten feet from the property line. These front yards often have retaining walls, and houses sit a few feet above Ankeny Street, which had been cut deeply into the ground, typical of many Portland streets.

The mix of commercial and residential land uses is evident in the photo sheet (see Figures 8.9 and 8.10). Ankeny Street has a right-of-way of 60 feet, although it is not using the full extent of the right-of-way. The roadway width is 34 feet-wide, with 4 foot-wide planting strips and 6 foot-wide sidewalks on both sides of the street. In some portions of the street, mature street trees are crowded in the planting strip. In other portions of the streetscape, no street trees exist at all.

Figure 8-6 portrays the narrow planting strip, without street trees. However, figure 8.4 and 8.5 shows how large trees have come to maturity in planting strips of that width. Figure 8.5 shows the impacts of such narrow planting strips; the tree is growing out of the room provided for it. The generously-sized roadway, combined with the narrow planting strips, suggests an opportunity to increase the size of the planting strips for infiltration facilities.

Gathering space opportunities also present itself in this streetscape. City Bikes, a worker-owned cooperative, is located on the south side of Ankeny Street between 18th and 20th Avenues. People often gather there, working on their bicycles on the sidewalk just outside the building. At the corner of 20th Avenue and Ankeny is an underutilized commercial development. The potential to redevelop the site and the adjacent streetscape could create another gathering place for the neighborhood, and assist in traffic-calming.

Ankeny Block, 16th to 17th Avenues


Figure 8.2. North at 16th


Figure 8.3. Commercial, south side at 16th


Figure 8.4. Mature tree

Ankeny Block, 17th to 18th Avenues


Figure 8.5. Mature tree roots at 16th -17th


Figure 8.6. Planting strip at 17th


Figure 8.7. Residential, south at 17th


Figure 8.8. Commercial, north side, 17th


Figure 8.9. Commercial, Residential


Figure 8.10. Commercial, Residential

Ankeny Block, 20th Avenue


Figure 8.11. City Bikes, south side

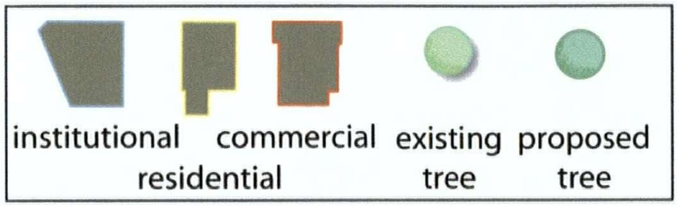

Figure 8.12. Residential, south side


Figure 8.13. Underused commercial

8.2. Ankeny Bikeway Plan

The plan below describes the general design for this portion of Ankeny Street (figure 8.14). The 60 foot-wide right-of-way has been reconfigured to reduce the amount of impervious surfaces and increase the amount of planting area.

Ankeny Street Plan



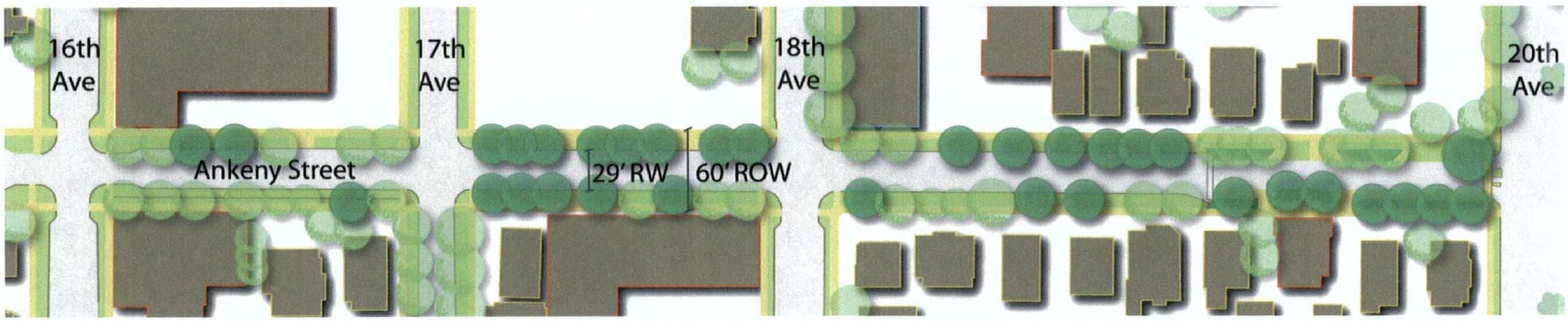
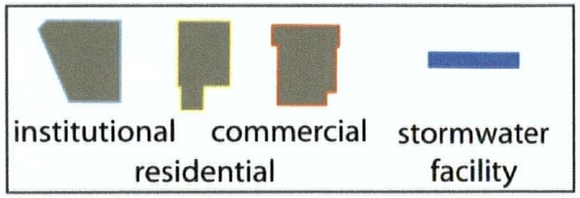


Figure 8.14. Ankeny Street plan

Currently Ankeny Street has a 34 foot-wide roadway and parking on both sides of the street. The proposed plan would reduce the road-way width to 29 feet, which suggests the dimensions appropriate for a queuing street. Narrowing the roadway will reduce the speed of traffic and would likely discourage unnecessary through-traffic on the street. The remainder of the roadway is transformed into planting strip or quasi-plaza space, much of which is available as stormwater facilities. Furthermore, this new green area is able to support new street trees. The number of street trees on this stretch of Ankeny Street increases from 29 to 63 – it more than doubles.

Ankeny Street Stormwater Plan



As a community-scale facility, Ankeny Street is meant to handle more than the one inch of stormwater per day as other streets. Ankeny Street is designed with extra infiltration capacity such that peak stormwater runoff is held on the site, thereby reducing flow and not contributing to combined sewer overflows. The simplified approach to stormwater sizing in the

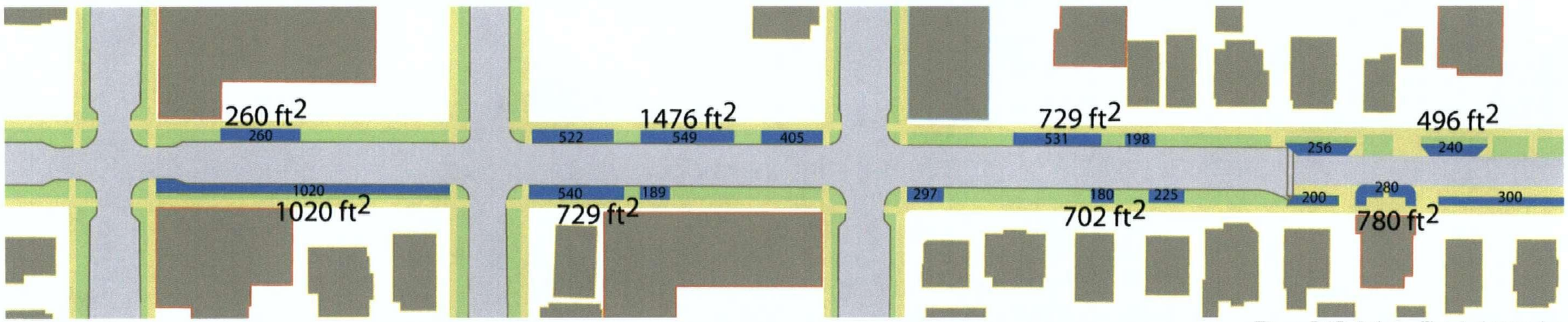


Figure 8.15. Ankeny Street stormwater

BES Stormwater Management Manual was using for estimating facility size. The simplified sizing method is based on the 25-year, 24-hour storm, which has more volume than the AFSO-ordered storm event, although slightly less the 25-year, 6-hour storm of 1.89." As a general rule, the area required for stormwater facilities is based on 6% of the impervious surface catchment area. The catchment area of each block is approximately 12,000 square feet (CH2MHill, 2004). Using a sizing factor of 6%, the area required to infiltrate this stormwater per block is 720 square feet. The average size of stormwater facilities of the four north blocks is 740 square feet and the average size of facilities on the south side of the street is 807 square (figure 8.15).

8.2.1. Ankeny Plan Evaluation

This site plan meets the principle *mimic natural conditions* through providing distributed stormwater infiltration facilities and increased street trees, which helps to meet the goals of reducing the volume and rate of runoff, as well as increasing vegetation. This plan also helps establish a legible infrastructure by returning water through more natural and visible hydrologic pathways. Because this site is sized to accommodate greater stormwater flows than a typical green street, it alleviates the strain of peak flows on the combined sewer system. Increasing the greenspace on the streetscape and providing neighborhood amenities (discussed below), this plan also improves neighborhood livability.

8.3. Intersection: SE Ankeny and 16th Avenue

The intersection of Ankeny Street with 16th Avenue is significant because 16th Avenue is a City Bikeway as well. In order to better mark these streets functions as City Bikeways, the intersection has been given a special design treatment. Curb extensions have been employed on all four corners and are planted. The intention is to slow traffic and create a distinct identity as a Bikeway. Seating has been provided, as well as a water fountain made from bicycle parts (figure 8.16) for passing bicyclists and pedestrians.

Figure 8.16. Bike fountain

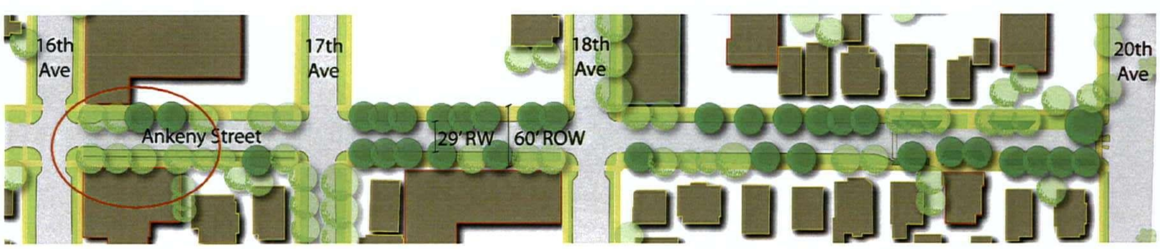


Figure 8.17. 16th Avenue context

The full 60 feet of right-of-way is being used; on the north side, an additional four feet from the back of the sidewalk to the property line has been designed for public use which is currently not being used as public space. The sidewalk has shifted north by four feet, which also shifts and expands the planting strip by four feet. The existing 34 foot-wide roadway has been narrowed to 20 feet wide at this intersection, and the planting strips increased in width on both sides of the street. The planting strips taper down so that the roadway width widens to 29 feet-wide, which re-establishes the ability to park on both sides of the street (see figure 8.19).

Figure 8.18. 16th Avenue elevation

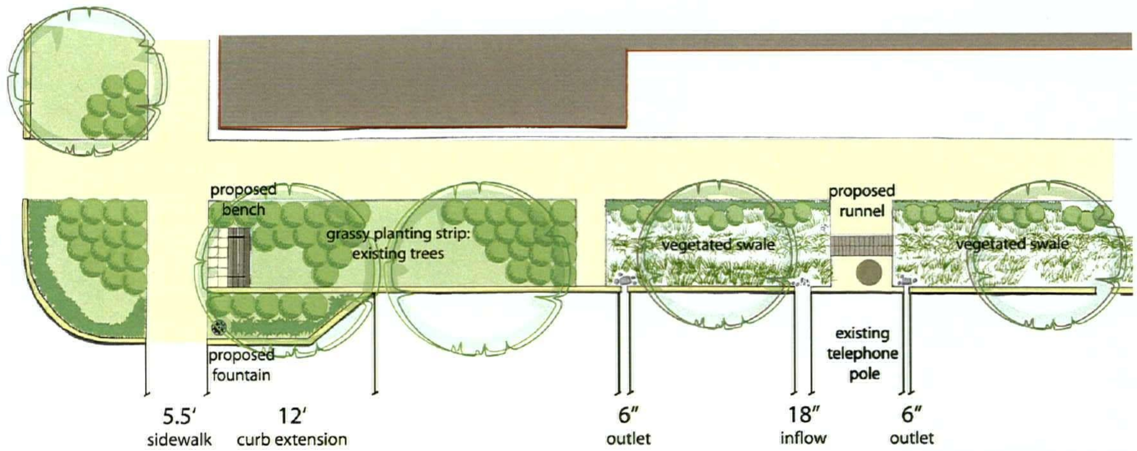


Figure 8.19. 16th Avenue plan

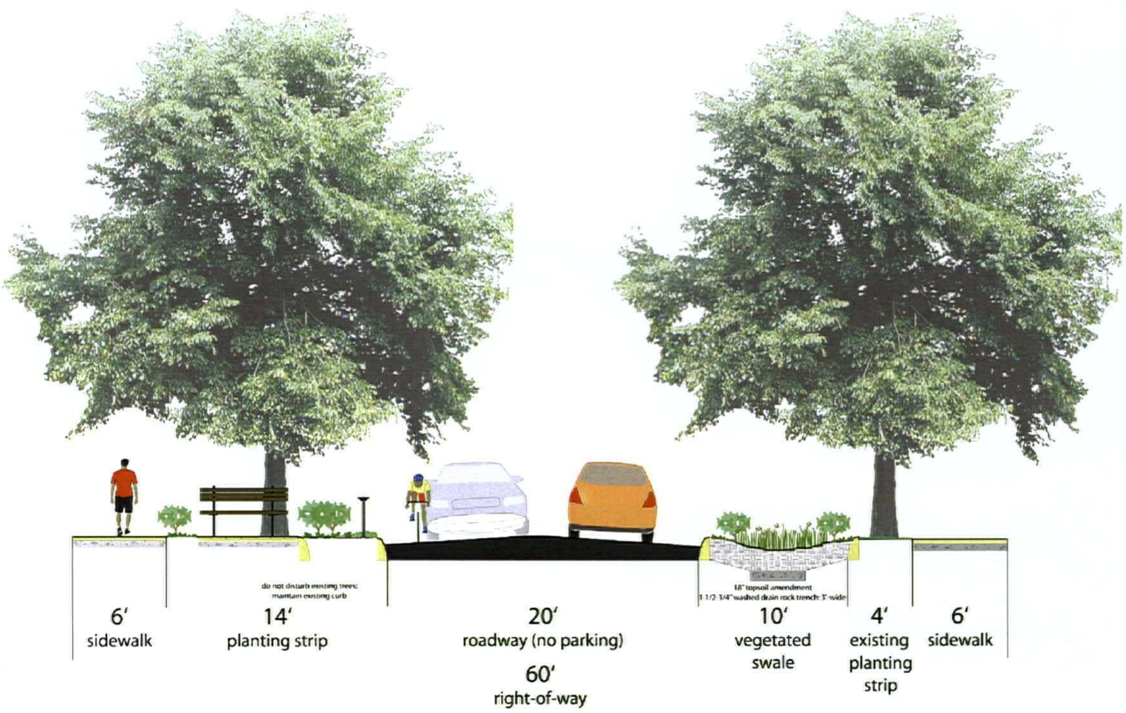


Figure 8.20. 16th Avenue section

On the north side of the street the curb has been retained where mature trees exist and new stormwater facilities have been located in areas where street trees are lacking. The plan view of this site (figure 8.19) indicates where the stormwater facility has been inserted into the planting strip on the north side of the street.

On the south side of the street, the planting strip has been extended through an addition of a stormwater facility; again, the existing curb is retained to protect existing trees. The Section (figure 8.20) indicates where the existing curb is retained on both sides of the street so that the tree roots will not be disturbed. The Section also illustrates how this street swale is constructed through the addition strategy on the south side of the street.

8.3.1. Evaluation

This block of Ankeny Street has a total of 1,280 square feet of stormwater facilities. The high number is possible primarily due to the addition of a 6-10 foot-wide stormwater facility along the south side of the street. Only three street trees were added, as this block contains a high number of existing mature trees. This site succeeds in infiltrating 90% of annual stormwater volumes, and will also assist with peak flows through extra capacity.

By surfacing the stormwater through the street swales, the system becomes more visible. The runnel on the north side of the street enables the water to flow on the surface, even though it is not possible to construct a swale in that location. In addition to the stormwater infrastructure, the transportation system has been made more transparent as well. Bicycle-oriented features such as the water fountain made from bicycle parts indicates that this street is a bicycle transportation route.

With the addition of street trees, a wider planting strip to buffer pedestrians from vehicular traffic and places for rest (i.e. benches), this portion of Ankeny Street better serves pedestrians and bicyclists. Furthermore it contributes to a greater amount of interstitial greenspace in a neighborhood that needs more vegetation.

8.4. Mid-street: SE Ankeny and 17^{th} Avenue


Figure 8.21. Stepping stones

The block between 17^{th} Avenue and 18^{th} Avenue is devoid of street trees entirely on the north side and partially lacking street trees on the south side, providing an opportunity to largely reconstruct the planting strips to accommodate stormwater and street trees. Again, the roadway has been reduced to 29 feet-wide instead of the existing 34 feet-wide. The plan view of this portion of the street describes the rhythm of the newly planted street trees and swales on the north side of the street (figure 8.25). Stepping stones have been provided to enable crossing of the swale. These stepping stones also serve another function as check dams. Set in gravel, these stones help slow the water and better enable it to infiltrate into the ground. The Section (figure 8.23) shows this conceptual check dam strategy and figure 8.21 is a precedent image that suggests the character of the stepping stone crossing.

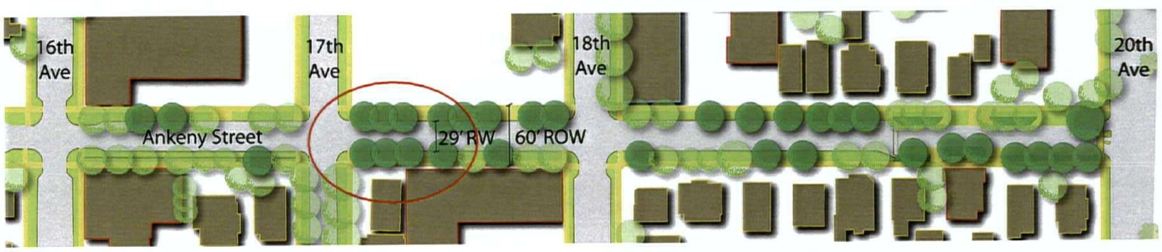


Figure 8.22. 17^{th} Avenue context

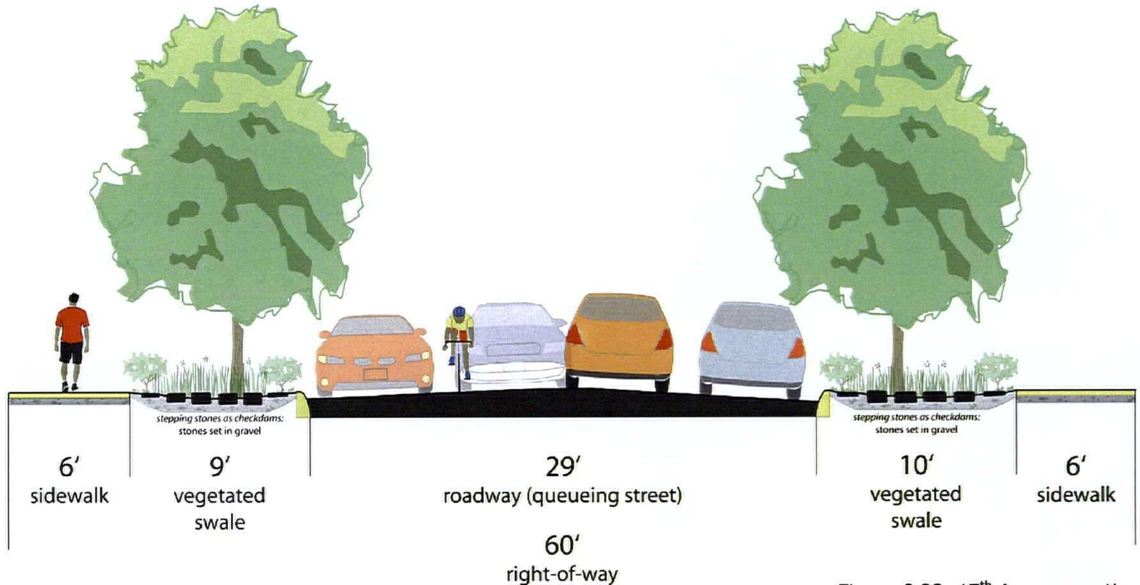


Figure 8.23. 17th Avenue section

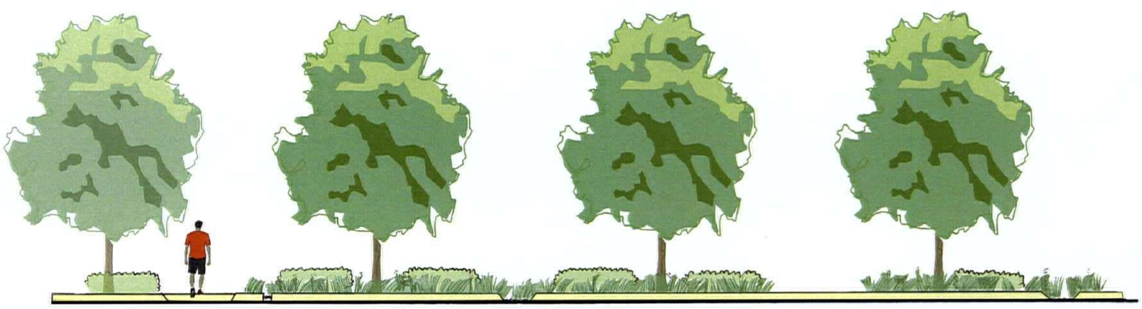


Figure 8.24. 17th Avenue elevation

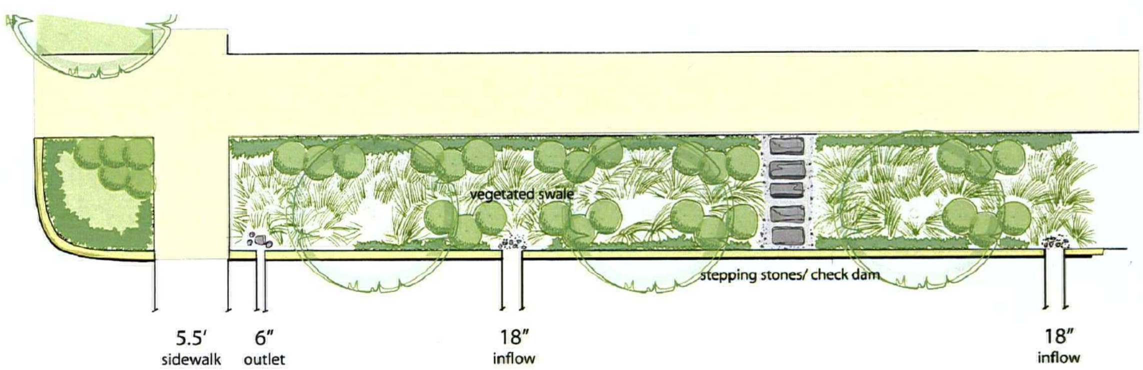


Figure 8.25. 17th Avenue plan

8.4.1 Evaluation

The stormwater facility square footage of 2,205 is made possible by the reconstruction of the north side of the street, which lacks street trees entirely. This block meets the green infrastructure target of providing infiltration capacity of 1.89." With the introduction of 13 new street trees, the character of the street is greatly improved. Crossing the swale via stepping stones is intended to be reminiscent of a stream-crossing.

8.5. Garden Street: SE Ankeny and 20th Avenue

The proposed design concept for this portion of Ankeny Street is a *garden street* where the experience of the streetscape is something between a plaza and a garden. This design employs a "woonerf" styled design which is to say that the street is designed to equalize the hierarchy among the pedestrian, bicycle and automobile. The term originated as a Dutch concept for traffic-calming, although it is similarly employed in Great Britain under the name "home zone." Figure 8.26 is an example of a home zone in England.

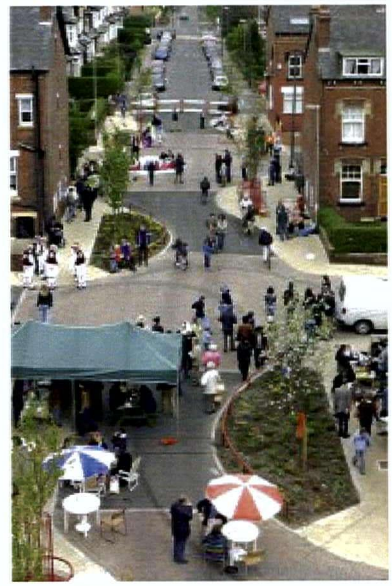


Figure 8.26. Home zone

The underutilized corner property at Burnside Street, Ankeny Street, and 20th Avenue is zoned for Storefront Commercial (CS), which is intended to encourage high site-coverage commercial development that addresses the street and pedestrian. This thesis assumes the site will be redeveloped, providing an opportunity to redesign not only the site but also the streetscape adjacent to it.

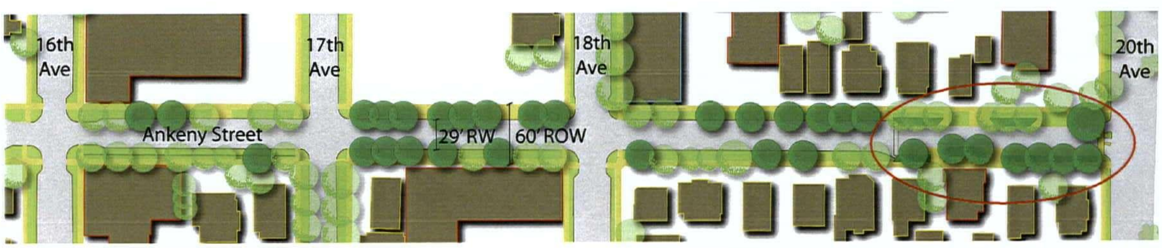


Figure 8.27. Garden street context

With its current designation as a City Bikeway, one of the few design interventions to support this designation is found at the intersection of 20th Avenue and Ankeny Street. A concrete curb-like barrier, painted yellow, minimizes through access on Ankeny Street, requiring automobile drivers to turn right and preventing them from moving forward or turning left. Curb cuts enable bicyclists to pass through the barrier and continue on Ankeny Street (see figure 8.28).

Figure 8.28. Existing barrier

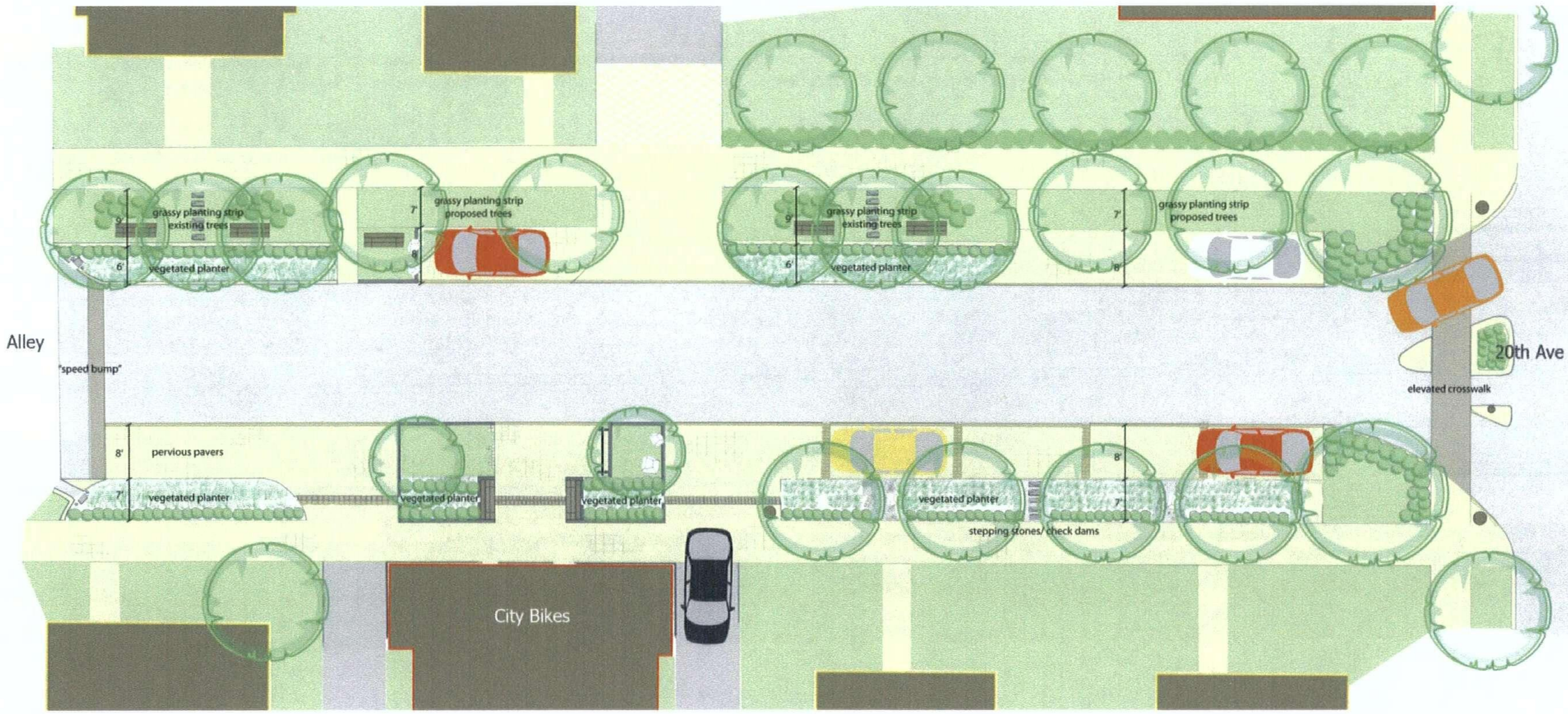


Figure 8.29. Garden street plan

This transition to the garden street begins at the alley where 19th Avenue would be (figures 8.29 and 8.34). The asphalt paving gently rises to meet the top of the curb, similar to a raised crosswalk (see precedent, figure 8.30). From this point forward to 20th Avenue, the asphalt travel lanes are at the same grade as the parking areas, planting areas, and pedestrian zones (common in woonerf designs). Although the travel lanes are straight, their edges are modulated by parking areas (surfaced with pervious pavers) and vegetated stormwater facilities. The effect is that the streetscape appears more serpentine, slowing down vehicular traffic (see also figure 8.34).

Figure 8.30. Elevated crosswalk

At 20th Avenue, the asphalt travel lanes descend six inches back to the regular roadway height, after passing an elevated crosswalk. The yellow concrete barrier in the center of 20th Avenue has been removed and a pedestrian refuge island (see precedent, figure 8.31), planted with shrubs, prevents cars from traveling straight across 20th Avenue.

Figure 8.31. Pedestrian refuge island

Pervious pavers have been selected for the sidewalks and parking areas. In addition to enabling rainwater to infiltrate to the ground below, they also contribute to a plaza aesthetic. Figure 8.32 is a photograph of a BES test site for pervious pavers. BES indicates that pervious pavers are only suitable for handling rainwater that falls onto them, and not as a strategy for receiving stormwater from other impervious surfaces (Bureau of Environmental Services, 2004). Since stormwater runoff from the asphalt travel lanes cannot be infiltrated via the pervious pavers, brick runnels have been provided to direct stormwater into planters. Figure 8.33 is a precedent image from Atelier Dreiseitl.

Figure 8.32. Pervious paving

Figure 8.33. Brick runnel

In order to better accommodate people gathering in front of City Bikes, a mini-plaza space has been created. Stormwater planters bookend the plaza's east and west sides, with benches facing each other to facilitate conversation. A small lawn area also exists for people to sit and talk. Currently, only one bicycle rack is located in front of City Bikes and a space has been carved out for additional bike parking.

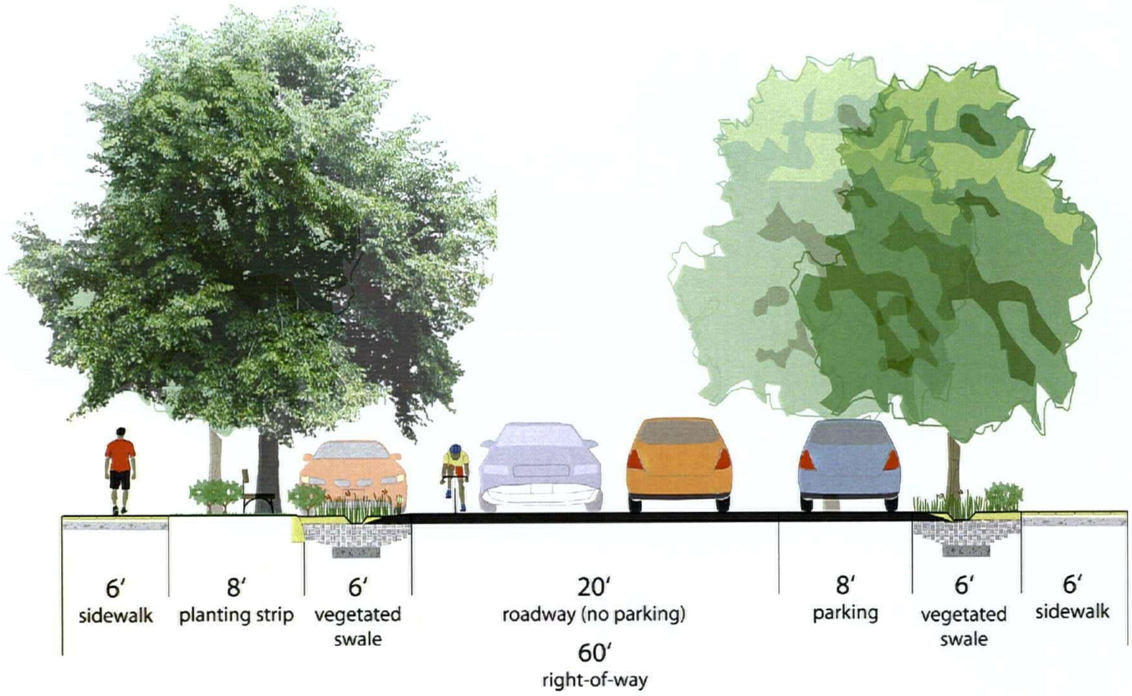


Figure 8.34. 19th Avenue section

8.5.1. Evaluation

Impervious surfaces have been minimized in this design through the narrowing of the roadway to 20 feet and by installing pervious pavers in the parking lanes and sidewalks. In addition to the stormwater reduction, the use of pervious pavers creates a more plaza-like experience. The use of pervious pavers has reduced the need and space available for vegetated stormwater facilities. The street has 2,687 square feet of stormwater facility for approximately 11,536 square feet of impervious area. The simplified sizing approach would require only 692 square feet of stormwater facilities. Twelve new trees are shown in the plan, which more than doubles the amount of street trees in this stretch of Ankeny Street.

8.6. Conclusion

In the Oak Basin, over half of impervious surfaces are comprised of streets, which was a strong influence on the decision to choose Ankeny Street for site-level designs. Re-designing streetscapes to accommodate stormwater management needs is an important component of a green infrastructure plan. The green infrastructure plan calls for all streets to stormwater facilities capable of infiltrating one inch of rainfall every 24 hours. In doing so, streets would be able to manage 90% of the rainfall events on-site.

Ankeny Street is one of a few streets in the Oak Basin that is designed to meet not only the 90% target, but also have extra infiltration capacity to assist with the detention of stormwater during times of peak flow (per the green infrastructure plan). While it is relatively easy to retrofit streets to manage one inch of stormwater through insertion or addition strategies, it becomes more difficult to get stormwater facilities in streets that are capable of handling larger storm events. Retrofitting streets to handle such large volumes may be cost-prohibitive. It is important to remember that the detention or extra infiltration capacity required by the green infrastructure plan also involved community-scale detention facilities at schools or parks.

In some places streets would only be able to support a minimal intervention and other streets might be able to support larger re-design efforts. Exploring the woonerf concept would be worthwhile to provide community gathering space, to create a pedestrian shopping mall, or as used a traffic-calming strategy. For these grander efforts, the streetscape could look less like a street and more like a plaza that accommodates automobile traffic. Furthermore, these efforts provide a greater opportunity to explore the use of rainwater as a form of place-making.

The additional greenspace from street trees and the wider planting strips would be a welcome improvement to this highly developed neighborhood. Street trees provide cover for pedestrians and create a more ambient urban environment. The more that streets become comfortable places for bicycles and pedestrians, the more likely it is that people will choose these forms of mobility. Greater pedestrian and bicycle activity not only creates more livable environments, but also reduces greenhouse gases and other noxious emissions. These strategies support the development of sustainable urbanism.

9. Conclusion

This project has created a framework for developing a green infrastructure plan in the Oak Basin. While this framework was built on the foundation of existing low-impact development or integrated stormwater management approaches, it was broadened to incorporate other urban sustainability principles. Although this framework has been applied in the Oak Basin, its potential application is broader. The higher-level principles will still hold in other contexts and particular regional conditions would dictate different goals and targets. It is hoped that this project might be a model for other jurisdictions who wish to employ integrated approaches.

9.1. Limitations

While this thesis has attempted to be as comprehensive as possible, it necessarily overlooks some aspects of work. These limitations are described below by system.

9.1.1. Watershed issues

In order to present a comprehensive analysis only a portion of an urban watershed was selected for the study. The Oak Basin is a sewerage basin within the Oak-Alder-Division watershed, as defined and characterized by the Bureau of Environmental Services (BES). The information on the pre-development conditions for the Oak Basin is taken from the watershed characterization work performed by BES for the Oak-Alder-Division watershed. The characteristics specific to the area of the Oak Basin were estimated. This has particular application in determining what the appropriate pre-development hydrological and vegetation conditions were.

This thesis focused on the hydrological component of watershed health issues. It did not directly address the other watershed benefits that result from stormwater management strategies – such as aquatic habitat protection or upland habitat connectivity. In part, the scope is dictated by the nature of the basin chosen, the Oak Basin, which calls for a hydrological focus more than other concerns. A comprehensive watershed plan would address not only the hydrology but also water quality, aquatic habitat, and terrestrial habitat. The *2005 Portland Watershed Management Plan* is an example of a plan that addresses the multidimensional aspects of watershed health.

9.1.2. Infrastructure issues

The Beech/Essex and Oak Basins Predesign Report (Predesign Report), prepared by CH2MHill for the City of Portland in June 2004, provided the base information for infrastructure conditions in the basin. For the most part, the analysis and findings from the Predesign Report are taken as a given. For example, it is assumed that the methodology for pipe grading, decisions for pipe replacement, and the final recommendation to upgrade size and condition of pipes in the basin are sound.

While every attempt was made to develop appropriate stormwater targets for the plan and sites, additional engineering work would have to be performed for a more accurate plan. To evaluate which strategies would meet stormwater targets, an engineering study calculating the removal of stormwater volumes would be required. Specific catchment areas and volumes were estimated in the site designs. To take this project to the next level, a more detailed approach to determine the exact volumes of water reaching the facility would be required.

As a result, it was difficult to tie back to the existing recommended infrastructure plan to determine how it might be modified. Speculation about how the plan could change was also complicated the fact that upgrades to the pipes are necessary regardless of innovative stormwater strategies, since the pipes are in such poor condition. Therefore, the incentive to develop alternative stormwater facilities is reduced because of the current investment in the piped system.

Another complicating factor is the combined sewer system, which is antagonistic to the concept of neighborsheds. Rather than managing stormwater on the basis of local catchment areas and finding localized solutions, the CSO "Big Pipe" has a number of basins in its catchment area, thereby negating the management value of localized boundaries. This artificial increase in pipe capacity is another disincentive to produce localized solutions. The CSO focuses the conversation on stormwater volumes in order to avoid CSO overflows into the Willamette. Water quality becomes a non-issue since stormwater is sent to a treatment facility for cleaning. If an area were separated, managing both volume and water quality becomes more important and generates incentives for the development of alternative stormwater facilities.

9.1.3. Neighborhood issues

While this thesis suggests that the neighborhood can be enriched through the greening and improved designs of neighborhood streets, additional layers of planning and design could take this concept further. For example, another layer of planning would have been to develop a green infrastructure system as a means to provide greater recreational opportunities and connectivity to urban parks. This thesis has only scratched the surface of the possibilities in demonstrating the value of a green and livable neighborhood.

Examining neighborhood redevelopment patterns more closely would yield a clearer understanding of how a green infrastructure plan would be implemented over time. While one can theoretically dictate that every site accept one inch of stormwater, the reality is that not every site will. Preliminary design work for this thesis included retrofitting an industrial site and a school site for a community detention facility. While technically challenging, it also proved to be difficult to make assumptions about the level of reinvestment participants would be willing to make to retrofit a facility. Would a school be willing to redesign its soccer field as a detention facility? Would they be willing to place an ecoroofs on the school itself? Technical challenges can be overcome, but at a cost.

Recognizing the difficulty in incentivizing participants to install stormwater facilities, some agencies are considering developing a stormwater marketplace. Much like carbon trading networks, a stormwater marketplace presumes that there will be buyers and sellers of stormwater credits. There may be those property owners unable or unwilling to provide stormwater facilities on-site and they would pay someone else to develop facilities on their site. The field of integrated stormwater management planning is emergent and its implementation strategies, such as a stormwater marketplace, as more emergent still.

9.1.4. Limitations summary

This thesis did not address a full range of livability and sustainability issues but instead focused on livability concerns as they relate to stormwater. Furthermore, this project was limited because integration occurred only to the extent of the author's personal knowledge and skills in those areas. Were this project undertaken in the "real world", a more in-depth analysis of the infrastructure system, watershed and livability concerns in the neighborhood would have occurred.

As an integrated and interdisciplinary exercise, it is imperative that engineering and planning work happen contemporaneously with the design process. A critical component of integrated stormwater management is working between disciplines. Planners, scientists, engineers and landscape architects should all be involved in the drafting of such a plan.

9.2. Cost

The cost of facilities may prove to be the most compelling argument for their implementation. Adequate cost/benefit analyses of these infrastructure plans that illustrate how they may save jurisdictions money over time may be the most useful strategy for promoting green infrastructure. However, calculating the cost of a green infrastructure plan is a complicated endeavor. Comparing the cost of stormwater facilities relative to the construction costs of conventional infrastructure systems captures only a fraction of the value the green infrastructure system provides. Integrating streetscape improvements (i.e. traffic-calming features) with stormwater facility construction is another potential cost savings. Furthermore, the ecosystem services stormwater facilities provide (improved air quality, reduced urban heat island effect) are challenging to quantify, although it is possible to do so. Although a worthy pursuit, estimating of the cost of this green infrastructure plan relative to the recommended infrastructure plan was out of the scope of this project.

9.3. Promotion and Acceptance

While integrated stormwater management planning and stormwater source control designs are becoming increasingly more popular, they are still considered experimental approaches and technologies in many places. Continued monitoring of facilities is required to ensure they are performing as expected and more pilot projects will continue to build confidence in these strategies.

However, technical feasibility is only one aspect of greater acceptance of stormwater facilities. Ultimately, the success of low-impact development strategies will likely rest of its ability to integrate into the landscape. The aesthetics of these facilities is a critical component to their success. This means not only the design of the facilities in the first place, using "cues to care" as described by Nassauer, but also in the ongoing maintenance to ensure that they continue to meet public expectations. As such, it is imperative that landscape architects get involved in creating stormwater solutions, both at a basin and site scale.

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Appendix A

Types of Stormwater Facilities

Strategies	Description
Interception	Catch rainwater before it comes into contact with an impervious surface[1,2]
Extensive green roofs (ecoroofs): *summer*	Shallow growing medium with vegetation on rooftops which intercepts rainwater, which would otherwise be covered in an impervious surface, and evapotranspirates the water in the summer months. Other benefits include a reduction in the urban heat island effect through evapotranspiration and reduced heating and cooling costs for the building itself, as the ecoroof provides additional insulation.
Trees	Trees capture and hold rainfall in leaves and branches, allowing for high levels of evaporation. They can reduce stormwater flow volumes by 35 percent or more for small storms. Trees also benefit water quality by filtering rainwater and holding soils in place, which is especially important along streambanks.[1]
Rainwater harvesting	Capture and store rainfall, generally for the purposes of reuse.
Rain barrels	Rain barrels operate by retaining a predetermined volume of rooftop runoff (i.e., they provide permanent storage for a design volume); an overflow pipe provides some detention beyond the retention capacity of the rain barrel.[5]
Cisterns	Stormwater runoff cisterns are roof water management devices that provide retention storage volume in underground storage tanks. On-lot storage with later reuse of stormwater also provides an opportunity for water conservation and the possibility of reducing water utility costs. [5]
Detention	Temporary storage system that holds water and releases it as a pre-determined rate.
Dry detention pond	Dry detention ponds are vegetation basins designed to fill during storm events and slowly release the water over a number of hours.[2]
Extended wet detention pond	Extended wet detention ponds are constructed with a permanent pool of water (called pool storage or dead storage) and additional storage above, which fills during storm events and releases water slowly over a number of hours.[2]
Detention vault	A detention vault is a structure that temporarily stores stormwater. Its primary function is to reduce peak discharge rates (high runoff flows resulting from large storms). The vault then releases the water over a few hours or sometimes a few days. By releasing the runoff over a longer time, the vault may help reduce erosion and in-stream scouring if used in the proper location in a watershed. Detention vaults can also remove pollutants by slowing the stormwater flow into and out of the vault, allowing solids to settle out and collect at the bottom.[1]
Ecoroofs: *winter*	Evapotranspiration on ecoroofs does not really occur during the winter months of the Pacific Northwest, making ecoroofs a strategy of detention more than interception since much of the water captured is eventually released.

Infiltration	A water volume management strategy that allows stormwater runoff to soak into the ground and may have water quality functions as well. The extent to which the runoff can infiltrate is directly linked to the site's soil structure, slope, and vegetated cover[2]
Drywell (sump)	A drywell is a precast pipe made from concrete, plastic, or other material that collects stormwater runoff and recharges it into the ground. The drywell is deeper than it is wide to facilitate water infiltration into the soil.[1]
Absorbent landscaping	Soil is the greatest water storage variable. With 6 inches of absorbent ground cover, rainwater is able to be absorbed, filtered, and returned to the groundwater table and provides interflow to streams. Additionally, other vegetation (trees and shrubs) provide rainwater interception and evapotranspiration functions.[3]
Infiltration swale	A strategy for water volume reduction and quality. Swales are designed to convey stormwater from impervious areas to a discharge point, meanwhile slowing and storing some water on the surface. Some water is also infiltrated.[3]
Vegetated basin/rain garden	These facilities are vegetated basins that are generally designed to stand-alone, without conveyance systems. On sites with poor soil hydraulic conductivity, the soils may be amended with rock and gravel to enhance infiltration.[3]
Pervious paving	Porous concrete, porous asphalt or interlocking pavers which allow water to infiltrate below. Some facilities are designed to allow full infiltration of water and others pipe some water away.[3] Porous pavement accepts only the rainfall that falls on it and should not be used to manage drainage from other areas.[1]
Infiltration trench	An infiltration trench is a shallow trench in permeable soil, backfilled with coarse stone and lined with filter fabric. The trench surface may be covered with grating, stone, sand, or a grassed cover with a surface inlet. The infiltration trench is designed to infiltrate stormwater into the ground within 48 hours of a storm event. This facility differs from a soakage trench because it lacks a sand filter and does not provide water quality treatment.[1]
Soakage trench	A soakage trench is designed to receive runoff from impervious areas, such as rooftops or parking lots, and allow the runoff to gradually seep into the underlying native soil. A soakage trench is backfilled with sand and coarse stone and lined with filter fabric to remove pollutants such as sediments, nutrients, floatable materials, oil, grease, and bacteria. The trench surface may be covered with grating, stone, sand, or a grassed cover with a surface outlet.[1]
Flow-through filtration	These facilities primarily have water quality functions rather than a water quantity function. They slow flow and treat stormwater by passing runoff through a pipe, treatment media, or vegetation.[1,2]
Sand filter	A sand filter is a layer of sand within a structure composed of stone, concrete, brick, wood, or other durable material. Pollutants are reduced as the stormwater filters through the sand, and flow is controlled by storing the water in a reservoir above the sand. A sand filter can be constructed in the ground or above grade. There are two filter options: lined (where the facility has an impervious bottom or is placed on an impervious surface) and infiltrating

	(where the facility allows filtered water to infiltrate into the ground). A sand filter is designed to drain within 2-3 hours after a storm event.[1]
Vegetated filter	Vegetated filter strips, or vegetated filters, are gently sloping areas used to filter, slow, and infiltrate stormwater flows. Stormwater enters the filter as sheet flow from an impervious surface or is converted to sheet flow using a flow spreader. Flow control is achieved using the relatively large surface area and for slopes greater than 5%, a generous proportion of check dams or berms. Pollutants are removed through filtration and sedimentation. Filters can be planted with a variety of trees, shrubs, and ground covers, including grasses. Sod may be used for single-family residential sites, where a simple downspout disconnection into lawn or landscaping is used.[2]
Flow-through planter	A flow-through planter box is typically made of wood or concrete and is designed with an impervious bottom or placed on an impervious surface. The box is filled with soil and plantings leaving water storage area up to the lip of the box. Pollutants are removed as the water filters through the soil, and flow control is obtained by storing the water in a reservoir above the soil. If properly lined, the planter can be used adjacent to a building.[1]
Other water quality facilities	These facilities rely on biological processes or vegetation to filter pollutants out of runoff.[1]
Constructed wetlands	Constructed treatment wetlands incorporate the natural functions of wetlands to help remove pollutants from stormwater. They use several processes: sedimentation (settling out soil particles), filtration, infiltration and biological uptake of pollutants.[1]
Wet pond	Wet ponds are constructed with a permanent pool of water (called pool storage or dead storage). Stormwater runoff enters the pond at one end and displaces water from the permanent pool. Pollutants are removed from stormwater through gravitational settling and biological processes. Suitable for pollution reduction, but additional facilities are required for volume control.[2]

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