A POLICY ROADMAP FOR LOW IMPACT DEVELOPMENT IN SPOKANE, WASHINGTON

By

ELISE LEBARRON

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of ELISE ODETTE LEBARRON find it satisfactory and recommend that it be accepted.

Chair

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Finally, a special thank you to my husband for giving me the space and time to accomplish this goal.

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Abstract

by Elise Odette LeBarron, MSLA
Washington State University
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Chair: William G. Hendrix

In the process of urban development, much of a site's existing vegetation may be removed and its soil compacted or covered with impervious roadways and buildings. These changes alter the hydrologic cycle, generating more runoff containing higher pollutant concentrations than occurred under pre-development conditions. Conventional stormwater management can exacerbate the situation by concentrating runoff into channels and pipes, which increases its flow rate. This generates runoff with greater erosive force that damages aquatic habitat. Stormwater pollutants also contribute to habitat degradation and water quality unsuitable for human uses.

As a result of urban stormwater's environmental impacts, federal and state environmental regulations now require more stringent stormwater controls. Technological approaches are an option, but are costly. Low impact development (LID) is an emerging, alternative. This approach strives to emulate a site's pre-development hydrologic function to prevent environmental impacts normally associated with urban runoff. In practice, LID combines natural hydrologic processes and site-specific design approaches to minimize runoff volume, rate, and pollutant concentrations.

Federal and state agencies actively encourage LID for stormwater management; unfortunately, several barriers may prevent successful LID implementation at the local level. Developers, contractors and inspectors may lack understanding and technical guidance for proper LID design, construction, and maintenance. Zoning and development codes may discourage or prohibit LID strategies.

Like other urban areas, Spokane, Washington is experiencing stormwater challenges and is obligated to address new stormwater regulations. This thesis investigates how LID can be implemented in the City of Spokane. An overview of LID establishes recommended design, construction, and maintenance approaches and reveals potential regulatory barriers. A review of federal and state environmental regulations and reports from local environmental investigations shows specific ways LID can support Spokane's regulatory and environmental concerns. Local policy, regulations, and technical guidance documents are then analyzed to determine if they support LID implementation. Where contradictions or weaknesses are identified, recommendations are offered that the City of Spokane should consider in its efforts to revise local stormwater management approaches.

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ABBEVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway Transportation Officials
ADT	Average Daily Trips (Auto)
AKART	All Known, Available and Reasonable methods of prevention, control, and Treatment
ASA	Aquifer Sensitive Area
ASCE	American Society of Civil Engineers
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CEC	Cation Exchange Capacity
CESCL	Certified Erosion and Sediment Control Lead
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
CHI	Center for Housing Innovation
CSO	Combined Sewer Overflow
CWA	Clean Water Act
CWP	Center for Watershed Protection
DNS	Determination of Nonsignificance
DO	Dissolved Oxygen
DPD	Department of Planning and Development
DSA	Development Sensitive Overlay
DU	Dwelling Unit
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESC	Erosions and Sediment Control
FAR	Floor Area Ratio
GMA	Growth Management Act (of Washington State)
GMA	Growth Management Act
HED	Hydroelectric Dam
HMP	Habitat Management Plan

HPA	Hydraulic Project Approval
IMP	Integrated Management Practices
ITE	Institute of Transportation Engineers
MEP	Maximum Extent Practicable
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
NAHB	National Association of Homebuilders
NH4-N	Ammonia-nitrogen
NOI	Notice of Infraction
NOV	Notice of Violation
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source
NRCS	Natural Resources Conservation Service
NRDC	Natural Resources Defense Council
NWS	National Weather Service
O&M	Operation and Maintenance
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PGC	Prince George's County
PGIS	Pollutant Generating Impervious Surface
PSAT	Puget Sound Action Team
PUD	Planned Unit Development
RA	Residential Agriculture
RCW	Revised Code of Washington
RHD	Residential High-Density
RMF	Residential Multi-Family
RSF	Residential Single-Family
RTF	Residential Two-Family
SAJB	Spokane Aquifer Joint Board

SCCD	Spokane County Conservation District
SCS	Soil Conservation Service
SDD	Special Drainage District
SDWA	Safe Drinking Water Act
SEA	Street Edge Alternatives
SEPA	State Environmental Protection Act
SMC	Spokane Municipal Code
SMP	Stormwater Management Program
SVRP	Spokane Valley-Rathdrum Prairie
SWMM	Stormwater Management Model
SWO	Stop Work Order
Tc	Time of Concentration
TKN	Total Kjeldlahl Nitrogen
TMDL	Total Maximum Daily Load
TPH	Total Petroleum Hydrocarbons
TR-55	Technical Release-55 (hydrologic model)
TSS	Total Suspended Sediments
UGB	Urban Growth Boundary
UIC	Underground Injection Control
ULI	Urban Land Institute
USFWS	US Fish and Wildlife Service
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WPCA	Water Pollution Control Act
WQS	Water Quality Standards
WRIA	Water Resource Inventory Area
WSDCTED	Washington State Department of Community, Trade, and Economic Development
WSDOE	Washington State Department of Ecology
WSU	Washington State University

Dedication

To all individuals seeking to make sustainable

development a reality in their communities

1 INTRODUCTION

…of all the infrastructure elements, the selected approach to stormwater management has the single greatest impact on the development's form, function, and likely quality of life.
(Stuart G. Walesh, consultant and author in Urbonas, 2001)

Urban stormwater is a significant part of watershed health. The Environmental Protection Ageny's (EPA) 1998 National Water Quality Inventory indicates that urban runoff is responsible for about 12 percent of impaired river miles, 15 percent of impaired lakes acres, 28 percent of impaired estuarine miles, and 62 percent of impaired ocean shoreline miles in the United States. (EPA, 2000). In addition, urban runoff volume and rate are associated with serious stream morphology and habitat impacts (Booth et al., 2002; Burton and Pitt, 2002; Dunne and Leopold, 1978).

While it is possible to reduce runoff impacts using purely technological means, this approach can be costly. In recent years another approach has emerged which is called low impact development or 'LID'. LID strives to maintain pre-development hydrologic function as measured by runoff volume, rate, and water quality (Hinman, 2005; Prince George's County [PGC], 1999a). Stuart Walesh might say LID's functional goals are achieved through the development's form; in other words, the site's design. The LID design approach:

- conserves open space and natural site features,
- minimizes site clearing and grading,
- incorporates compact design to minimize impervious surfaces, and
- uses distributed, on-site stormwater controls.

Some of the stormwater controls are vegetated with native or adapted species, providing both water quality and aesthetic enhancements. Between storms, larger controls that are vegetated with grasses may provide recreational space. Some proponents believe LID enhances quality of life by maintaining open space for active and passive recreational use, and providing landscape amenities that improve a development's experiential qualities (EPA, 2005b; PGC, 1999a; Prairie Crossing, 2001). If applied comprehensively on a regional scale, LID also has potential to support watershed health by:

- reducing urban sprawl (Arendt, 1996; EPA, 2005b),
- conserving large tracts of environmentally sensitive areas and habitat including wetlands, riparian areas, and forest land (Arendt, 1996; Hinman, 2005), and
- reducing stream channel and aquatic habitat impacts caused by poorly managed stormwater (Hinman, 2005; PGC, 1999a; Schueler, 1995; Schueler and Caraco, 2001).

The concept of LID is intriguing, but it is not a panacea. Environmental goals, cultural attitudes, and physical and climatic conditions may limit LID's application in a given location (Hinman, 2005; PGC, 1999a). Many appropriate LID strategies are difficult to implement because of inconsistent policies (Center for Watershed Protection [CWP], 1998). Several authors emphasize that poor design, construction, and maintenance can diminish LID's effectiveness (Greer, 2004; Hinman, 2005; Horner et al., 2001, Strecker, 2001). LID should not be overestimated. Low impact does not mean "no impact". Development alters site hydrology. Even with extensive LID design, it may be impossible to fully preserve a site's pre-development hydrology. Frequently, supplemental conventional stormwater management techniques are needed on-site or downstream.

These potential limitations, however, do not mean the LID concept should be abandoned. In Connecticut, studies comparing a LID-designed neighborhood to traditional neighborhood development demonstrated the LID design had lower runoff volume and peak flow rate (Hood et al., 2006). Downstream flood control measures were still necessary for larger storms, but the LID design experienced far fewer runoff-producing events. In Seattle, Washington, a LID retrofit demonstrated similar results. Runoff events from an urban neighborhood were reduced by 97 percent or more following LID installation (Horner et al., 2004). These examples demonstrate that LID can effectively reduce stormwater impacts.

Like most urban areas in the U.S., water quality in Spokane, Washington fails some regulatory criteria (Washington State Department of Ecology [WSDOE], 2006d). Spokane is obligated under the Clean Water Act (CWA) and the Washington State Environmental Policy Act (SEPA, Chapter 43.21C Revised Code of Washington [RCW]) to protect and improve local surface and groundwater quality. Current federal and state stormwater management guidelines strongly recommend LID. However, being a comparatively new approach it is not always clear how LID should be applied in a given location. Existing literature and case studies suggest the key to success is supportive local policy combined with selection of site-appropriate strategies that are properly designed, constructed, and maintained.

1.1 RESEARCH INTENT

The goal of this thesis is an assessment of how the City of Spokane can implement LID. LID strategies are not universal; rather, they should be applied to meet specific environmental needs and must also consider potential constraints. Environmental needs include both water and habitat quality. Several agencies in Spokane are conducting environmental studies addressing these issues. Available reports and accompanying recommendations will be reviewed to identify specific conditions LID can address.

Potential constraints include site physical conditions, as well as policies and regulations. Spokane is situated over a sole source aquifer whose water quality must be protected. Some LID strategies rely on stormwater infiltration. If selected, these strategies must supply sufficient stormwater quality treatment to protect groundwater quality. Treatment capacity may be limited in Spokane's sandy soils. Other parts of Spokane have shallow bedrock or shallow groundwater conditions that limit overall subsurface water storage capacity. These conditions will be evaluated to determine appropriate LID strategies.

LID attempts to limit stormwater runoff by minimizing impervious surfaces, protecting and enhancing natural areas, and capturing stormwater for on-site uses. Existing municipal codes may impose the following limitations:

- prohibit impervious surface minimization,
- provide inadequate natural areas protections, or
- limit stormwater management options.

Washington water laws may limit stormwater re-use. Local and state policies and regulations will be analyzed to determine how they support or hinder LID specific strategies. The study will conclude with a summary of recommendations and questions Spokane should address that will improve the city's ability to successfully implement LID.

1.2 RESEARCH QUESTIONS

The primary question of this thesis is:

1. In what ways should the City of Spokane consider changing its policies and regulations to implement LID?

Supporting questions include:

1. What is LID?
2. Which water quality regulations affect Spokane?
3. Which watershed health issues are influenced by the City of Spokane?
4. Which LID strategies can support Spokane's watershed health and regulatory compliance?
5. Do locally applicable policies and regulations support LID?

1.3 THESIS ORGANIZATION

This thesis is organized into six chapters including:

1. Introduction: an outline of the research problem, intent, and research questions.
2. Low Impact Development: a summary of urbanization's impact on hydrology, a description of seven typical LID measures with a general overview of policies that affect LID implementation.
3. Regulatory and Environmental Context for Stormwater Management in Spokane: a description of federal and state regulations affecting Spokane's stormwater management, local water quality, as well as aquatic and riparian habitat quality.

These elements in conjunction with Chapter 2 lay the foundation for subsequent local policy analysis.

4. Methodology: describes the analysis process used to understand if and how current policies and regulations support LID in Spokane.

5. Findings and Recommendations: a summary of how applicable policies and regulations promote or prohibit LID with suggestions that will better support LID.

6. Conclusion: includes final remarks, discusses limitations of the thesis study, and suggests questions for further research.

2 LOW IMPACT DEVELOPMENT

This chapter addresses research question 2: What is LID? Briefly, LID is a design approach that attempts to integrate *with* the existing landscape rather than imposing the most convenient design *onto* the landscape. Effective LID design requires thorough understanding of the project site's hydrology and how it may be altered through development. With this knowledge the designer develops a combination of conservation measures, building layouts, and stormwater controls that best mimic the site's pre-development hydrologic function. This chapter introduces stormwater hydrology and urbanization, then describes benefits, limitations, and approaches for seven LID measures. General policies and regulations that can support or hinder LID are discussed. LID development costs and marketability are also considered. The chapter concludes with examples of regulatory measures local jurisdictions are enacting to implement LID in their communities.

2.1 STORMWATER HYDROLOGY AND URBANIZATION

Figure 2.1-1 represents the hydrologic cycle for an undeveloped area. Rainfall is intercepted, flows overland, or infiltrates. Intercepted rainwater evaporates. Infiltrated rainwater is stored in soil or groundwater, or is transferred back to the atmosphere through evaporation and plant transpiration. Some of the stored subsurface water flows underground to surface streams and lakes. When soils are fully saturated, excess rainfall collects in shallow surface depressions (until it evaporates or infiltrates), or flows overland as runoff until it reaches a surface water body (Dunne and Leopold, 1978). For average rain events, areas with thick vegetative cover and good soil infiltration capacity will experience little surface runoff. In most locations, the 2-year return storm will generate sufficient surface and near subsurface runoff for streams to fill to the tops of their banks. A ‘return storm’ (or recurrence interval) is “the average interval in years between events equaling or exceeding a given magnitude” (Dunne and Leopold, 1978, p. 53). Storms larger than the 2-year return storm will cause streams to overtop banks, spreading water into the floodplain and potentially causing streambank erosion. Areas with poor ground cover and/or low infiltration capacity tend to experience more flooding and/or more stream channel erosion.

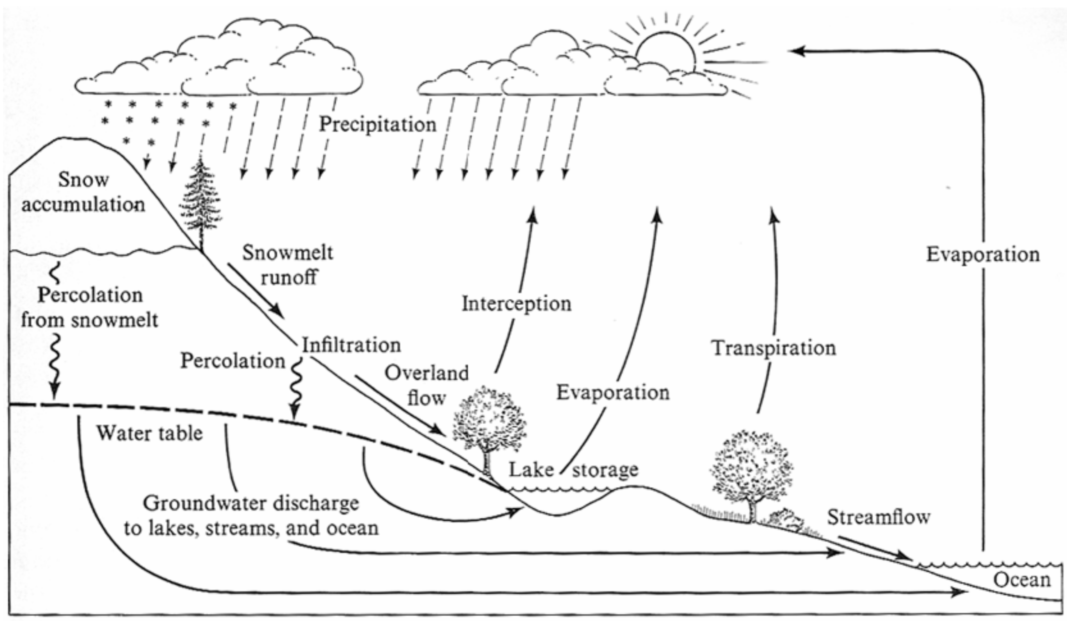

Figure 2.1-1. Diagram of hydrologic cycle prior to development (Source: Dunne and Leopold, 1978, p. 5).

Urbanization changes the hydrologic process. In typical urban development, the majority of vegetation is removed and much of the ground surface is regraded, eroded, or compacted. Buildings and pavement introduce impervious surfaces which block rainwater infiltration. With less infiltration, the frequency of runoff-producing events increases, accompanied by increasing total runoff volume, flow rate, and flow duration (Dunne and Leopold, 1978; Schueler, 2000a). See Figure 2.1-2. Stormwater also collects urban pollutants including sediments, fertilizers, pesticides, herbicides, petroleum hydrocarbons, and metals.

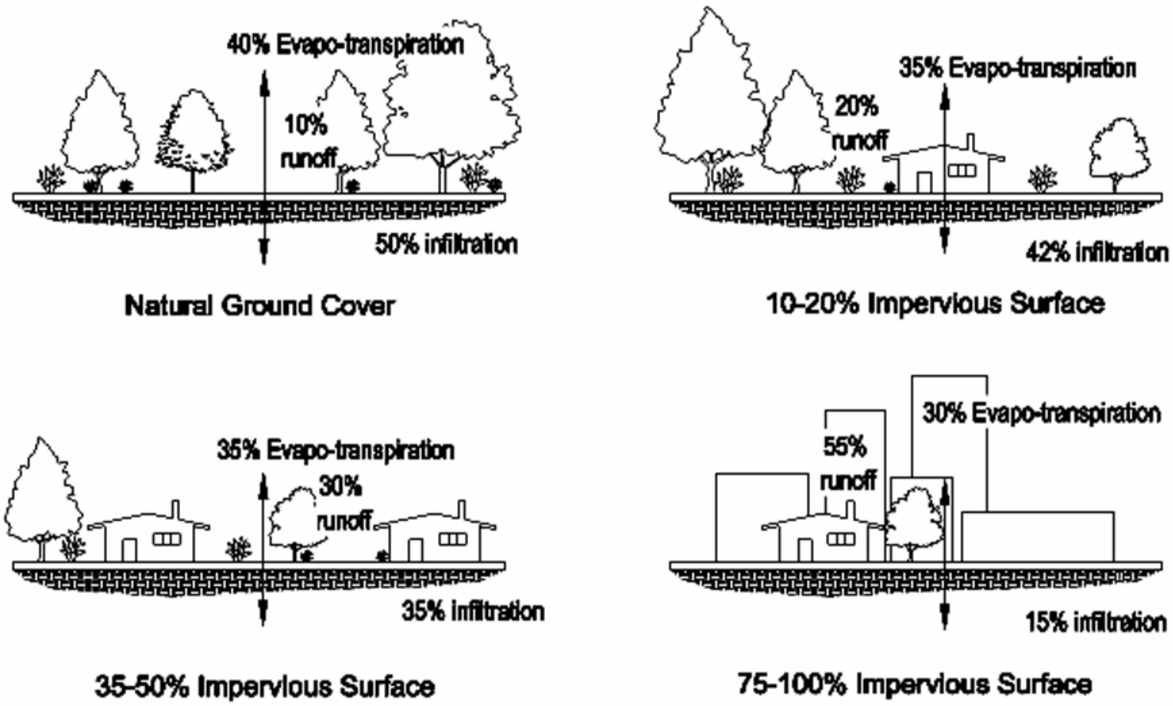

Figure 2.1-2. Changes in runoff and infiltration with increases in imperviousness (Source: Prince George's County [PGC], 1999, p. 2-9).

In most natural settings, the small amount of stormwater runoff that occurs is broadly dispersed throughout the environment. In many developed settings, stormwater flow is concentrated in gutters, drains, and sewers. In most cases the runoff is temporarily stored in detention facilities, where it is slowly released through pipes and culverts to receiving streams. Detention facilities control the stormwater runoff rate, but have little or no effect on total runoff volume and pollutant loads released to receiving streams. The high volume, concentrated flow causes streambed erosion, downstream flooding, channel instability, and habitat degradation (Burton and Pitt, 2002; Dunne and Leopold, 1978; Schueler, 2000a).

Regulations authorized by the CWA now require better urban stormwater controls. In many cases, technological controls may be sufficient to meet stormwater quality requirements but are costly. LID is an alternative that uses natural hydrologic processes and preventive measures, limiting the need for technological solutions.

2.2 LID OVERVIEW

Development alters site hydrology. LID combines land development and stormwater management strategies to mimic a site's predevelopment hydrologic function. The LID concept can be organized into seven measures, each supported by specific strategies (Table. 2.2-1).

Table 2.2-1. LID Measures[1]

Site Hydrology	a. Understand pre- and post-development runoff, emphasizing time of concentration (see Section 2.2.2), runoff volume and rate. b. Model and revise design alternatives as needed to maintain the site's potential post-development hydrologic function as near pre-development levels as possible.
Conservation	a. Preserve features with high hydrologic function: riparian areas, soils with high infiltration capacity, wooded areas, open space. b. Incorporate naturally existing drainage features into the design. c. Wherever possible, restore vegetation and soil condition for better hydrologic function.
Site Planning	a. Buffer conservation areas from developed areas b. Develop site configurations that minimize impervious surfaces.
Stormwater Controls	a. Distribute small stormwater controls throughout a site to manage stormwater as close to the source as possible. b. Create vegetated landscape features that slow and filter runoff flow, and infiltrate stormwater. Infiltration reduces site runoff and may be beneficial for groundwater recharge. c. Use LID stormwater controls in series increase their effectiveness and reduce reliance on conventional stormwater management practices. d. Incorporate stormwater controls in the landscape design to create functional and aesthetic amenities.
Construction Controls	a. Minimize clearing, soil compaction, and erosion. b. Use the smallest practical equipment. c. Time the construction sequence to minimize pieces of heavy equipment on site. d. Use construction site erosion control measures.
Maintenance	a. Establish a detailed maintenance program with enforceable guidelines.
Education	a. Educate construction workers, homeowners, maintenance contractors, and the general public about the goals, functions, and maintenance of LID projects and stormwater control elements.

1. Adapted from Hinman (2005) and PGC (1999a)

LID can be applied in both new and redevelopment projects at any development density from low-density rural sites, to high-density urban and commercial sites (Arendt, 1999; EPA, 2005a; Horner et al., 2002). Low-density and rural sites more easily accommodate conservation areas. Commercial and high-density development rely more on distributed stormwater controls to compensate for lost site hydrologic function. The following sections describe the seven LID measures in detail.

2.2.1 Stormwater Management Practices - Terminology

Before proceeding, some clarification of terminology will be helpful. Extant stormwater literature commonly uses the terms “best management practice” (BMP), “integrated management practice” (IMP), and “stormwater management practice” to describe stormwater control procedures or structures aimed at reducing receiving water impacts. The term BMP is used most frequently, especially by the EPA. In most cases this is a generic term that, depending on the context, refers to regulatory, structural, or behavioral stormwater management approaches. The term IMP refers to *structural* stormwater control systems associated with LID site design (Coffman, 2002; Hinman, 2005; PGC, 1999a). The term “stormwater management practice” seems to be interchangeable with BMP, but usually refers to structural stormwater controls.

The EPA categorizes stormwater management practices as structural and non-structural (EPA, 2005c):

- Non-structural practices are actions and site design approaches aimed at minimizing runoff and preventing pollutants from contacting runoff. Non-structural practices include:
    - regulatory controls - codes, ordinances, regulations, standards, rules;
    - land use practices – to prevent or control development of sensitive areas, and minimize total land area used for development; and

- source control practices – to prevent or reduce pollutants contacting runoff at the runoff-generating source. This includes voluntary pollution prevention practices such as limiting the use of lawn care chemicals and keeping chemicals from storm drains. Source control practices also include site design approaches aimed at minimizing impervious surfaces.

- Structural practices are engineered structures and systems designed to manage runoff by controlling stormwater volume, velocity, or flow duration. Some structural practices infiltrate stormwater for groundwater recharge. Structural practices may also reduce pollutant levels (treatment practices).

The EPA (2005c) states that the term “best” in “best management practices” can be misleading. A stormwater management approach that is “best” in one application may be entirely inappropriate in another. Nonetheless, BMP is a convenient abbreviation that is widely used by stormwater professionals and will be used in this document.

2.2.2 Site Hydrology

In the first stage of LID design, the site’s pre-development hydrology is analyzed to establish a baseline target for post-development hydrology. At each subsequent design stage, the design hydrology is analyzed and compared to the pre-development condition. The design is repeatedly refined with alterations to conservation areas, total impervious surface, and layout until it approaches the pre-development condition as closely as possible. The hydrology of the final site layout determines the number, size, type, and distribution of structural BMPs necessary to manage excess, post-development runoff. The quantity of runoff that must be managed varies from site to site. Local law usually establishes allowable runoff quantities. Within regulatory requirements and environmental and economic constraints, design and hydrologic modeling continue until the site plan has the best possible post-development hydrologic function.

Unless state or local regulations require another method, the EPA suggests *Low Impact Development Hydrologic Analysis* (PGC, 1999b) for hydrologic analysis of LID projects (EPA, 2005c). This analysis method is based on the Soil Conservation Service (SCS - now the Natural Resources Conservation Service or NRCS) Technical Release 55 (TR-55) model (NRCS, 1986). Both analysis methods use synthetic design storms, generalized site soil types and land covers to estimate the time of concentration (Tc), peak runoff rate, and storage volume needed to manage post-development runoff (PGC, 1999b). The synthetic design storm is based on local rainfall data (NRCS, 1997).

The Tc is the time it takes water to travel from the hydraulically most distant point in a watershed to reach the outlet (NRCS, 1997). Development typically reduces Tc by smoothing the land surface and increasing imperviousness, ultimately increasing peak runoff rate (PGC, 1999b). The optimum is for LID to maintain the pre-development Tc by (PGC, 1999b):

- minimizing disturbances to existing vegetation and pervious soils,
- increasing flow path lengths using swales and by conserving natural drainages,
- increasing surface vegetation ('roughness'),
- reducing grades in disturbed areas, and
- directing runoff to pervious areas.

In the ideal LID project, post-development runoff volume and rate would not exceed the pre-development condition for any storm condition. Unfortunately the ideal is often limited by site conditions (available land, subsurface storage conditions, and storm intensity), other project goals, and economics. When it is not possible to manage the post-development runoff volume to the pre-development level, PGC (1999a) recommends managing at least the first ½-inch, or "first flash" of runoff with retention BMPs (see Section 2.2.5.2). The first flash contains the highest concentration of pollutants. Retention BMPs allow stormwater to infiltrate, thereby reducing runoff volume and the total pollutant load released from the site. Pollutant load is the product of pollutant concentration and total runoff volume, expressed as a mass (in grams or kilograms). Retention BMPs also reduce Tc and peak flow rate, thereby reducing runoff pollutant transport capacity (PCG, 1999).

Retained runoff in LID projects is commonly called the water quality volume. Research reveals environmental impacts from as little as 10 percent of the annual runoff (Schueler, 1995). Stephens et al. (2002) suggest that the water quality volume should target 90 percent of annual runoff. In Washington, about 90 percent of the annual rainfall comes from events that are equivalent to the 6-month, 24-hour design storm (WSDOE, 2004a). The WSDOE (2004a) recommends that at the minimum, volume-based BMPs be sized to treat runoff from storms of this size. The WSDOE also encourages stormwater infiltration be used to the greatest possible extent.

High runoff rate can cause stream channel erosion. Often with significant impervious surface increases, volume control alone is not enough to prevent stream channel erosion (PGC, 1999a). Detention facilities that release excess runoff at pre-development rates are also needed. LID retention BMPs can be designed to provide both retention and detention capability.

The premise that maintaining pre-development Tc, runoff volume and rate helps protect water and habitat quality is seldom questioned in the literature. TR-55 and other SCS methods are comparatively easy to use and well accepted for stormwater system design. However, some question the appropriateness of these methods for LID application. *Low Impact Development Hydrologic Analysis* (PGC, 1999b) and TR-55 cannot analyze storage and flow relationships between sequential BMPs. The methods are also incapable of responding to time-dependent variations in storm intensity, duration, and soil moisture, as well as soil structure variations (Cheng et al., 2004; Strecker, 2001). Both authors argue that continuous modeling may provide more reliable results. There are also upper and lower limitations on the land area TR-55 can analyze, and the number and distribution of stormwater controls for a site (NRCS, 1986).

For complex sites with sequential stormwater controls, other models are more appropriate. Elliot and Trowsdale (2007) reviewed ten models that are used for LID. Due to the limitations mentioned above, TR-55 was not among them. In their review the authors considered how the models address:

- temporal resolution (event-based or continuous) and scale (month, day, second),
- catchment and drainage network representation,
- spatial resolution and scale,
- runoff generation,
- flow routing,
- stormwater pollution (contaminants, generation, transport, and treatment), and
- LID BMP representation (explicit or through manipulation of other parameters).

All the reviewed models demonstrated weaknesses, however, two provided the greatest range of uses for both preliminary and detailed site design: MOUSE™ (DHI, 2002 in Elliot and Trowsdale, 2007) and Stormwater Management Model (SWMM; Rossman, 2004 in Elliot and Trowsdale, 2007). Of the two, SWMM was able to represent the broadest range of LID BMPs.

SWMM can use SCS methods, but can also operate in continuous mode. SWMM has greater flexibility than TR-55 in representing land area and the number and distribution of stormwater controls. SWMM can also account for evaporative losses, snow accumulation and runoff, groundwater interactions. With calibration, SWMM can also estimate pollutant treatment.

2.2.3 Conservation

LID conservation measures seek to preserve site features that promote good hydrologic function. Important hydrologic features include (Hinman, 2005; PGC, 1999a):

- topography that disperses and slows runoff;
- existing drainages and areas that retain runoff for infiltration or evaporation;
- riparian areas, wetlands, wooded areas, mature forest or prairie lands which promote stormwater retention, infiltration, and evapotranspiration; and
- highly permeable soils.

Conservation areas are identified from local zoning and planning maps, during initial site visits, and during predevelopment hydrology analysis. Typically however, local soil maps provide limited information about distribution and infiltration capacity of site soils. Hinman (2005) recommends detailed soil characterization from test pits during initial site assessment. Depending on local and state requirements, qualified personnel may be required to inspect wetlands and riparian. These inspections will also determine the wetlands and riparian areas condition and determine the allowable type and extent of adjacent development. Required inspections are usually addressed in the development application process (Hinman, 2005). If potentially important hydrologic features are in poor condition, restoration efforts should be considered. If disturbing a site area could exacerbate runoff effects, it too should be conserved (PGC, 1999a). Such areas include steep slopes and areas with highly erosive soils.

Conservation areas preserve a portion of predevelopment hydrologic function, and reduce potential stormwater impacts by limiting the development envelop (CWP, 1998; Hinman, 2005; PGC, 1999a). A smaller developed area can result in less total impervious surface over the project site. The CWP (1998) summarizes the results of five studies comparing conventional and conservation or ‘open space’ designs. Compared to conventional designs, open space design reduced impervious cover by as much as 58 percent. The greatest gains were achieved for medium density conventional developments (1/2 to 1 acre lots) which were redesigned to include narrower streets and smaller lots (final size not specified). Smaller impervious surface reductions (approximately 7 percent) were gained with the redesign of a development beginning with 1/8 acre lots. The studies also estimated 8 to 66 percent reductions in stormwater runoff compared to conventional development, though part of this decrease may have resulted from structural BMPs. A comparison of developments using conventional and conservation approaches is shown in Figures 2.2-1 and 2.2-2.

Conservation on private lands is encouraged by federal, state, and local programs which protect wetlands and critical habitats (Randolph, 2004). With considerate design, conservation areas included in LID site designs can support conservation programs, as well as local policies promoting recreational open space. Adjacent developments should work together to incorporate contiguous open space (Arendt, 1996; Randolph, 2004; Smart Growth Network, 2002 and 2003). Many consumers also consider conservation areas a benefit to their neighborhood and quality of life, and are willing to trade off smaller lots for more open space (CWP, 1998; Lehner et al., 1999; Prairie Crossing, 2001; EPA, n.d.d).

Figure 2.2-1. Example of a low density residential development: conventional design (left), conservation design (right) (Source: Arendt, 1996, pp. 78, 82)

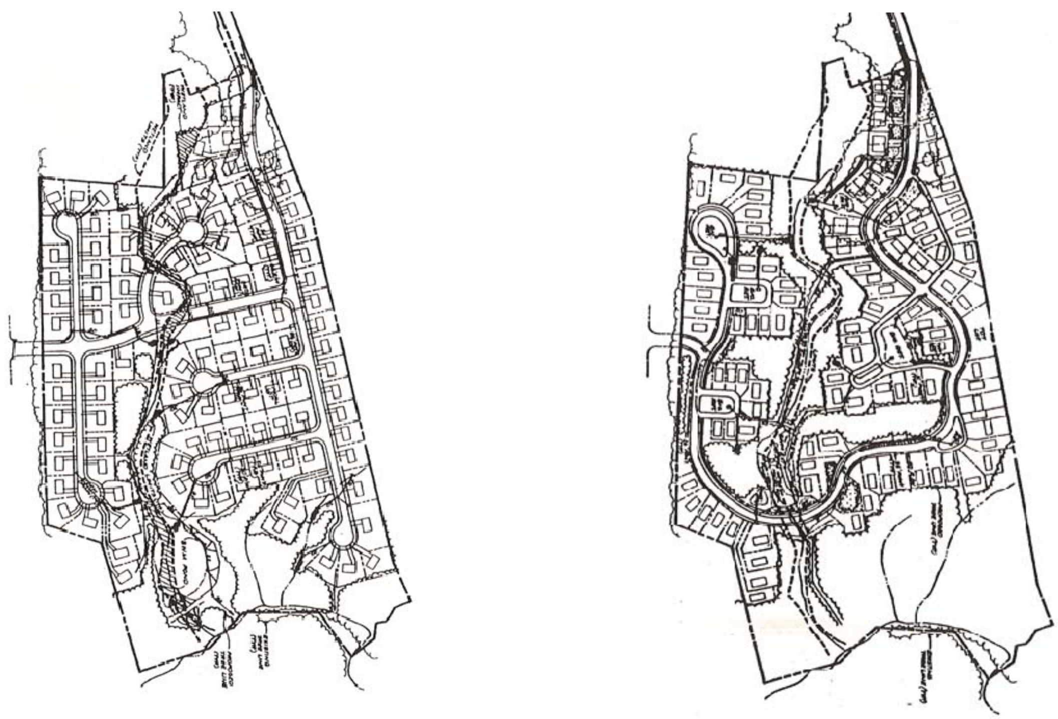

Figure 2.2-2. Example of a medium density residential development: conventional design (left), conservation design (right) (Source: Caraco et al., 1998, pp. 18-19)

There are drawbacks and potential roadblocks to conservation design. For example, the approach is impractical for single-family, detached housing at development densities requiring 6 or more dwelling units per acre (Hinman, 2005; EPA, 2005b). If local development policies or market conditions do not favor flexible zoning and housing options, the development will need to place higher emphasis on voluntary pollution prevention and structural BMPs for stormwater management. Jurisdictions must be careful of policies that result in extra permitting as these may discourage conservation design approaches (CWP, 1998; EPA, 2005b; Smart Growth Network, 2002). Incentives including density bonuses or expedited permitting may also be useful in encouraging conservation development.

2.2.4 Site planning

Once predevelopment hydrology is characterized and conservation areas delineated, site planning begins. Important considerations at this stage of the design process include:

- buffers to protect conservation areas from developed areas,
- site configurations that minimize impervious surface; and
- site configurations that maximize views onto open space and provide alternative transportation pathways for pedestrians and bicyclists.

2.2.4.1 Buffer Zones

Vegetated buffer separate conservation areas from developed areas, and protect conservation areas from runoff effects. Buffers reduce stormwater impacts by stabilizing soil, preventing erosion, and filtering suspended solids, nutrients, and toxic substances, and promoting a degree of infiltration and evapotranspiration (Coffman, 2002; PGC, 1999a; Mitchell, 2002; Schueler, 2000b). Hinman (2005) recommends using the best available science to determine appropriate buffer widths. The best available science references in Washington State include Washington State Department of Community, Trade, and Economic Development [WSDCTED] (2002), Granger et. al. (2005), Knutson and Naef, (1997), and Sheldon et al. (2005).

For unrestricted runoff flow into a buffer, Schueler (2000b) recommends limiting runoff from pervious areas to 75 feet and 150 feet from impervious areas. Runoff entering and moving through buffers should be maintained as sheet flow. This will reduce its erosive force and provide the greatest potential for pollutant removal. Use of a level spreader causes runoff to enter the buffer as sheet flow. See Figure 2.2-3.

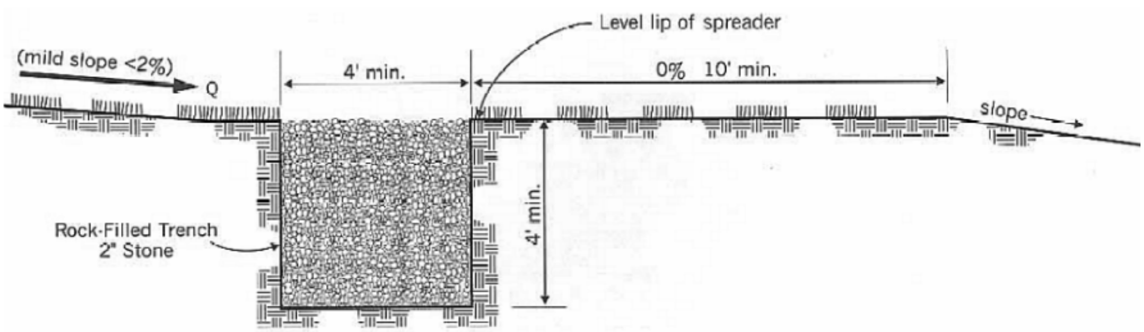

Figure 2.2-3. Section of a typical level spreader (Source: National Association of Homebuilders [NAHB], 2003, p. 39)

Schueler (2000b) recommends a three-zone buffer system with streamside, middle, and outer zones. The streamside and middle zones protect aquatic system ecology, and encompass the 100-year floodplain, wetlands, and steep slopes. Land use in the streamside zone is limited to foothpaths, and if necessary, a few utility or road crossings and stormwater channels. The middle zone allows more recreational uses and stormwater practices. The outer zone is the “buffer’s buffer”, extending from the outer edge of the middle zone to the nearest structure. Although turf grass is allowed in this area, native vegetation is encouraged to improve the effectiveness of the entire buffer. Local and regional plant restoration guidelines should be consulted for plant selection and installation. The Washington State University Extension website Washington's Water (http://wawater.wsu.edu/FocusAreas/Environmental%20Restoration.htm) provides an extensive list of plant restoration publications appropriate in Washington State.

2.2.4.2 Minimizing Imperviousness

Imperviousness is any barrier that prevents stormwater infiltration into the soil. Roadways, parking areas, and buildings are the most common types of impervious surface. Compaction reduces soil permeability, causing more runoff than uncompacted soils. If all impervious and low-permeability surfaces drain to the curb and gutter system, the development's "effective' impervious area is increased. The next several sections describe alternatives to conventional development practices aimed at reducing total and effective impervious surfaces.

2.2.4.2.1 Roadways

Roadways and parking areas account for the majority of impervious surfaces and pollutant loads in urban settings (Arnold and Gibbons, 1996; City of Olympia, 1995; Schueler, 2000). Part of the problem stems from municipal residential street standards requiring wide roadways (commonly 36 feet or wider), and long frontages (75 feet or longer to accommodate 2 to 2.5 street parking spaces for each lot) (CWP, 1998; Fader, 2000; Hinman, 2005). Side yard setbacks can increase the distance between houses, and ultimately, roads lengths. In addition, typical parking ratio requirements are excessive for single-family residential areas, shopping centers, and medical offices (EPA, 2005b).

2.2.4.2.1.1 Roadway Length

Residential road networks commonly create unnecessary imperviousness. The two most common networks in the U.S. are the traditional urban grid and the contemporary suburban curvilinear network (‘loops and lollipops’) (Ewing, 1996). See Figure 2.2-4. The grid pattern is the most efficient for auto traffic, which promotes smooth, dispersed flows with few backups. With long streets and low interconnectivity, the suburban network keeps traffic volumes low by discouraging all but local auto traffic. The CWP (1998) estimates the grid pattern requires 20 to 25 percent more street length than the curvilinear pattern. Both layouts create excess total roadway area where building codes require wide streets with wide frontages.

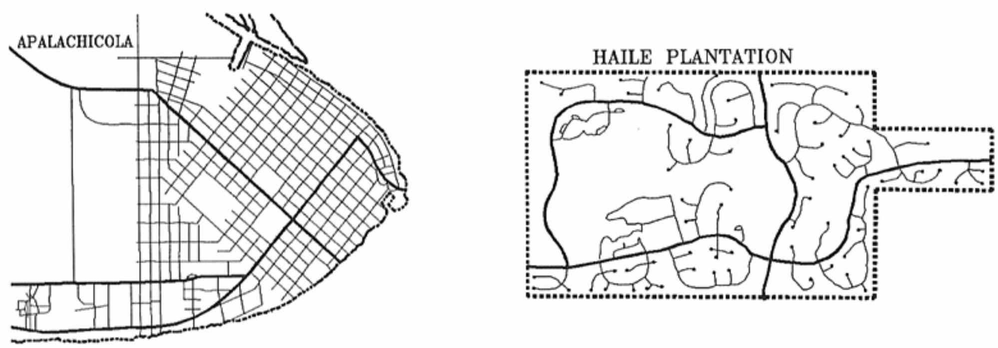

Figure 2.2-4. Common road networks: traditional urban grid (left), suburban ‘loops and lollipops’ (right) (Source: Ewing, 1996, p. 55)

However, both the grid and curvilinear approaches offer some potential environmental advantages. With high interconnectivity, the grid network may increase pedestrian and public transit access, while reducing personal auto travel and associated stormwater pollution (Ewing, 1996; Center for Housing Innovation [CHI], 2000). The curvilinear network can more easily bypass natural features and reduce excavation work, but discourages pedestrian travel and increases personal auto travel. The urban grid is a good system when local building codes don’t encourage excess imperviousness. Another promising alternative is the hybrid road network which combines a traditional network with curved and looping streets (CHI, 2000; CWP, 1998; Ewing, 1996; Fader, 2000; Hinman, 2005). See Figure 2.2-5. Both systems accommodate open space and include alternative pedestrian paths. Loop roads containing vegetated stormwater infiltration areas in the center replace cul-de-sacs. The loop configuration assures emergency vehicle access and eliminates large areas of otherwise unused paving typical in cul-de-sacs. The book Density by Design (Fader, 2000) contains several case study examples of urban grids and hybrid developments. CHI (2000) performed a detailed study that compared environmental benefits and capital costs of two developments types: the conventional suburban with loops and lollipops, and the hybrid (two developments). The results show the hybrid developments require less impervious surface and can require less capital expenditure per lot than a conventional suburban development.

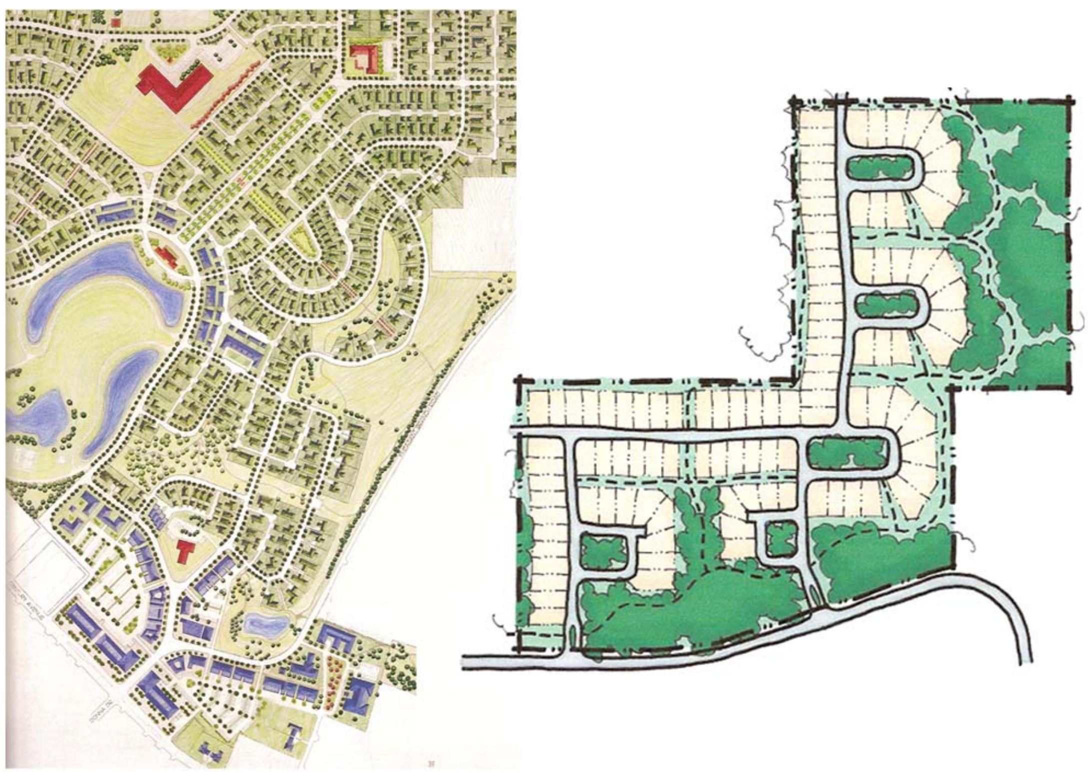

Figure 2.2-5. Two examples of hybrid road networks (Sources: Right, Fader, 2000, p. 23; Left, AHBL Engineering in Hinman, 2005, p. 31)

Smaller lots reduce road lengths, but narrow lots can be awkward for traditional single-family housing. With flexible zoning codes there are several alternative concepts for single-family housing on narrow lots.

- Zero-lot line development (Figure 2.2-6). One side of the house is built on the side yard property line. This configuration makes best use of the opposite side yard. Fire code usually prohibits windows on the lot-line wall. (Arendt, 1996; Fader, 2000; Hinman, 2005)
- Passive use easement zoning (Figure 2.2-6). One wall is placed 3 to 5 feet from the side property line. An easement allows the adjoining neighbor to passively use the setback area. Windows are allowed on all walls, however, for more privacy windows should be positioned high on the wall. (Fader, 2000)
- Cottage housing. Small, detached units (typically 1,000 square feet or smaller) are clustered onto small lots. A courtyard-style development in Langley, Washington (Figure 2.2-7) has been very popular and has stimulated the development of similar projects. (Smart Growth Network, 2003)
- Air space condominiums. There are no minimum lot sizes; instead, buyers purchase the dwelling and some additional yard area (Hinman, 2005). The remainder of the property is held and managed by a homeowners’ association.

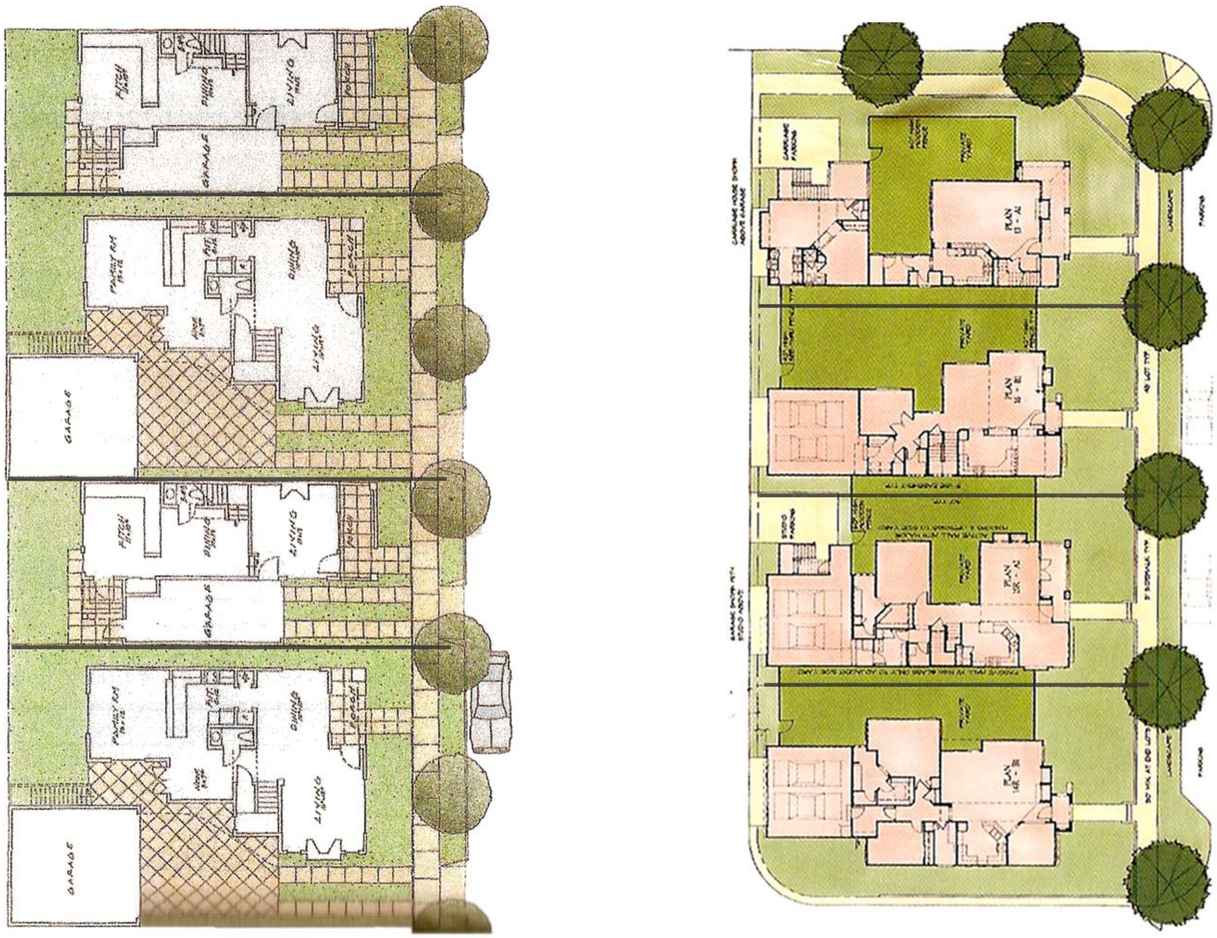

Figure 2.2-6. Example of a zero-lot line development (left), and a passive use easement development (right) (Sources: Right, Fader, 2000, p. 7)

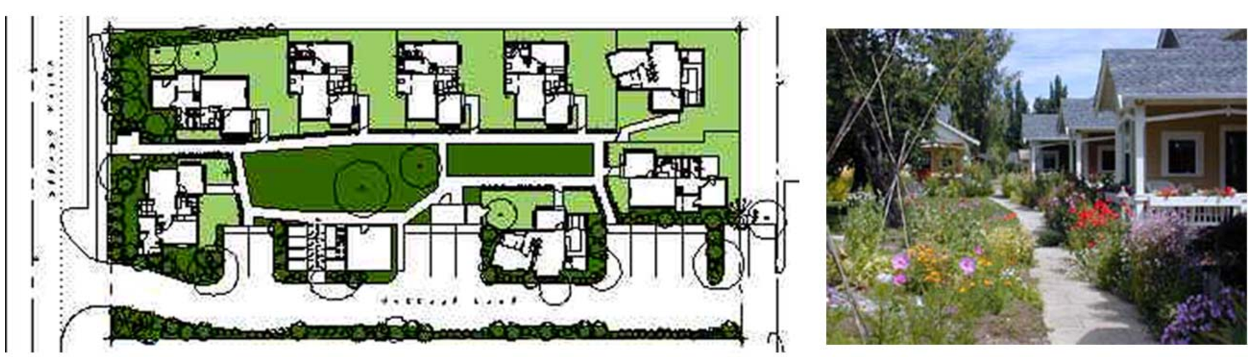

Figure 2.2-7. Cottage development, Langley, Washington (Source: both images, http://www.cottagecompany.com/cctsc.html)

These concepts are appropriate for any density, but the LID literature stresses they are most useful in areas where zoning codes allow mixed lots sizes and shapes, or mixed-use developments. Additional examples of these applications are shown in CWP (1998), Fader (2000), Hinman (2005), and EPA's Smart Growth Illustrated website (http://www.epa.gov/smartgrowth/case.htm). Fader provides case-study information about development costs, land use allocation, and occupancy rates. The EPA website provides brief case studies of developments it considers good examples of Smart Growth. It should be noted that the EPA considers Smart Growth an important stormwater management approach.

2.2.4.2.1.2 Roadway Width

As Kulash (2002) describes, residential street standards during the post-World War II construction boom became an urgent necessity. Commonly, existing state highway standards were adapted for residential settings. As with other road design, residential street design was viewed as a balance between mobility (speed), and access for cars, large trucks, and emergency vehicles. Little consideration was given to neighborhood character or pedestrian mobility (Kulash, 2002), and certainly not to the potential environmental consequences of stormwater runoff.

In the 1970s, neighborhood character and pedestrian safety and mobility concerns stimulated efforts to change residential street standards (Kulash, 2002). The American Society of Civil Engineers (ASCE), the National Association of Homebuilders (NAHB), the Urban Land Institute (ULI), and the Institute of Transportation Engineers (ITE) published and continue to update new guidelines. Of course auto access remains an important factor, but the desire for more pleasant neighborhood character has replaced historical emphasis on lane capacity and design speed. Instead of requiring full-width parking lanes (10'-14'), residential streets can be limited to one or two narrow parking lanes (7'-8') with a single, wider travel lane (American Association of State Highway and Transportation Officials [AASHTO], 2001; Burden et al., 2002; CWP, 1998; Institute of Transportation Engineers, 1999; Kulash, 2002). See Figure 2.2-8. Another option is to replace on-street parking with parking bays (Burden and Zykofsky, 2000; Ewing, 1996) See Figure 2.2-9.

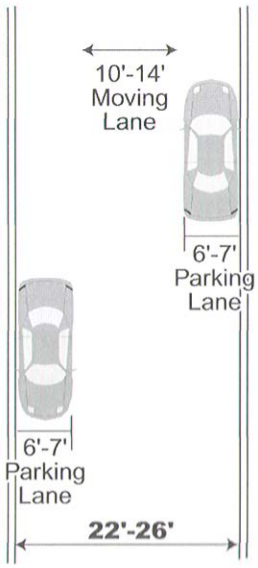

Figure 2.2-8. Narrow parking lane configurations for street parking (Sources: Right, Kulash, 2002, p. 24)

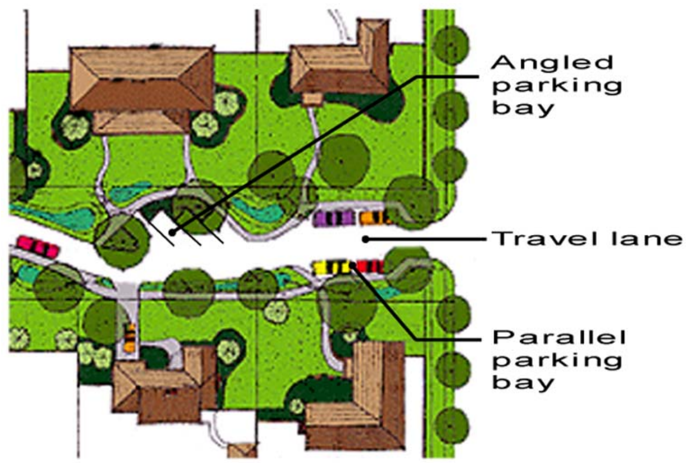

Figure 2.2-9. Parking bays provide street parking on very narrow streets, Seattle Street Edge Alternatives (SEA) Streets project (Adapted from: http://www.djc.com/ stories/images/20000306/36map.gif,)

Queuing streets, where travelers share a single lane, cause few congestion problems and offer safety benefits (Burden and Zykofsky, 2000; ITE, 1999; Kulash, 2000). Queuing streets were the norm prior to 1960 and are still the most prevalent type of local street. If the local road network includes high interconnectivity (short roads with 2 access points), travelers have multiple access options, which help to disperse traffic (CWP, 1998; CHI, 2000; EPA, 2005b; Hinman, 2005). Several authors note that narrower streets reduce traffic speeds, and in turn reduce the number of accidents and injury severity (Burden et al., 2002; ITE, 1999; Kulash, 2002; CWP, 1998). A study in Longmont, Colorado suggested the safest streets are 22 to 30 feet wide (CWP, 1998). For streets with up to 150 dwelling units (DU) receiving 1500 or fewer average daily auto trips (ADT), Kulash (2002) suggests 24- to 26-feet-wide pavement is best. For low-volume streets (ADT < 500, and DU <50), street width can be reduced to 22 to 24 feet if parking is limited. If no on-street parking is allowed, 18 to 20 feet is sufficient.

Service and emergency vehicle access is a common argument used against narrow streets. In spite of this argument, a study in Portland noted that there were no citizen complaints about delayed fire truck response times resulting from narrow streets (CWP, 1998). Burden et al. (2002) studied very narrow streets in a Florida town. Although local fire trucks were 9.5 feet wide from mirror to mirror and the fire department reported they “could handle any street in town” (Burden et al., 2002, p. 7). While evidence indicates fire trucks can negotiate narrow streets, several authors note that this is practical only in networked streets with 2 access points (Burden et al., 2002; ITE, 1999; Kulash, 2002). In developments with cul-de-sacs, two travel lanes wide enough to allow two fire trucks to pass are necessary.

A number of U.S. cities have adopted narrow residential street design standards (CWP, 1998; ITE, 1999; Kulash, 2002). A summary of street design standards for a few cities receiving average annual snowfall amounts comparable to Spokane is given in Table 2.2-2. The standards listed in Table 2.2-2 approach Kulash’s recommendations. The City of Missoula noted snow plowing problems with pavement widths of 27 feet or less when parking is unrestricted (Doug Harby, personal communication, July 27, 2006). Plow operators find it difficult to clear travel lanes adequately when cars are parked along both sides of the roadway.

Table 2.2-2. Narrow Street Standards Examples, Northern-Tier U.S. Cities

Pavement Width	Use	On-Street Parking	Location
20 feet face-to-face[1]	Local street, non-business, non-industrial zone	One side	Birmingham, MI (Dembiec, 1997)
26 feet face-to-face	Local street, non-business, non-industrial zone	Two sides	
32 feet	Residential	No restrictions specified	Minneapolis, MN (City of Minneapolis, 2006, Title 22, Article III, 598.230)
20 feet (minimum)	Short court private road, 3 to 6 lots or dwelling units (DU)	No parking	Missoula, MT (City of Missoula, 1999)
24 feet (minimum)	Private road, 3 or more lots or DU	Not specified	
26 feet back-to-back [2]	3-80 DU with boulevard sidewalks	Public works director may require parking pullouts	
28 feet back-to-back [3]	3-80 DU, no boulevards	No restrictions	
26 feet face-to-face	3 DU/acre or less	No restrictions specified	Madison, WI (City of Madison, 2006)
28 feet face-to-face	A. 5.44 DU/acre or less B. 5.44-8.71 DU/acre[4] C. 8.72-12.44 DU/acre[5]	No restrictions specified	
32 feet face-to-face	Minimum for local streets with no restrictions on residential density	No restrictions specified	
30 feet face-to-face	Minor streets	No parking 3:00-5:00 AM, 365 days, otherwise no restrictions	Green Bay, WI (City of Green Bay, n.d., p. 153)

1. Face-to-face means curb face-to-curb face
2. Back-to-back means back of curb-to-back of curb. Pavement width varies 24.5 to 25 feet based on curb type.
3. Pavement width varies 26.5 to 27 feet based on curb type.
4. 75% of subdivision units must have 2 car garages with minimum 20-foot long driveways and driveways able to accommodate 2 cars
5. Subdivision must meet requirements of item B and must receive City Council approval

Limiting parking to one side of the street under snowy conditions is an option, but can be a difficult ordinance to enforce. Parking bays like those used in the Seattle SEA Streets project (Figure above) may be a viable alternative. Parking bays are mentioned in Missoula's standard for 26-feet wide streets. Bays can provide greater separation from the travel lane than standard on-street parking, and they require less paving if 90-degree angle parking is used instead of parallel parking. Bays may reduce the amount of available on-street parking, but evidence suggests that most spaces on single-family residential streets aren't used (Cnare, 2005; 2004; EPA, 2005b). In Madison, Wisconsin the actual usage ranged from 2 to 15 percent of available spaces (Cnare, 2005). Additionally, when the bays are underutilized, plowed snow could be stored temporarily in the empty space. Alternatively, some bays could be designated "no parking" in snowy conditions.

2.2.4.2.1.3 Residential Driveways

The CWP (1998) estimates driveways account for 20 percent of the impervious cover in residential subdivisions. For garages accessed from the front of the house, setback requirements of over 20 feet add unnecessary driveway length. Driveway width requirements can also be reduced to 9 feet for single-car access and 16 feet for two-car access (Hinman, 2005). Impervious cover is reduced even further if only the wheel tracks are paved. The remaining driveway area is replaced with pervious materials such as gravel or pervious pavers (Bay Area Stormwater Management Agencies Association, 1997; Ferguson, 2005; Hinman, 2005). Figure 2.2-10 shows an application of this concept used in Vancouver B.C. See Section 2.2.5.5 for more on pervious paving. Shared driveways also reduce impervious paving. Several possible configurations are shown in Figure 2.2-11.

Figure 2.2-10. Reduce impervious areas in driveways and alleys by paving only the wheel tracks (Photo courtesy of Curtis Hinman)

Figure 2.2-11. Shared parking configurations. The narrow roadway connecting driveways in the lower right diagram is considered part of the driveway system and typically does not have to meet standard road design criteria. (Sources: Top and bottom left - Fader, 2000, pp. 30 & 32. Bottom right - Author, adapted from CWP, 1998, p. 116)

Rear garages with alley access are another, although somewhat controversial, option. While there are advantages for on-street parking, reduced congestion, and aesthetics, some consider alleys equivalent to doubling the total street area (Fader, 2000). With careful design, this is not necessarily true. Alleys typically are not required to meet street design standards and driveways lengths can be reduced to 10 feet or less (Fader, 2000; Hinman, 2005). The City of Madison calculated that, compared to front-accessed garages, less total pavement was needed when alleys were used (Cnare, 2005). In addition, an alley access provides two access routes for every lot, which is advantageous to emergency vehicles.

2.2.4.2.1.4 Commercial Parking

For businesses parking lots, most jurisdictions specify minimum numbers of parking spaces based either on business type (medical office, etc.) or floor area (e.g. 3 spaces per 1,000 sq. ft.) (CWP, 1998; EPA, 2005b; Hinman, 2005). In most instances, a maximum capacity is not regulated, therefore businesses tend to supply parking to accommodate peak business hours or days. The EPA (2005b) and Hinman (2005) summarized studies that indicate there is an average 25 to 50 percent overcapacity in commercial area parking. Hinman suggests parking policies should include both minimum and maximum parking ratio based on local need assessments, rather than standardized averages. If property owners can demonstrate a higher actual use than what policy allows, additional spaces can be permitted. However, to assure adequate stormwater management for the additional runoff, the policy should include strict requirements for on-site treatment, or extra financial assessments to support centralized treatment facilities.

In some cases, businesses cannot obtain loans if the lending agency perceives insufficient parking will be available (CWP, 1998). An alternative is shared parking. This arrangement works best for neighboring businesses that have different peak hours (CWP, 1998; EPA, 2005b). For example, daytime bank and business office hours contrast with nighttime restaurant and theater hours. The total number of parking spaces should be based on the business with the highest parking demand. Volunteer shared parking arrangements can present liability and maintenance problems. Both the CWP (1998) and the EPA (2005b) recommend that communities interested in shared parking arrangements implement supporting policies. Case study examples of shared parking and other innovative parking programs can be found in EPA (2005b), ITE (1995), and Stein Engineering (1997). Model shared parking agreements and programs are included in CWP (1998), ITE (1995), and Stein Engineering (1997).

The last set of strategies address parking lot configuration:

- use a percentage of compact spaces 7.5 by 15 feet (Hinman, 2005);
- use angled parking and one-way travel aisles to reduce imperviousness (CWP, 1998);
- at a minimum, use pervious paving for spillover areas (see Section 2.3.4.1.5);
- use parking structures (or parking floors within a building) where land values are high (CWP, 1998; Hinman, 2005);
- cover parking to minimize stormwater contacting roadway; and
- incorporate on-site stormwater management systems (see Section 2.3.5).

2.2.4.2.2 Reduce Effective Imperviousness

In conventional development, roads and parking areas are connected to storm drains via curbs and gutters. Curbs and gutters channel water to centralized BMPs or directly to receiving streams. When downspouts drain to paved surfaces or directly to storm drains, rooftops are another part of this ‘connected’ runoff conveyance system. Nearly 100 percent of the stormwater that falls onto connected impervious surface translates into runoff (Schueler, 1995). Lawns and playfields contribute to ‘effective imperviousness’. These areas typically have compacted soils with lower infiltration capacity than native soils (Ferguson, 1994), and produce more runoff than native soils. When lawns and playfields are built to drain directly to paving or the storm sewer, the development’s imperviousness is effectively increased.

In LID, impervious surfaces are ‘disconnected’. Storm sewers are reduced or eliminated and runoff is instead directed to infiltration zones (see Retention BMPs, Section 2.2.5.2). In places with shallow groundwater or impervious subsurface layers (bedrock, clay), exfiltration devices may be an option (see Exfiltration BMPs, Section 2.2.5.3). Rooftop runoff can also be collected in rain barrels or cisterns for on-site reuse (see Rainfall Collection and Re-Use, Section 2.2.5.4).

2.2.4.2.3 Reduce Building ‘Footprint’

Building design can reduce site imperviousness. For the same square-footage, a multi-story building has less roof area than a single-story building. Garages can be built into the main structure of the house, rather than being fully or semi-detached. Hinman (2005) describes minimal excavation foundation systems that have been permitted for use in parts of Western Washington. These systems use piers with above-ground foundation walls (Figures 2.2-12 and 2.2-13). The soil under the structure remains mostly undisturbed, maintaining a nearly pre-development capacity for stormwater infiltration.

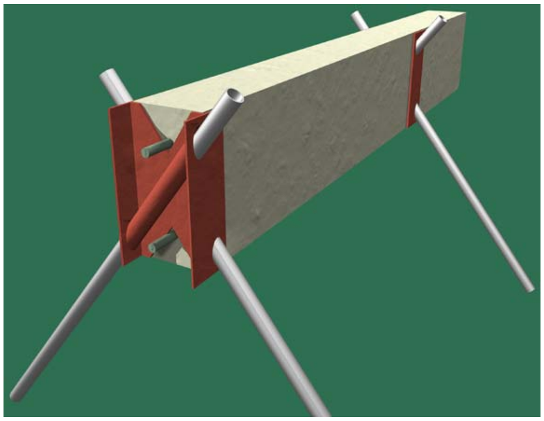

Figure 2.2-12. Pier support system for minimal excavation foundation (Sources: Pin Foundations, Inc., Hinman, 2005, p. 129)

Figure 2.2-13. Diamond Pier™ minimal excavation foundation system used on Bainbridge Island, WA (Sources: Pin Foundations, Inc., Hinman, 2005, p. 129)

2.2.5 Stormwater Controls

In the site planning stage of the LID design process, alternatives are developed and modeled to determine which site design has the least hydrologic impact while still meeting project goals. In most cases the estimated post-development runoff will exceed pre-development runoff. When all site planning options to reduce stormwater impacts are exhausted, structural stormwater practices (BMPs) must be added. In LID, small BMPs are distributed throughout the site as close to runoff-generating sources as possible. The BMPs slow and filter runoff, infiltrate a portion of site rainfall, and wherever possible, are used in series to increase their effectiveness. Most above-ground BMPs are integrated into the landscape as multi-functional and aesthetic amenities. This section describes the six LID BMPs: filtration, retention, exfiltration, rainfall re-use, pervious paving, and vegetated roofs.

The goal of LID is to emulate pre-development hydrology. However, site conditions may limit the extent to which LID can be applied, leaving some amount of runoff that will require off-site management using conventional practices (storm sewers, detention and retention facilities). The important benefit of LID to conventional management approaches is that, by controlling a portion of the runoff quantity and quality impacts on site, the capacity of off-site practices can be reduced.

2.2.5.1 Filtration BMPs

LID filtration BMPs are vegetated features designed to reduce pollutant concentrations in runoff through filtration, sedimentation, soil adsorption, and plant and soil microbe metabolic processes (WSDOE, 2004a). They are not intended to reduce runoff volume, although losses may occur depending on the design, soil type and root penetration (Hinman, 2005; Reeves, 2000). Filtration BMPs should not be used alone, but rather as pretreatment upstream of other stormwater controls, or at the outlet of other BMPs.

Traditionally, for most swales and filter strips, grass was used as the primary plant cover (Reeves, 2000; PGC, 1999a). Hinman (2005) states that the most appropriate plant materials should provide dense cover in the water treatment zone, and should be adapted to the local climate and site hydrologic conditions. Plants in the swale pollutant removal studies to be discussed below were all grass species. Filter strips consisted mostly of grasses with some additional, yet unspecified, species. From a site design perspective, species flexibility is important since it allows greater aesthetic integration with the landscape.

2.2.5.1.1 Biofiltration Channels

In the LID literature, biofiltration channels are also called biofiltration swales, grassy or vegetated swales, and stormwater swales. In general, they are gently sloped, vegetated channels that convey runoff to other BMPs. See Figure 2.2-14. Water enters a channel either as dispersed flow or through inlets such as curb cuts. Some infiltration may occur, though this is not the primary purpose. Channels designed to infiltrate a portion of runoff are more properly called "bioinfiltration" or "bioretention" swales or channels. See Section 2.2.5.2.1.

Figure 2.2-14. A biofiltration channel with outflow inlet (Source: http://www.wsdot.wa.gov/Environment/WaterQuality/Research/LinksLiterature.htm

A study performed on a Western Washington swale in a residential development indicates the best treatment was obtained from grassy channels with a minimum 9 to 10 minutes residence time (Reeves, 2000). Residence time is the length of time required for stormwater to travel through a swale. A study of highway median strip swales in Texas, however, found most pollutant removal occurred along the side slopes as water traveled to the bottom of the channel (Barrett et al., 1998). In that study residence time appeared to be a less important factor. This result indicates that the Texas channels behaved essentially like vegetated filter strips (described below). The contrast between these two studies may have resulted from the differences in side slope: the Washington study channel had 33 percent side slopes: the Texas channels had side slopes between 9 and 12 percent. The side slope lengths in the Washington channels were not indicated, but the Texas side slopes were between 6 and 8 meters (from top of slope to bottom).

A gentler slope promotes sheet flow, minimizes concentrated or channelized flow, and allows greater contact of the water with soil and vegetation. However, to achieve adequate channel depth, a gentle side slope will also requires more land area. Unfortunately, less land area may be available in a residential or dense urban setting. In this situation, design guidelines should probably rely on residence time as recommended by Reeves (2000).

Pollutant removal rates in the two studies were very similar, ranging from 80 to 85 percent for suspended solids, and 36 to 91 percent for metals. Nutrient (phosphorous and nitrogen) removal was more variable. Reeves (2000) indicated this may be related to sampling artifacts. However, Reeves (2000) and Barrett et al. (1998) also commented that poor and inconsistent pollutant removal is likely when channels are poorly designed and maintained.

2.2.5.1.2 Vegetated Filter Strips

In concept, vegetated filter strips are similar to biofiltration channels, but should convey water only as sheet flow. In a study of eight vegetated slopes adjacent to highways in California, Barrett et al. (2005) reported good performance for suspended solids and metals removal. The best performance occurred when vegetated cover was at least 80 percent and when buffer widths were:

- 4.2 meters for slopes less than 10 percent
- 4.6 meters for slopes 10 to 35 percent
- 9.2 meters for slopes 35 to 50 percent.

In North Carolina, Han et al. (2005) found that a vegetated highway filter strip measuring 55-feet long with 4 percent slope in the flow direction removed more than 85 percent of total suspended sediments (TSS) with a diameter of 8 micrometers (μm) and larger. The authors reported that mean sediment in urban stormwater ranges from 8 to 200 μm. Computer modeling of the system indicated 80 percent TSS removal likely occurred in the first 10 meters, with little influence from infiltration losses on larger particles. However, infiltration likely accounts for the removal of particles smaller than 8 μm. The model also showed a 20 percent reduction of TSS removal when grass spacing increased from 2 to 7 cm. Unfortunately, since the grass species was not indicated, it is unknown if the spacing was for grass blades or for bunch grass forms. The results for spacing of other vegetation types were not reported.

2.2.5.2 Retention BMPs

LID retention BMPs reduce site runoff by infiltrating stormwater into the soil. Vegetated retention BMPs, such as bioretention cells, also provide water quality treatment. Non-vegetated retention BMPs such as drywells provide no treatment and should be preceded by a water quality treatment BMP.

2.2.5.2.1 Bioretention cells

Bioretention cells are commonly called bioinfiltration cells or basins, and rain gardens. They are perhaps the most recognized LID BMP. Functional elements should include inlet controls; native, amended, or engineered soil; a ponding area; ground cover layer, plants, and one or more outlet controls (Hinman, 2005). See Figure 2.2-15. In most cases bioretention cells are placed “off-line”, meaning they are not part of the runoff conveyance system (Figure 2.2-16). If placed “in-line” as a part of the conveyance system, they are more properly called bioretention or bioinfiltration swales (Figure 2.2-17).

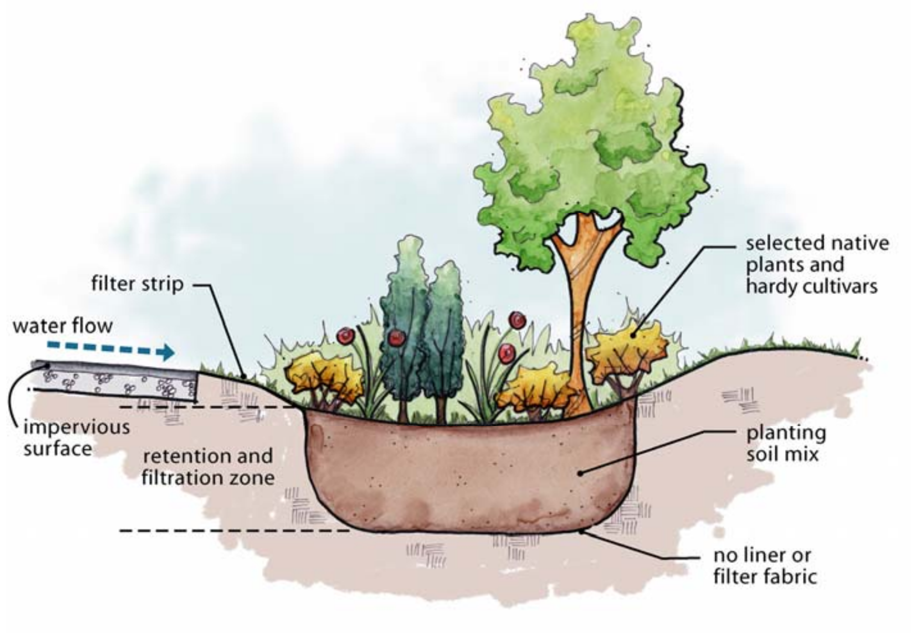

Figure 2.2-15. Section of a typical bioretention cell (Image courtesy of AHBL)

Figure 2.2-16. Off-line bioretention cell (Image by Larry Coffman, in Hinman, 2005, p. 69)

Figure 2.2-17. In-line bioretention swale with check dams (Source: Landers, 2004, p. 55)

Water may enter a bioretention cell either as dispersed flow from a landscaped or impervious surface, or as concentrated flow through curb cuts, pipes, or catch basins (Hinman, 2005; PGC, 1999a). Erosion control such as rip-rap or rock piles must be used at the mouth of concentrated flow inlets. Woody plants should be avoided near concentrated flow inlets where root damage can occur. Complete drainage that allows soils to dry completely is necessary to maintain healthy soil oxygen levels for plants and microorganisms. Outlet controls allowing surface overflow are necessary for storm flows that exceed design capacity (Hinman, 2005; PGC, 1999a).

Bioretention cell soils must have adequate infiltration rate and pollutant removal ability. Soil organic content and cation exchange capacity (CEC) are the primary factors determining pollutant removal capacity (Hinman, 2005). If necessary, native surface soils can be amended or be replaced with engineered soils. A ground cover layer such as composted mulch should also be used in bioretention cells. Mulch provides nutrients, improves soil moisture retention, and helps prevent weed growth. Mulch also promotes metals treatment. Mulch removed from older bioretention cells is not considered hazardous and requires no special disposal (Hinman, 2005).

Current plant materials recommendations include native and non-invasive species adapted to local climate and growing conditions (Hinman, 2005; PGC, 1999a; Richman et al., 1998). Plants provide filtration, and promote soil structure and infiltration capacity. As shown in the vegetated filter strip study (Barrett et al., 2004) plant species appear to have little impact on BMP effectiveness. Instead, vegetation coverage seems to be the most important factor, 80 percent or more being the most effective. Plants should be placed in and around swales based on their soil moisture tolerance (Hinman, 2005; Richman et al., 1998). The lowest (hydric) zone is appropriate for grasses and grass-like species (rushes, sedges); the middle zone for more mesic species (including woody species); and the highest zone for dry (xeric) species. Woody species should not be placed where high flows could erode the root zone.

2.2.5.2.2 Bioretention Cell Performance

Bioretention cells can be very effective for reducing runoff volume and rate. Horner et al. (2004) describe a project in Seattle where a residential street was retrofitted with bioretention cells and swales. Hydrologic modeling predicted the retrofit should be able to reduce total site discharge by at least 42%. Construction was completed at the end of 2000, and monitoring began in January 2001. Up to 11 rain events produced outflow (site runoff) prior to December, 2002. No runoff resulted after that time, even during two large rain events in October and November of 2003. The earliest results indicated the site could fully attenuate up to a 0.75 inch event. Although a numeric value was not provided, later results showed a much higher attenuation potential. The authors speculated that maturing vegetation improved the performance over time.

Hinman (2005) provides summaries of selected field and laboratory pollutant removal studies published through 2003. Metals (copper, lead, and zinc) and petroleum hydrocarbons removal was 87% or higher. Phosphorous removal was low at shallow soil depths, but up to 81% at 36 inches deep. Hinman notes soil oxygen and pH levels affect phosphorous removal efficiency, and emphasizes that bioretention cells must be allowed to dry out periodically. Nitrogen removal was fair (37 – 86%) for total Kjeldahl nitrogen (TKN) and ammonia-nitrogen (NH4-N), but low (43%) to negative (-194%) for nitrate and total nitrogen. Negative removal indicates effluent nitrogen concentrations were higher than influent nitrogen. Ammonification and nitrification processes may account for variable nitrogen results. Kim (as described by Hinman, 2005) suggests a fluctuating aerobic/anaerobic zone at the bottom of the bioretention cell can improve denitrification.

A study in New Hampshire performed side-by-side evaluations of conventional and LID stormwater practices (University of New Hampshire Stormwater Center, 2005). Compared to conventional and commercially available treatment systems, bioretention cells performed best with reported reductions of 97% for total suspended solids (TSS), 44% for nitrate-nitrogen, and 99% for zinc and average peak flow. Only a gravel wetland performed better, with a 99% reduction of nitrate.

Additional studies are underway that may help refine bioretention cell design, and perhaps LID design in general. An 8-acre residential development using cluster development and LID BMPs is under construction in Pierce County, Washington (Hinman, 2004). Prior to site development, surface and subsurface runoff flows were monitored during seven months of the rainy season. Monitoring will continue for three years after construction to evaluate stormwater performance for the entire site as well as for individual BMPs. A second study in Trondheim, Norway will evaluate bioretention BMP performance in cold climates (Nordberg and Thorolfsson, 2004). Detailed hydrologic data has been collected on that site since 1986. A bioretention test cell will be installed and monitored for two years through all seasons. The investigators hope the study results will shed light on common LID design assumptions and changes that are appropriate for designs in cold climates.

2.2.5.2.3 Drywells and Infiltration Trenches

Low Impact Development Design Strategies (PGC, 1999a) describes drywells as excavated pits that are backfilled with aggregate and are used most commonly to infiltrate roof runoff. See Figure 2.2-18. These types of drywells are also called soakaway pits, downspout infiltration or roof leader infiltration systems. In Washington, drywells consist of buried, pre-cast concrete vaults. They are used to infiltrate any type of stormwater (roof, street, parking lot, etc). See Figure 2.2-19. These drywells discharge to deep subsurface soils where the absence of plant or microbial activity provides no water quality treatment. Where groundwater quality is a concern, drywells should be preceded by a stormwater quality treatment BMP (WSDOE, 2004a). Overflow outlets must also be provided to accommodate large storm events.

Infiltration trenches are simply rock-filled trenches that infiltrate runoff over several hours or days (PGC, 1999a). See Figures 2.2-20 and 2.2-21. The surface of the trench can remain exposed, or be covered with a variety of materials including turf and pea gravel. Inflow may be from dispersed overland flow, or concentrated though pipes. If concentrated, a distribution pipe is used through the trench length to assure adequate water distribution (WSDOE, 2004a).

Infiltration trenches are susceptible to sediment clogging and should be used with some type of pre-treatment (filtration, bioretention, or settling basin). To trap sediments, filter fabric should also be placed about 6 inches below the trench surface (Barr Engineering, 2001; WSDOE, 2004a). Like drywells, stormwater disposed to infiltration trenches may require water quality treatment to protect groundwater quality. Overflow outlets are also necessary to bypass large storm flows.

With the exception of inlet risers and manhole covers, drywells are mostly invisible in the landscape. Infiltration trench surfaces, however, are fully visible. Most of the literature reviewed for this study consider infiltration trenches an eye-sore, and recommend limiting their use to parking lot and road median applications. Unsightliness is a problem when trenches are surfaced only with drain gravel. However, nearly any type of pervious surface can be used, barring interference with water distribution and drainage into the trench. Trenches can easily be disguised as pervious paver walkways (described in Section 2.2.5.5). They can also be surfaced

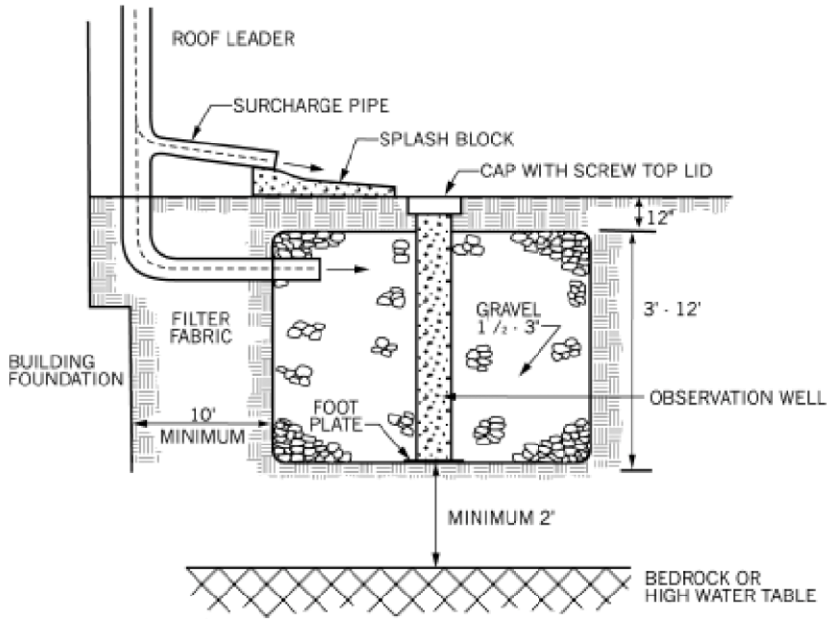

Figure 2.2-18. Typical drywell used in Maryland for roof runoff drainage (Source: PGC, 1999a, p. 4-11)

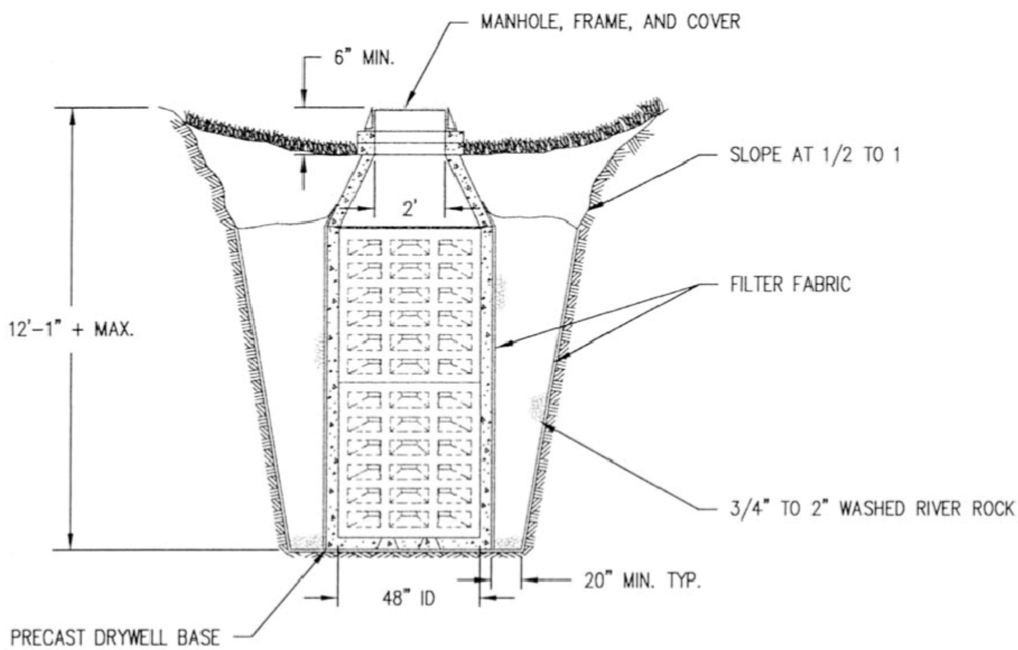

Figure 2.2-19. Typical drywell used in eastern Washington for general stormwater infiltration (Source: WSDOE, 2004a, p. 6-36)

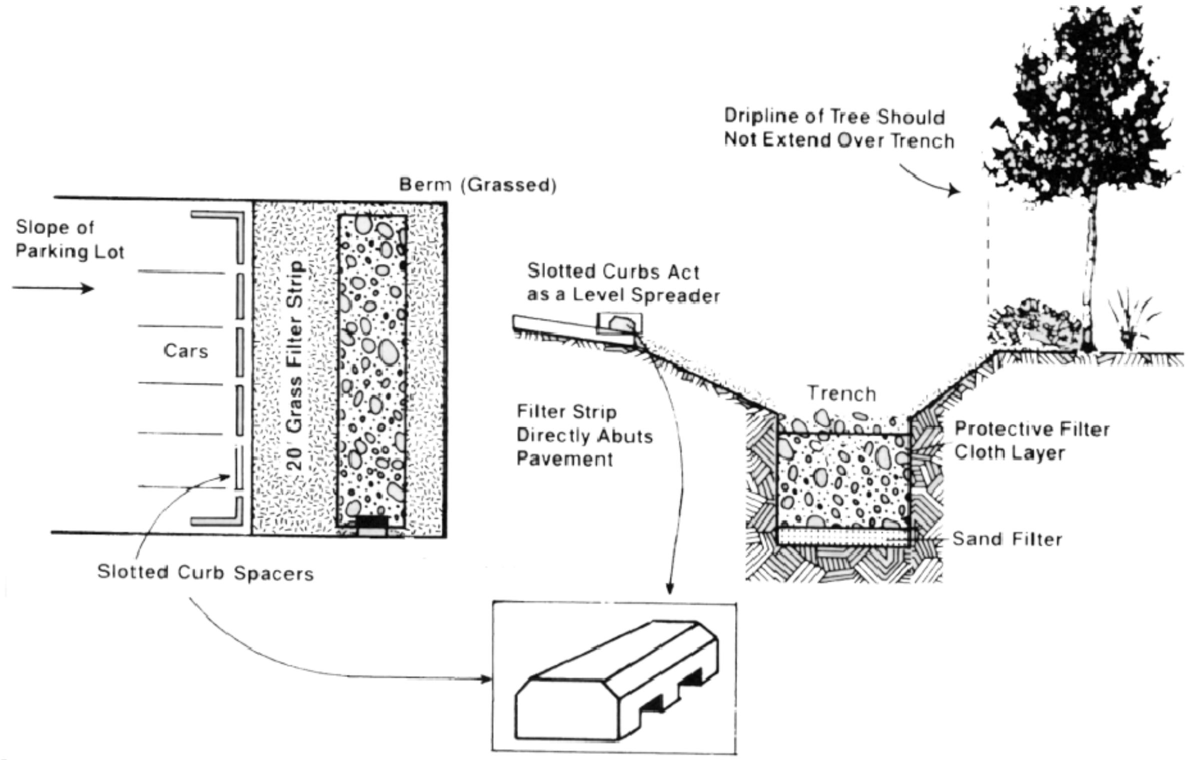

Figure 2.2-20. Typical parking lot infiltration trench used in Minnesota (Source: Barr Engineering, 2001a, p. 3-171)

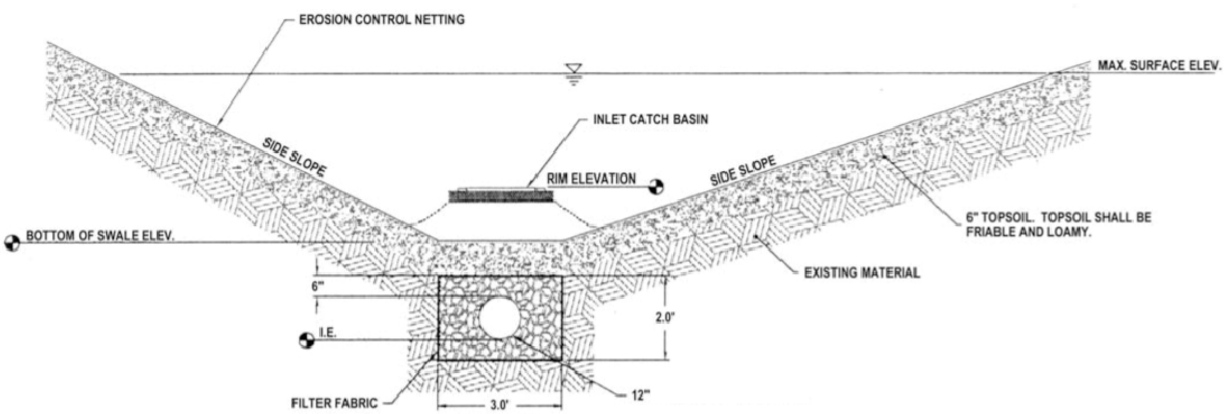

Figure 2.2-21. Typical infiltration trench with distribution pipe (Source: WSDOE, 2004a, p. 6-36)

Figure 2.2-22. Infiltration trench with aesthetic elements, Melbourne, Australia (Source: http://wsud.melbournewater.com.au/content/treatment_measures/infiltration_trenches/overview.asp)

with shallow rooted vegetation that won't penetrate shallow filter fabric, or use a combination of stone and vegetation (Figure 2.2-22).

2.2.5.2.4 Retention BMP Placement

Retention BMP placement must consider soil infiltration rate, subsurface soil layers, and distance from structures, drinking water sources, septic tanks and septic leach fields (Ferguson, 1994; Hinman, 2005). Inadequate infiltration rates causes water to pool at the surface for extended periods. Extended pooling can damage plant materials, reducing both the water quantity and the quality management capacity. Pooling can also stimulate mosquito breeding, stimulating a public perception that retention BMPs are a safety hazard and an eye-sore. Shallow groundwater, bedrock, or other impervious layers (clay, hardpan, gravel lens) can limit treatment and subsurface storage capacity, potentially causing contaminated groundwater (Pitt, 1996) or localized flooding (Brown and Caldwell, 2003; MWH and Woodward-Clyde, 2002). When these conditions exist, retention BMPs modified with underdrains are an option. See Exfiltration BMPs, Section 2.2.5.3.

2.2.5.3 Exfiltration BMPs

Some sites have little or no infiltration capacity due to very dense development, shallow groundwater, or impervious layers (clay lenses, bedrock). Bioinfiltration cells and swales can still treat runoff for water quality, but must be modified with an underdrain to convey treated runoff elsewhere for infiltration or surface water disposal. In addition to water quality treatment, exfiltration BMPs detain water on site, slowing the runoff rate that must be managed (Hinman, 2005). Exfiltration BMPs can be placed in open landscapes if space is available, or can be built into foundation planters or other contained systems. For contained systems, impervious liners must be used to prevent water leaching out of the system. See Figures 2.2-23 and 2.2-24.

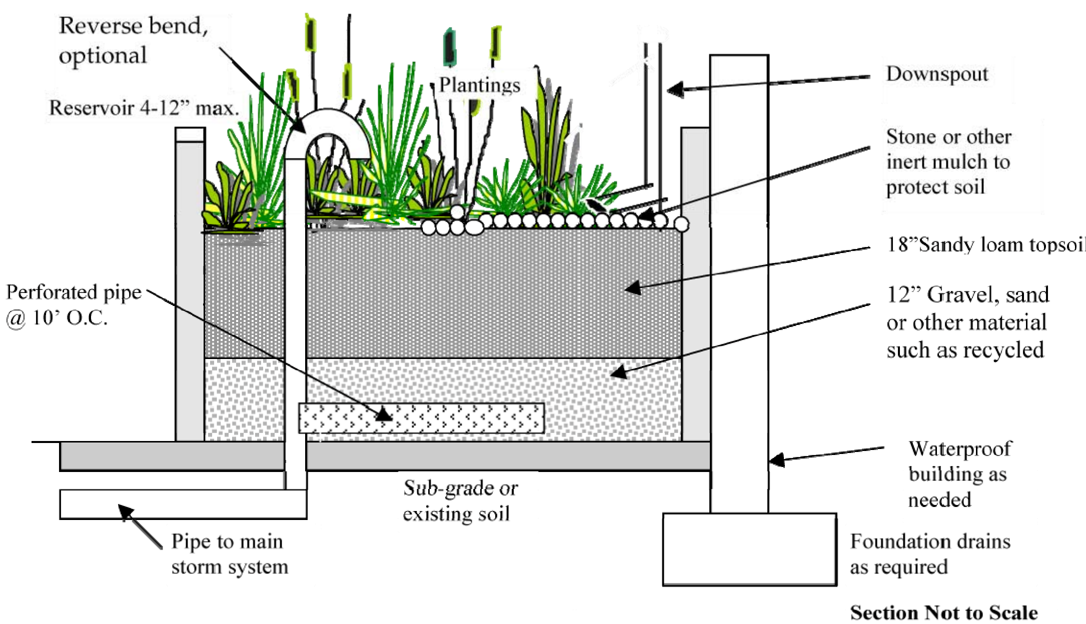

Figure 2.2-23. Section of a typical exfiltration BMP adjacent to a building (Source: Liptan and Murase, 2000, p. 17)

Figure 2.2-24. An exfiltration BMP in Portland, Oregon (Source: Liptan and Murase, 2000, p. 18)

2.2.5.4 Rainfall Re-Use

Around the world for thousands of years, rainwater collection for agricultural and domestic uses has been common practice (Texas Water Development Board, 2005). While this practice has been less common in the U.S., low water supplies or poor water quality are increasing the demand in for rainwater collection in Texas, Florida, Hawaii, and the San Juan Islands of Washington state. Most systems consist of:

- a collection area (usually rooftops);
- gutters and pipes to channel the water to storage containers;
- a debris screen;
- a roof washer or diverter to minimize animal wastes and other pollutants from entering the storage container;
- one or more tanks (cisterns) or barrels;
- a distribution system (gravity or pump); and
- a purification/disinfection system for potable systems (Texas Water Development Board, 2005).

With sufficient storage capacity, cistern systems can reduce the load on stormwater management systems. British Columbia currently encourages rooftop rainwater collection for landscape irrigation, toilet flushing, and washing machines in order to reduce stormwater runoff volumes (Stephens et al., 2002). At City Hall, the City of Seattle has installed a 30,000 cubic foot system for toilet flushing and irrigation. It is expected the system will reduce stormwater runoff from the site by 76 percent (Accetturo, 2006). A similar system at the King Street Center In Seattle is estimated to reduce municipal water needed for toilet flushing by 64 percent (Accetturo, 2006).

Cisterns may also be helpful in preventing combined sewer overflow (CSO) events. Many cities use combined sanitary and stormwater sewer systems, or ‘combined sewers’. Large storm events can overload system capacity. To prevent system damage, much of the sewage is bypassed directly to a receiving water body without being treated. Invariably, CSO releases violate water quality regulations. In Seattle, a CSO-reduction pilot program is currently evaluating residential cisterns effect (Johnson, 2005). In winter, captured water will be released slowly without on-site re-use. In summer, the water will be used for site irrigation.

2.2.5.5 Pervious Paving

Pervious paving allows stormwater infiltration and reduces pollutant loads (Clausen, 2004; EPA, n.d. a and c; Ferguson, 2005; Hinman, 2005; Dierkes et al., 2002). Pervious pavements consist of a surface (or wearing) course, a base course, and subgrade material (Ferguson, 2005). The surface course may consist of porous Portland cement, hot-mix asphalts, aggregate, or interlocking pavers made of plastic or concrete with joints or cells that hold aggregate or topsoil and turf. See Figures 2.2-25 through 2.2-27

The quantity of stormwater that can be managed with pervious paving depends on the permeability of the subgrade material and the reservoir volume contained in the base course. Suspended solids, metals, and oil-based pollutants are reduced by a combination of filtration and microbial activity in all paving materials (surface, base, and subgrade), and cation exchange in the subgrade material (Ferguson, 2005). Microbial activity is enhanced in pavements that contain geotextile fabrics or geomembranes. Geotextiles are common in pervious turf pavers to prevent sediment migrating into the base course. Geomembranes are applied under the base course and prevent stormwater infiltration into the subgrade. This application is used for pervious paving designed as a detention facility that subsequently drains via an outlet channel or pipe.

Figure 2.2-25. Aggregate-filled pavers in a residential driveway in Minneapolis, MN (Source http://www.marcy-holmes.org/projects/rainwater/5.html)

Figure 2.2-26. Pervious pavers using grass and soil media in paver pore spaces. (Left: http://revelle.net/LAKESIDE/photos/july/July-Pages/Image6.html, ; Right: http://er1.org/docs/ sample solutions/products/Landscaping with load-bearing grass paver systems.jpg)

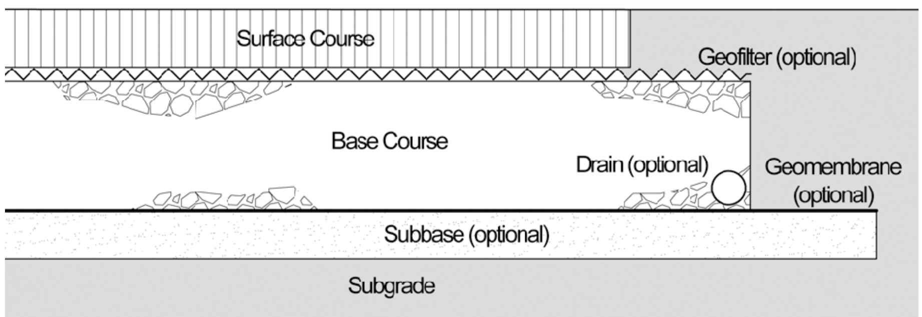

Figure 2.2-27. Section of a typical pervious pavement system. In cold climates the base course must be thick enough to prevent frost heaving. (Adapted from Ferguson, 2005).

In cold climates, pervious paving is sometimes considered a controversial practice (EPA n.d. b and c; Ferguson, 2005) However, pervious paving projects are currently operating successfully in Chicago, Brooklyn, Waterford, CT, State College, PA, Dearborn, MI, Ontario, Canada, and Luleå, Sweden (within 1 degree of the Arctic Circle) are operating successfully (Adams, 2003; Clausen, 2004; Ferguson, 2005; Hun-Dorris, 2005) Although most of the projects use pervious pavers, porous asphalt is used in the Mustang auto parking lot at the Ford plant in Dearborn (Adams, 2003). The key to success is selection of the proper material for the given conditions, and proper installation, and maintenance. Installation must include a base course thick enough to prevent frost heaving. Interestingly, the base course depth does not have to extend below the local frost depth for adequate protection (Ferguson, 2005). Maintenance includes avoiding sand for ice control, and periodically sweeping the area to remove accumulated particulates. Ferguson (2005) provides a detailed explanation of site analysis and base course depth estimation procedures necessary for pervious pavement applications in cold climates. Snowplows have also been a concern with paver systems because plow blades can catch and displace the paver stones. Ferguson (2005) describes case studies where, with proper installation, plowing has not been a problem. He also notes that plow blades can be fitted with flexible rubber edges, skids, or rollers to prevent paver displacement.

Pervious paving is susceptible to clogging. Also, the large pore spaces that allow stormwater to infiltrate make most currently available pervious paving too weak for heavy traffic loads (National Concrete Pavement Technology Center, 2006). Given these considerations, the EPA (n.d. b and c) and Hinman (2005) recommend pervious paving for access and maintenance roads, alleys, parking areas, pedestrian plazas, and walkways. Ferguson (2005) provides extensive explanations of material selection, design, installation, and maintenance considerations, and describes numerous case studies. Hinman (2005) provides a brief, but detailed, summary of design and construction details, and recommended maintenance procedures. Since Hinman’s recommendations are for warmer climates, they should be supplemented with Ferguson’s recommendations for freeze-thaw conditions.

2.2.5.6 Vegetated Roofs

Vegetated (green) roofs reduce roof runoff volume and attenuate peak flow (Moran et al., 2004; Stephens et al., 2002). Moran et al. (2004) note that because atmospheric deposition can account for 10 percent or more of nutrients in stormwater, they believe green roofs have the potential to reduce these contaminants. Vegetated roofs practical for stormwater management use a shallow planting medium, small, drought-tolerant plants (succulents, grasses, herbs, and wildflowers), a drain layer, and a waterproof membrane (Hinman, 2005; Liptan and Murase, 2000). See Figures 2.2-28 and 2.2-29

Green roof runoff studies show stormwater volume retention of 40 to 66 percent with planting media between 4 and 5 inches (Moran et al., 2004; Stephens et al., 2002). Retention is higher for short-duration storms with dry periods in between. Peak runoff rate was generally reduced between 60 and 87 percent. Stephens et al. (2002) also concluded that green roofs are most practical for dense developments, where 45 percent or more of the lot is covered by rooftops. This was more common in multi-family housing developments and commercial areas. Results improve where covered parking with a green roof application was used.

Moran et al. (2004) evaluated green roof nutrient retention, but had negative results. Nutrient concentrations in the roof runoff were higher than in untreated stormwater. A subsequent laboratory study indicated that planting media with higher relative mineral content and lower relative organic content would probably produce better results. A German study (Kölher and Schmidt, 2003) indicates green roofs are effective in treating both nutrients and metals contamination in stormwater.

Figure 2.2-28. Left: mature vegetated roof. Right: installation of a commercially available vegetated-mat system. (Sources: Left, Liptan and Murase, 2000, p. 20; Right, http://marcy-holmes.org/projects/ rainwater/6.html)

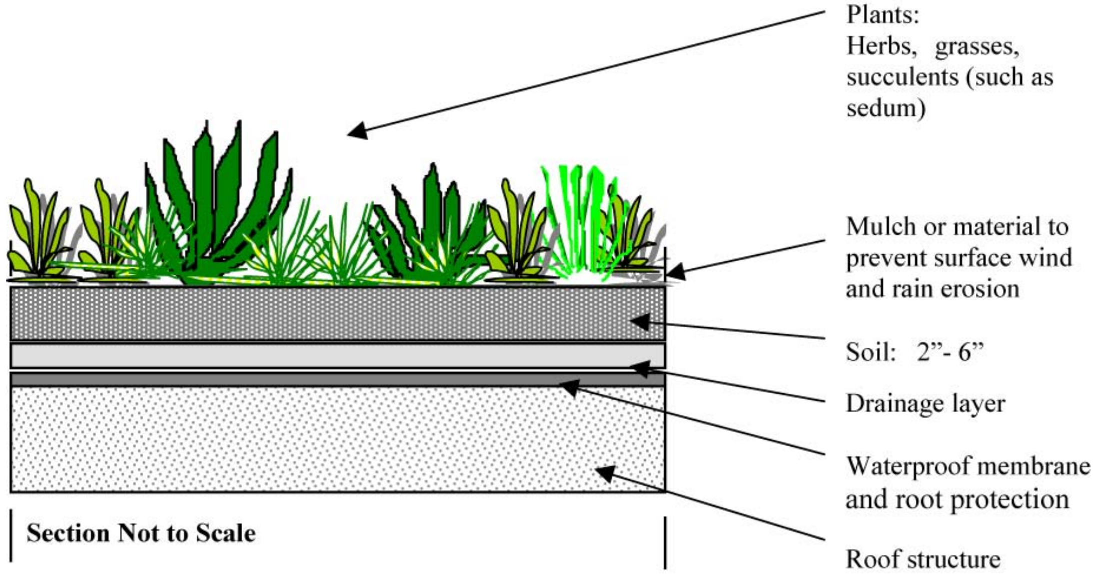

Figure 2.2-29. Section of a typical vegetated roof (Source: Liptan and Murase, 2000, p. 19).

Europe has used green roofs for decades and the practice is gaining popularity in North America. Peck and Goucher (2005) estimated at least 15 local governments had policies promoting green roofs including Portland, Seattle, Chicago, Atlanta, Washington, D.C., and Toronto, Canada. From 2004 to 2005 in the U.S., Green Roofs for Healthy Cities (2006) reports an 81 percent increase in green roof square footage from 777,052 to 1,570,352. While green roofs are more expensive to install than conventional roofs, they can last twice as long while reducing the need for other stormwater controls (Hinman, 2005).

2.2.6 Construction Site Controls

Prior to the Depression, residential construction was best described as a craft. At best, most builders completed a few projects per year. Then during the 1930's and 40's the character of residential development changed when affordable, government-backed building and mortgage financing programs became available (Rome, 2001). Builders quickly discovered the positive economical benefits of larger-scale projects which involved tens to hundreds of acres. In many cases, in order to improve construction efficiency, vegetation and topsoil were cleared over an entire project site. Slopes were reduced or eliminated. Heavy construction equipment was allowed anywhere, and construction materials were stockpiled wherever convenient.

These construction practices have several consequences for site hydrology and stormwater management (Corish, 1995; Craul, 1999; Hinman, 2005; Brown and Caraco, 2000; Virginia Department of Conservation and Recreation, 1992):

- Removing vegetation exposes soils to erosion and reduces rainfall interception, transpiration, and infiltration.

- Removing topsoil reduces the site's infiltration and water storage capacity, and ability to support newly planted vegetation.
- Grading generally increases runoff volume, flow rates, and erosion by removing surface depressions and channels that support pre-development hydrologic function.
- Construction equipment and stockpiled materials, further reducing infiltration and storage capacity.

In 1970, the U.S. Department of Housing and Urban Development estimated 400,000,000 tons per year of sediment resulted from highway and land development (Virginia Department of Conservation and Recreation, 1992). The majority of erosion and sediment from land development occurs during construction, but post-construction erosion in urban settings can still be twice the pre-development rate (Corish, 1995). Since 1970 many communities have implemented construction erosion and sediment control (ESC) programs. Unfortunately the results have been mixed due to inadequate practices and poor implementation (Corish, 1995; Brown and Caraco, 2000; Virginia Department of Conservation and Recreation, 1992).

There are many ESC measures: seeding or sodding of exposed soils, mulch or other temporary surface erosion controls, and sediment traps. These measures alone may be up to 90 percent effective at preventing sediments from leaving the construction site (Caraco, 2000). This level of protection is only possible if controls are fully implemented. Surveys reveal that *implementation* is one of the primary weaknesses with ESC programs (Paterson, 2000). Far better control results when ESC programs include preventive measures and inspection and maintenance standards in addition to ESC measures.

LID site design includes preventive measures that protect pre-development hydrology. Such measures include designating conservation areas and creating site layouts that minimize grading. Once the site plan (with all structural stormwater practices) is completed, construction ESC measures are specified in an ESC site plan. The first measure is erosion prevention. Craul (1999) emphasizes sequencing construction and enforcing clearing and grading limits that allow equipment access, while minimizing site disturbances. Construction should be scheduled for the driest months to minimize erosion caused by rainfall. Also, it is best to phase construction so that only part of the site is exposed at any one time (Craul, 1999; Hinman, 2005; Brown and Caraco, 2000). Exposed areas must be stabilized before subsequent phases begin. Unfortunately, the phased construction approach is not popular with contractors because of potential cost increases and the need for increased oversight. Proponents, however, contend that phased construction actually saves money by reducing costs for ESC structural practices.

Avoiding soil compaction is critical for stormwater infiltration BMPs, and in open vegetated areas where intercepted rainfall can infiltrate directly. Hinman (2005) citing soil compaction studies performed on various construction vehicles, recommends using the smallest practical equipment. Hinman also recommends limiting site access to one route that will later be used for future site roads and utilities. At the beginning of construction, clearing and grading limits should be fenced off. Structural and vegetative ESC practices should be implemented before, or immediately after, construction begins. This limits both erosion potential and soil compaction.

Corish (1995) and Brown and Caraco (2000) detail the problems encountered by many communities with ESC programs. Some of the most significant problems resulted from inadequately trained contractors and inspectors, insufficient inspections, poor or nonexistent maintenance, lack of enforcement, and inadequate funding. Brown and Caraco (2000) make the following recommendations:

- Require that at least one on-site state/locally certified contractor implement ESC plans.
- Immediately inspect and repair ESC measures after storms. If necessary, modify the ESC plan to better meet the needs of actual field conditions.
- Cross train planning and inspection staff.
- Prioritize inspections so that sites with higher erosion risk are inspected more frequently.
- Consider using private-sector inspectors to supplement government inspection.

In the past it has been a common practice to lump erosion control into ‘incidental’ costs. Contractors tend to bid low on this item to remain competitive (Brown and Caraco, 2000). To avoid negligence of ESC performance standards, the WSDOE (2004a) recommends a variety of bidding and contracting approaches to assure contractors are adequately funded for ESC measures.

In Washington, D.C. the Department of Health enforces stormwater management and ESC programs. New inspection and enforcement programs were implemented in 1998 (Burrell and Karimi, 2002; Burrell et al., 2004). New inspection procedures were developed for construction inspection; and separately, for maintenance inspection. Inspectors have enforcement authority through a system of written notifications and fines. Notifications include (from least to most severe) Notice of Violation (NOV), Notice of Infraction (NOI), and Stop Work Orders (SWO). Fines may be levied for NOIs and SWOs. While the system is punitive, the authors reported that since inception of the enforcement program: 1) the construction community has been more responsive to erosion and stormwater regulations, 2) there have been fewer citizen complaints about sediment control problems.

2.2.7 Maintenance

Like any other stormwater management system, LID BMPs require long-term maintenance. Even with excellent siting, design and construction, over time LID BMPs are susceptible to a variety of problems (Greer, 2004; Hinman, 2005; Reeves, 2000). These problems include:

- erosion at inlets, outlets, or around plant roots,
- plant death (Hinman recommends 80% survival for best function) due to;
  - erosion
  - inadequate watering during dry periods
  - excessive sediment accumulation (preventing adequate root aeration);
  - excessive weeds
  - inadequate mowing - mowing keeps grass in the active growth phase, which maintains the desired coverage
  - inappropriate species for growing conditions
- excessive sediment or debris accumulation which may prevent proper inflow or drainage,
- ‘crusted’ mulch which may also prevent proper drainage, and
- BMP alteration (by uninformed homeowners).

Very little is known about successfully implementing LID maintenance programs. PGC (1999) suggests that with education about LID goals, functions, and care, property owners can perform most routine maintenance procedures. Hinman (2005) agrees property owners must be educated, but suggests that easements, covenants, or even local land trusts are necessary for reliable maintenance programs. These mechanisms provide written agreements that can be enforced by local jurisdictions.

More jurisdictions are developing ordinances specifying minimum maintenance measures that include utility easements (EPA, n.d.e; Puget Sound Action Team [PSAT], n.d.). Homeowners are made responsible for at least a portion of the maintenance. Some of the maintenance requirements are enforceable by the local jurisdiction through property liens. The PSAT has published a maintenance manual that differentiates procedures appropriate for homeowners and those appropriate for municipal or contracted personnel (Washington State University [WSU] Pierce County Extension and AHBL, 2005). In all cases, property owners and contractors should have access to technical information and assistance, whether through the jurisdiction or a qualified third party.

The City of Portland Stormwater Management Manual (City of Portland, 2004) provides a detailed chapter on operation and maintenance (O&M) of LID systems. As part of project approval, all projects must submit an O&M plan. The plan must identify the parties responsible for inspection and maintenance, and include O&M requirements for each facility type (e.g., bioinfiltration system, vegetated roof, pervious paving system, etc.). The Portland stormwater manual provides a table of suggested maintenance specifications and schedules that that developers may use in project-specific O&M plans. Additionally, the parties responsible for maintenance are required to record their activities in an Inspection and Maintenance log. The log includes a checklist derived from the facility-specific O&M plans.

2.2.8 Education

Part of the success of LID projects relies on property owners and contractors. Until recently however, local governments have relieved it citizens of being responsible for managing their neighborhood’s stormwater. This has left many individual with little understanding of stormwater and its management. The EPA recommends public outreach to educate the public about their role in stormwater management (EPA, 2005b). Outreach materials may include brochures for property owners, technical manuals for developers, television announcements, billboards, and websites. Education programs may include: public meetings and seminars, training and certification programs for contractors, and volunteer programs. Steps for creating and implementing a public outreach program include (PGC, 1999a; Lehner et al., 1999):

- defining objectives,
- identifying target audiences (including construction contractors),
- developing audience-specific educational materials (examples are provided in PGC, 1999a), and
- materials distribution.

An excellent example of public outreach materials and distribution is the PSAT low impact development website (http://www.psat.wa.gov/Programs/LID.htm). The site focuses on LID development in western Washington, but it is also a comprehensive resource for educational materials with links to LID research and resources from around the country. Case study examples of education programs used across the U.S. are provided in Lehner, et al. (1999). Examples of programs used in Puget Sound are described in PSAT (2000).

2.2.9 LID Costs and Marketability

Contractors commonly cite potentially higher construction costs as a reason to avoid LID techniques (CWP, 1998). However, evidence is accumulating about built projects that have realized savings over conventional development. EPA (2005a) and Landers (2004) describe the financial benefits of several projects across the U.S. Compared to conventional development, savings were gained in costs for site grading, pavement, and structural stormwater controls including cost-reductions for curb and gutter. The reports are summarized in Table 2.2-3.

Several reports express concern that LID properties will be harder to market and potentially less profitable. This concern is partly due to a LID property's smaller-than-average size and greater maintenance requirements (Clar, 2005; CWP, 1998; Edde and Bicknell, 2004; Haub, 2002). Other authors state that people are becoming increasingly concerned about the environment and desire to live in more 'sustainable' communities which promote the protection of natural areas and resources (Arendt, 1996; Lehner et al., 1999; Richards and VanLare 2004). Although a review of buyer's attitudes toward LID properties was not identified during this literature review, a few case-studies show positive perceptions.

- The Natural Resources Defense Council (NRDC, 2001) notes that affected residents gave 94 percent approval for the Seattle SEA Streets pilot project, even though this project resulted in narrower streets and limited on-street parking.
- Sherwood, Arkansas homebuyers appear to prefer LID over conventional development. Within the first year of development at Gap Creek, over 80 percent

of the properties had sold at $3,000 per lot higher than adjacent developments with larger lots (NRDC, 2001).

- In Maryland, the Pembroke Woods development “exceeded all estimates and removed all concerns related to the viability of (LID) development, and the developers are having a difficult time keeping up with demand” (Clar, 2005, p. 8).
- Prairie Crossing in Grayslake, Illinois has also been extremely popular with buyers. In 2001, developed properties sold at prices approximately 20 to 30 percent higher than similarly-sized properties in nearby developments (Prairie Crossing, 2001).

This is not to say that every LID project has been hugely successful. The Sweetwater Farm redevelopment project in Pennsylvania has not been well received by all affected residents (McIntyre, 2006). The project added a riparian buffer to an existing detention pond system that originally had been surrounded by manicured lawns. Regarding stormwater management and other ecologic functions, the project is a great success; however, many of the neighborhood residents feel the new landscape is unacceptably ‘messy’. While some seem willing to pay a premium to live adjacent to natural areas, others prefer a more conventional landscape and resent drastic change. However, the local jurisdiction is very happy with the project and is looking for opportunities for similar projects elsewhere.

Table 2.2-3. LID Construction Cost Savings

Project Name Location Type	Project Description	LID Costs	Conventional Costs
Somerset Subdivision[1] Prince George's County, MD New construction	80-acre subdivision, 200 homes, 10,000 sq. ft./lot and 1, 300-400 sq. ft. rain garden per lot.	$100,000 total for all rain gardens	$400,000 for conventional detention ponds. Untallied additional for curb and gutter (not installed)
Gap Creek Subdivision[1] Sherwood, AR New construction	Conserved 23.5 acres of green space and accommodated 17 additional lots over conventional development	Project costs reduced by $4,800 per lot and resulted in $2.2 million dollars additional project profit.	Not specified
Circle C Ranch Subdivision[1] Austin, TX Redevelopment	Point discharge converted to sheet flow system with 4 biodetention areas.	$65,000 for 4 biodetention ponds (~$450 per lot)	Saved $250,000 ($1,700 per lot) over conventional development
Street Edge Alternatives (SEA) and Cascade[2] Seattle, WA Redevelopment	SEA and Cascade are street redesign alternatives using bioretention techniques, applicable to many locations in Seattle	Savings of $50,000 to $200,000 per city block over conventional development	
Meadow on the Hylebos[2] Pierce County, WA New construction	9-acre subdivision, 35 single-family homes	9 percent savings over conventional development	
Pembroke Woods[2] Emmittsburg, MD New construction	43-acre subdivision, 50 percent conserved as green space, 70 units on 0.5 acre lots	$420,000 savings over conventional development, plus 17 percent savings on pavement costs	

1. EPA, 2005a
2. Landers, 2004

LID construction costs and marketability are not a developer's only concerns. Permitting may be the biggest hurdle. Hinman (2001) suggests that both regulatory and institutional barriers can hinder LID implementation. Regulatory barriers are development codes that counter LID principles and practices. Institutional barriers include a lack of "technical understanding and the ability to review and approve projects" (Hinman, 2001, p. 88). Where these barriers are present, developers may be subject to additional permitting scrutiny normally not required for conventional design proposals (Arendt, 1996; Clar, 2005; CWP, 1998; Edde and Bicknell, 2004; Landers, 2004). This can be a disincentive for LID proposals, as extended permitting can raise costs and decrease profits. According to Larry Coffman, developers "don't care how they have to manage stormwater, as long as the permitting process is not burdensome" (as quoted in Landers, 2004, p. 57).

Local governments interested in promoting LID realize regulatory and institutional changes are needed and are developing new policies and technical guidance. Some western Washington jurisdictions are also considering incentive programs to encourage developers and homeowners to use LID. Some of these changes are discussed in the next section.

2.2.10 Regulatory Approaches to Promote LID

As described in the sections above, LID is best supported with policies and regulations that allow, promote, or require:

- preservation of natural areas and open space,
- flexible lot sizes and shapes,
- narrow or zero side yard set backs and shallow front and rear set backs,
- hybrid roadway networks,
- imperviousness reductions (narrow roadway widths, pervious paving),
- flexible parking standards for both residential and commercial zones,
- smaller building footprints (multi-story buildings and minimal excavation foundations),
- impervious surface disconnection,

- stormwater BMPs that include vegetated filtration and infiltration systems, on-site rainwater collection and reuse, and green roofs,
- effective construction site controls including erosion and sediment control,
- enforceable maintenance requirements, and
- education and outreach for public agencies, contractors and the general public.

Many local and state governments recognize the need for LID approaches and supporting policies. Huntersville, N.C. has passed an ordinance requiring LID in most new developments (Brewer and Fisher, 2004; Rozzelle, 2004). Several of the policy recommendations listed above are included in the ordinance. Institutional barriers were reduced with new technical manuals and a LID water quality model. Both tools provide necessary technical guidance to assist developers and permit reviewers with LID design development. According to Rozzelle, developers are adjusting to the new requirements and the city is seeing positive water quality effects (Landers, 2004).

In 2001 the City of Olympia, Washington adopted mandatory LID regulations in the Green Cove watershed (Haub, 2002). The new regulations were developed based on extensive analysis of Green Cove hydrology, environmental impacts from existing and anticipated development, and local design and development practices. The three-year process resulted in amendments to the Comprehensive Plan and the Olympia Municipal Code. Potential institutional barriers were addressed with new development guidelines and public works standards, and a drainage design and erosion control manual. There were some concerns the new regulations would deter developers; instead, several development plans for Green Cove “have been submitted and/or built” (Haub, 2004, p. 6).

The PSAT is currently assisting several western Washington counties and cities to revise local codes and building standards to promote LID (PSAT, n.d.). The revisions also address incentives for developers and homeowners. See Table 2.2-4. The program outcome is “ready-for-adoption ordinances and standards” (AHBL, 2006, p. 2). A free CD-ROM containing complete summaries of the policy-review process and resulting ordinances is available. See PSAT (n.d.) for ordering information.

2.2.11 Summary

This chapter has provided an overview of LID principles and recommended practices. Also considered are regulatory and institutional barriers that can hinder LID implementation. Alternatives are introduced. Together, these elements provide the foundation of the framework that will be used to review Spokane’s policies and regulations. However, LID application in Spokane must also be considered in the context of applicable federal and state regulations, Spokane’s existing stormwater infrastructure, and environmental conditions. These topics are discussed in Chapter 3. Having placed LID in Spokane-context, the policy review framework is described in Chapter 4.

Table 2.2-4. LID Incentives (AHBL, 2006, Appendix G)

Incentive	General Description	Justification	Costs	Developer Interest
Increased densities	Allow greater residential densities with the implementation of LID techniques	With more sensitive design the land is able to manage more units	Potentially greater impacts needing mitigation	High
Reduced review time or expedited review	Commit to a priority status on LID projects with a minimum time between receipt and review	LID projects may need special studies and reviews that must be identified early	Impacts to staffing resources and other project review schedules. Outside consultants could be used to expedite	High
Administratively approved rather than with hearing	Allow LID subdivisions up to 9 lots in size to be reviewed as short plats. Allow increased SEPA thresholds for LID projects	Lower impact results from LID projects and all reviewers may still provide input	Reduced process may create public perception issues.	High
Property tax reduction	Reduce or waive property taxes on LID projects for a given number of years	Lower service requirements result from lower impacts	Reduced revenues	High
Reduced application fees	Waive all or a portion of the submittal fees on LID projects	Due to lesser impacts to the community, lower fees are charged	Impacts to jurisdiction resources. May be offset by reduced habitat restoration and environmental costs	Medium - High
Public recognition	Emphasize LID projects on website, at Council meetings and in utility mailers	Highlight the great development projects going on throughout the area & create public awareness	Staff resource impacts	Medium
Dedicated review team	Create a LID review team that is familiar with and dedicated to LID projects	Specialized team with technical expertise necessary and more efficient assistance and review	Initial training of team members in LID techniques will be required in any event. Outside consultants could also be used - charge to applicant or paid for by jurisdiction	Medium
Flexibility in bulk, dimensional & height restrictions	Allow greater building heights and floor area ratios as well as reduced setbacks	Provides flexibility in overall site design. Allows reductions in building footprint. Addresses clustering needs	Consistency/compatibility with existing development and urban design goals	Low
Lower storm system development fees	Reduce charges when development meets thresholds	Lower impact to system capacity, so lower fees are appropriate	Reduced capital funds. Compensate by raising charges for conventional developments	Low

3 REGULATORY AND ENVIRONMENTAL CONTEXT FOR STORMWATER MANAGEMENT IN SPOKANE

This chapter begins with an outline of existing and emerging water quality regulations affecting Spokane (research question 3). The chapter continues with a review of regional watershed health, addressing surface and groundwater quality, as well as and aquatic and riparian habitat quality (research question 4). The chapter concludes with a discussion of the how low impact development can address Spokane's regulatory and environmental concerns (research question 5).

3.1 REGULATORY OVERVIEW

The primary federal legislation directly influencing Spokane's stormwater management includes the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA). Specific regulations include the National Pollutant Discharge Elimination System (NPDES) (P.L. 402), Total Maximum Daily Load (TMDL) program (P.L. 303(d)), and the Underground Injection Control (UIC) program (40 Code of Federal Regulations [CFR], 144). The CWA authorizes NPDES and TMDL, while the SDWA authorizes UIC. NPDES and TMDL affect pollutant discharges into surface water, while the aim of UIC is to protect groundwater quality. Through agreements with the EPA, the WSDOE administers NPDES and UIC in Washington State. NPDES is implemented under Chapter 173-220 Washington Administrative Code (WAC), and UIC under Chapter 173-218 WAC. The EPA administers TMDL. The Endangered Species Act (ESA) can indirectly influence Spokane's stormwater management through requirements for aquatic habitat protection. The ESA is administered by the US Fish and Wildlife Service (USFWS).

Applicable state legislation includes the State Water Pollution Control Act (WPCA, RCW 90.48), the Washington Growth Management Act (GMA, RCW 36.70) and the Washington Hydraulic Code (RCW 77.55). The WPCA sets standards for surface and groundwater quality. The GMA has important implications for both stormwater prevention and management policies. The Washington Hydraulic Code regulates projects that may alter aquatic beds or flow regimes of state waters.

3.1.1 National Pollutant Discharge Elimination System

Under NPDES, Phase I and Phase II permit programs regulate municipal separate storm sewer system (MS4) discharges. Federal law (40 CFR, 122.26(b)(8)), defines a MS4 as "a conveyance system including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains, owned or operated by a (public agency)… (and) designed for collecting or conveying stormwater" which discharges to waters of the United States. The Phase I and II programs do not regulate combined sewage discharge (sewer systems conveying both stormwater and sanitary sewage).

Phase I regulates cities and counties with MS4s serving populations over 100,000 (EPA, 2006a). Phase II applies to small MS4s serving populations between 10,000 and 100,000. Presently, Spokane manages stormwater with both combined sewers and MS4s. As of 2000, Spokane's MS4s served slightly fewer than 100,000 people, therefore Phase II requirements apply (Brown and Caldwell and URS, 2004). If the population using MS4s eventually exceeds 100,000, Spokane will likely be required to obtain a Phase I permit. Since Spokane may eventually fall under Phase I requirements, it is worthwhile to consider the implications of both permits.

In Washington, the core requirement of Phase I and II is the development and implementation of stormwater management programs. These programs are intended to reduce stormwater pollution to the maximum extent practicable (MEP) using all known, available and reasonable methods of prevention, control, and treatment (AKART) (WSDOE, 2006a). In most cases, insufficient data exists on which to base numeric stormwater effluent standards (EPA, 1996a). Instead, EPA allows local permitting authorities to "employ a variety of conditions and limitations in storm water permits including best management practices, performance objectives, narrative conditions, monitoring triggers, and action levels (e.g., monitoring benchmarks, toxicity reduction evaluation action levels) as the necessary water quality-based limitations" (EPA, 1996a, Answer 1). However, if periodic local reviews indicate water quality standards (WQS) are not being met, more stringent requirements such as numeric limitations could be imposed. Until then, municipalities are compliant with MEP and AKART provisions upon implementation of an approved stormwater management program.

In addition to minimum NPDES requirements, WSDOE has included a number of provisions for TMDL and state WPCA requirements, which include regulating discharges to groundwater that are not regulated by UIC. Table 3.1-1 shows a summary comparison of current Washington State Phase I and II permit requirements. At this time there is a single Phase I permit for western Washington. Because of their very different physical environments, separate Phase II permits were developed for eastern and western Washington. The Phase II permit for eastern Washington became effective February 16, 2007. Presently, there are no Phase I permits planned for eastern Washington. This could change, however, if the population in Spokane served by MS4s expands to more than 100,000.

Table 3.1-1. Comparison of WSDOE Phase I and Phase II Permits[1]

Stormwater Management Program	
General Requirement 1.	Implement a written stormwater management program (SMP) during the permit term that includes requirements to meet applicable TMDLs
Phase I Requirement	Establish legal authority to control discharge from permittee's MS4s.
Phase II Requirement	None
General Requirement 2.	Include structural BMPs[2] owned, operated, and maintained by permittee, plus tributary conveyances, associated drainage areas, and land use
Phase I Requirement	None
Phase II Requirement	None
General Requirement 3.	Provide ongoing opportunities for public participation in the permittee's stormwater management program, and make the SMP and supporting documentation available to the public through the permittee's or Ecology's website.
Phase I Requirement	None
Phase II Requirement	None
General Requirement 4.	Runoff control program (included in SMP) for new development and redevelopment
Phase I Requirement	a. Must include site planning process and BMP selection and design criteria (including on-site and regional structural stormwater controls) b. Program must allow LID (or similar) techniques c. Source control program requiring operational and structural source control BMPs and treatment BMPs if necessary d. Establish program to identify sites which are potentially pollution generating e. Establish a permitting, review, and inspection process operated by trained personnel f. Permittee must establish legal authority to inspect private stormwater facilities and enforce performance and maintenance standards
Phase II Requirement	a. Adopt an ordinance or other regulatory mechanism requiring post-construction stormwater controls that also maintain natural drainages to MEP and reduces the total amount of impervious surfaces created by the project. b. The ordinance must include BMP selection, design, installation, operation, and maintenance standards. Must also include requirements to implement runoff treatment, flow control, and source control based on land use. c. A source control program (like that described for Phase I) is not specifically discussed. d. Not required by Phase II permit e. Requirements similar to Phase I apply f. Permittee must establish legal authority to inspect private stormwater facilities and implement enforcement provisions. Ordinance may require private property owners provide annual certification by a qualified third party that system is operating as required.
General Requirement 5.	Construction site stormwater runoff controls
Phase I Requirement	a. Project size described in Phase I Permit Appendix 1 (WSDOE, 2006b) b. The SMP must include a program for stormwater site plan review, site inspection, training of review and inspection personnel, provisions to train project proponents in developing construction and erosion control plans, use of LID techniques and BMPs.
Phase II Requirement	a. For projects disturbing cumulative area of 1 or more acres b. Requirements similar to Phase I, but LID techniques and BMPs to mitigate runoff are not discussed.

Table 3.1-1 Comparison of WSDOE Phase I and Phase II permits[1] (continued)

Stormwater Management Program	
General Requirement 6.	Illicit discharge detection and elimination
Phase I Requirement	a. Permittee shall include an ongoing program to detect, remove, and prevent illicit connections and illicit discharges to MS4s owned and operated by the permittee. b. Permittee shall use illicit connection detection methods discussed in the Center for Watershed Protection's 2004 publication, Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments.
Phase II Requirement	a. Requirements similar to Phase I apply b. Phase II permittees may develop their own standards for detecting and addressing illicit connections.
General Requirement 7.	Operation and maintenance program
Phase I Requirement	a. The permittee shall include in the SWMP a program of maintenance activities for public an private stormwater facilities, a program to reduce stormwater impacts from permittee's streets and highways, a program to reduce application of pesticides, herbicides and fertilizers applied by permittee, and reduce impacts from heavy equipment maintenance and storage facilities owned an operated by permittee.
Phase II Requirement	a. Requirements similar to Phase I apply
General Requirement 8.	Education and outreach program
Phase I Requirement	a. Permitte shall implement or participate in a public education program to increase public and business persons' awareness of the importance of: water quality, reducing impervious surfaces, illicit discharges, stormwater impacts from landscape maintenance practices and household/commercial/industrial chemical use.
Phase II Requirement	a. Permittee must develop and implement a program to distribute educational materials to the community or conduct equivalent outreach about stormwater impacts, actions the public can take to reduce stormwater pollution and improve water quality, and help prevent illicit discharges. b. Permittee must identify and characterize target audiences within their jurisdiction and use a multimedia information distribution approach.
Monitoring	
Phase I Requirement	a. Permittee's shall implement a long-term monitoring program that includes stormwater monitoring, SMP effectiveness monitoring, and stormwater treatment and hydrologic management BMP evaluation monitoring. b. The types, numbers, locations of samples collected and parameters analyzed shall comply with specifications given in Phase I permit section S8.
Phase II Requirement	a. Permittee's are *not* required to perform water sampling or other testing during the effective term of this permit with the exception of monitoring required for TMDL compliance and illicit discharge characterization. B. Permittee will prepare for future, long-term monitoring by identifying appropriate outfalls and conveyances where sampling will occur, preparing a plan to determine effectiveness of permittee's SWMP, and preparing a plan to monitor the effectiveness of runoff treatment BMPs.

1. WSDOE, 2006b, c
2. Best Management Practices. BMPs may be structural or nonstructural, and may be vegetated.

3.1.1.1 Relationship between NPDES and LID

As Table 3.1-1 shows, Phase I compliance explicitly requires LID or similar techniques. Phase II does not discuss LID specifically. However, Phase II communities must adopt ordinances that protect natural drainages and minimize impervious surfaces. As described in Chapter 2, these development approaches are a normal part of LID site planning. While the Phase II permit does not explicitly address LID, the WSDOE includes a variety of LID approaches in the *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a). The manual was developed to support eastern Washington communities who must comply with NPDES requirements. In the manaul, LID techniques are repeatedly recommended as an effective way to prevent stormwater runoff and to manage runoff volume and stormwater quality. Communities are also encouraged to incorporate LID as policy into their local stormwater management programs. The primary concern is implementation of a stormwater management program that meets Phase II permit requirements. The stormwater program must be implemented no later than August, 2012 (WSDOE, 2007a).

3.1.2 Total Maximum Daily Load Program

Section 303(d) of the CWA requires all states to identify waters that do not satisfy the state WQS (EPA, 2006b). Surface WQS in Washington are defined by WAC 173-201A, and groundwater standards by WAC 173-200. For 303(d)-listed waters, states must determine the maximum amount of each pollutant the waterbody can tolerate from all sources while satisfying WQS. The “pollutant load” is then allocated among all point and non-point sources. Point sources include commercial, industrial, municipal and other operations that discharge pollutants at discrete locations (such as outfall pipes) (EPA, n.d.a). Non-point sources include runoff discharged via overland or groundwater flow from undisturbed lands, agricultural fields, streets, and landscaped areas.

The TMDL (also called the Water Cleanup Plan) identifies allowable pollutant loadings and how allocations will be achieved through practices and technologies to control pollutant discharges (EPA, n.d.b). EPA requires TMDL pollutant allocations be expressed in numeric form, but recognizes this can be difficult for stormwater (Wayland and Hanlon, 2002). For stormwater, EPA accepts a presumptive approach whereby TMDL pollutant allocations may be expressed in terms of BMPs rather than numeric effluent limits. For a specific discharge, it is presumed water quality criteria will be met if approved BMPs are implemented. EPA allows this as an interim approach, anticipating “that a suite of BMPs will be used in the initial round of permits and that these BMPs will be tailored in subsequent rounds” based on long-term monitoring results (Waylon and Hanlon, 2002, p. 4).

3.1.2.1 Relationship between Phase II and TMDL

Under Phase II rules, communities must comply with effluent limitations imposed by an approved TMDL (40 CFR 122.34(b)(6)). In eastern Washington, if a TMDL has less stringent requirements than Phase II, a community is in TMDL compliance when it meets Phase II requirements (WSDOE, 2007a). Currently, no Spokane-area TMDLs have more stringent requirements for stormwater than Phase II. If in the future TMDLs with more stringent requirements are approved, the WSDOE may modify the permit, listing new requirements in Appendix 2 of the Phase II permit (WSDOE, 2007a).

3.1.3 Groundwater Quality Protection and the Underground Injection Control Program

The SDWA authorizes the UIC program to protect groundwater that may be used as drinking water. UIC regulates stormwater that is disposed into the ground via injection (infiltration), or ‘UIC wells’ (WSDOE, 2006c). This method of stormwater disposal is common throughout Washington. Drywells and infiltration trenches fitted with perforated pipe are two common types of UIC wells. Infiltration BMPs fitted with perforated pipe are also UIC-regulated.

Stormwater discharged from a UIC well must not threaten groundwater quality. In general, if the soil below the UIC well has insufficient treatment capacity to manage the expected pollutant load, the stormwater must be treated (WSDOE, 2006c). Treatment is accomplished with stormwater BMPs approved by WSDOE. For low and medium pollutant loads, treatment may be accomplished with filtration and infiltration BMPs such as vegetated filter strips or bioretention cells. High pollutant loads may require treatment with oil-water separators or sand filtration systems. The UIC program references the WSDOE-approved stormwater management manuals for eastern and western Washington for specific BMP guidance.

In Washington, infiltration BMPs without perforated pipe are UIC-exempt under two conditions: 1) the BMP must be less than the largest surface dimension, and 2) the facility cannot be operated in stormwater discharge prohibition areas, such as vehicle maintenance yards (WSDOE, 2006c). UIC-exempt infiltration BMPs are regulated through Phase I and II (WSDOE, 2006a and b). EPA Phase I and II rules do not address groundwater quality, however, Washington’s Phase I and II permits are issued under joint federal and state regulations. The

State Water Pollution Control Act (Chapter 90.48 RCW) requires permits for waste disposal into any state water, including groundwater (WSDOE, 2006a).

3.1.4 Endangered Species Act

The ESA prohibits 'take' of an animal species listed as endangered or threatened (US Fish and Wildlife Service [USFWS], 2006). Section 3(19) of the ESA defines take as "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct". Harm includes death or injury to the animal and any significant habitat degradation that would impair its ability to survive and reproduce (50 CFR 222.102). The ESA includes provisions for designation of critical habitat areas, especially those necessary to conserve a listed species. Incidental species take can occur during otherwise lawful activities that result from development, commercial or industrial operations. Such take may be excused by one or more provisions of the ESA including: implementing species recovery plans (Section 4(F)) and habitat conservation plans (Section 10(2)(A)) (USFWS, 2006).

In western Washington several species of salmon are listed as threatened or endangered (Shared Strategy for Puget Sound [SSPS], 2005). Under the ESA, western Washington must implement a species recovery plan (SSPS, 2005). A significant part of the plan focuses on urban runoff. Implementing LID is encouraged to minimize the impacts on both habitat and water quality. Recovery plan developers are also working to link CWA and ESA requirements into a joint program which would simplify compliance with NPDES, TMDL, and ESA regulations.

While many of the listed species are known to exist in eastern Washington, no critical habitats for these species have been designated in Spokane County, nor along any stream reaches downstream of Spokane County (NMFS, 2005). In 2005, critical habitat for bull trout (*Salvelinus confluentus*) was designated in much of Washington State (50 CFR Part 17.95 (70FR 56265)).

Again, no reaches within or downstream of Spokane County were included in that designation. However, critical habitat designations are updated routinely. If Spokane eventually faces ESA species or habitat protection requirements, western Washington's experiences will provide useful guidance.

3.1.5 Washington Growth Management Act

In 1990, Washington enacted the Growth Management Act (GMA) in an effort to manage urban growth, sustain economic development, and protect and enhance Washington's environment and quality of life. Under the GMA, all counties are required to designate and protect critical environmental areas, natural resource lands, agricultural, and forestlands, as well as provide necessary public services and facilities for newly approved residential subdivisions (Washington State Department of Community, Trade, and Economic Development [WSDCTED], 2003a). Urban counties and inclusive cities including Spokane are required to:

- develop county-wide planning policies,
- adopt an urban growth boundary (UGB) and plan urban growth within the UGB,
- identify lands appropriate for public facilities (including stormwater facilities), and
- adopt and implement a comprehensive plan (WSDCTED, 2003a).

The comprehensive plan is the foundation of local policy and is implemented through plan-consistent zoning and regulations. At a minimum, the plan must address land use, utilities, housing, transportation, capital facilities, rural development (county-level only), and shorelines (as required by the Shoreline Management Act, RCW 90.58) (WSDCTED, 2003a). Comprehensive plans directly address local stormwater planning within the land use element.

Stormwater is addressed indirectly through the shorelines, critical areas and wildlife habitat protection elements. The comprehensive plan must include a review of drainage, flooding, and runoff issues, and provide guidance for corrective actions to mitigate or cleanse those discharges that pollute waters of the state (RCW 36.70A.070(1)). Among other elements, WSDCTED (2005) recommends comprehensive plans include provisions for:

- incorporating NPDES Phase II requirements into stormwater policy guidelines,
- creating stormwater guidance manuals (associated with Phase II),
- retaining pre-development hydrology,
- clearing and grading ordinances,
- minimizing impervious surfaces, and
- promoting low impact development.

3.1.6 Washington Hydraulic Code

The goal of the Washington Hydraulic Code is to preserve, protect, and perpetuate state fish and shellfish resources (Washington Department of Fish and Wildlife [WDFW], n.d.). Any construction project that will use, divert, obstruct, or change the bed or flow of state waters must obtain a Hydraulic Project Approval (HPA) permit. State waters include all state marine and fresh waters, but exclude entirely artificial waterways such as irrigation canals. When issued, HPA permits identify allowable construction activities and any required mitigation. WDFW does not have direct authority over stormwater programs, but does require HPA permit application for all stormwater projects that affect the bed or flow of state waters (CH2M Hill, 2001).

3.2 SPOKANE REGIONAL WATERSHED HEALTH

Urbanization's impact on water quality in the Spokane region has been a concern for decades. Stormwater quality gained attention in the late 1970's when it was discovered that stormwater was affecting groundwater quality (Esvelt, 1978). Most of the region depends on groundwater for drinking water. More recent investigations have revealed surface water quality impacts from industrialization, urbanization, and agriculture. These factors also affect riparian and aquatic habitats.

3.2.1 Watersheds Overview

The City of Spokane extends into four water resource inventory areas (WRIAs): 54 (Lower Spokane), 57 (Middle Spokane), 55 (Little Spokane), and 56 (Hangman). See Figure 3.2-1. A WRIA is the portion of a watershed that is partially or fully contained within state boundaries. As shown in Figure 3.2-1, WRIA's 55, 56, and 57 extend into Idaho. Regional average precipitation ranges from 15 inches annually at lower elevations to over 45 inches at higher elevations (Spokane County, 2005a, Spokane County Conservation District [SCCD], 2005a). Annual precipitation averages 16 to 18 inches within the City of Spokane (Kahle et al., 2005). The majority of precipitation (70 %) falls between October and March, with 25-40 percent as snow depending on elevation. Intense, short-duration storms are also common from April into June, and from late August through September. July and August are the driest months, receiving on average 0.76 and 0.68 inches of rain (National Weather Service [NWS] Forecast Office, n.d.a).

Figure 3.2-1. Spokane-area water resource inventory areas (WRIAs). Large portions of the Hangman Creek and Middle Spokane watersheds extend into Idaho. (Source: Map graphic, Author; GIS Data: Urban boundaries, courtesy City of Spokane; State and WRIA boundaries, Waterways, WSDOE, 2005c)

Major surface water bodies include the Spokane River, Little Spokane River, and Hangman Creek. Very few tributary streams exist within the city limits (Figure 3.2-3). In most locations, glacio-fluvial deposits containing little sand, silt, or clay below five feet subsurface make Spokane soils highly pervious (Spokane County, 1979; Spokane County, 2005a). Water collecting in drainages tends to infiltrate before reaching a higher order stream.

The other dominant water body in the region is the Spokane Valley – Rathdrum Prairie (SVRP) Aquifer, which underlies the majority of Spokane (Figure 3.2-3). The SVRP Aquifer is unconfined in sediments ranging from 150 to greater than 780 feet deep (Kahle, et al., 2005) and is estimated to contain approximately 10 trillion gallons of water (Spokane Aquifer Joint Board [SAJB], 2004). The SVRP Aquifer is the primary drinking-water source for over 500,000 people in Spokane County and adjoining Kootenai County, Idaho. In 1978 it was designated by the EPA as a sole source aquifer. In response to the sole source aquifer designation, Spokane has implemented an aquifer protection program (Spokane Municipal Code [SMC], 17E.010). Land areas in Spokane that directly recharge the SVRP Aquifer are designated aquifer sensitive areas, or ASAs (SMC 17A.020.010). ASAs require special consideration for stormwater management, which will be discussed more in subsequent sections.

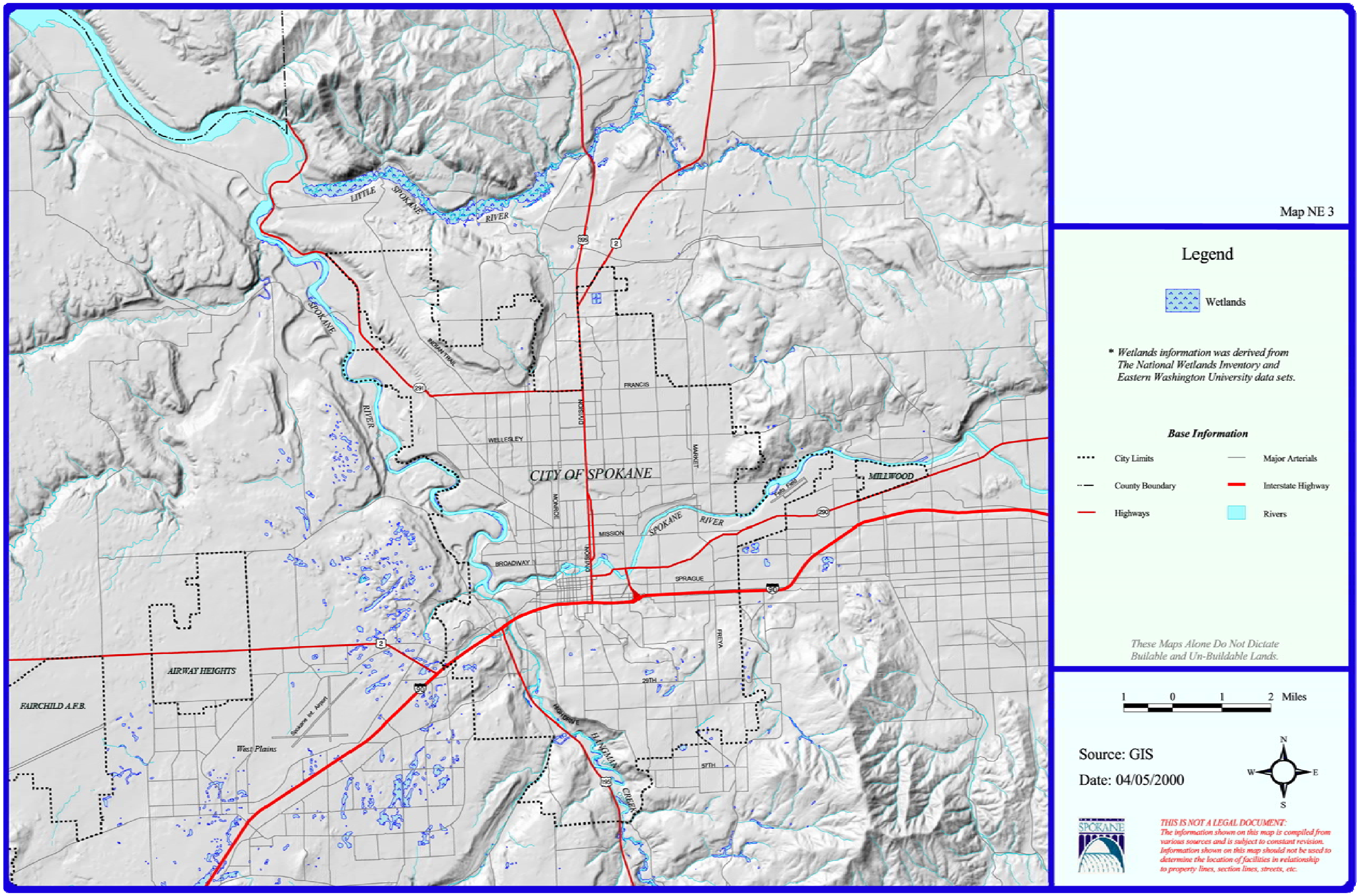

Figure 3.2-2. Surface water bodies in the Spokane region (Source: City of Spokane, 2000a, Map NE-3)

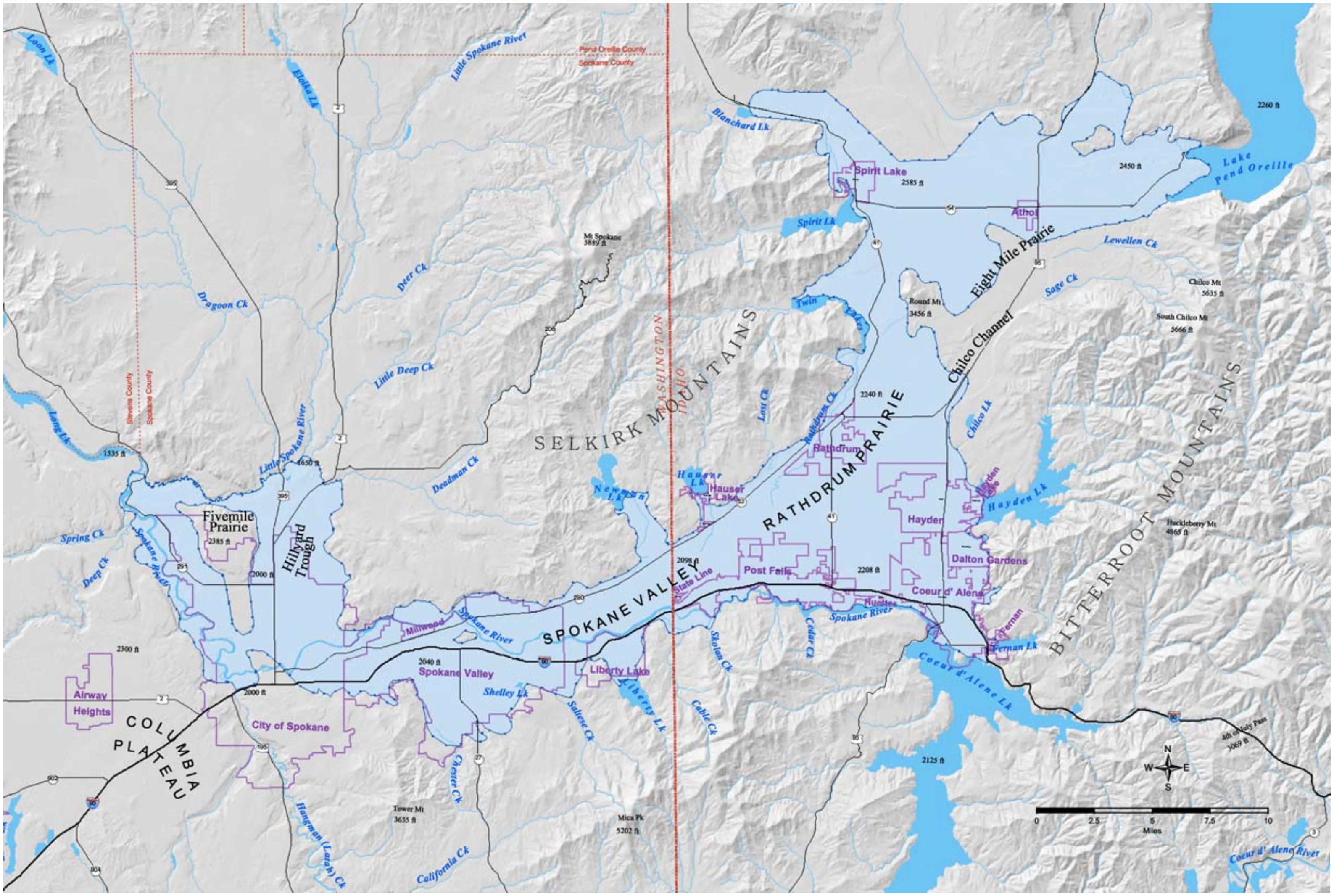

Figure 3.2-3. Spokane Valley-Rathdrum Prairie (SVRP) Aquifer (Adapted from: SAJB, 2004, p. 7)

3.2.2 Surface Water Quality

Local surface waters are used primarily for aquatic habitat, recreation, and agricultural irrigation (SCCD 2005a, Spokane County, 2005a). Drinking water is supplied by several aquifers, the SVRP Aquifer being the most important. Stormwater is disposed to both surface and ground waters (Brown and Caldwell and URS, 2004). Several reports indicate extensive surface water – groundwater interactions creating potential for cross-contamination (Kahle, et al., 2005; Molenaar, 1988; Spokane County, 1979 and 2005a).

The Spokane and Little Spokane Rivers and Hangman Creek fail State WQS for several parameters. TMDLs are in progress for all three streams. Table 3.2-1 lists constituents impairing water quality and current TMDL project status.

Dissolved metals, polychlorinated biphenyls (PCBs) and total dissolved gas concentrations in the Spokane River are attributed to current or historic commercial and industrial operations, including those in Idaho, which discharge into the Spokane River (WSDOE, n.d.a; WSDOE, 1999). While industrial facilities and municipal wastewater dischargers require permits addressing these compounds, no permits have been imposed for stormwater (WSDOE, 2007a).

Poor dissolved oxygen (DO) levels in the Spokane River are associated with nutrients (nitrogen and phosphorous) and biochemical oxygen demand (BOD) loadings from point and non-point sources (WSDOE, 2004c). Point sources include Spokane-area wastewater treatment plants and industrial operations. Non-point sources include river tributaries, combined sewer overflows (CSOs) and stormwater. Combined sewers contain both sanitary sewage and stormwater. Several times per year, the combined sewer system overflows, releasing untreated water containing raw sewage (CTE Engineers, 2005). Most frequently, CSOs occur during

Table 3.2-1. Spokane Area Water Quality Impairments

Waterway (WRIA #)	Constituent	TMDL Status	Stormwater Management Requirements[1]
Spokane River	DO	Draft TMDL published 2004[3]	None at this time
(54, 57)[2]	Dissolved Metals : Cadmium, Lead, Zinc	Approved August 1999	
	PCBs	In progress	
	Total Dissolved Gas	Addressed with Avista dam relicensing (Avista, 2005)	
	Temperature	Not yet scheduled (WSDOE, 2004b)	
	BOD	Addressed with Draft TMDL	
	Total Phosphorous	Addressed with Draft TMDL	
Little Spokane	DO	In progress	None at this time
River (55)[4]	Fecal coliform	In progress	
	PCBs	Addressed with Spokane River PCB TMDL (in progress)	
	pH	In progress	
	Temperature	In progress	
	Turbidity	In progress	
	Total Phosphorous	In progress	
Hangman Creek	Ammonia-nitrogen	Draft expected Fall 2006	None at this time
(56)[5]	Dissolved oxygen (DO)	(SCCD, n.d. a)	
	Fecal coliform		
	pH		
	Temperature		
	Turbidity/Sediment		
	Total phosphorous		
	Low flow		

1. WSDOE, 2007a
2. Constituents as described by WSDOE 1999, 2005a, and 2006b,
3. WSDOE, 2004b
4. Constituents as described by WSDOE, 2006b and Spokane County, 2005a (PCBs)
5. Constituents as described by SCCD, 2005b and WSDOE, 2006b.

large rain events when the system is inundated with stormwater. While Spokane's CSOs violate State WQS for frequency (see Section 3.2.4), the nutrient and BOD contributions from CSOs and stormwater are considered minor in comparison to other sources (WSDOE, 2004c). No stormwater TMDLs have been imposed, however, Phase II permitting requires periodic reassessments. Stormwater management requirements for the Spokane River could change depending on water quality improvements between Phase II permit renewal periods

Specific pollutant allocations for the Little Spokane River and Hangman Creek have not yet been finalized. Available Hangman Creek reports indicate water quality problems result primarily from middle and upper watershed forestry, farming, and livestock practices (Spokane County, 2005a; SCCD, 2005a and b). Contributions from urbanization and associated landscape practices (fertilizer use, riparian zone clearing) are present in the lower watershed reaches. No reports for the Little Spokane River TMDLs have been published at this time.

3.2.3 SVRP Aquifer Quality

Most Spokane County residents rely on the SVRP Aquifer for drinking water (SAJB, 2004). The SVRP Aquifer is held in highly pervious glacial flood deposits which readily support stormwater disposal via infiltration (Spokane County, 1979; Spokane County, 2005a). For decades, the City of Spokane and Spokane County have disposed large portions of runoff through drywells, and with minimal pre-treatment (Stan Miller, personal communication, July 16, 2006). Local studies in the 1970s revealed potentially serious SVRP Aquifer quality impacts from drywells and other subsurface waste disposal methods (Esvelt, 1978). Compared to unpopulated areas, dissolved solids, salts, nitrates, cyanide, mercury, and organochlorides were elevated in SVRP Aquifer waters under or near populated and industrial areas. Urbanization, waste disposal, and industrial practices over SVRP Aquifer recharge areas were identified as most detrimental.

Based on these findings, the City of Spokane and Spokane County initiated a stormwater quality treatment program in the early 1980s. Within ASAs, all stormwater disposed via infiltration must be treated with grassed percolation swales, also called ‘208 swales’ (Spokane County, 1979). Grassed percolation swales are roughly equivalent to bioretention cells (Section 2.2.5.2.1), and are now widely used throughout the Spokane region (Brown and Caldwell and URS, 2004).

Aquifer water quality monitoring is ongoing. The most recently reported results (Spokane County, 2004) show detectable levels of contamination, but none that require a cleanup response. As described in Section 3.1.3, ground disposal of stormwater continues to be regulated under UIC and Phase II requirements.

3.2.4 Stormwater

Spokane’s stormwater is disposed in three ways; though combined sewers, separated (stormwater only) sewers, and infiltration facilities (Brown and Caldwell and URS, 2004). Stormwater discharges to the Spokane and Little Spokane Rivers, Hangman Creek, and to groundwater, including the SVRP Aquifer. The combined sewer system receives stormwater from approximately 8,000 acres, primarily on the south side of the Spokane River (Figure 3.2-4) Approximately 9,900 acres are served by separated sewers. See Figure 3.2-5. Another approximately 4,000 acres are drained by drywells. Drywells installed after 1979 in ASAs are preceded by bioinfiltration swales (Brown and Caldwell and URS, 2004).

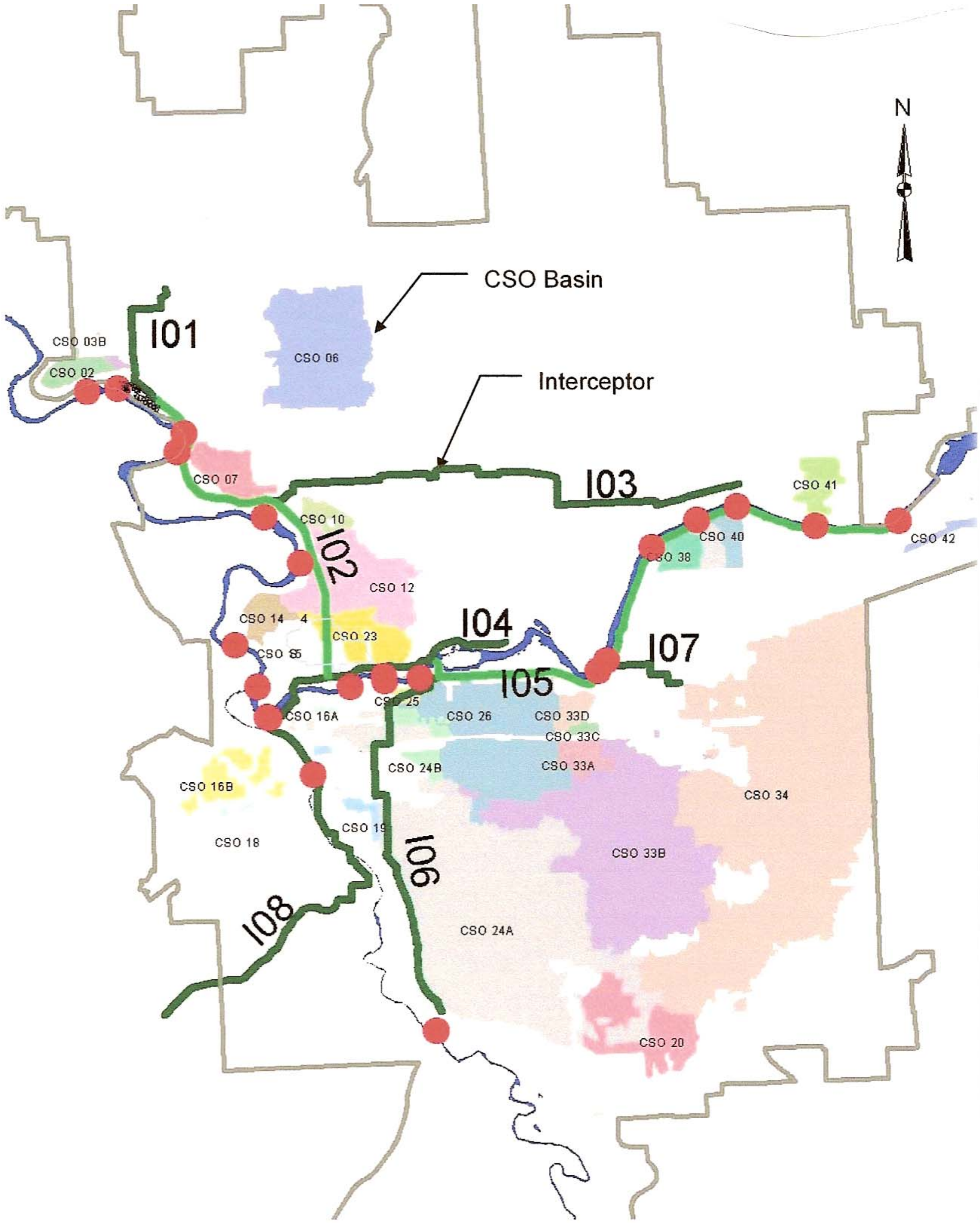

Figure 3.2-4. City of Spokane combined sewer system basins, interceptors, and outfalls (Source: CTE Engineers, 2005, p. ES-2)

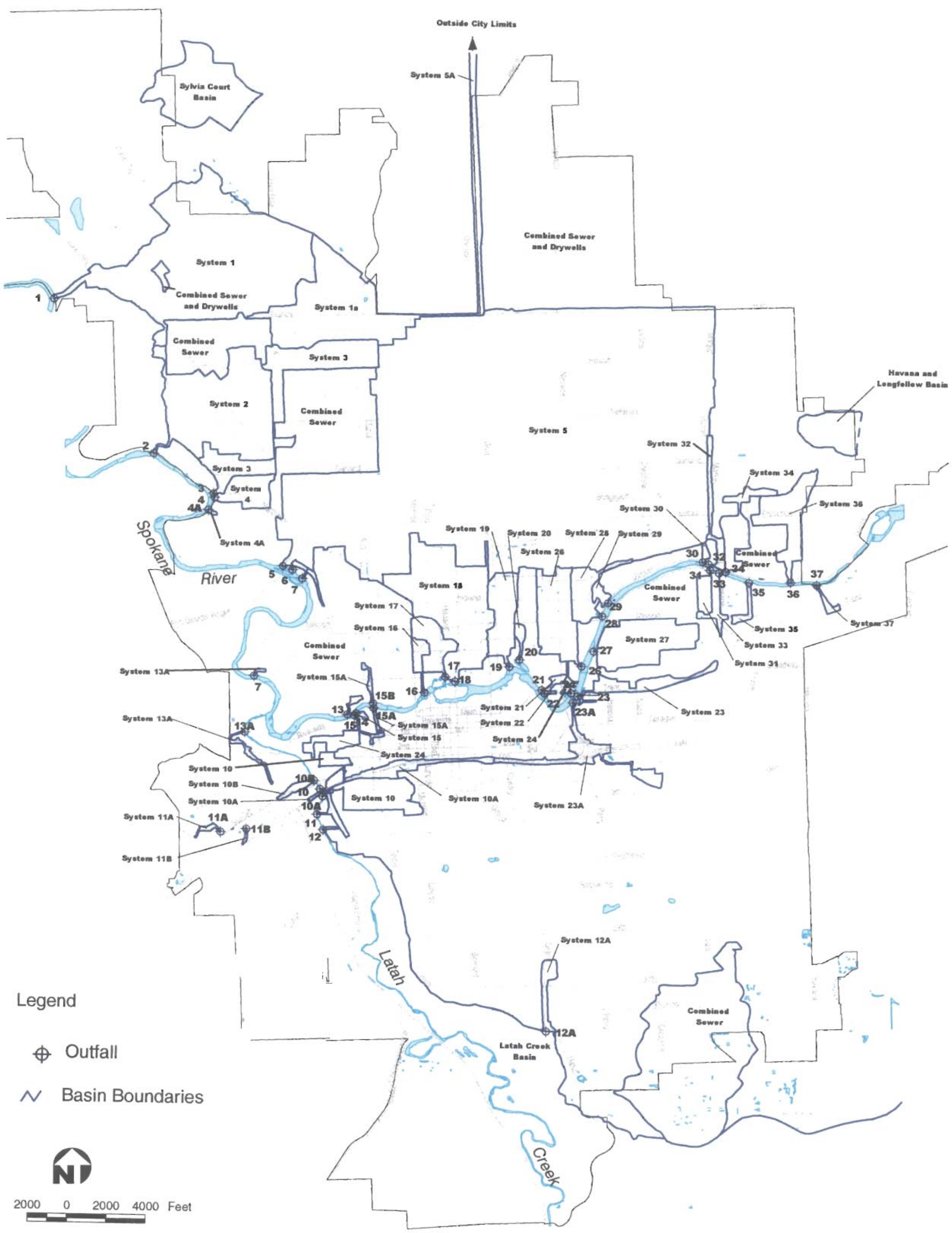

Figure 3.2-5. City of Spokane stormwater drainage basins (Source: Brown and Caldwell and URS, 2004, p. 2-21)

The combined sewer system is regulated under the City's NPDES permit for point source discharges (CTE Engineers, 2005). The separated storm sewer system is regulated under the Eastern Washington NPDES Phase II permit. Spokane's drywells are regulated by the UIC program. Bioinfiltration swales are UIC-exempt and are regulated by the Phase II permit.

Spokane's combined sewer system has a history of overflow events that violate state water quality standards (Brown and Caldwell and URS, 2004). A major abatement effort in the 1980's reduced CSO volumes by approximately 86 percent through a program that separated 64 percent of the combined sewer system (CTE Engineers, 2005). However, the City is still exceeding the WSDOE allowance of one CSO event on average per year (Chapter 173-245 WAC). CTE Engineers (2005) performed a study to identify best alternatives for reducing CSOs. Among a total of 67 alternatives, diverting part of the system flow to bioinfiltration swales was considered. The CSO report does not go into detail, but bioinfiltration swales were eliminated from consideration. The most favored alternative was increasing the storage capacity in the system's interceptor pipes and it appears the City is proceeding with this alternative. However, the report also noted that forthcoming TMDL requirements may result in more stringent system and treatment controls that will affect at least parts of the combined sewer system. Once these requirements are implemented, the City must again re-evaluate CSO alternatives (CTE Engineers, 2005).

Extensive urban runoff monitoring was performed in Spokane in the 1970's and 1980's (Brown and Caldwell and URS, 2004). With the exception of lead, Spokane's runoff quality is similar to other U.S. cities. See Table 3.2-2. Spokane's lead data is from 1983, when leaded gasoline was still in common use. Brown and Caldwell and URS (2004) speculate that current lead concentrations in Spokane's runoff are lower than in 1983.

Table 3.2-2. Comparison of Stormwater Runoff Concentrations (Brown and Caldwell and URS, 2004, p. 215)[1]

Land Use	Spokane (1983)	Boise (1993-94)	Oregon ACWA(1990-96)	City of Stockton (1993)	Fresno (1981-83)	NURP[2] (1983)
Residential						
Copper (ug/L)	20	19	10	11	14	33
Lead (ug/L)	40	20	10	15	170	144
Zinc (ug/L)	60	223	69	119	90	135
COD (mg/L)	89	210	33.4	74	95	73
TDS (mg/L)	44	79	n/a	65	34	n/a
Total P (mg/L)	0.28	0.52	0.15	0.37	0.39	0.38
TKN (mg/L)	1.65	2.4	0.84	1.9	2.7	1.9
Nitrate-N (mg/L)	0.79	1.06	0.37	0.42	0.49	n/a
Commercial						
Copper (ug/L)	40	62	22	19	18	29
Lead (ug/L)	400	63	26	24	100	104
Zinc (ug/L)	290	590	115	194	150	172
COD (mg/L)	215	635	47.2	71	63	57
TDS (mg/L)	182	199	n/a	50	29	n/a
Total P (mg/L)	0.39	1.36	0.21	0.33	0.25	0.20
TKN (mg/L)	2.30	5.6	1.00	1.6	2.3	1.20
Nitrate-N (mg/L)	0.83	1.33	0.36	0.39	0.41	n/a
Industrial						
Copper (ug/L)	70	n/a	32	16	66	n/a
Lead (ug/L)	530	n/a	21	14	74	n/a
Zinc (ug/L)	300	n/a	251	139	535	n/a
COD (mg/L)	270	n/a	68.8	84	490	n/a
TDS (mg/L)	113	n/a	n/a	105	165	n/a
Total P (mg/L)	0.70	n/a	0.38	0.43	6.3	n/a
TKN (mg/L)	2.31	n/a	1.53	1.9	24	n/a
Nitrate-N (mg/L)	0.78	n/a	0.30	0.63	1.0	n/a

ug/L = micrograms per liter

mg/L = milligrams per liter

1. This is a rough comparison as sampling procedures and storm events differ between sources. The Spokane and Boise data are average concentrations; the ACWA, City of Stockton, and Fresno are median concentrations.
2. NURP = National Urban Runoff Program

To address lead and other data gaps, Spokane has implemented a limited stormwater monitoring plan. A complete analysis of recent data has not been published (Lars Hendron, personal communication, July 28, 2006), therefore it is unknown if Spokane's stormwater quality is still comparable to other U.S. cities. In the immediate term however, numeric stormwater quality will probably not affect stormwater management approaches in Spokane. As discussed previously, current Phase II and TMDL requirements do not impose numeric stormwater limitations. Recent data will be more important over the long term for monitoring requirements, or if the population served by Spokane's MS4 exceeds 100,000 and triggers Phase I compliance. Anticipating this possibility, Spokane is not planning any new separate sewers, though extensions may be allowed in some areas (Lars Hendron, personal communication, May 25, 2006). However, the City of Spokane's population is expected to reach approximately 250,000 by 2020 (Spokane County, 2005a). It seems likely that existing stormwater and combined sewer system management approaches will continue to be challenged.

3.2.5 Riparian and Aquatic Habitat Summary

Few minor streams exist within Spokane city limits, but there are several small wetlands, and more are known in the West Plains area outside of city limits (Figure 3.2-2). While it seems likely that there has been urban and stormwater impact to these waters, no reports describing potential or actual impacts were identified in the literature. The sections below describe known riparian and aquatic habitat conditions for the Spokane and Little Spokane Rivers, and Hangman Creek.

3.2.5.1 Spokane River

Much of the entire Spokane River is under high development pressure (SCCD, 2005c), which has significantly changed the river's character. The Post Falls Hydroelectric Dam (HED) in Idaho regulates the river's flow regime from four to six months a year (Spokane County, 2005a). This dam and other HEDs nearer the City of Spokane have altered sediment distributions necessary for spawning habitat (Whalen, 2000). Most of the river's banks are considered stable, but riparian areas are significantly reduced, leaving some sections susceptible to erosion (SCCD; 2005c). Development has reduced shade cover both adjacent to the river and upland. Reduced shade cover leads to faster snow melt, flashier spring flows and low late-summer base flows (Whalen, 2000). These processes have not been quantified, yet probably have contributed to increased average water temperatures and lower DO levels. While fish still exist in the Spokane River, Whalen (2000) notes that low flows, high temperatures, low DO, and toxic chemical concentrations limit aquatic community success.

Fish communities require minimum stream flows to complete their life cycle. If flows are too low, certain species may be unable to spawn, or even obtain enough oxygen to breathe (Whalen, 2000). In 1999, WSDOE recommended 2,000 cubic feet per second (cfs) minimum flow for fish habitat (Spokane County, 2005a). The river's yearly average flow exceeds this recommended minimum, but the 7-day average low flow has declined to approximately 800 cfs in the last 10 to 15 years (Figure 3.2-6). Not all causes for the decline are understood. One factor seems to be the SVRP Aquifer withdrawal rates. Hydrologic modeling shows that when SVRP Aquifer pumping is 360 cfs in July and August, Spokane River peak flow decreases by 206 cfs in August (Spokane County, 2005a). Similar changes are noted by the model in winter months.

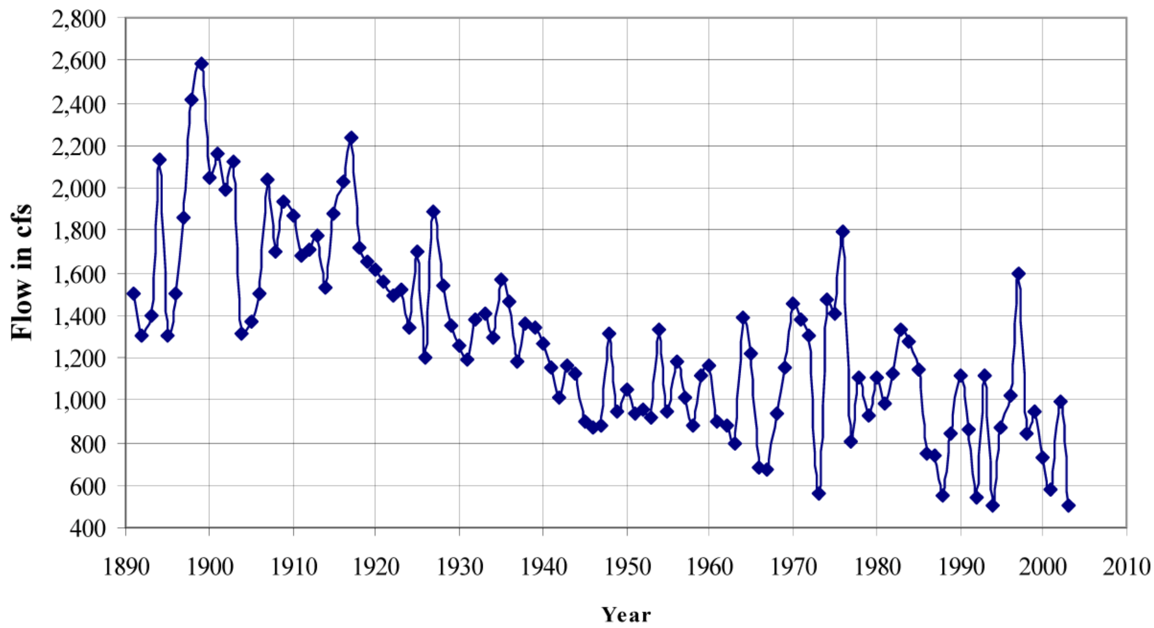

Figure 3.2-6. 7-day average low flow of Spokane River at the Spokane gage (Source: Spokane County , 2005a, p. 50)

3.2.5.2 Little Spokane River

Far less development exists along the Little Spokane River, most being rural residential. Although the population is increasing, the SCCD (2005c) considers the development pressure overall to be moderate to low. Compared to the Spokane River or Hangman Creek, more segments of the Little Spokane are rated being in good ecologic condition (SCCD, 2005c). However, riparian vegetation loss and erosion are present in reaches containing livestock operations, shoreline development, road and rail development, and golf courses. Specific water quality impacts from development are under study as part of the TMDL process and have not yet been published (WSDOE, 2006d).

The watershed management plan for WRIA 55 (Spokane County, 2005a) discusses water availability. Monthly minimum instream flow was established in 1976. Studies in 2003 confirmed instream flows were adequate to protect fish habitat at 3 of 4 locations. Studies were not completed for the fourth location. Stream flow records show the 7-day average low flow was below the minimum instream flow 15 times between 1976 and 2004 (Figure 3.2-7). Little Spokane flows are influenced by groundwater pumping, but the effects are delayed by approximately 5 months. The decreases in stream flow due to pumping are highest in January (approximately 13 cfs), and lowest in June and July (approximately 6 cfs). The WSDOE currently limits water rights on the Little Spokane, and is issuing no new rights for irrigation wells. However, there is no limitation on domestic wells. Current domestic well withdrawal rates nearly equal those of irrigation wells. Some wells run dry during years with low precipitation.

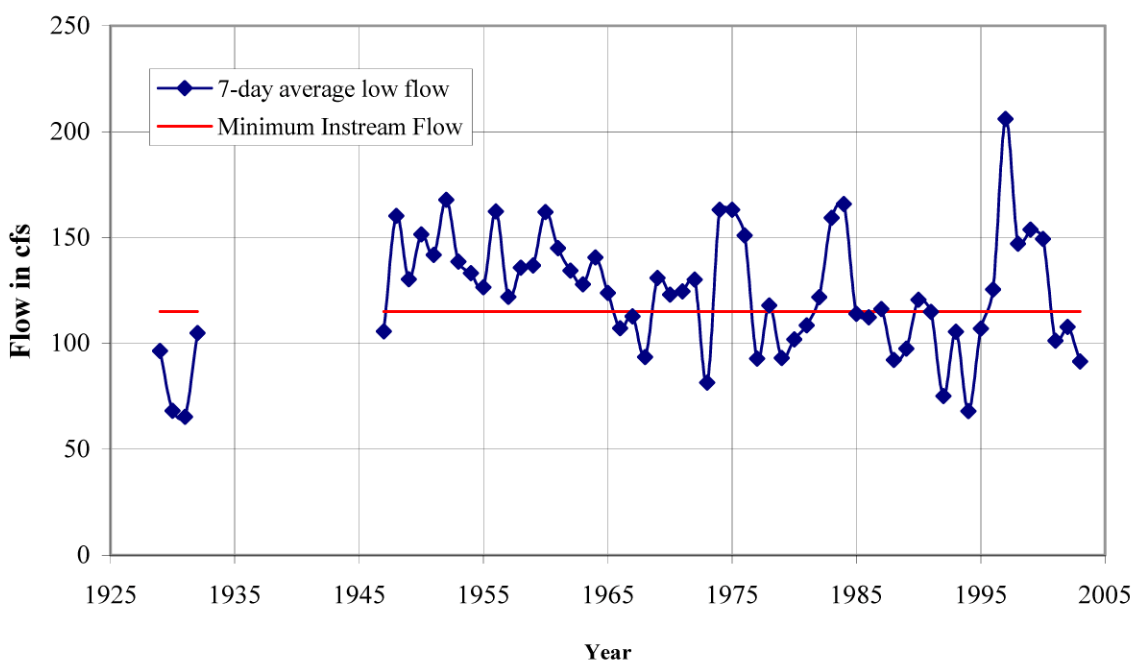

Figure 3.2-7. 7-day average low flow of Little Spokane River at the At Dartford gage (Source: Spokane County , 2005a, p. 52)

3.2.5.3 Hangman Creek

Hangman Creek is considered one of the most degraded streams in eastern Washington (SCCD, 2005c). Only 10.1 of the creek's 46.7 miles are rated as having a 'good' ecological condition. Forestry practices have exposed soils in the system's upper reaches, and middle reach riparian areas have been cleared to the stream edge for cropland (SCCD, 2005a; Whalen, 2000). Lower reaches of Hangman Creek, from approximately river mile 14 to the mouth, lie in the southwest quadrant of the City of Spokane. This area is expected to absorb approximately 50% of Spokane's population growth through 2010 and is the section of Hangman Creek under greatest development pressure (SCCD, 2005a). Roads, and residential and golf course landscapes are encroaching on shorelines in this segment (SCCD, 2005c).

The combined land uses in the Hangman Creek watershed have contributed to increased flooding, erosion, turbidity, channel instability, and water temperatures and have helped decrease stream base flows, DO, and general water quality (SCCD, 2005a, Whalen, 2000). Optimum flow levels for salmonid habitat are achieved less than 5% of the time July through October (SCCD, 2005a). Water resources for human use already exceed typical summer water flow. Hangman Creek is not associated with the SVRP Aquifer, and no significant groundwater sources that influence the Creek's flow exist in the lower reaches (SCCD, 2005a). Most of the population in this area uses water supplied by the City of Spokane from the SVRP Aquifer. Short of artificial storage or increased precipitation, there is little that can be done in the lower reaches to increase Hangman Creek flows (SCCD, 2005a).

3.2.6 Development in the Watershed Context

As shown above, development is affecting Spokane's natural environment. Studies in other regions suggest that limiting development, particularly in the most sensitive watersheds, may reduce future aquatic impacts (Arnold and Gibbons, 1996; Booth et al., 2002; May et. al., 2000; Schueler, 1995). Schueler (1995) refers to this as the watershed-based zoning approach.

Watershed-based zoning protects the most sensitive areas while still allowing growth and development. Watersheds are evaluated at the subwatershed scale (1 to 10 square miles) to determine their sensitivity to future development. Sensitive subwatersheds are those exhibiting good pre-development hydrology, or at least minimal impacts from development. In Schueler's scheme these subwatersheds should be maintained at 10% or less impervious cover. Degrading subwatersheds (11-25% imperviousness) exhibit decreased water and habitat quality, yet support some biodiversity. Non-supporting subwatersheds (26-100% imperviousness) support little aquatic life or species diversity. Once subwatersheds have been categorized, future development can be directed away from sensitive subwatersheds into non-supporting and degrading subwatersheds.

Some have expressed concern that this scheme can promote low-density development, leading to sprawl, adverse environmental impacts and economic strain (EPA, 2005b, Randolph, 2004). Sprawl can be avoided if watershed-based zoning is paired with policies addressing compact development and flexible density standards. As explained in Chapter 2, compact development minimizes impervious surface and can protect natural areas. Policies for sensitive subwatersheds could require an overall low development density, concentrated through compact development into a small percentage of the subwatershed's land area. To avoid penalizing existing landowners who want to develop, while still supporting regional growth, a system allowing development transfers can be established (Randolph, 2004). In this system, the right to develop is transferred from one parcel to another. The landowner of the original parcel is paid for the development right, and development density on the original parcel is kept low.

The watershed-based zoning concept has merit, but in addition to imperviousness, should consider local biophysical conditions and stormwater management practices (Bledsoe, 2001; Hinman, 2005). For sensitive Puget Sound subwatersheds, Booth et al., (2002) suggest retaining 50 percent or more of the existing forest-cover and limiting total imperviousness to 20 percent. Booth states that these strategies should also be combined with stormwater infiltration and detention. Like Schueler, they also note that full protection of hydrologic and ecologic function is not possible in more developed areas. In these areas, minimizing stormwater impacts is the only reasonable goal. Therefore at higher densities, there must be greater reliance on comprehensive LID strategies and structural stormwater controls (Hinman, 2005; Schueler, 1995).

The City of Olympia and Thurston County, Washington recently have adopted new LID policies (Haub, 2001), and in the process have applied the watershed-based zoning concept. Local policies had included goals to accommodate growth as well as protect designated critical areas and water quality. However, a detailed local watershed study concluded that these goals could not be realized adequately in all areas. Further analysis suggested specific watersheds where new zoning and development standards had best potential to protect environmental quality. The City and County elected to designate one watershed, Green Cove Creek, as a sensitive drainage basin. The majority of the basin lies in Thurston County, with the remainder inside Olympia city limits. Both jurisdictions amended their comprehensive plans to include a 'sensitive drainage basin' designation. This was is in addition to other critical areas designations. The amendments specifically address development density and LID. The amendments were implemented through specific land-use regulations, street and lot design standards, and stormwater and site construction standards.

Suggestions for how Spokane might apply watershed-based zoning and LID are provided below.

3.2.7 A Framework for LID in Spokane

As described in Section 3.1, federal and state regulations provide Spokane with incentives for a LID-based stormwater management approach. Local studies described in Section 3.2 verify measurable environmental effects have resulted from development and that must be addressed. Stakeholders in WRIAs 55, 56, and 57 recommend planning, conservation, and corrective actions to assure adequate water quantity and quality for all needs (Spokane County, 2005a, SCCD, 2005a and c). The SCCD (2005a) also recommend that the city and county jurisdictions coordinated planning efforts with watershed stakeholders to address growth and development. Given these considerations, Spokane’s situation presents an excellent opportunity for watershed-based zoning and comprehensive LID approaches.

The SCCD (2005c) indicates WRIA 56 (Hangman Creek) shorelines are in poorer condition overall than WRIA 55 (Little Spokane), and have a lower restoration potential due to natural and land use conditions. Available information suggests WRIA 55 could be categorized as sensitive and WRIA 56 as degrading. WRIA 57 is most likely degrading or non-supporting. Under Schueler’s scheme development should be directed first toward WRIA 57, then 56, and lastly to WRIA 55. But growth must be managed properly to minimize impacts. Subwatershed analysis in all 3 WRIAs would reveal which areas are best suited for development and at what densities development should proceed. As has been suggested earlier, not all LID stormwater controls are appropriate for every site. Subwatershed analysis will also help identify the best controls for a given area. Additional considerations for LID application in Spokane are discussed below.

Spokane currently uses one LID strategy, infiltration, to dispose a large portion of the city's stormwater. Newer infiltration systems within ASAs include bioinfiltration for water quality treatment. However as suggested in Section 3.2, these practices alone may not be enough to manage all of Spokane's existing and emerging stormwater issues. Reducing imperviousness will generate less total stormwater, which will reduce the need for stormwater management facilities. Open space conservation and compact development standards promote reduced imperviousness. Effective imperviousness can be reduced with pervious pavement, green roofs, and pin foundation systems.

Rainwater re-use also offers benefits. During summer months in Spokane, demand for landscape irrigation water is high in Spokane can double or triple SVRP Aquifer withdrawal rates (SAJB, 2004; Spokane County 2005a). Stuart (2001) estimates between 10,000 and 20,000 gallons annually are needed per residence in western Washington for irrigation alone. Spokane's climate differs somewhat from western Washington, yet the two regions' summer rainfall totals are similar. Rainfall at the Seattle-Tacoma airport averages 1.48, 0.79, and 1.02 inches for June, July, and August (NWS Forecast Office, n.d.b). Spokane's average rainfall for the same period is 1.18, 0.76, and 0.68 inches (NWS Forecast Office, n.d.a). Since most of Spokane's precipitation occurs outside of the growing season; large cisterns would be necessary to store adequate irrigation water. Widespread use of this approach, however, could offset some of the summertime SVRP Aquifer withdrawals.

The positive impacts of cistern use could be even more pronounced in the areas of Spokane that are built over soils with limiting layers (e.g., shallow bedrock, clay, shallow groundwater). Moran Prairie is one example. Stormwater management via infiltration is a common practice in Moran Prarie, but has been applied in areas with low subsurface storage capacity (MWH and Woodward-Clyde, 2002). A number of problems have resulted:

- stormwater infiltration into sewer systems which contributes to CSOs,
- standing water in stormwater swales and drywells,
- soggy yards and surfacing springs, and
- water infiltration into basements and crawl spaces that must be removed with pumping.

Overwatering of landscapes is suspected of contributing to these problems (MWH and Woodward-Clyde, 2002). If Moran Prairie residents used local groundwater for irrigation the problems listed above might be less pronounced. If sufficient local groundwater were withdrawn, depths to remaining groundwater would increase. Some of the withdrawn water would be lost to evapotranspiration, returning less water to the ground than was withdrawn. The common practice of most Moran Prairie residents, however, is to irrigate with imported municipal water from the SVRP Aquifer. This effectively increases the total amount of water dispersed to local soils beyond that which is normally intercepted under natural rainfall conditions. In a region with limited subsurface capacity it is not surprising that saturated surface soils and property damage have resulted. A prevalence of cistern use would provide two benefits: 1) less water would be disposed to the ground during the wet season, potentially decreasing the frequency and severity of soil saturation; and 2) stored water used for irrigation would reduce withdrawals from the SVRP Aquifer.

In dense urban developments there may be less need for irrigation. However, larger stormwater volumes are generated from rooftops in this setting. Dense development also provides less space for bioinfiltration systems to manage runoff as it is generated. For this situation, cisterns could be used purely as detention systems to supply small bioinfiltration systems at a manageable flow rate. Alternatively, exfiltration BMPs could be used where infiltration is impractical. As mentioned in Section 2.2.5.4, another option is to use detained water for toilet flushing.

Cisterns seem to offer benefits, but groundwater recharge must also be considered, particularly to the SVRP Aquifer. When properly applied, most irrigation water is lost to evapotranspiration (Terrell, n.d.). Therefore, water detained in cisterns and used for irrigation could potentially reduce recharge to the SVRP Aquifer. However, existing hydrologic models also show little delay between SVRP Aquifer withdrawals and reduced flows in the Spokane River (Section 3.2.5.1). Reduced summer withdrawals afforded by cisterns may have a more positive impact on Spokane River water volume and flow than potential recharge losses. A similar approach that diverts and temporarily stores river water is already being discussed to address low flows in the Little Spokane River (Spokane County, 2005a). In order to verify the benefits and potential drawbacks of widespread cistern-use, detailed water balance modeling is needed.

LID is a useful approach in new developments, but it is also applicable to redevelopment and wherever stormwater retrofits are necessary. In these situations, natural area conservation may be less practical, but there are opportunities for imperviousness reduction and LID stormwater controls. Seattle has retrofitted several streets with bioinfiltration systems (Horner et al., 2004; Seattle Public Utilties, n.d.; Dunphy and Ford, n.d.). The SEA Streets retrofit project in Seattle also reduced imperviousness by reducing the street width to 18 feet. A former low-income housing project in West Seattle has been redeveloped and includes extensive LID strategies (Staeheli, 2004). Portland's Green Streets project encourages retrofitting streets with biofiltration and infiltration systems to reduce CSOs and pollutants disposed in rivers and streams (Arvidson, 2004; Portland Bureau of Environmental Services, 2007). Portland also encourages green roof installation.

LID retrofits that include pervious paving, bioinfiltration, green roofs and cisterns could reduce the load on Spokane's MS4 and the combined sewer system. LID retrofits are not inexpensive, and due to their dispersed nature cannot be implemented quickly. Spokane's immediate need to reduce CSOs likely will require conventional engineered solutions. However, as suggested in Section 3.2.4, Spokane's growth will continue to create water management challenges. With thoughtful planning and supportive policies, LID has the potential to gradually reduce current and future loads on municipal sewers as well as the region's water resources.

This analysis shows that the City of Spokane can realize stormwater, as well as wastewater and habitat quality benefits from LID. What must be considered now is whether local policies and regulations support LID. The next chapter describes the policy review framework that will be used for this determination.

4 METHODOLOGY

In Chapter 2 typical LID strategies, design and policy considerations were described. Chapter 3 built an argument for specific ways LID can help Spokane meet its regulatory and environmental needs. Two research questions posed in Chapter 1 remain:

1. Do locally applicable policies and regulations support LID?
2. In what ways should the City of Spokane consider changing its policies and regulations to implement LID?

For question 1, written policy and regulations will be reviewed. Spokane's policies are defined in the *City of Spokane's Comprehensive Plan* (City of Spokane, 2001), and implemented through regulations contained in the Spokane Municipal Code (SMC). Some city codes also refer to technical guidance manuals. Developers must comply with conditions defined by applicable guidance documents. These guidance documents will be reviewed. Some of the LID strategies (Chapter 2) are not addressed by the SMC or other local guidance, but have state-level requirements. Local and state codes and guidance documents will be reviewed for LID planning and implementation considerations described in Chapters 2 and 3. Table 4-1 outlines the review framework.

Answers to Question 2 will be informed by the policy review. For each LID measure, the review will show whether and how locally-applicable regulations parallel or diverge from recommendations given in Chapters 2 and 3. Where divergence is found, or no regulations exist, recommendations for LID-supportive approaches will be provided.

Table 4-1. Policy Review Framework

Issue	Applicable Policy, Codes and Guidance Documents[1]
Spokane Policy	
Does the comprehensive plan address LID principles and practices?	*City of Spokane Comprehensive Plan* (City of Spokane, 2001)
Site Hydrology	
What are the requirements, if any, for post-development runoff volume and rate? What hydrologic analysis methods are required or recommended?	SMC Title 17D.060 Stormwater Facilities *City of Spokane Design Standards* (City of Spokane, 2000b) *Guidelines for Stormwater Management* (Spokane County, 1998) *Spokane Regional Stormwater Manual, 2005 Public Review Draft* (Spokane County et al., 2005)
Conservation	
How do regulations address protection and/or restoration of environmentally sensitive areas and areas with high hydrologic function? Do regulations provide for ways to limit the development envelop? Do regulations support conservation programs?	SMC Title 11.15 Shoreline Management SMC Title 11.19 Zoning Code SMC Title 17D.060 Stormwater Facilities SMC Title 17E.050 State Environmental Protection Act (SEPA) SMC Title 17G.070 Planned Unit Developments
Site Planning	
How do regulations address buffer zones between developed and natural areas? What are the requirements for lot size, shape, and setbacks? What are the street design standards in terms of roadway network, width, curb and gutter? What are the parking allocations and space requirements for on and off-street parking, including residential driveways? How is impervious surface reduction addressed? How is pervious paving addressed?	SMC Title 11.19 Zoning Code SMC Title 17C.110 Residential Codes SMC Title 17C.230 Parking and Loading SMC Title 17G.070 Planned Unit Developments SMC Title 17G.080 Subdivisions SMC Title 17H.010 Street Development Standards *City of Spokane Design Standards* (City of Spokane, 2000b) *Spokane Regional Stormwater Manual, 2005 Public Review Draft* (Spokane County et al., 2005) *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a)
Stormwater Controls	
Do stormwater control system requirements include or allow LID or similar approaches?	SMC Title 17D.060 Stormwater Facilities *City of Spokane Design Standards* (City of Spokane, 2000b) *Guidelines for Stormwater Management* (Spokane County, 1998) *Spokane Regional Stormwater Manual, 2005 Public Review Draft* (Spokane County et al., 2005) *Introduction to Washington Water Law* (Washington State Office of the Attorney General, 2000)

Table 4.1 Policy Review Framework (continued)

Issue	Applicable Policy, Codes and Guidance Documents[1]
Construction Site Controls	
What are the requirements for construction site erosion and sediment control (ESC), including inspection and maintenance of ESC systems? How is ESC enforced?	SMC Title 17D.060 Stormwater Facilities, *Construction Stormwater General Permit* (WSDOE, 2005b) *Eastern Washington Phase II Municipal Stormwater Permit* (WSDOE, 2007a) *Guidelines for Stormwater Management* (Spokane County, 1998) *Spokane Regional Stormwater Manual, 2005 Public Review Draft* (Spokane County et al., 2005) *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a)
Maintenance	
What are the maintenance requirements for on-site stormwater management systems? Who has primary responsibility for maintenance? How is maintenance enforced?	SMC Title 17D.060 Stormwater Facilities *Eastern Washington Phase II Municipal Stormwater Permit* (WSDOE, 2007a) *Spokane Regional Stormwater Manual, 2005 Public Review Draft* (Spokane County et al., 2005)
Education	
What programs are planned to educate the public about stormwater and stormwater management? What programs are planned to educate designers, developers, and contractors about stormwater management?	*City of Spokane Stormwater Management Plan* (Brown and Caldwell and URS, 2004) *Eastern Washington Phase II Municipal Stormwater Permit* (WSDOE, 2007a)

1. Other documents referenced by Code or listed guidance manuals will also be reviewed as needed.

4.1 REGULATIONS IN TRANSITION

It should be noted here that Spokane's stormwater regulations are in a transitional stage. Currently, the City's stormwater regulations are addressed in SMC Title 17D.060, Stormwater Facilities, plus a set of standard references defined in SMC 17D.060.030B. The standard stormwater references pertinent to this study include the:

- *City of Spokane Design Standards* (City of Spokane, 2000b),
- *City of Spokane Standard Plans* (City of Spokane, 2004), and
- *Guidelines for Stormwater Management* (Spokane County, 1998).

Given their age, these references do not address more recent Phase II or potential TMDL requirements. Historically, the City of Spokane and Spokane County have worked cooperatively on stormwater regulations and continue to do so. Presently, the City and County are developing the *Spokane Regional Stormwater Manual* in order to comply with Phase II and potential TMDL requirements. The manual is based on the *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a), a publication developed to guide communities in complying with Phase II.

The draft version of the *Spokane Regional Stormwater Manual* is currently in technical review and is expected to be finalized during the summer of 2007 (Matt Zarecor, personal communication, December, 14, 2006). The City of Spokane is expected to formally adopt the *Spokane Regional Stormwater Manual*, which will replace the *Guidelines for Stormwater Management* (Spokane County, 1998) as well as portions of the City's design standards and standard plans (Mike Yake, personal communication, Januray, 9, 2007).

In 2005, a draft of the *Spokane Regional Stormwater Manual* was made available to the public. While some changes are expected, it is considered substantially complete (Matt Zarecor, personal communication, December, 14, 2006). The draft manual will be included in the review performed here. See Table 4-1. Where existing regulations are expected to be replaced by the *Spokane Regional Stormwater Manual*, the policy review will focus primarily on the new requirements.

5 FINDINGS & RECOMMENDATIONS

This chapter is organized into sections defined by the eight topics; each section beginning with a summary of findings which answer the questions posed in Table 4-1. Each section contains an analysis with recommendations for modifying policies and regulations. This chapter ends with an overall assessment of how Spokane is positioned to implement LID and additional questions Spokane should address in pursuing LID policies and regulations.

5.1 SPOKANE'S COMPREHENSIVE PLAN

Under Washington's GMA requirements, Spokane adopted a new comprehensive plan in 2001. Current state guidelines recommend comprehensive plans include policies addressing Phase II and LID (see Section 3.1). Spokane's comprehensive plan was published prior to these guidelines, and does not specifically address Phase II or LID. However, the plan contains several policies expressing principles which parallel LID or could be supported by LID policies and regulations.

Spokane's stormwater policy (Capital Facilities and Utilities [CFU] policy 5.3) expresses the intent to reduce stormwater impacts through thoughtful design and construction and "retaining natural drainage functions and patterns" (City of Spokane, 2001, p. 5-18). This policy embodies LID in all but name. The impervious surface reduction policy (Natural Environment [NE] policy 4.3) recognizes stormwater and pollutant impacts resulting from imperviousness and stresses reducing imperviousness through more compact development. This policy demonstrates Spokane recognizes some of the ways site design and conservation can reduce stormwater impacts. This and other policies can easily be modified or supplemented to include LID explicitly as an acceptable or even preferred approach. Some examples are shown in Table 5.1-1.

Table 5.1-1. Spokane Comprehensive Plan Policies[1] Modified to Include LID

Policy (plain text - original; italic text - author)	**Intent (plain text - original; italic text - author)**
CFU 5.3 Stormwater (p. 5-18): Implement a stormwater management plan to reduce impacts from urban runoff	*Flooding, erosion, and water quality impacts from stormwater can be reduced through integrated planning, design, construction, and maintenance. Planning and design approaches should promote conservation and emulation of natural drainage function, should minimize imperviousness, and should maximize on-site stormwater management. Development plans should be designed to avoid habitat loss, retain and create features that promote natural hydrologic function, and minimize stormwater production and contamination.* Disposal of stormwater to either sanitary or combined sewers is not allowed in new developments. *Since natural drainage function may be limited in high-density urban settings, off-site facilities such as playgrounds will be considered for supplemental stormwater management. Similarly, coordinated efforts will be considered for areas with limiting subsurface conditions.* In addition, the City of Spokane should work toward the reduction of existing combined sewer overflows wherever technically, economically, and environmentally appropriate. *Low Impact Development is an approach that embodies the goals of this stormwater policy, and along with other developing strategies and technologies should be encouraged.*
NE 1.6 Natural *Hydrologic Function* (p. 9-10): Identify and preserve areas that have traditionally provided natural water drainage, *as well as site features that promote natural hydrologic function. Where feasible, restore degraded features and drainage.*	*Site features that support natural hydrologic function are those that promote stormwater retention, infiltration, evaporation, transpiration, and historic drainage patterns.* Natural drainage areas should be preserved or acquired to accommodate future stormwater runoff and protect surface and ground water. *Additional site features that promote natural hydrologic function and that should be preserved include wetlands, prairies, riparian and wooded areas, mature native vegetation, highly pervious soils, and topography that slows and disperses runoff.*
NE 4.3 Impervious Surface Reduction (p. 9-13): Continue efforts to reduce the rate of impervious surface expansion in the community.	Impervious surfaces do not allow stormwater to naturally percolate into the soil and recharge ground and surface waters, and cause an increased amount of stormwater runoff that can affect adjacent properties or water bodies. Mitigating the negative effects of increased stormwater often requires expensive engineered solutions. Some impervious surfaces are contaminated with substances that are carried with stormwater to ground and surface waters. Increases in impervious surface area do not need to accompany all growth; the alternative is to grow more efficiently and effectively. This can be accomplished by maintaining natural drainage patterns, increased vertical development and higher housing densities (which decreases the amount of impervious surfaces per person). *Low Impact Development is a comprehensive design approach that strives to preserve natural drainage areas and minimize imperviousness. This approach, along with other developing strategies should be encouraged.*

1. City of Spokane, 2001

There is also an opportunity to incorporate the concept of watershed-based zoning into the comprehensive plan. As discussed in Section 3.2.7 of this thesis, there are compelling reasons for the City and County to coordinate local growth in order to protect environmental health and water resources. The City of Spokane and Spokane County collaborating such planning efforts (City of Spokane, 2001). The comprehensive plans of both jurisdictions could be amended to address specific land areas where growth should be encouraged or limited. However, as cautioned by Haub (2002), watershed-based policies and regulations should be developed from best available science. When there is insufficient local data and analysis, a watershed-based zoning goal is more appropriate than a policy. Drafting watershed-based zoning as a goal will allow Spokane the time to adequately characterize local watersheds and form appropriate policies.

The following sections will address whether and how Spokane's regulations support LID. Recommendations that will more effectively support LID are also suggested.

5.2 SITE HYDROLOGY

As discussed in Section 2.2.2, LID attempts to emulate a site's pre-development hydrology. Hydrologic analysis of the site's existing condition provides the baseline for comparison. Modeling is repeated at each design stage and the design is refined to maximize time of concentration (Tc) and minimize runoff volume and runoff rate. Analysis methods based on TR-55 are commonly used, but SWMM is suggested as a model more appropriate for LID.

5.2.1 Site Hydrology – Policy Summary

In Spokane, the size of a stormwater quality treatment facility is determined by the volume of runoff generated by the 6-month SCS Type II 24-hour storm (Spokane County et al., 2005). A facility of this size will provide treatment for 90 percent of annual rainfall and meets recommendations discussed in Section 2.2.2. After sufficient treatment, most runoff in new developments must be disposed via infiltration. At a minimum, infiltration controls must be capable of managing runoff from the 10-year storm. Infiltration facilities can be larger if subsurface storage capacity and soil infiltration rates are adequate. Some projects may be given surface discharge approval, in which case the peak runoff rate may not exceed the pre-development peak rate. If the project will discharge to a Special Drainage District (SDD), the runoff volume must also not exceed the pre-development volume. A SDD is:

> "typically characterized as having shallow soils, bedrock near the surface of the land, and soils or geological features that may make long-term infiltration of stormwater difficult or a potential problem for onsite and/or adjacent properties. These areas may also contain steep slopes where infiltration of water and dispersion of water into the soils may be difficult or delayed, creating drainage or potential drainage problems such as erosion. Known areas of flooding or areas that historically have had drainage and/or high groundwater problems… are also SDDs." (Spokane County et al., 2005, p. 7-18)

The SDDs within Spokane City Limits include Moran Prairie and Five-Mile Prairie (SMC 17D.060.130). Depending on local conditions within a SDD, a development may be required to provide full containment (Spokane County et al., 2005), which means that no runoff may leave the site through surface runoff or infiltration. In other cases, pre-development runoff may be authorized to leave the site. If releases are allowed, they must meet rate and volume requirements described previously.

The draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) specifies hydrologic analysis methods for Tc, runoff rate and volume. The developer may use any software program that performs these methods: SCS or Santa Barbara Unit Hydrograph, SCS Curve Number, Level Pool Routing, Rational, and Modified Rational. Level Pool routing is used for detention and retention system design. The other methods are used for estimating flow rate, volume, or Tc.

5.2.1 Site Hydrology - Analysis and Recommendations

Spokane's requirements for post-development water quality treatment volume, runoff volume and rate are in good agreement with LID. There are some differences however, which should be addressed if Spokane adopts a LID policy.

The draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) does not address Tc as a design control factor: it is considered simply as an interim parameter for other calculations. While Spokane requires runoff rate and volume control, the emphasis is placed on stormwater control structures. In contrast, LID first emphasizes non-structural approaches to maximize Tc (see Section 2.2.2), followed by structural controls to manage flow and volume. Spokane, however, does not ignore non-structural approaches. City codes require natural drainages, some existing vegetation, and some pervious soils be conserved (see Section 5.4). However for LID purposes, local guidance manuals should discuss these approaches and others mentioned in Section 2.2.2 explicitly in relation to site hydrologic analysis and design.

Spokane's current hydrologic analysis methods have worked reasonably well for site analysis and design of stormwater systems typically used in Spokane (Matt Zarecor, personal communication, December 14, 2006). Typical stormwater systems include open-channel conveyance, dry wells, bioinfiltration cells, and conventional retention/detention systems. Fully-integrated LID includes more BMPs, frequently in sequence. Elliot and Trowsdale (2007) suggest that comparatively simple methods such as the SCS and the Rational methods are insufficient for LID analysis and design. If Spokane chooses to implement LID, a new hydrologic analysis approach such as SWMM should also be adopted.

5.3 CONSERVATION

One way to protect pre-development hydrology is to leave portions of the site undisturbed. As described in Section 2.2.3, the LID approach recommends or supports a variety of conservation measures which include:

1. preserving:
    a. riparian areas, wetlands, mature forest, and other areas that promote stormwater retention, infiltration, and evapotranspiration,
    b. area that if disturbed would exacerbate runoff (including geologically hazardous areas and areas with highly erosive soils),
    c. natural drainages and areas which retain runoff for infiltration and evaporation,
    d. topography that disperses and slows runoff,
    e. highly permeable soils, and
    f. recreational open space,
2. restoring hydrologic features that are in poor condition,
3. limiting the development envelop, and
4. supporting conservation programs.

The section below describes whether and how Spokane's regulations address these conservation measures.

5.3.1 Conservation Measures - Policy Summary

In Spokane, most development applications include an environmental review (SMC 17E.050, Article III). A developer is required to submit an environmental checklist (SMC 17E.050.100). Proposed project sites known or believed to contain critical areas area are required to submit additional, supporting documentation. Critical areas include flood prone areas, geologically hazardous areas, fish and wildlife habitat, aquifer sensitive areas, and wetlands. Mandatory supporting documentation may include one or more of the following:

- a geohazard evaluation and geohazard mitigation plan (SMC 11.19.2528);
- a habitat management plan (SMC 11.19.2566.E);
- a wetland delineation, rating, and functional values assessment (SMC 11.19.3073.C); and
- a drainage plan (SMC 17D.060.140).

With these submittals, City reviewers determine whether a proposed project is likely to cause negative environmental impacts. If no impacts are identified, a determination of nonsignificance (DNS) is issued (SMC 17E.050.110). If potential impacts are expected and the developer chooses to proceed, the proposal can be modified until no impacts are likely. Alternatively, mitigation measures can be proposed. Mitigation measures can include (SMC 11.19.3042):

- restoration or enhancement,
- reducing or eliminating an impact over time,

- restoring, enhancing, or creating similar environmental features at another location (off-site mitigation), or
- monitoring impacts over time and implementing specific corrective actions.

Approved projects are then subject to specific zoning and development codes. Spokane uses a traditional zoning approach to “separate zones in which specific types of structures, uses of land and activities, [are] grouped on the basis of similarity of impacts upon surrounding properties” (SMC 11.19.010). For example, Residential-Single Family (RSF) zones normally include only housing and accessory buildings (such as garages), with some allowances for recreational open space. General zoning requirements address development density, lot dimensions, and structural design standards.

Development Sensitive Overlay (DSA) zones “establish supplemental regulations to allow development without degradation of environmental quality” (SMC 11.19.255). Any development zone may be subject to DSA requirements if it contains critical areas. Any zone known or believed to contain critical areas, must comply with Development Sensitive Area (DSA) overlay zoning. “Developments located wholly or partially within a DSA are allowed only as planned unit developments (PUDs)… or as specified in the ordinance establishing each individual DSA overlay zone” (SMC 11.19.255.F1).

A PUD “shall preserve or appropriately mitigate impact to identified critical areas…” (SMC 17G.070.120B). Recreational open space equaling 10% of the gross land area in a PUD must also be provided (SMC 17G.070.030.E1a). There is no requirement that this space be kept in a primarily natural condition. However, if the developer preserves “environmentally constrained land” (critical areas, flood zones, etc.), then up to 50% of this area may be applied to the open space requirement. This allowance is applicable provided that the space is accessible physically (if practical) or is visible from common open spaces (SMC 17G.070.030.E1c).To meet PUD requirements for critical areas protection and open space, most projects will need to limit the development envelop. Non-conventional design standards such as clustered development are allowed (SMC 17G.070.010).

Recreational open space is also addressed in the City's Shoreline Management codes (SMC 11.15). In designated shoreline areas, recreational uses and public shoreline access have priority over other development (SMC 11.15.260). Shoreline management codes also emphasize pedestrian access trails and vegetation preservation near shorelines (SMC 11.15, Article IV).

The regulations described above support conservation measures 1a, 1b, 1f, and 3 (above). Conservation measure 2, restoring hydrologic features that are in poor condition, is broadly addressed by mitigation options defined in SMC 11.19.3042 (discussed above). Other development codes do not specifically require or recommend hydrologic feature restoration. Nevertheless, since Spokane's comprehensive plan (City of Spokane, 2001) supports environmental restoration, it is likely that most proposed restoration efforts would be approved.

Currently, existing drainages (conservation measure 1c) must be preserved only in Spokane's Special Drainage Districts (SDDs) (SMC 17D.060.150). Due to naturally shallow impervious layers or shallow groundwater, SDDs have limited stormwater infiltration capacity. Before development, natural drainages in SDDs managed most stormwater. During development, many drainages were filled or altered, and replaced with drywells for stormwater management. Over time, SDD's limited subsurface water storage capacity has been overwhelmed, leading to flooding and property damage (MWH and Woodward-Clyde, 2002; Brown and Caldwell and URS, 2004). The City has since found that preserving natural drainages supports overall stormwater management and reduces flooding problems. The draft *Spokane Regional*

Stormwater Manual (Spokane County et al., 2005) states that natural drainages must be preserved in all County-regulated areas. It is unknown whether the City of Spokane will adopt natural drainage protection requirements outside of SDDs.

Spokane has no requirements or recommendations to preserve topography that disperses or slows runoff (measure 1d). Measure 1e, preservation of highly pervious soils, is addressed only in terms of planned bioinfiltration facilities. To receive final certification, planned facilities must be protected from compaction during construction, and must pass an infiltration test (Spokane County et al., 2005).

The Spokane Zoning Code (SMC 11.19) addresses conservation measure 4, conservation programs, in terms of incentives. Land owners participating in recognized conservation programs may be eligible for County property tax relief if at least part of their land contains fish and wildlife habitat or geologically hazardous areas (SMC 11.19.2530 and 2568).

Spokane provides one conservation-related incentive: transfer of development rights. Transfers of development rights are allowed for PUD applicants with lands containing designated critical areas (SMC 17G.070.030.B4). This allows the developer to realize the maximum allowable density for the property. Density bonuses are also listed as an incentive for PUDs (17G.070.030.B1). However, Spokane's density bonuses are based on minimum requirements for affordable housing (17G.070.030.5), and not specifically because an applicant proposes a PUD or some type of conservation measure.

5.3.2 Conservation Measures – Analysis and Recommendations

Spokane's regulations are reasonably supportive of LID conservation measures, particularly for applicants planning to develop in critical areas. Unfortunately, these regulations also have some weaknesses. There is no guidance for conservation measure 1d, and few references to guidance documents for effective mitigation and restoration design. Additionally, the regulations concentrate too narrowly on minimum standards to comply with state environmental laws, and prevention of stormwater management-related flooding and property damage. These issues must obviously be addressed, but too-narrow focus on minimum standards may impede truly effective conservation-oriented efforts.

For example, the PUD code (SMC 17G.070) allows compact development as an approach to preserve critical areas. This regulation supports compliance with state environmental laws. Unfortunately, the code neglects recommendations for preserving highly pervious soils or encouraging sheet flow of runoff into conserved areas. Spokane's regulations do not necessarily hinder these conservation approaches. Neglecting to mention them however, may cause some developers and project review personnel to overlook more holistic design approaches. This in turn may cause projects to fail in attaining their full potential for preventing negative environmental impacts.

Conservation-oriented regulations and recommendations are mentioned in four Spokane City codes, as well as in the city's stormwater management guidance documents. Cross-references in the codes and guidance documents assist users in complying with all minimum requirements, but are inadequate to support more holistic conservation design. If Spokane chooses to adopt a LID-oriented policy, it will be beneficial if conservation measures are addressed as a whole. One option is to add a chapter titled "Conservation" to SMC Title 17E (Environmental Codes). This chapter could establish conservation-oriented aspects of Spokane's regulations as an overall site design approach. The chapter could also define conservation codes and recommendations that are applicable at each stage of the development process. Such a chapter might seem redundant, but would be more coherent than existing regulations. A conservation chapter would also be more effective at integrating the policies expressed in the Spokane comprehensive plan with regulations in the municipal code. In turn, this will promote greater understanding throughout the community as to how the comprehensive plan is being implemented.

5.4 SITE PLANNING

After conservation measures, the primary LID strategies for minimizing stormwater runoff are addressed with site planning. The focus of site planning is on limiting imperviousness. In this section, Spokane's regulations for buffer zones, lot configurations, street design and parking standards will be analyzed.

5.4.1 Buffer Zones

In LID, conservation areas are protected from development with buffers. Wildlife habitat and recreation are the most appropriate land-uses in buffers. Buffers may also be used to filter stormwater if the flow is limited and runoff rate is controlled.

5.4.1.1 Buffer Zones - Policy Summary

The SMC discusses two types of buffers: riparian habitat areas (SMC 11.19.2566D.1.a) and wetland buffers (SMC 11.19.3091). City codes require buffer vegetation remain undisturbed except for weed removal and to protect public safety and health. Low-intensity and passive recreational uses, as well as scientific study are the primary activities approved in buffers. Occasionally, development may be allowed if there is evidence that there will be no adverse environmental effects will result, or in the case of roadways, no alternative exists.

The riparian buffers ordinances are based on the most-recently published guidance from the WDFW, *Management Recommendations for Washington's Priority Habitats: Riparian* (Knutson and Naef, 1997). Many of the SMC's requirements, including buffer widths, planned activities and development in riparian buffers, depend on habitat management plans (HMPs). For each project, the applicant must submit a HMP that has been prepared by a qualified biologist and approved by the Director of Planning Services (SMC 11.19.2566E). Wetlands considered in a project proposal must be delineated and assessed by a qualified professional (SMC 11.19.3073.C). For activities or developments within wetland buffers, an applicant may be asked to submit additional information "sufficient to enable evaluation of the proposed activity or the preparation of any necessary environmental documents" (SMC 11.19.3083.C). There is no explicit requirement for a HMP or equivalent plan for wetland buffers.

Stormwater management facilities are also allowed in wetland buffers if no other reasonable on-site alternatives are available. The facilities must be "sited and designed so that the buffer zone as a whole provides the necessary biological, chemical anxd physical protection to the wetland in question, taking into account the scale and intensity of the proposed land use" (SMC 11.19.3091.F2). Applicants are referred to the *Spokane County Guidelines for Stormwater Management* (Spokane County, 1998) for stormwater facility design guidance. The County Guidelines however, offer no specific guidance for precautions in wetland buffers. The draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) also neglects to address stormwater management approaches in and around wetlands.

5.4.1.2 Buffer Zones – Analysis and Recommendations

Spokane's buffer regulations generally agree with LID in that they protect critical areas from development and may be used for passive recreation and limited stormwater management.

Protection and development standards are more clearly defined for riparian buffers than wetland buffers. Spokane's wetland buffer requirements should be updated based on the most recent guidance: *Washington State Wetland Rating System for Eastern Washington – Revised* (Hruby, 2004), and *Wetlands in Washington State* (Granger et al., 2005). A requirement for a 'wetland management plan' would improve planning efforts in wetland areas. Guidance for developing wetland plans are discussed in Granger et al. (2005), and WSDCTED (2003b).

Spokane's stormwater management requirements for buffers are not clearly defined. In LID, buffers may be used as vegetated filters if stormwater flow is controlled (see Section 2.2.4.1). Granger et al. (2005) also provides general stormwater management guidance near and within wetland buffers. With approval from the WDFW, it is possible that these recommendations could be applied to riparian buffers. The SMC and the *Spokane Regional Stormwater Manual* should be updated to include specific stormwater management requirements near and within buffers.

5.4.2 Lot Requirements

Long lot frontages, wide setbacks, and uniform lot sizes and shapes can increase the distance between residences. This leads to longer road systems and excessive imperviousness. To decrease imperviousness, LID encourages minimizing lot frontages, setbacks, and allowing mixed lot sizes and shapes. Zero-lot line, passive use easement, cottage housing, and attached housing are also recommended for small lots.

5.4.2.1 Lot Requirements – Policy Summary, Analysis, and Recommendations

Spokane uses two lot standards: conventional and PUD. Where no critical areas exist, developers may use conventional standards. Where critical areas are identified, developers must apply for a PUD (SMC 11.19.255.F1). Developers are also encouraged to apply for a PUD in any residential zone. Spokane's residential zones are designated agriculture (RA), single-family (RSF), two-family (RTF), multi-family (RMF), and high density (RHD) (SMC 17C.110.030). Lot development standards for conventional developments and PUD are compared in Table 5.4-1.

In Chapter 2, lot frontages of 75 feet were identified as excessive. Spokane's standards are well below this. Spokane's conventional lot frontage minimums range from 25 to 40 feet. PUDs may be as narrow as 18 feet. Setbacks are flexible in PUDs. No minimums are specified, except for garages and lots within 80 feet of a project's perimeter.

A range of housing structures may be used. Spokane's Alternative Residential Development and PUD codes (SMC 17C.110.300 and SMC 17G.070, respectively) allow zero-lot lines and cottage housing. Passive use easements for maintenance access are required on zero-lot line properties, and may be used through private arrangements in any residential zone (Louis Meuler, personal communication, November, 29, 2006). Under the Alternative Development standards up to two houses may be attached in RA and RSF zones, and up to eight houses may be attached in RTF zones (SMC 17C.110.310.G). There are no limitations for attached housing in RMF and RHD zones. In PUDs there is no specified limit to the number of attached single-family houses in RA, RSF, and RTF zones (SMC 17G.070.030.A). Air space condominiums are allowed in PUDs, but in RA and RSF zones they cannot be stacked one dwelling on top of another (Louis Meuler, personal communication, November, 29, 2006).

Table 5.4-1. Spokane Residential Lot Standards[1]

	Zone[2]				
Standard minimums	**RA**	**RSF**	**RTF**	**RMF**	**RHD**
Density (conventional) (lots per acre, min.- max.)	4-10	4-10	10-20	15-30	15-no requirement
Density (PUD)	Same as underlying zone. Minimum density may be waived to protect agricultural lands or critical areas.				
Lot area - sq. ft. (conventional)	7,200	4,350	4,350[3]	2,500	2,500
Lot area (PUD)	May be reduced to 18 feet wide by 20 feet deep.				
Frontage length (conventional)	40 ft.	40 ft.	40 ft.[4]	25 ft.	25 ft.
Frontage length (PUD)	18 ft.				
Front yard setback (conventional)	15 ft.	15 ft.	15 ft.[5]	15 ft.	15 ft.
Front yard setback (PUD)	Same as underlying zone for structures within 80 ft. of project perimeter. Otherwise, may be modified, except for ground-level garage setbacks.				
Side lot line setback - lots 40 ft. or wider	5 ft.				
Side lot line setback - lots 25 ft. or wider	3 ft.				
Side-street setback (corner lot)	5 ft.[5]				
PUD side setbacks	May be modified, except for ground-level garage or carport that opens facing a street				
Rear yard setback[6] (conventional)	25 ft.	25 ft.	25 ft.	10 ft.	10 ft.
Rear yard setback (PUD)	See PUD front yard setback				

1. Table adapted from SMC 17C.110.200, Table 17C.110-3, and SMC 17G.070.030.B and C.
2. RA = residential agriculture, RSF = residential single-family, RTF = residential two-family, RMF = residential multi-family, RHD = residential high density.
3. Minimum lot size may be reduced to 2,500 for attached housing development.
4. Minimum lot width may be reduced to 25 feet for attached housing development.
5. Attached garage or carport entrance on a street is required to be set back 20 feet from the property line
6. Attached garages may be built to 5 feet from the rear property line, except as specified in SMC 17C.110.225.C6b. Garages built 5 feet from the property line cannot contain living space.

As written, the SMC prefers lot uniformity. All lots should be "as nearly rectangular as possible" (SMC 17G.080.070.C5), within the "limitations and opportunities of topography" (SMC 17G.080.070.C1). According to Louis Meuler (personal communication, November, 29, 2006), mixed lot sizes and shapes are allowed in PUDs. However, this allowance is not clearly stated in the PUD codes. If the City of Spokane adopts LID regulations, the regulations should explicitly address flexible lot size and shape standards.

Spokane has one additional requirement that poses a minor limitation to LID. Under SMC 17C.110.200.C1:

> "For sites two acres or greater, transition lot sizes are required…as a buffer between existing platted land and [the] new subdivision… The purpose of [this] section is to… facilitate compatible development and a consistent development pattern... Lots proposed within the initial eighty feet of the subject property [in RA and RSF zones] are required to transition lot sizes based on [lot size] averaging…"

An example of how lot sizes are calculated is illustrated in Figure 5.4-1. The requirement applies to all developments, including PUDs. In situations where transition zoning demands large lots, the clustered housing design approach preferred in LID may be limited. For these lots, stormwater management will need to rely more on conservation design strategies at the individual lot scale, and on stormwater BMPs. Transition lots aren't expected to be required in all developments; only those bordering existing large-lot developments. Since LID emphasizes both stormwater management and quality of life, the benefits of transitional lots enhancing the character of a neighborhood outweigh the limitations posed to LID.

As shown by this discussion, Spokane's residential lot standards closely parallel LID recommendations. Other than addressing allowances for flexible lot sizes and shapes (above), no additional recommendations are suggested.

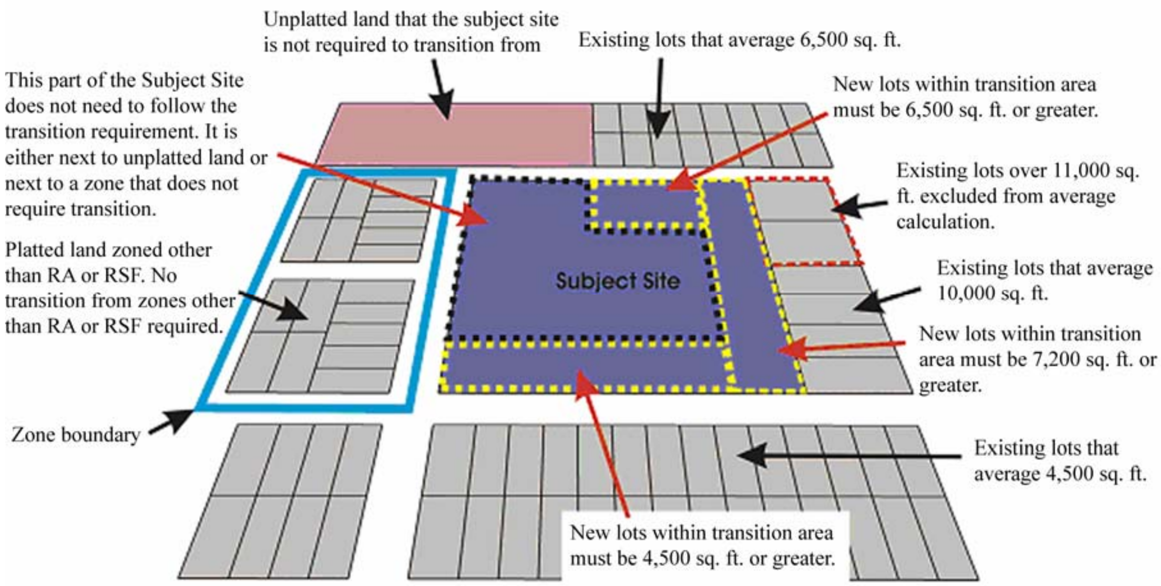

Figure 5.4-1. Transition lot-size calculation (Source: SMC, 17C.110.200C)

5.4.3 Street Design Standards

Road networks and road width can create unnecessary imperviousness. LID recommends traditional urban and hybrid networks rather than suburban 'loops' and lollipops'. LID suggests road widths can be minimized by changing the requirements for travel lane widths and on-street parking. Imperviousness can also be reduced in alleys using a combination of paved wheel tracks and pervious paving.

5.4.3.1 Street Design Standards – Policy Summary

Spokane's street layout requirements are defined in SMC 17H.010.030. The preferred layout is the grid pattern, modified whenever necessary to accommodate topography and existing or planned streets. Wherever possible, shorter block lengths are preferred. The minimum allowed distance between intersection centerlines is 150 feet, with a maximum of 600 feet. Dead-ends and cul-de-sacs are allowed only where "the property is isolated by topography or the configuration of existing platted lots and streets" (SMC 17H.010.030.P).

Spokane's standard residential street width for new development is 36 feet, curb face-to-face (SMC Table 17H.010-1). Parking is required on both sides (SMC 17H.010.120). This requirement provides a 20-foot wide 'clear width' for emergency vehicle access and two 8-foot wide parking lanes. In low-density developments (10 units per acre or less) streets may be 32 feet curb face-to-face, with parking along both sides in 7-foot lanes (SMC Table 17H.010-1). Spokane has one additional, narrow street standard. Low density developments may have streets 27 feet wide when parking on only one side is also allowed (SMC Table 17H.010-1). Spokane limits one-side parking to three locations (SMC 17H.010.120D):

- where topography limits the housing development to one side of the street,
- where the primary garage access is via alleys, and
- where only side or rear lot lines, or common areas, adjoin one side of the street.

5.4.3.2 Street Design Standards – Analysis and Recommendations

Spokane's street layout standards are favorable with respect to LID in that they recommend shorter block lengths, limit cul-de-sacs, and prefer a grid pattern. To better support LID, the standards, at a minimum, should require limiting imperviousness in cul-de-sacs. The strategy in this case is to incorporate bioretention 'islands' in the center. The preferred LID approach, however, is to avoid cul-de-sacs entirely and instead use the hybrid road network (see Section 2.2.4.2.1.1).

At 36 feet, Spokane's standard residential street width is at least 4 feet wider than standards of other cities shown in Table 2.2-2. Where Spokane allows streets narrower than 36 feet, the standards are more restrictive that other northern-tier U.S. cities with similar snowfall. All of Spokane's street width standards are based on providing a 20-foot clear width for emergency access (Louis Meuler, personal communication, December 14, 2006), and providing two-side parking except in the limited cases listed in Section 5.4.3.1. By analyzing alternative parking configurations, it is possible to reduce Spokane's street requirements, while still preserving the emergency access requirement.

The City of Madison has shown that on-street parking in residential areas is underused (see Section 2.2.4.2.1.3). With local analysis, it should be possible to reduce the number of on-street parking spaces by at least half in Spokane's RA and RSF neighborhoods. This is equivalent to allowing parking on only one side of the street. A reduction in the number of on-street parking spaces may also be possible in RTF zones depending on local observations. While one-side parking can be difficult to enforce under normal road configurations (straight roads with no significant separation between travel and parking lanes), parking bays offer another alternative.

As discussed in Chapter 2, parking bays can be configured for parallel parking or angled parking using bump-outs to separate parking from the normal travel lane (see Figure 2.2-9). If parking is limited to bays, the remaining roadway can be reduced to 20 feet. Angled parking may more easily accommodate topography or other design features. The 20-foot width provides adequate space for cars backing from driveways or parking bays and will allow two fire trucks to pass. Snow storage can be provided in roadside swales. The swales should be configured with very low or no curbs in order to accommodate plow blades. The swale edges can be reinforced with pervious pavers or reinforced turf to prevent damage from tires and plow blades. See Figures 5.4-2 and 5.4-3.

Figure 5.4-2. Narrow street with low/no curbs. Street edge swales can be used for plowed snow storage. Unlike this example, woody plant species should be placed away from roadside swale edges to avoid damage from plow blades. (Source: http://www2.cityofseattle.net/til/tours/seastreet/slide6.htm)

Figure 5.4-3. Grass pavers and mesh reinforced turf for swale edge reinforcement. Rubber/plastic plow blades may be needed to prevent tearing mesh reinforcement. See Ferguson (2005) for additional turf reinforcement methods (Source: Top - http://revelle.net/LAKESIDE/photos/july/July-Pages/Image6.html; Bottom - http://grasstrac.com/case_univ_ga.htm)

In contrast to Spokane's 36-foot standard, a 20-foot wide street with 8-foot wide parallel parking bays can reduce imperviousness by approximately 22 percent. This estimate assumes Spokane's on-street parking requirement in low-use residential areas is reduced by 50 percent; the equivalent of parking on only one side of the street. If parking bays are angled, the following approximate imperviousness reductions are possible:

- 23 percent for 90-degree parking,
- 20 percent for 60-degree parking,
- 16 percent for 45-degree parking, and
- 9 percent for 30-degree parking.

5.4.3.3 Alley Paving Standards – Policy Summary and Recommendations

Spokane has two alley paving requirements:

1. "new alleys shall have a paved width of at least twelve feet and a clear width of at least twenty feet. The twenty-foot width shall not be obstructed in any manner, including the parking of vehicles, fences or utility structures" (SMC 17H.010.130.G).
2. "alleys that serve as a primary access or as a fire access must have a paved width of at least twenty feet. Unless specifically approved by the city fire department, alleys are not considered a fire access" (SMC 17H.010.130.H).

There seems to be little need for so much impervious surface in residential alleys. At a minimum, Spokane should limit paving in new alleys (item 1 above) to *no more than* twelve feet. Alternatively, since these alleys provide only secondary access, impervious paving could be limited to just the wheel tracks. The remaining clear area could be surfaced with pervious paving (Figure 2.2-10).

Similarly the paving requirement for item 2 could also be reduced for lower-use alleys, particularly in low- and medium-density housing developments. In these developments, it should be possible to limit imperviousness to a 10- or 12-foot wide strip, with pervious paving used for the remaining clear area. The impervious strip would accommodate delivery and service truck loads. While pervious pavers do not wear well under frequent, heavy loads, they do provide adequate support for infrequent emergency-vehicle access, like fire trucks (Ferguson, 2005).

Pervious pavers are considered in more detail in Sections 5.5.4.3 and 5.5.4.4, below.

5.4.4 Off-Street Parking

Sections 3.4.2.1.3 and 3.4.2.1.4 describe approaches to minimize impervious surfaces in driveways and parking lots. Recommendations include:

1. minimizing driveway width and length,
2. minimizing the number of parking spaces,
3. sharing driveways,
4. using shared parking, covered parking and a percentage of compact parking spaces,
5. incorporating pervious paving, and
6. dispersing runoff to infiltration areas.

The first four recommendations are discussed in the next two sections. Because of SVRP Aquifer protection requirements, pervious paving is a complex issue. This topic is discussed in Section 5.3.4.3. Runoff dispersion to infiltration areas is addressed in Section 5.5, Stormwater Controls.

5.4.4.1 Residential Driveway Standards – Policy Summary and Recommendations

All residential lots in Spokane must have a minimum of one, nine-foot wide vehicle area (SMC 17C.230.145). If used for parking, the vehicle area must be at least nine feet wide by eighteen feet long. These requirements compare well with LID recommendations given in Section 3.4.2.1.3.

Spokane also sets maximums on paved residential vehicle areas. In RA and RSF zones, paved vehicle areas cannot exceed 40% of the lot frontage, nor 20% of the side lot area for corner lots. In RTF, RMF, and RHD zones paved vehicle areas cannot exceed 40% of either the front or side lot (SMC 17C.230.145C). Exceptions are made if the minimum nine-foot wide area exceeds the maximum allowed paved area.

The City code lists no covered parking requirements as a means to reduce stormwater impacts. Covered parking can reduce stormwater contamination if the runoff is diverted away paved surfaces. If Spokane adopts LID policy, covered parking should be encouraged as a stormwater BMP.

The SMC does not address shared driveways; however, the PUD ordinance states that minimizing impervious surfaces is required (SMC 17E.070.125B). No recommendations are offered on how this might be accomplished. Shared driveway configurations, some of which are described in Section 2.2.4.2.1.3, should be included in the SMC's design guidelines.

5.4.4.2 Parking Lot Standards – Policy Summary and Recommendations

Spokane's Parking and Loading ordinance (SMC 17C.230) specifies both minimum and maximum numbers of parking spaces in non-residential lots (SMC Table 17C.230-2). The code does not address compact spaces, but these are allowed if they are included in addition to the minimum number of required spaces (Louis Meuler, personal communication, December 14, 2006). Parking can be reduced twenty percent below the required minimum through shared parking arrangements (SMC 17C.230.130B). If businesses share parking and operate on opposite hours, the number of spaces is based on the business with the larger minimum parking requirement (SMC 17C.230.130B). The SMC also allows parking reductions for bicycles and carpooling. Up to ten percent of parking spaces may be substituted with bicycle parking (SMC 17C.230.110B3), and five spaces or five percent of parking spaces (whichever is less) must be designated for carpool parking when the lot contains more than 20 spaces (SMC 17C.230.110C).

Also allowed are angled parking lots with one-way travel lanes (SMC Table 17C.230-3), and parking structures (SMC 17C.230.110B2). Parking maximums are not imposed on parking structures.

Overall, these requirements are in good agreement with LID recommendations. One minor recommendation would be to encourage the use of compact spaces, or requiring a minimum number of compact spaces when total parking exceeds stipulated minimums. One other recommendation is for the SMC to encourage covered parking as a stormwater BMP.

5.4.4.3 Pervious Paving – Policy Summary and Analysis

The SMC allows a percentage of pervious surfacing in angled parking stalls. Instead of a paved surface, the first two feet of each stall may be vegetated with groundcovers. No other types of pervious surfaces are mentioned in the SMC, or in the standard references defined in SMC 17D.060.030B. While pervious pavers are recommended in the *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a), they are not mentioned in the draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005). There are two concerns about pervious pavers: 1) they will not perform well under local climatic conditions, 2) they will not adequately protect SVRP Aquifer water quality (Louis Meuler, personal communication, December 14, 2006).

Evidence presented in Chapter 2 suggests pervious pavers, if properly installed, can support light to medium traffic even in cold climates. Results of a local demonstration project using pervious pavers are promising. In May, 1998, the Spokane County Conservation District installed approximately 6,000 square feet of grassed pavers in a public parking lot. The lot is used by approximately ten to fifteen cars and trucks per day. As of January, 2007 the lot has “held up beautifully” to traffic and snow plows (Jim Armstrong, personal communication, January 8, 2007). So far, paver replacement has not been necessary and the lot continues to drain stormwater. Unfortunately, this project does not include formal monitoring and its effluent water quality is unknown. Whether pervious paving has potential to meet local groundwater quality requirements is considered below.

Under Phase II, stormwater from pollutant generating impervious surfaces (PGIS) requires water quality treatment prior to disposal (Spokane County et al., 2005). PGIS includes any paved or unpaved roadway receiving regular auto traffic, plus “roads… driveways, sidewalks adjacent to the road, (and) parking lots” (Spokane County et al., 2005, p. 6-6). Water quality treatment requirements vary depending on the level of use of a PGIS. Table 5.4-2 describes water quality treatment requirements, level of use categories for parking areas, treatment goals, and approved LID treatment facilities.

Table 5.4-2. Stormwater Quality Treatment Requirements for Parking Area PGIS[1]

Stormwater Quality Treatment Requirement		
· TSS for low-use areas · TSS plus metals for moderate-use areas · TSS, metals, and total petroleum hydrocarbons (TPH) for high-use areas · Total phosphorus for all areas with an approved phosphorus TMDL[2]		
Use Categories for Parking Areas		
Low	· Daily expected trip end (DETE) counts less than 40 per 1,000 square feet of gross building area · DETE less than 100	
Medium	· DETE counts between 40 and 100 per 1,000 square feet of gross building area · DETE between 100 and 300	
High	· DETE greater than 100 per 1,000 square feet of gross building area · DETE greater than 300	
Treatment Goals		
Constituent	*Treatment*	*Approved LID Treatment Facilities*
Total Suspended Sediments (TSS)	80 percent removal for influent concentrations between 100 and 200 mg/L	bioinfiltration, biofiltration, evaporation ponds
Metals	no specific treatment goal	bioinfiltration, biofiltration, evaporation ponds
Total Petroleum Hydrocarbons (TPH)	non visible sheen, 24-hour average TPH concentration ranging from 10 to 15 mg/L	bioinfiltration, biofiltration, evaporation ponds; Oil/water separator required upstream of other BMPs if high oil concentrations are expected
Total Phosphorus	50 percent removal for influent concentrations between 0.1 and 0.5 mg/L	bioinfiltration, evaporation ponds

1. Derived from Spokane County et al., 2005, Chapter 6
2. At this writing, no phosphorus in stormwater TMDLs have been imposed in the Spokane region (WSDOE, 2007a).

Based on requirements shown in Table 5.4-2, pervious paving must provide stormwater quality treatment if it is used to infiltrate stormwater from PGISs. At least two studies indicate pervious systems may be capable of meeting Spokane's TSS standards. A study in England reported suspended solids discharge by an aggregate-paver system "was usually 20 mg/L and always less than 50 mg/L" (Pratt et al. as described in Ferguson, 2005, p. 158). The report also states that effluent solids concentrations declined over time and stabilized at low levels after six months. The system was constructed in a fashion similar to that shown in Figure 2.2-27. Clausen (2004) reported mean weekly TSS concentrations of 15.8 mg/L in effluent collected from an aggregate-paver system in Waterford, Connecticut. Neither of these studies indicated the TSS influent concentration; consequently, they cannot be compared directly to Spokane's TSS treatment standard. Other findings in the literature report 'good' TSS removal, but because of differences in reporting formats, could not be compared in a meaningful way to Spokane's standards.

A German laboratory study shows metals removal is achieved with four pervious paver types, with best results gained from grassy pavers (Dierkes et al., 2002). The same research group also analyzed a pervious paver parking lot fifteen years after installation. The pavers consisted of porous concrete blocks with narrow joints containing 1 to 3 mm sand joint filling. Metals concentrations in the paver stones and joint filling were comparatively high. Metals concentrations in the soils below the paver bedding layer were in the range of natural background concentrations and met German standards for playground soils. Brattebo and Booth (2003) analyzed the effluent from pervious pavers in a Puget Sound parking lot. The parking lot contained two types of aggregate-filled pavers, and two types of grass pavers. Analyzed six years after its installation, the metals concentrations were below toxic levels in 86 percent of the samples, with most samples even below method detection limits.

Both of these research groups also assessed petroleum hydrocarbons. In Germany, petroleum hydrocarbons were analyzed as mineral and polycyclic aromatic hydrocarbons (PAHs). Fifteen years after installation, PAHs were below detectable levels in the soils under the pervious concrete paver parking lot. Mineral oils were detected at very low concentrations that were not considered endangering (Dierkes et al., 2002). Brattebo and Booth (2003) analyzed petroleum hydrocarbons as motor oil and diesel fuel. Neither constituent was observed above method detection limits in any of the four paver systems. Due to differences in analytical methods, results from these studies are not directly comparable to Spokane’s total petroleum hydrocarbons (TPH) requirement (Table 5.4-2). Both studies however, indicate significant petroleum hydrocarbon treatment is achieved with pervious pavers.

The EPA has reported that pervious paving systems can reduce total phosphorus by as much as 65% (EPA, 1999). More recent research indicates variable results ranging from approximately 27% phosphorus removal (Boving et al., 2006); to a net export of phosphorous as compared to a control site (Clausen, 2004). Both reports however, noted problems during the studies that may account for non-representative results. No other recent studies investigating phosphorus treatment were identified within the literature.

5.4.4.4 Pervious Paving – Recommendations

Evidence presented above indicates that pervious pavers provide TSS, metals, and petroleum hydrocarbons treatment. Pervious paver treatment capability for phosphorus is less certain. The WSDOE approves BMPs for water quality treatment using either the presumptive or demonstrative approaches (WSDOE, 2004a). In the presumptive approach, the developer must design and construct WSDOE-approved stormwater BMPs. Approved LID BMPs for the Spokane area are listed in Table 5.4-2. In the demonstrative approach, the developer must show:

> “ how stormwater BMPs were selected; the pollutant removal performance expected… the scientific basis, technical studies, and (or) modeling which supports the performance claims… and an assessment of how the BMP will comply with state water quality standards and satisfy AKART requirements and federal technology-based treatment requirements” (WSDOE, 2004a, p. 1-3).

To meet these requirements it may be necessary to perform local studies on pervious paver systems. Research cited above, as well citations provided in Ferguson (2005) and Hinman (2005) provide study design guidance. At a minimum, local pervious paver studies should analyze:

- multiple paving types (e.g., aggregate pavers, grass pavers, and pervious concrete pavers),
- multiple base materials (with combinations of sand, gravel, and filter fabric layers),
- infiltration rates during different storm intensities and performance over time,
- influent and effluent concentrations of TSS, metals, TPH, and phosphorus, and
- maintenance demands and system response to maintenance activities such as pressure washing.

In addition, the study should consider site design. In most cases pervious paving systems are intended only to manage direct rainfall. Stormwater intercepted via overland flow (run-on), especially from a PGIS, could overwhelm the water quality treatment capability for all constituents. Adjacent surfaces should either slope away from the pervious system, or additional treatment capacity should be designed in. The study should also compare treatment efficacy for pervious systems which manage only direct interception, to systems managing interception plus run-on from adjacent surfaces.

If pervious paving obtains stormwater quality treatment approval, then it should be recommended in local guidance documents for driveways and low to medium-use parking areas. At this time pervious paver systems are generally not recommended for high-use areas due to poor resilience under high traffic loads (Ferguson, 2005; Hinman, 2005). Spokane-specific design standards would need to be developed. Ferguson (2005) and Hinman (2005) provide general design guidance. Local guidelines should limit pervious systems where there is limited clearance between the bottom of the paving system and an impervious layer or groundwater. This condition is common in the Moran Prairie and Five-Mile Prairie areas of Spokane. Local studies will also confirm whether pervious systems can manage both direct interception and run-on. If not confirmed, specific site grading guidelines will also need to be addressed.

5.4.5 Effective Imperviousness – Policy Summary and Recommendations

The concept of effective imperviousness was introduced in Section 2.2.4.2.2. It was recommended there that effective imperviousness should be reduced using stormwater infiltration, exfiltration devices, and rainfall re-use. In new developments, Spokane's regulations avoid effective imperviousness by requiring on-site stormwater infiltration (City of Spokane, 2000; Spokane County et al., 2005). However, some effective imperviousness is present in older developments that are connected to the sewer system. In these older developments, Spokane should adopt requirements for disconnecting imperviousness in redevelopment projects connected to the storm sewer. Occasionally, new developments are allowed to connect to the sewer (City of Spokane, 2000b). Requirements for minimizing effective imperviousness should also be adopted for these developments.

5.4.6 Reduce Building Footprint – Policy Summary and Recommendations

Section 2.2.4.2.3 recommends reduced building footprints to minimize imperviousness. This can be accomplished with multi-story buildings, placing garages within the primary building structure (as opposed to semi and fully detached garages), and using pier and piling foundations.

5.4.6.1 Reduce Building Footprint – Policy Summary

Spokane's building coverage and height standards are shown in Table 5.4-3. The maximum building coverage for most residential lots is 60%, including accessory buildings. Building coverage can be at high as 70% for lots under 3,000 sq. ft. Multi-story buildings are encouraged through floor area ratio (FAR) requirements. A FAR is the amount of floor area in relation to the total lot area, expressed as a ratio. In RA, RSF and RTF zones, the FAR cannot exceed 0.5. For a 5,000 sq. ft. lot, the FAR is 2,500 sq. ft. Since the building coverage on a 5,000 sq. ft. lot cannot exceed 40%, a building with 2,500 sq. ft. will have to contain more than one story.

The SMC does not discuss specific criteria for building foundations. Instead, residential structures in Spokane must meet standards of the International Building Code and International Residential Code (SMC 17F.040.010). Both the International and Residential Building Codes (International Code Council, 2003 and 2006, respectively) detail specifications for pier and pier foundations. Systems that meet the International Codes' specifications can be considered for approval by local jurisdictions.

Table 5.4-3. Spokane Residential Building Coverage and Height Standards[1]

	Zone[2]				
Standard (maximum)	**RA**	**RSF**	**RTF**	**RMF**	**RHD**
Primary Structure					
Lots 5,000 sq. ft. or larger	40%	40%	40%	50%	60%
Lost 3,000-4,999 sq. ft.	1,500 sq. ft. + 37.5% (portion of lot over 3,000 sq. ft.)				
Lots less than 3,000 sq. ft.	50%				
Roof Height	35 ft.	35 ft.	35 ft.	35 ft.	35 ft.
Wall Height	25 ft.	25 ft.	25 ft.	30 ft	--
Floor Area Ratio (FAR)	0.5	0.5	0.5[3]	--	--
Accessory Structures					
Building Coverage	20%	15%	15%	See Primary Structure	See Primary Structure
Roof Height	30 ft.	20 ft.	20 ft.	35 ft.	35 ft.
Wall Height	30 ft.	15 ft.	15 ft.	35 ft.	35 ft.

1. Information taken from Table SMC 17C.110-3
2. RA = residential agriculture, RSF = residential single-family, RTF = residential two-family, RMF = residential multi-family, RHD = residential high density.
3. FAR may be increased to 0.65 for attached housing development only

5.4.6.2 Reduce Building Footprint – Analysis and Recommendations

Spokane's maximum building coverage is reasonable for multi-family and high-density zones, and lots less than 3,000 sq. ft. It seems excessive however, for single and two-family residential zones, especially since Spokane has a policy for reducing impervious surface expansion (City of Spokane, 2001, policy NE 4.3). For comparison, the City of Olympia, WA allows maximum impervious coverage of 2,500 sq. ft. in its Residential Low Impact (RLI) zones (Olympia Municipal Code, Title 18, Table 18.04.080). All structures that contribute to imperviousness are calculated into the allowance, including buildings and driveways. If Spokane adopts a LID policy it should consider adopting an impervious coverage regulation for LID projects.

Pier and piling foundations lift structures above the ground, preserving most of the soil's original capacity for stormwater infiltration. For Spokane, they could be included as a general requirement or recommendation in LID design guidance. They could also be part of an incentive program. In this case, developers could be allowed more building coverage if pier and piling foundations are employed. Additional considerations for pier and piling systems in LID are given in Hinman (2005).

5.5 STORMWATER CONTROLS

As discussed in Section 5.2, Spokane's stormwater control requirements are in transition. A comparison of existing requirements with those described in the draft *Spokane Regional Stormwater Manual* show mostly minor differences. The policy summary here primarily describes draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) requirements, and only refers to other regulations when appropriate.

5.5.1 Stormwater Controls – Policy Summary

In Spokane, infiltration is the primary stormwater disposal method (City of Spokane, 2000; Spokane County et al., 2005). Discharge to storm sewers or regional facilities is allowed only in limited cases. Bioinfiltration systems and drywells are the primary infiltration facilities. Any other type of infiltration system, such as an infiltration gallery or absorption trench is considered non-standard (City of Spokane, 2000; Spokane County et al., 2005). To receive approval, non-standard infiltration facilities must be shown to provide adequate infiltration.

Runoff generated by a PGIS must be treated for water quality. The manual defines PGIS as:

> "surfaces subject to vehicular use, industrial activities, or storage of erodible or leachable materials that receive direct rainfall. A surface, whether paved or not, shall be considered a PGIS area if it is regularly used be motor vehicles. The following are considered PGIS areas: roads, unvegetated road shoulders, bike lanes within the traveled lane of a roadway, driveways, sidewalks adjacent to the road, parking lots, fire lanes, vehicular storage yards and airport runways. Metal roofs are considered to be PGIS unless coated with an inert, non-leachable material…" (Spokane County et al., 2005, p. 6-6).

In general, roof areas isolated from mechanical systems are not PGIS, and runoff from these surfaces does not require treatment. At a minimum, the PGIS runoff volume equal to the 6-month SCS Type II 24-hour storm must be treated (Spokane County et al., 2005). Excess volume does not require treatment, and can be released to a drywell or flow control facility. LID treatment options include bioinfiltration and biofiltration using channels and vegetated filter strips.

As mentioned in Section 5.3, infiltration and surface release of runoff have limited application in Spokane's SDDs. Instead, evaporation systems may be used. In these systems, the post-development runoff is evaporated from a pond or swale. In some cases, the entire pre-development and post-development runoff volume are managed through evaporation (Spokane County et al., 2005). In other cases, the pre-development volume may be allowed to infiltrate, or is released from the site. If released as surface runoff, it must not exceed the pre-development runoff rate or volume. Water quality treatment is required for systems that allow surface releases.

Evaporation systems that collect and store the entire pre-and post-development runoff volume do not require water quality treatment.

Developers wishing to use stormwater controls that “do not conform to or are not explicitly addressed by [the *Spokane Regional Stormwater Manual*]” must request a variance (Spokane County, et al., 2005, p. 2-4). The manual states that new design approaches and proposals that exceed the minimum standards are welcomed. Variance request submittals must include data and information similar to that required for the WSDOE demonstrative approach (see Section 5.5.4.4, above).

5.5.2 Stormwater Controls – Analysis and Recommendations

Spokane’s existing and forthcoming stormwater control requirements are somewhat progressive. Infiltration is the standard stormwater management approach, and treatment using bioinfiltration or biofiltration is required for PGIS runoff. Evaporation systems are not discussed in extant LID literature, but can achieve the LID goal of controlling post-development runoff volume and rate. For the purposes of this study evaporation systems are considered a LID BMP.

The draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) describes four common LID controls (biofiltration channels, vegetated filter strips, bioinfiltration cells and drywells); yet excludes four additional LID options: exfiltration BMPs, rainfall collection and re-use, pervious paving, and vegetated roofs. Spokane’s variance request process provides an avenue for developers to propose these BMPs, but this could slow the permitting process. As discussed in Chapter 2, delayed permitting can increase development costs and discourage developers from proposing alternatives. Adding these LID stormwater controls to the *Spokane Regional Stormwater Manual* will provide developers with more options, potentially encouraging them to use more LID strategies. Some regulatory considerations and technical guidance recommendations for the *Spokane Regional Stormwater Manual* are given below.

5.5.2.1 Exfiltration BMPs

Exfiltration BMPs are a variation on bioinfiltration cells, and are appropriate where infiltration capacity is limited. They can be used in residential neighborhoods and dense urban settings. Like bioinfiltration cells, they provide water quality treatment via soil filtration and plant and microbial metabolism. Runoff that cannot be infiltrated is detained by the system, and released slowly to an underflow pipe that channels the water to another stormwater facility. Stormwater facilities in older parts of Spokane would most likely include the storm sewer system. In newer areas, the water could be channeled to a dry well. Exfiltration BMP design guidance is provided in City of Portland (2004). In this reference, exfiltration BMPs are described as 'flow-through planters' and 'street swales'.

5.5.2.2 Rainfall Re-Use

Sections 2.2.5.4 and 3.2.7 describe the benefits of rainfall re-use for stormwater management in Spokane, as well as other potential benefits for instream flows and CSO control. There is, however, a potential legal impediment against rainfall re-use in Washington. State law defines all water in the state as a resource held in the public trust (Washington State Office of the Attorney General, 2000). To use the resource legally, a person or entity must obtain a permit from WSDOE. Permits are required if the water is intended for a beneficial use (as defined by 90.03 RCW). If rainwater is simply detained until it can be released to the stormwater system, then no permit is necessary (Roma Call, personal communication, January 17, 2007). Releases to bioinfiltration systems are included in this case; therefore, no permit would be required. In contrast, collected rainwater used for landscape irrigation or toilet flushing *is* considered a beneficial use and requires a permit. With new legislation, this requirement could be reversed. Recently, bills to exempt beneficial uses of collected rainwater have been introduced to the Washington legislature (Dedyo and von Schrader, 2006). Unfortunately all introduced bills have failed. Until one is passed, permits will continue to be required.

Due to competition for rights to increasingly limited water resources, obtaining a water right permit in Washington can take years (WSDOE, 2006d). Requiring individuals to obtain permits for cisterns would be cumbersome. To simplify this issue, the City of Seattle Public Utilities department is working with WSDOE to obtain a blanket permit for cistern operation within the City of Seattle (Roma Call, personal communication, January 17, 2007). This permit will allow individuals and other entities within Seattle to collect rainwater for beneficial uses. To expedite the permitting process, the City of Seattle is participating in Ecology's Cost Reimbursement program. Under this option, a private consultant performs activities normally conducted by WSDOE in permit review (WSDOE, 2006d). The WSDOE performs only the final review and makes the final permitting decision. The applicant in the cost reimbursement program:

- pays the private consultant's fees,
- reimburses WSDOE for time spent on review and permit authorization, and
- pays the application fees of all competing applicants (WSDOE, 2006f).

Competing applicants are those in the application queue ahead of the cost reimbursement applicant. In Seattle's there are comparatively few competing applicants and the permit is expected to be issued before the end of 2007 (Roma Call, personal communication, January 17, 2007). The cost reimbursement program would not be an inexpensive option for Spokane, but funding may be available through stormwater fees already charged to Spokane residents in their utility bills (SMC 13.03.1137).

To provide the most benefit for stormwater management, CSO control, and instream flows, large cisterns will be necessary in Spokane. Cisterns are commonly made of fiberglass, polypropylene, prefabricated or cast-in-place concrete, ferrocement (Gunite™ or Shotcrete™) sprayed over a metal rod and wire frame, even wood (Texas Water Development Board, 2005). Tanks do not have to be imposing features of the landscape. Some can be buried; others can be hidden under decks or in foundation access areas. See Figure 5.5-1. Cast-in-place concrete and ferrocement systems offer imaginative landscape architects opportunities for creating integrated landscape elements. The Texas Manual on Rainwater Harvesting (Texas Water Development Board, 2005) provides detailed explanations of typical cistern system components and general design considerations. General diagrams for a large system planned for a King County Administration building are shown in Dedyo and von Schrader (2006).

Figure 5.5-1. Cistern as deck foundation (Source: http://www.rainwaterconnection.com/rainwater_harvesting/basic_components.htm).

5.5.2.3 Pervious Paving

Pervious paving can reduce site runoff. Because of treatment requirements for stormwater generated by PGIS, Spokane may need to seek approval from WSDOE for pervious paving as a treatment BMP (Section 5.5.4.3 and 5.5.4.4). If phosphorus-TMDLs for stormwater are not enacted, there may be sufficient existing evidence to justify using pervious pavers in driveways and off-street parking areas. Local studies may be necessary to demonstrate whether pervious paving provides adequate treatment for phosphorus. See Section 5.5.4.3. There should be no reason, however, to limit pervious pavers in sidewalks and pedestrian areas that do not receive regular vehicle traffic. Ferguson (2005) and Hinman (2005) provide detailed design guidance for pervious paving systems.

5.5.2.4 Vegetated Roofs

Like pervious paving, vegetated roofs also reduce site runoff. Vegetated roof systems may be constructed from commonly available materials. General design guidelines are given in Hinman (2005) and City of Portland (2004). Pre-assembled modular systems are also available from several North American firms specializing in vegetated roof design and installation (Greenroofs.com, n.d.). Some design guidelines mention fertilizer use. If a phosphorus-TMDL for stormwater is approved in Spokane, it will be important to minimize fertilizer use on vegetated roofs.

The percentage of runoff reduction expected from vegetated roofs for Spokane is unknown, but is probably not 100 percent. Therefore, sequential stormwater controls will be necessary. Vegetated roof runoff can be estimated with computer modeling. Several groups in the U.S., Canada, and Germany are developing or have developed simulation modeling approaches to predict runoff attenuation (Jarrett et al., 2006; Roofscapes, 2000). None of the models described seem to be available commercially; however, a model described by Jarrett et al. (2006) can simulate the runoff rate using an adaptation of the Modified Puls routing model. Modified Puls routing is available in publicly available software such as the US Army corps of Engineers model HEC-HMS. Some vegetated roof consulting firms also offer modeling services specific to their roofing systems (Roofscapes, n.d.).

5.5.2.5 Additional Considerations

Local developers and development permit reviewers are familiar with bioinfiltration cells, drywells and biofiltration channels because they have been used in Spokane for many years. Local experience with other LID controls is limited. This situation creates a potential for institutional barriers (see Section 2.2.9) that may hinder implementation of the new BMPs. One approach for minimizing institutional barriers is to provide technical guidance. The *Spokane Regional Stormwater Manual* is appropriate for this purpose, but should be supplemented with guidelines based on the recommendations given above. It should be understood, however, that the *Spokane Regional Stormwater Manual* is essentially an engineering design manual with an emphasis on the technical details for achieving minimum stormwater control requirements. The manual is not designed to address the comprehensive integration of planning, design, construction, and maintenance necessary for LID's success.

Adding LID-oriented regulations to the SMC as well as adding LID stormwater controls to the *Spokane Regional Stormwater Manual* will reduce some barriers. Developers and reviewers must also understand how to select from all of the LID options and how to properly evaluate their applications. This understanding requires tools and guidelines appropriate for hydrologic analysis, site planning and design approaches, as well as specific stormwater controls. It is probably inappropriate to include all of this information solely in an engineering design manual. An approach used in other jurisdictions is development of a separate manual that addresses LID in a more comprehensive fashion. At least two manuals have been developed recently that could act as models for Spokane: the *Minnesota Small Urban Sites BMP Manual* (Barr Engineering, 2001), and the *Low Impact Development Technical Guidance Manual for Puget Sound* (Hinman, 2005). Both provide general design guidelines for LID stormwater controls. Equal or greater emphasis is placed on comprehensive understanding of LID and how to select appropriate strategies for local conditions. Both of these manuals are intended to be used in conjunction with other detailed engineering design guidance texts.

5.6 CONSTRUCTION SITE CONTROLS

Section 2.2.6 discussed the important of construction site controls to minimize impacts from erosion and to preserve a site's hydrologic integrity. Erosion and sediment control are also a requirement of the Phase II permit (WSDOE, 2007), and UIC rules (WAC 173-219-090(1).c.i.C). Both regulations require that Spokane implement ESC requirements described in the *Stormwater Management Manual for Eastern Washington* or other manual approved by WSDOE. Under Phase II requirements, ESC regulations and an enforcement program must be implemented by February, 2010 (WSDOE, 2007a).

5.6.1 Construction Site Controls – Policy Summary

Presently only very general ESC requirements are listed in the Spokane municipal code (SMC 17D.060), and no ESC-specific inspection, maintenance or enforcement standards are described. However, existing regulations will be supplemented by ESC requirements in the *Spokane Regional Stormwater Manual* upon its approval. Under the new requirements, most projects will be required to develop and implement an ESC plan. The draft *Spokane Regional Stormwater Manual* (Spokane County et al, 2005) lists fifteen mandatory measures of a plan and suggests appropriate BMPs for each measure. The draft manual does not include BMP specifications, but instead refers to the *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a), for BMP specifications, maintenance, and inspection recommendations. The fifteen ESC measures and their associated BMPs reflect recommendations offered in Section 2.2.6 of this thesis. Two recommendations in Section 2.2.6, however, are not mentioned in the Spokane manual. These recommendations pertain to requirements for on-site, ESC-certified contractors to oversee ESC operations, and to clearly defined enforcement measures.

5.6.2 Construction Site Controls - Analysis and Recommendations

Within the contents of both the *Spokane Regional Stormwater Manual* and the *Stormwater Management Manual for Eastern Washington*, most of the ESC recommendations discussed in Section 2.2.6 are addressed. Together, the two manuals provide the basis for a construction site controls program that supports LID in Spokane. Recent LID experience in Seattle also provides useful guidance. The City of Seattle has noted some weaknesses in state-level ESC guidance when applied to its municipal LID projects (Masako Lo, personal communication, December 20, 2006). Existing vegetation and soils with good infiltration capacity were not protected adequately by standard ESC requirements. The City of Seattle is responding to this discrepancy by developing supplemental requirements. In the interim, project bid documents include new specifications that better address soil and vegetation protection. Example specifications are given Table 5.6-1. The City of Spokane should consider similar language when developing a LID ESC program. When Seattle completes its ESC regulations updates, additional useful information may be found in the Seattle Municipal Code Chapters 22.800 through 22.808, and the Department of Planning and Development (DPD) Director's Rules. Links to both sets of documents can be found on the City of Seattle's DPD Codes website under “Stormwater, Grading, and Drainage Control Code” at: http://www.seattle.gov/dpd/Codes/.

Section 2.2.6 recommends on-site ESC-certified contractors to oversee ESC operations. The State of Washington requires on-site certified erosion and sediment control lead (CESCL) personnel by contractors operating under the State Construction Stormwater General Permit (WSDOE, 2006f). Contractors are required to obtain this permit for construction sites that discharge to surface water; however, the permit specifically excludes sites discharging to ground water. In Spokane, since most new construction sites discharge to groundwater, the state’s CESCL requirement technically does not apply in many cases. Despite this, the draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) requires written ESC plans for most construction sites, regardless of discharge receiving area. To better ensure adequate implementation, Spokane should adopt CESCL requirements for all sites requiring ESC plans.

Inadequate enforcement of ESC regulations has been noted as one of the most significant problems affecting ESC program success (Corish, 1995, Caraco, 2000). The Phase II permit requires Spokane to implement an enforcement program by early 2010. Neither the draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) nor current City of Spokane development codes detail ESC enforcement measures. Washington, D.C. implemented an enforcement program in 1998 that could be used as a model. See Section 2.2.6. Existing ESC enforcement codes that may also provide guidance are available through Portland’s and Seattle’s municipal codes websites (City of Portland, 2007; City of Seattle, 2006).

Table 5.6-1. City of Seattle Supplemental Requirements (Seattle Public Utilities, 2005)

Section 1-07.16(2) TREES, SHRUB, AND PLANT MATERIAL PROTECTION

Tree protection measures shall be provided and maintained by the Contractor per this section and Standard Plan No. 133[1]. Protection measures including but not limited to the following shall be in place and approved prior to the beginning of construction:

A. Temporary construction fencing shall be installed to identify the construction limits of the project and to restrict equipment operation and/or material storage from the "critical root zone" of trees to be retained unless otherwise approved by the Engineer. Approval for work activity within the critical root zone shall require protection methods to mitigate impact to soil, tree roots and/or tree canopy.

B. Surface protection measures shall be required for all areas within the construction limits and within the dripline of trees to be retained.

Pruning shall be limited only to the extent necessary to allow safe operation of equipment and/or prevent damage to trees. Pruning shall not occur to expedite construction and/or allow for the use of large equipment where alternative methods of construction are feasible as determined by the Engineer.

1-07.16(2)A SOIL AND ROOT PROTECTION

Soil protection measures shall be installed, inspected, and approved by the Engineer prior to construction and shall be maintained by the Contractor until notified by the Engineer.

Soil surface protection consisting of a 4" minimum depth of wood chips or equal as approved by the Engineer shall be provided and maintained for all non-paved surfaces subject to construction impacts.

Soil structure protection consisting of a 4" minimum depth of wood chips and steel plates (or equal) shall be provided to prevent compaction for all unpaved areas subject to equipment operation or material storage.

2-01.3(5) PROTECTION OF EXISTING IMPROVEMENTS

Existing trees identified as protected within the right-of way shall be protected by installing temporary high visibility fencing, on the construction side of vegetation to be protected, at a minimum distance equal to one-half the distance to the drip line away from the trunk, or as directed by the Engineer. Existing trees to be protected will be flagged by the Engineer prior to the start of construction on each Avenue or Street. All clearing and grubbing around native trees shall be selective, by hand methods only and as directed by the Engineer.

High visibility fencing shall be composed of a High Density Polyethylene material and shall be at least 4 feet high. Posts for fencing shall be placed every 5 to 10 feet on center or as directed by the Engineer to ensure rigidity. On long continuous runs exceeding 8 feet, a tension wire or rope shall be used as a top stringer to prevent sagging between posts.

Fencing material shall be free of any chemical treatment and meet the following requirements:

PROPERTY	VALUE	TEST METHOD
Tensile strength	360 lbs / ft	ASTM D4595
Color	High Visibility Orange	

The Contractor shall furnish a certificate or affidavit attesting that the fabric meets all the requirements stated above

1. Plan may be viewed at: http://www.seattle.gov/util/Engineering/Standard_Plans_&_Specs/index.asp, 2005 Standard Plans for Municipal Construction, 100 Landscape.

5.7 MAINTENANCE

Like other stormwater management systems, LID controls require maintenance for proper long-term function. Because LID controls are typically dispersed throughout a development, it is appropriate for homeowners to take partial responsibility for maintenance. The local jurisdiction should also establish appropriate maintenance guidelines and an enforcement program.

5.7.1 Maintenance – Policy Summary

In Spokane, developers must submit maintenance plans for onsite stormwater systems (SMC 17D.060.140F). Responsible parties then take responsibility for maintenance in accordance with the developer's plan (SMC 17D.060.050). Responsible parties include homeowners associations, property owners associations, small businesses created for maintenance purposes, or "other entity acceptable to the local jurisdiction" (Spokane County et al., 2005, p. 11-1). Specific maintenance procedures and schedules are not defined in the stormwater manual; instead, these elements are determined by the project's design engineer. Maintenance plans must include descriptions and schedule of maintenance tasks, and a replacement schedule for system components.

Access routes must be provided for all facilities located "25 feet or more from an all-weather, drivable surface" to ensure maintenance access (Spokane County, et al., 2005, p. 11-2). To further ensure access, all stormwater facilities outside of the public right-of-way must be located in tracts that are separate from private lots. The tracts must be sized appropriately to allow maintenance access without risking damage to adjacent property.

Maintenance is enforced by Spokane's Wastewater Management department (SMC 17D.060.070D). Wastewater Management is authorized to perform onsite inspections and conduct other inquiries, as needed, to ensure onsite facilities are functioning properly. If corrective action is necessary, the Wastewater Department may work informally with the responsible party (SMC 17D.060.110). If the issue is not resolved, Wastewater may initiate a Notice of Inquiry (SMC 17D.060.080) and formal Departmental Hearing (SMC 17D.060.090). If "satisfactory action does not occur, the City may thereafter correct the problem and costs thereof may be added to the utility bill for the premises concerned" (SMC 17D.060.080B7).

5.7.2 Maintenance – Analysis and Recommendations

The maintenance access requirements described above generally agree with recommendations given in Section 2.2.7; therefore, no additional recommendations are suggested. Few recommendations for successful enforcement programs are described in the LID literature; however, the Phase II permit requires "an ordinance or other regulatory mechanism [that] shall include appropriate, escalating enforcement procedures and actions" (WSDOE, 2007a, p. 21). The City of Spokane's policies appears to meet this requirement.

Beyond access and enforcement policies, The City of Spokane's maintenance requirements are too general. The regulations appear to place all maintenance decisions in the hands of the project design engineer. It is entirely appropriate for a design engineer to specify maintenance details and schedules for specific facilities; however, a lack of defined, minimum maintenance requirements introduces a potential institutional barrier (see Section 2.2.9). This will be even more important if Spokane approves more LID controls. As mentioned previously, Spokane has had little experience with LID controls; consequently, without stronger guidance, reviewers may not always recognize a poor maintenance plan. Even if maintenance is performed regularly, poorly defined procedures and inspection schedules can contribute to system failure. Over time, some facilities may develop an unrealistic reputation for poor performance; a reputation that may have been avoided had adequate maintenance been defined.

The draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) is based heavily on the *Stormwater Management Manual for Eastern Washington* (WSDOE, 2004a). In Appendix 5A of the WSDOE manual, there is a table of minimum maintenance criteria for all stormwater quality treatment BMPs listed in the manual. At a minimum, the *Spokane Regional Stormwater Manual* should refer to this table for BMPs that are approved in Spokane. Ideally, Spokane should refine the WSDOE maintenance recommendations for local application. Four LID BMPs recommended by this thesis are not addressed in draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005) (see Section 5.6.2). If Spokane adopts these BMPS, appropriate maintenance guidelines should also be developed. Useful guidance for such an effort can be found in City of Portland (2004), and WSU and AHBL (2005). As mentioned in Section 2.2.7, these references differentiate appropriate maintenance procedures for homeowners and professionals, and detail facility-specific procedures and schedules.

Photo logs are not mentioned (or recommended) in any of the LID-maintenance literature reviewed for this thesis. Although photographs may be unreliable for enforcement purposes, they can be invaluable as an educational tool. Photo logs could help track long-term system performance. This may help City personnel or qualified contractors trouble-shoot system problems and determine appropriate corrective action. During property transfers, photos would help new owners identify and understand site-specific stormwater systems.

5.8 EDUCATION

Part of LID's success relies on education. Section 2.2.8 suggests several approaches for programs to train contractors and inform the public about everyone's role in supporting LID projects. The Phase II permit also requires the City of Spokane to make educational materials and programs available to contractors and the public (WSDOE, 2007a).

Only limited educational materials and training sessions are now available in Spokane. Contractors can obtain local stormwater guidance manuals from the City of Spokane and Spokane County (Eldon Brown, personal communication, January 19, 2007). The City of Spokane holds occasional training seminars for contractors and inspectors, although there are no formal programs. Citizens can obtain limited information about stormwater management from two internet sites: the City of Spokane's Wastewater Management webpage (http://www.spokanewastewater.org), and the Spokane Aquifer Joint Board (SAJB) webpage (http://www.spokaneaquifer.org/index.htm). Stormwater information brochures are distributed occasionally in utility bills. Water quality information and notices are also provided through CityCable 5, the local government access cable television station.

These outreach program elements do not adequately meet Phase II permit requirements. Recognizing this deficiency, the City of Spokane has initiated development of a comprehensive public education program (Brown and Caldwell and URS, 2004). The tasks of this development program match those recommended in Section 2.2.8. The City also plans to draw on the experience and educational materials from other cities in developing their own program.

At this time, the education program focuses on bioinfiltration swales, their operation and maintenance, general water quality, and construction site runoff control. Given the current direction of Spokane's stormwater management approach, this focus is a good start. If more LID approaches are approved for use in Spokane, the education program will need to be expanded. A local LID manual like that suggested in Section 5.6.2.5 would support this expansion.

5.9 SUMMARY

This review shows that the City of Spokane does not have an explicit LID policy. The city does however, have policies and regulations that partially support LID. Natural environment and stormwater policies in the city's comprehensive plan are closely aligned with LID conservation and stormwater management principles. These policies are supported by regulations that require conservation of critical areas and stormwater management using vegetated controls. Spokane's conservation regulations directly support the LID strategy to minimize the development envelop. Associated PUD regulations allow non-conventional lot sizes, shapes, and configurations that can help minimize imperviousness. Four LID stormwater controls are recommended or required in Spokane. The primary stormwater control for new developments is bioinfiltration. Bioinfiltration systems must be equipped with a drywell overflow system. Biofiltration channels and vegetated filter strips are also approved locally for stormwater quality treatment.

Combined, Spokane's policies and regulations allow LID-knowledgeable developers to pursue a portion of the LID conservation, site design, and stormwater control strategies. However limitations in state and local regulations make it impractical to pursue LID to its maximum potential. Areas of greatest concern include the following.

Hydrologic models required for drainage planning may be inadequate for analyzing proposed LID designs. Residential street width and on-street parking requirements prevent minimizing imperviousness to the extent that is possible while still meeting safety considerations. Pervious paving is not mentioned in local stormwater guidance documents. There is no reason to exclude its use in pedestrian areas. For use in automobile areas; however, pervious paving must gain WSDOE approval as a water quality treatment BMP. Three other LID stormwater controls are also problematic: rainfall re-use, exfiltration BMPs and vegetated roofs. Rainfall re-use requires a water right permit, which may take years to obtain. Exfiltration BMPs and vegetated roofs are not addressed by the draft *Spokane Regional Stormwater Manual* (Spokane County et al., 2005). The manual encourages the use of new stormwater controls that meet or exceed minimum standards; nevertheless, a developer wishing to use stormwater controls "not explicitly addressed by (the) manual" must obtain a variance (Spokane County et al., 2005, p. 2-4). The variance request process can be a disincentive to developers if it slows permit approval. Spokane's regulations and programs addressing construction site controls, maintenance and education are also inadequate to fully support LID.

As stated in Chapter 1, the key to LID's success is supportive policies combined with selection of site-appropriate strategies that are properly designed, constructed, and maintained. Chapter 3 shows how a variety of LID measures offer benefits within Spokane's physical conditions and regulatory needs. While local policies partially support LID, there is room for improvement. Recommendations have been discussed throughout this chapter and are summarized in Table 5.9-1.

Table 5.9-1. Recommendations Summary

Topic Area
1. Spokane Policy - Comprehensive Plan (reference thesis Section 5.1) i. Modify policies to include the concept of LID ii. Add a watershed-based zoning goal
2. Site Hydrology (reference Section 5.2) i. Include Tc as a site-design control factor. ii. Adopt SWMM as the preferred hydrologic analysis model for LID projects
3. Conservation (reference Section 5.3) i. Adopt specific regulations, recommendations, and incentives for restoring hydrologic features in poor condition. ii. Provide guidance, or reference federal and state guidance documents for effective mitigation and restoration design. iii. Identify conservation programs that qualify for tax incentives, or direct users to organizations and resources that provide this information. iv. Adopt regulations to preserve natural site drainages in all City-regulated areas, not just SDDs. v. Recommend preserving topography that disperses and slows runoff vi. Adopt regulations to preserve highly pervious soils in all site areas that remain unpaved or that are not planned for heavy uses. In addition to infiltration areas, this includes lawn and garden areas, unpaved recreation areas, and greenways. vii. Provide density bonuses for LID projects. viii. Add a Conservation chapter to the SMC. (see Section 5.3.2 for additional recommendations)
4. Site Planning a. Buffer Zones (reference Section 5.4.1): i. Update wetland buffer requirements based on most recent guidance. ii. Add requirements for 'wetland management plans'. iii. Develop specific stormwater management requirements for areas near and within buffer zones. b. Lot Requirements (reference Section 5.4.2): i. Revise SMC to clearly state that a mixture of lot sizes and shapes is allowed for project-types such as PUDs and LID.

c. Street Design Standards (reference Section 5.4.3):

i. Recommend limiting imperviousness in the center of cul-de-sacs (using bioretention 'islands').
ii. Recommend hybrid road networks
iii. Reduce road width and street parking requirements for lower-density neighborhoods.
iv. Reduce impervious paving requirements for alleys.

d. Off-Street Parking (reference Section 5.4.4):

i. Recommend shared driveway configurations as a way to minimize imperviousness in residential settings.
ii. Recommend covered parking in residential and commercial parking areas as a way to reduce PGIS-contaminated runoff
iii. Encourage use of compact spaces &/or require compact spaces when the total exceeds stipulated minimums.
iv. If water quality treatment approval is obtained, recommend pervious paving for residential driveways and low- and medium-use parking areas.
v. Add pervious paving design guidance to the *Spokane Regional Stormwater Manual.*

e. Reduce Effective Imperviousness (see Section 5.4.5):

i. Adopt requirements for disconnecting imperviousness in redevelopments, especially those on City sewer.
ii. Adopt effective imperviousness minimization requirements for new developments connected to City sewer.

f. Reduce Building Footprint (see Section 5.4.6):

i. Adopt impervious surface maximum coverage requirements for LID projects.
ii. Encourage use of pier and piling foundations. Could also be used as an incentive, allowing developers more building coverage if all or portions of foundations are on pier and piling systems.

5. Stormwater Controls (see Section 5.5)

i. If a blanket water right permit can be obtained, recommend rainfall re-use.
ii. Recommend pervious paving (refer to Street Design Standards and Off-Street Parking recommendations, above.
iii. Recommend exfiltration BMPs and vegetated roofs.

6. Construction Site Controls (see Section 5.6)

i. If Spokane adopts LID policies and regulations, add LID-specific construction controls to the *Spokane Regional Stormwater Manua*l, or other ESC manuals that may be developed.
ii. Adopt CESCL requirements for all sites requiring ESC plans, including LID sites.
iii. Develop more clearly defined ESC inspection and enforcement regulations and programs.

7. Maintenance (see Section 5.7)

i. Develop more clearly defined maintenance requirements, and inspection and enforcement requirements.
ii. Recommend parties responsible for stormwater controls maintain photo logs, particularly for vegetated systems.

8. Education (see Section 5.8)

i. Continue existing plans for education and outreach programs.
ii. Expand program to include LID concepts and stormwater controls.

9. General

i. Develop a LID manual (see Section 5.6.2.5)
ii. Consider incentives to encourage developers and homeowners to implement LID strategies (see Section 2.2.10).

These recommendations address comprehensive plan policies, development codes, technical guidance, and incentives. The intent is to provide developers with more LID options, and to reduce existing regulatory and institutional barriers. Incentives are suggested as a way to stimulate more community interest in LID and help offset the risks developers take when adapting to new methods.

If Spokane chooses to consider these recommendations, policy-makers must also decide whether to implement them as voluntary standards, as mandatory regulations, or in combination. During this study, no literature was identified that indicates which approach is most effective. Olympia, WA uses mandatory LID standards in the Green Cove watershed (Haub, 2002). Haub cautions that mandatory standards must be “legally defensible in terms of property rights, growth management law, and public safety” (Haub, 2002, p. 6). When considering an approach such as Olympia’s; decisions should be based on the best available science, and the analysis of local development practices and markets. Haub also states that mandatory regulations should be adopted gradually. This allows municipal staff time to develop consensus and to communicate with the public in an open process. To gain the greatest community support, Haub’s recommendations probably should be followed even for voluntary standards.

Based on these considerations, limitations to the recommendations in Table 5.9-1 should be noted. The existing Spokane-area scientific data were sufficient for the author of this thesis to substantiate potential LID-benefits and to make general policy recommendations. The data were insufficient to justify more detailed recommendations. In addition, addressing local development practices and market conditions was beyond the scope of this study. Therefore, the recommendations in Table 5.9-1 will require further study and refinement before they can be considered either for voluntary or mandatory standards.

While this study does not provide a set of fully-developed LID policies and regulations, it has explained how LID can benefit Spokane, and has highlighted policy areas that will support this integrated LID implementation. The author hopes that the City of Spokane takes notice of these recommendations and actively considers an LID-oriented approach in its planning efforts.

6 CONCLUSIONS

Like many U.S. urban areas, Spokane, Washington is obligated to comply with increasingly stringent environmental and stormwater management regulations. The regulations do not require specific management methods, only that the affected jurisdictions implement effective approaches. Low impact development has been suggested as a general stormwater management strategy that also supports environmental regulations and is actively encouraged by federal and state agencies. It is up to Spokane to determine whether and how LID will be incorporated into local policy. This thesis provides preliminary considerations for this process.

A variety of LID strategies are known and are used throughout the country. Local physical conditions and regulatory climate may limit LID application in a given area. Spokane is no exception. While the LID strategies discussed in this thesis have their place in Spokane, the following considerations were revealed:

1. Conservation requirements do not adequately protect pervious soils and features that promote natural hydrologic function.
2. Development standards promote unnecessary imperviousness, particularly in residential roadways and alleys.
3. Infiltration has limited applicability in some areas due to low subsurface water storage capacity.
4. Base course construction of pervious paving systems requires consideration of freeze/thaw conditions.
5. Pervious paving systems will require WSDOE approval for use as stormwater quality treatment BMPs before they can be used in vehicle areas.

6. Rainfall re-use systems intended for beneficial uses such as landscape irrigation or toilet flushing require a state water right permit.

As a whole these limitations do not preclude LID's use in Spokane, only the combination of strategies that are possible at a given site. Spokane can, however, go much further in supporting LID, and reduce its overall need for managing stormwater runoff, by taking a more aggressive stance on items 1 and 2, above. A variety of recommendations addressing conservation measures and site development standards are suggested by this thesis. In addition, if the approvals listed in items 5 and 6 above can be obtained; LID will have few physical and regulatory limitations in Spokane. Suggestions for how Spokane can facilitate items 5 and 6 are offered.

Once regulatory hurdles that limit LID implementation are overcome, Spokane must address LID awareness. Awareness applies to everyone: private citizens, municipal personnel, developers, and construction contractors. In varying levels of detail, each group requires knowledge of proper design, construction, and maintenance of LID sites and stormwater controls. Education can be accomplished partly through additions to existing technical guidance manuals, supplemented with a more general manual that describes LID's application in the Spokane region. Education and outreach programs are also needed. To ensure proper LID construction practices and maintenance are conducted, inspection and enforcement regulations must be adopted. Several recommendations are suggested. Knowledge and mandatory standards will be sufficient to stimulate some developers to begin using LID. Others may continue to balk, citing costs or other potential risks to adopting new methods. A variety of incentives are suggested as a way to offset potential risks and encourage developers toward LID approaches.

6.1 STUDY LIMITATIONS

This thesis provides policy recommendations that will help Spokane implement a low impact development stormwater strategy. The recommendations are based on a preliminary evaluation of federal and state regulations, and reports of local environmental conditions. As discussed in Section 5.9, however, the analysis performed here is insufficient to support implementing the recommendations, as written, with full, legal defensibility. The City of Spokane will need to perform further analysis and refine the policy recommendations before they can be considered for final regulations.

While this study shows LID's potential in Spokane for supporting stormwater and environmental regulations, it does not consider in detail the financial costs to implement LID. Since LID disturbs less site area, uses less curb and gutter, and preferentially incorporates vegetated stormwater controls over engineered structural systems; a common assumption is that LID projects costs less to build than conventional developments. Case studies mentioned in Chapter 2 support this assumption, showing construction costs for some LID projects were lower than conventional construction. Unfortunately the studies gave little detail about the specific LID strategies that were included. It is therefore impossible to draw firm conclusions from these case studies about potential LID construction costs in Spokane. The case studies also did not discuss the long-term costs to maintain LID systems. Again, a common assumption is that LID systems are less expensive to maintain than conventional stormwater systems, but this has not been thoroughly documented either in this thesis or in extant LID literature.

Costs of government oversight must also be considered. This thesis suggests changes to local policy, regulations, development standards, and technical guidance documents. These changes alone will require time and effort by municipal personnel, and probably additional assistance from private consultants. Once promulgated, municipal personnel must be educated about the new regulations and how to enforce them. It may also be necessary to dedicate some personnel strictly to LID issues. These individuals will act as in-house experts, clarifying LID policy, practice, and enforcement questions from city personnel and the public. A new municipal department or specialty division may be the most effective approach in this situation.

6.2 SUGGESTIONS FOR FURTHER RESEARCH

To implement the LID strategy suggested by this study, the City of Spokane will need to conduct at least three studies.

1. An evaluation of pervious pavement under local conditions for treating, at a minimum, TSS and phosphorus to meet water quality requirements. This information will support the demonstrative approach for obtaining WSDOE approval to use pervious paving as a stormwater quality treatment BMP in vehicle areas.
2. Water balance modeling to evaluate the effects of widespread rainfall re-use on SVRP Aquifer recharge, instream flows, CSO events, and senior water right permit holders' water allocations. Results of this model will support a blanket water right permit application for rainfall re-use in Spokane.
3. Further and more detailed evaluation of best available science, growth management law and local development practices to formulate legally defensible policies and regulations.

Hydrologic modeling is another significant study area for LID. Hydrologic modeling is fundamental to the LID design process. Poor or inappropriate models create significant risks for

LID failure. There are also implications for future NPDES municipal stormwater permits. Each permit is evaluated and renewed on a regular basis. If a community does not meet the goals of a given permit cycle, requirements may be tightened in the next permit cycle. There is the potential that LID projects that are poorly designed due to poor modeling practices will lead to more stringent NPDES permit obligations. It is in the community's best interest to implement the best available LID model. The hydrologic model SWMM was suggested in Chapter 2 as the most appropriate existing model for LID planning and design. The model reviewers (Elliot and Trowsdale, 2007) however, discussed several shortcomings of the model. Areas needing further study and modification to strengthen the SWMM model include:

- Direct representation of LID systems and stormwater controls, rather than indirect approximations. For example, SWMM represents infiltration as a tank outlet rather than as a direct interaction with the soil.
- Incorporation of evapotranspirative effects on hydrologic function that considers species type and species distribution across a site.
- Improvements in contaminant loading, transport, and removal processes.
- Groundwater and development's affect on baseflow and recharge.
- Incorporation of a cost analysis module and environmental or receiving water risk assessment modules.
- Prediction of LID effects at subdivision and catchment scales.

LID construction costs and program oversight are two research topics that should be addressed. No fully-integrated LID projects have been completed in Spokane that can provide data for a post-construction cost analysis. An alternative is to compare construction cost-estimates of proposed projects. In this study a site could be designed on paper using 1) conventional design and 2) LID design. Construction costs can then be estimated and compared. Such a study should also compare design costs (including site investigation time, materials, and labor, and hydrologic modeling), construction costs (including costs to implement LID-appropriate ESC), and long-term maintenance costs. Since Spokane has sites with high infiltration and others with poor capacity, at least one site under each scenario should be evaluated. Preliminary LID program oversight costs can be estimated from extant LID literature and from interviews with personnel in cities with LID programs. This information can help Spokane determine a locally-appropriate program structure and help the city identify potential funding sources.

6.3 IMPLICATIONS OF THIS STUDY FOR STORMWATER PLANNING IN OTHER COMMUNITIES

This study has evaluated LID application in one community facing NPDES municipal stormwater and other environmental protection regulations. Many communities across the U.S. are similarly regulated and are evaluating how they will address new requirements. Cities such as Portland, Seattle, and Olympia, as well as Prince George's County, Maryland and Mecklenburg County, North Carolina have implemented a variety of LID policies and regulations. Communities in the process of adopting new stormwater approaches can look to these cities and counties for model regulations; however, the decision process that resulted in a given set of regulations typically is not clear from the regulations themselves. There is some risk that time-stressed planners and policy-makers will simply 'borrow' regulations from other communities without adequately evaluating whether the regulations are best under local conditions. This may lead to ineffective LID application and potentially costly repercussions for regulatory compliance.

This thesis provides the basis of a logical framework for evaluating LID's place under any set of local conditions and the considerations that should be addressed in developing local LID policies. The following framework was used in this thesis.

1. Develop a fundamental understanding of LID and its strategies.
2. Formulate a preliminary LID approach that is appropriate for local conditions and that addresses applicable federal and state regulations.
3. Evaluate the LID approach in the context of local growth policies, zoning and development regulations, and technical guidance documents. The LID approach must also consider local development and construction practices and market conditions, though this evaluation was not performed for this thesis.

As emphasized by Haub (2002), legal defensibility is a primary consideration for any change to regulations and standards. Any proposed LID approach should be supported with local studies that evaluate surface, storm, and groundwater quality and wildlife habitat. Additionally, depending on local needs, the LID evaluation likely will be an iterative process requiring several modifications to the proposed LID approach before the most appropriate policies and technical approaches are identified. The community should be prepared for a process that takes several years. With sufficient patience and open-mindedness however, a LID approach that supports regulatory compliance, and hopefully a more sustainable community overall, should be achievable.

CITATIONS

Accetturo, A. (n.d.). *Seattle highlights rainwater harvesting at ARCSA 2005*. Retrieved December 27, 2006 from http://www.harvesth2o.com/seattle.shtml.

Adams, M.C. (2003). Porous asphalt pavement with recharge beds: 20 years and still working. *Stormwater: the Journal for Surface Water Quality Professionals* 4 (3). Retrieved July 25, 2006 from http://www.forester.net/sw_0305_toc.html.

AHBL. (2006). *Low impact development local regulations assistance project.* Olympia, WA: Puget Sound Action Team.

American Association of State Highway and Transportation Officials (AASHTO). (2001). *A policy on geometric design of highways and streets*. Washington, D.C.: Author.

Arendt, R.G. (1996). *Conservation design for subdivisions: a practical guide to creating open space networks*. Washington, D.C.: Island Press.

Armstrong, Jim. Director of Communications. Spokane County Conservation District. Personal communication, January 8, 2007.

Arvidson, A.R. (2006). A green demonstration. *Landscape Architecture, 96*(9), 50-63.

Avista Corporation. (2005). *Spokane River hydroelectric project FERC no. 2545: application for new license major project – existing dam* (volume II). Spokane, WA: Author.

Arnold, C.L. & Gibbons, C.J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American Planning Association*, *62*(2), 243-258.

Barr Engineering. (2001). *Minnesota small urban sites BMP manual: stormwater management practices for cold climates*. St. Paul, MN: Metropolitan Council Environmental Services.

Barrett, M., Lantin, A., & Austrheim-Smith, S. (2004). Storm water pollutant removal in roadside vegetated buffer strips. In *Highway facility design 2004 including 2004 Thomas B. Dean Distinguished Lecture* (Transportation Research Record: Journal of the

Transportation Research Board, No. 1890). Washington, D.C.: Transportation Research Board.

Barrett, M.E., Walsh, P.M., Malina, J.F., & Charbeneau R.J. (1998). Performance of vegetative controls for treating highway runoff. *Journal of Environmental Engineering, 124* (11), 1121-1128.

Bay Area Stormwater Management Agencies Association (BASMAA). (1997). *Start at the source: residential site planning and design guidance manual for stormwater quality protection*. Palo Alto, CA: Tom Richman & Associates.

Bledsoe, B.P. (2001). Relationships of stream responses to hydrologic changes. In Urbonas, B. R. (Ed.), *Linking stormwater BMPs designs and performance to receiving water impact mitigation* (pp. 60-77). Reston, VA: American Society of Civil Engineers.

Booth, D.B., Hartley, D., & Jackson, R. (2002). Forest cover, impervious-surface area, and the mitigation of stormwater impacts. *Journal of the American Water Resources Association, 38*(3), 835-845.

Boving, T.B., Stolt, M.H., Augenstern, J. Brosnan, B., University of Rhode Island, & BETA Group, Inc. (2006). *Porous pavement and water quality: investigation of a parking lot and its potential impact on subsurface water.* Kingston, RI: University of Rhode Island Transportation Center.

Brattebo, B.O. & Booth, D.B. (2003). Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research, 37*(2003), 4369-4376.

Brewer, K., & Fisher, H. (2004). Succesfully developing a low-impact design ordinance. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD, September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Brown and Caldwell. (2003). *Stormwater management plan for the West Plains planning area*. Spokane, WA: Spokane County Public Works, Stormwater Utility.

Brown and Caldwell & URS. (2004). *City of Spokane stormwater management plan*. Spokane, WA: City of Spokane, Wastewater Management.

Brown, Eldon. Principal Engineer. City of Spokane Engineering Services Department. Personal communication January 19, 2007.

Brown, W.E., & Caraco, D.S. (2000). Muddy water in, muddy water out? In T. R. Schueler & H.K. Holland (Eds.), *The Practice of Watershed Protection* (pp. 305- 313). Ellicott City, MD: Center for Watershed Protection.

Burden, D., Wallwork, M., Sides, K., Trias, R., & Rue, H.B. (2002). *Street design guidelines for healthy neighborhoods*. Sacramento, CA: Center for Livable Communities.

Burden, D., & Zykofsky, P. (2000). *Emergency response: traffic calming and traditional neighborhood streets*. Sacramento, CA: The Center for Livable Communities.

Burrell, C.R., & Karimi, H. (2002, September/October). Implementation of an effective erosion control and stormwater management enforcement program in Washington, D.C. *Stormwater: the Journal for Surface Water Quality Professionals* 3(6). Retrieved September 5, 2006 from http://www.stormh2o.com/sw_0209_toc.html.

Burrell, C.R., Karimi, H., & Caldwell, W. (2004). Inspection requirements for low impact development BMPs in the District of Columbia. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD, September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Burton, G.A, & Pitt, R.E (2002). Stormwater effects handbook: a toolbox for watershed managers, scientists, and engineers. New York: Lewis Publishers.

Call, Roma. Water Resources, Northwest Regional Office, Washington State Department of Ecology. Personal communication January 17, 2007.

Caraco, D.S. (2000). Keeping soil in its place. In T. R. Schueler & H.K. Holland (Eds.), *The Practice of Watershed Protection* (pp. 323- 327). Ellicott City, MD: Center for Watershed Protection.

Center for Housing Innovation (CHI). (2000). *Green neighborhoods: planning and design guidelines for air, water, and urban forest quality*. Eugene, OR: University of Oregon.

Center for Watershed Protection (CWP). (1998). *Better site design: a handbook for changing development rules in your community*. Ellicot City, MD: Center for Watershed Protection.

Cheng, M.S., Coffman, L.S., Zhang, Y., Riverson, J., & Zhen, J. (2004). BMP model for low-impact development. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD, September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

CH2M Hill. (2001). *Final report to the Washington State Legislature: Washington stormwater management study report and recommendations from the stormwater policy advisory committee.* Olympia, WA: Washington State Department of Ecology and Washington State Department of Transportation.

City of Green Bay. (n.d.). *City ordinance code book, chapter 13 zoning ordinances*. Green Bay, WI: Law Department.

City of Madison. (2006). *Variable street width* (Ordinance file number 02634, version 2). Madison, WI: Author.

City of Minneapolis. (2006). *Code of ordinances City of Minneapolis: codified through ord. no. 2006-Or-138, adopted Dec. 1, 2006* (Supplement No. 33, Update 5). Retrieved February 10, 2007 from http://www.municode.com/resources/gateway.asp?pid=11490&sid=23.

City of Missoula. (1999). *City subdivision regulations article 3-2: streets, access and transportation*. Retrieved July 27, 2006 from http://www.ci.missoula.mt.us/publicworks/Public_Works_Documents.htm.

City of Olympia. (1995). City of Olympia's impervious surface reduction study. Olympia, WA: Public Works Department.

City of Portland. (2004). *Stormwater management manual, revision #3*. Portland, OR: City of Portland Bureau of Environmental Services (BES).

City of Portland. (2007, January 12). *Title 10 erosion and sediment control regulations: Chapter 10.70 enforcement and penalties*. Retrieved February 1, 2007 from http://www.portlandonline.com/auditor/index.cfm?c=28175.

City of Seattle (2006). *Title 22 building and constructions codes: Subtitle VIII grading and drainage control: Chapter 22.808 administration and enforcement*. Retrieved February 1, 2007 from http://clerk.ci.seattle.wa.us/~public/toc/t22.htm.

City of Spokane (2000a). *Draft comprehensive plan and environmental impact statement.* Spokane, WA: Author.

City of Spokane (2000b). *City of Spokane design standards, 2000 revision*. Spokane, WA: Engineering Services Department.

City of Spokane. (2001). *City of Spokane's comprehensive plan: revised edition as of July, 2005*. Spokane, WA: Planning Services Department.

City of Spokane (2004, November). *City of Spokane Standard Plans, 2004-2nd update*. Spokane, WA: Engineering Services Department.

Clar, M. (2005). Pembroke Woods: lessons learned in the design and construction of an LID subdivision. In Moglen, G.E. (Ed.) *Managing Watersheds for Humna Impacts: Engineering, Ecological, and Economic Challenges* (electronic resource). Reston, VA: American Society of Civil Engineers.

Clausen, J.C. (2004). *Annual report Jordan Cove urban watershed section 319 national monitoring program project*. Storrs, CT: University of Connecticut, Department of Natural Resources Management and Engineering.

Cnare, R. (2005). Street width and efficiency discussion. (Interdepartmental correspondence). Madison, WI: City of Madison, unpublished.

Coffman, L.S. (2002). Low-impact development: an alternative stormwater management technology. In. R.L. France (Ed), *Handbook of water sensitive planning and design.* (pp. 97-124). New York: CRC Press.

Corish, K.A. (1995). *Clearing and grading strategies for urban watersheds*. Washington, D.C.: Metropolitan Washington Council of Governments.

Craul, P.J. (1999). *Urban soils: applications and practices*. New York: Wiley.

CTE Engineers. (2005). *Combined sewer overflow reduction system wide alternative report* (City Project No. 2005265). Spokane, WA: City of Spokane, Public Works and Utilities.

Davis, A.P, & McCuen, R.H. (2005). *Stormwater management for smart growth*. New York: Springer Science + Business Media, Inc.

Dedyo, P., von Schrader, T. (2006, March). *Cistern project examples and the water rights issue*. Paper presented at the Green Roofs and Cisterns a Practical Design Workshop, a stormwater seminar sponsored by Seattle Public Utilities and the University of Washington Botanic Gardens, Seattle, WA. A Powerpoint presentation may be downloaded at: http://depts.washington.edu/urbhort/html/education/CisternExamples&WaterRights.pdf.

Dembiec, D.A. (1997). *Street widths* (memorandum). Birmingham, MI: City of Birmingham, Engineering and Public Services.

Dierkes, C., Kuhlmann, L., Kandasamy, J., & Angelis, G. (2002). Pollutions retention capability and maintenance of permeable pavements. In Strecker, E.W. & Huber, W.C. (Eds.), *Global solutions for urban drainage 9ICUD* (CD ROM). Reston, VA: American Society of Civil Engineers.

Dunne, T., & Leopold, L.B. (1978). *Water in environmental planning*. San Francisco, CA: W.H. Freeman and Company.

Dunphy, K., & Ford, J. (n.d.) *Growing vine street*. (electronic resources). Viewed October 30, 2006 at http://www.growingvinestreet.org/index.php.

Edde, G.G., & Bicknell, J.C. (2004). Understanding potential barriers to better site design for water quality protection. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD, September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Elliot, A.H., & Trowsdale, S.A. (2007). A review of models for low impact urban stormwater drainage. *Environmental Modeling and Software, 22*(2007), 394-405.

Environmental Protection Agency (EPA). (2000). *The quality of our nation's waters: a summary of the National Water Quality Inventory: 1998 Report to Congress.* (EPA-841-S-00-01). Washington, D.C.: Office of Water.

Environmental Protection Agency (EPA). (2005a). Low impact development pays off. *Nonpoint source news-notes, 75*, 7-10. Washington, D.C.: Author.

Environmental Protection Agency (EPA). (2005b). *Using smart growth techniques as storm water best management practices.* (EPA 231-B-05-002). Washington, D.C.: Development, Community, and Environment Division; Office of Policy, Economics, and Innovation.

Environmental Protection Agency (EPA). (2005c). *National management measures to control nonpoint source pollution from urban areas.* (EPA 841-B-05-004). Washington, D.C.: Office of Water.

Environmental Protection Agency (EPA). (2006a). *Phases of the NPDES stormwater program*. Viewed June 15, 2006 at http://cfpub.epa.gov/npdes/stormwater/swphases.cfm.

Environmental Protection Agency (EPA). (2006b). *Overview of current total maximum daily load – TMDL – program and regulations.* Viewed June 17, 2006 at http://www.epa.gov/owow/tmdl/overviewfs.html.

Environmental Protection Agency (EPA). (n.d.a). Alternative pavers. In *Post construction stormwater management in new development and redevelopment* (Innovative BMPs for site plans). Retrieved July 25, 2006 from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5.

Environmental Protection Agency (EPA). (n.d.b). *Overview of the TMDL process.* Viewed June 17, 2006 at http://yosemite.epa.gov/R10/water.nsf/ac5dc0447a281f4e882569ed0073521f/2ac95839fe692ab6882569f100610e6a!OpenDocument.

Environmental Protection Agency (EPA). (n.d.c). Porous pavement. In *Post construction stormwater management in new development and redevelopment* (Innovative BMPs for site plans). Retrieved July 25, 2006 from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5.

Environmental Protection Agency (EPA). (n.d.d). Abacoa, Jupiter, Florida and East Lake Commons, Decatur, Georgia.. In *Smart Growth Illustrated.* Retrieved July 25, 2006 from http://www.epa.gov/smartgrowth/case.htm.

Environmental Protection Agency (EPA). (n.d.e). *Stormwater control, operation, and maintenance*. Retrieved September 18, 2006 from http://www.epa.gov/owow/nps/ordinance/stormwater.htm.

Esvelt, L.A. (1978). *Summary report of '208' water quality results and cause and effect relationships for water quality in the Spokane – Rathdrum Aquifer.* (Spokane Aquifer cause and effect report). Spokane, WA: Spokane County 208 Program.

Ewing, R. (1996). *Best development practices: doing the right thing and making money at the same time*. Washington, D.C.: Planners Press.

Fader, S. (2000). *Density by design new directions in residential development* (2nd Ed.). Washington, D.C.: Urban Land Institute.

Ferguson, B.K. (2005). *Porous pavements*. Boca Raton, FL: Taylor and Francis Group.

Ferguson, B.K. (1994). *Stormwater infiltration*. Boca Raton, FL: CRC Press.

Granger, T., Hruby, T., McMillan, A., Peters, D., Rubey, J., Sheldon, D., et al. (2005). *Wetlands in Washington State volume 2: guidance for protecting and managing wetlands*. Olympia, WA: Washington State Department of Ecology, Shorelands and Environmental Assistance Program.

Greenroofs.com (n.d.) *The greenroof directory*. Viewed January 15, 2007 at http://www.greenroofs.com/view.php?search=1.

Green Roofs for Healthy Cities. (2006, April). *Final report green roof industry survey 2004 & 2005*. Retrieved August 15, 2006 from http://www.greenroofs.org/resources/surveyreport.pdf.

Greer, R.K. (2004). Past, present, and future of bioretention: a Delaware perspective. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Harby, Doug. Construction Projects Manager. City of Missoula, Engineering Division. Personal communication. July 27, 2006.

Han, J., Wu, J.S., & Allan, C. (2005) Suspended sediment removal by vegetative filter strip treating highway runoff. *Journal of Environmental Science and Health, 40*, 1637-1649.

Haub, A. (2002). *Low impact development strategy for Green Cove Basin: a case study in regulatory protection of aquatic habitat in urbanizing watershed*. Olympia, WA: City of Olympia.

Haub, A. (2004). Low impact development standards for Green Cove Basin: a case study in regulatory protection of aquatic habitat in urbanizing watershed. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development*

Conference. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Hendron, Lars. Principal Engineer. City of Spokane Wastewater Management Department. Personal communications, May 25, 2006, and July 28, 2006.

Hinman, C. (2001, June). *Integrating and implementing low impact development in the Pierce County land use development process*. Paper presented at the Low Impact Development in Puget Sound Innovative Stormwater Management Practices conference, Seattle, WA., June 5-6, 2001. Retrieved April 20, 2006 from http://www.psat.wa.gov/Programs/LID/LID_pubs.htm.

Hinman, C. (2004). WSU Puget Sound low impact development pilot project monitoring. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Hinman, C. (2005). *Low impact development technical guidance manual for Puget Sound*. Olympia, WA: Puget Sound Action Team.

Hood, M., Clausen, J.C., & Warner, G.S. (2006, Mar/April). Low impact development works! *Journal of Soil and Water Conservation, 61*(2), 58A-61A.

Horner, R., May, C., Livingston, E., Blaha, D., Scoggins, M., Tims, J., et al. (2001). Structural and non-structural best management practices (BMPs) for protecting streams. In Urbonas, B. R. (Ed.), *Linking stormwater BMPs designs and performance to receiving water impact mitigation* (pp. 60-77). Reston, VA: American Society of Civil Engineers.

Horner, R.R., Lim, H., & Burges, S.J. (2002). *Hydrologic monitoring of the Seattle ultra-urban stormwater management projects*. (Water Resources Series Technical Report No. 170). Seattle, WA: University of Washington, Department of Civil and Environmental Engineering.

Horner, R.R., Lim, H., & Burges, S.J. (2004). *Hydrologic monitoring of the Seattle ultra-urban stormwater management projects: summary of the 2000-2003 water years*. (Water

Resources Series Technical Report No. 181). Seattle, WA: University of Washington, Department of Civil and Environmental Engineering.

Hruby, T. (2004). *Washington state wetland Rating system for eastern Washington - revised*. (Washington State Department of Ecology Publication No. 04-06-15). Olympia, WA: Washington State Department of Ecology.

Hun-Dorris, T. (2005). Advances in porous pavement. *Stormwater: the Journal for Surface Water Quality Professionals* 6 (2). Retrieved July 25, 2006 from http://www.stormh2o.com/sw_0503_toc.html.

Institute of Transportation Engineers (ITE). (1999). Traditional neighborhood development street design guidelines. Washington, D.C.: ITE Transportation Planning Council Committee 5P-8.

International Code Council. (2003). 2003 international building code. Country Club Hills, IL: Author.

International Code Council. (2006). 2006 international residential code for one- and two-family dwellings. Country Club Hills, IL: Author.

Jarrett, A.R., Hunt, W.F., Berghage, R.D. (2006) *Annual and individual storm green roof stormwater response models* (ASABE Paper Number 062310). St Joseph, MI: American Society of Agricultural and Biological Engineers.

Johnson, J. (2005). *Seattle raincatchers*. Paper presented at the North American Rainwater Harvesting Conference, Seattle Center, Seattle, WA, July 14-15, 2005. Retrieved December 27, 2006 from http://www.arcsa-usa.org/2005_conf/documents/conference_abstracts.pdf.

Kahle, S.C., Caldwell, R.R.,& Bartolino, J.R. (2005). Hydrologic information. In *Compilation of Geologic, Hydrologic, and Ground-Water Flow Modeling Information for the Spokane Valley–Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho.* Retrieved July 10, 2006 from http://pubs.usgs.gov/sir/2005/5227/index.html.

Köhler, M., & Schmidt, M. (2003). *Untersuchungen an extensiven Dachbegrünungen in Berlin: Teil III: Stoffruckhalt*, (Investigations of Extensive Roof Greening in Berlin). English translation retrieved August 15, 2006 from http://www.roofmeadow.com/technical/publications/SWQuality_Berlin_MSchmidt.pdf.

Knutson, K.L. & Naef, V.L. (1997). *Management recommendations for Washington's priority habitats: riparian*. Olympia, WA: Washington State Department of Fish and Wildlife.

Kulash, W.M. (2002). *Residential streets, third edition*. Washington, D.C.: Urban Land Institute.

Landers, J. (2004, February). High-impact innovation. *Civil Engineering, 74*(2), 50-57, 80.

Lehner, P. H., Aponte Clark, G. P., Cameron, D. M., & Frank, A. G., (1999). *Stormwater strategies: community responses to runoff pollution.* New York: Natural Resources Defense Council.

Liptan, T., & Murase, R.K. (2000). *Watergardens as stormwater infrastructure in Portland, Oregon*. Paper presented at the Water Sensitive Ecological Planning and Design Symposium, Harvard Design School, February 25-26, 2000.

Lo, Masako. Engineer. City of Seattle Public Utilities, Engineering Division. Personal communication December 20, 2006.

May, C.W., Horner, R.R., Karr, J.R., Mar, B.W., & Welch, E.B. (2000) Effects of urbanization on small streams in the Puget Sound Ecoregion. In T. R. Schueler &H.K. Holland (Eds.), *The Practice of Watershed Protection* (pp. 87-98). Ellicott City, MD: Center for Watershed Protection.

McIntyre, L. (2006, September). Parting of the waters. *Landscape Architecture: the Magazine of the American Society of Landscape Architects, 96*(9), 34-49.

Meuler, Louis. City Planner. City of Spokane Planning Department. Personal communications, November 29, 2006, December 14, 2006.

Miller, Stan. Water Resources Program Manager (retired). Spokane County Public Works, Utilities Division. Personal communication, July 16, 2006.

Mitchell, F. (2002). Shoreland buffers: protecting water quality and biological diversity (New Hampshire). In. R.L. France (Ed), *Handbook of water sensitive planning and design.* (pp. 97-124). New York: CRC Press.

Molenaar, D. (1988). *The Spokane Aquifer, Washington: its geologic origin and water-bearing and water-quality characteristics*. (U.S. Geological Survey Water Supply Paper 2265). Denver, CO: U.S. Geological Survey.

Moran, A., Hunt, B., & Jennings, G. (2004). A field study of greenroof runoff quantity, runoff quality, and plant growth. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

MWH & Woodward-Clyde Consultants. (2002). *Report for Glenrose/Central Park stormwater management plan*. Spokane, WA: Spokane County.

National Association of Home Builders (NAHB) Research Center. (2003). *The practice of low impact development.* Washington, D.C.: U.S. Department of Housing and Urban Development.

National Concrete Pavement Technology Center. (2006). *Mix design development for pervious concrete in cold weather climates, final report*. Ames, IA: Iowa State University, Center for Transportation Research and Education.

National Marine Fisheries Service (NMFS). (2005). Critical habitat for ESU's in Washington. Retrieved October 14, 2006 from http://www.nwr.noaa.gov/Salmon-Habitat/Critical-Habitat/Index.cfm.

National Weather Service (NWS) Forecast Office. (n.d.a). *Spokane, WA observed weather* (monthly weather summary). Viewed September 18, 2006 at http://www.weather.gov/climate/?wfo=otx.

National Weather Service (NWS) Forecast Office. (n.d.b). *Seattle, WA observed weather* (monthly weather summary). Viewed September 18, 2006 at http://www.weather.gov/climate/index.php?wfo=sew.

Natural Resources Defense Council (NRDC). (2001). Low impact development. In *Stormwater strategies: community responses to runoff pollution* (Chapter 12). Retrieved February 20, 2006 from http://www.nrdc.org/water/pollution/storm/stoinx.asp.

Natural Resources Conservation Service (NRCS). (1986). *Urban hydrology for small watersheds, TR-55*. Beltsville, MD: Natural Resources Conservation Service.

Natural Resources Conservation Service (NRCS). (1997). *National engineering handbook part 630 hydrology*. Beltsville, MD: Natural Resources Conservation Service.

Nordberg, T.M., & Thorolfsson, S.T. (2004). Low impact development and bioretention areas in cold climates. In *Critical transitions in water and environmental resources management proceedings of the 2004 World Water and Environmental Resources Congress* (electronic resource). Reston, VA: American Society of Civil Engineers.

Paterson, R.G. (2000). Construction practices: the good, the bad, and the ugly. In T. R. Schueler & H.K. Holland (Eds.), *The Practice of Watershed Protection* (pp. 348- 352). Ellicott City, MD: Center for Watershed Protection.

Peck, S., & Goucher, D. (2005, October). Overview of North American policy development and the policy development process. In *Greening rooftops for sustainable communities conference, awards, and trade show*, Washington. D.C. (May, 2005). [Electronic Resource].

Pin Foundations, Inc. (2007). *Diamond Piers Systems* (brochure). Retrieved February 2, 2007 from http://www.pinfoundations.com/home.php.

Prairie Crossing in Grayslake, Illinos. (2001, Spring/Summer). In *Terrain.org a Journal of the Built and Natural Environments* (UnSprawl Case Studies). Retrieved July 18, 2006 from http://www.terrain.org/unsprawl/9/.

Prince George's County (PGC), Maryland. (1999a). *Low impact development design strategies an integrated design approach*. Largo, MD: Department of Environmental Resource Programs and Planning Division.

Prince George's County (PGC), Maryland. (1999b). *Low impact development hydrologic analysis*. Largo, MD: Department of Environmental Resource Programs and Planning Division.

Pitt, R. (1996). *Groundwater contamination from stormwater infiltration*. Chelsea, MI: Ann Arbor Press.

Puget Sound Action Team (PSAT). (2000). *Stormwater education programs selected examples from Puget Sound*. Olympia, WA: Puget Sound Action Team Office of the Governor.

Puget Sound Action Team (PSAT). (n.d.). *Low impact development local regulation assistance project 2005*. Viewed September 18, 2006 at http://www.psat.wa.gov/Programs/LID/assistance/LID_assistance.htm.

Randolph, J. (2004). *Environmental land use planning and management*. Washington, D.C.: Island Press.

Reeves, E. (2000). Performance of biofilters in the Pacific Northwest. In T. R. Schueler &H.K. Holland (Eds.). *The Practice of Watershed Protection* (pp. 559-561). Ellicott City, MD: Center for Watershed Protection.

Ruchards, L., & VanLare, P. (2004). Working together: smart growth and low impact development. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Richman, T., Lichten, K.H., Worth, J., & Ferguson, B.K. (1998). *Vegetated swales*. (Landscape Architecture Technical Information Series). Retrieved August 15, 2006 from http://www.asla.org/latis/Latis2.pdf.

Rome, A. (2001). *The bulldozer in the countryside*. New York, Cambridge University Press.

Roofscapes, Inc. (2000). *Mathematical simulation models: a foundation for developing a general-purpose green roof simulation model*. Philadelphia PA: Author. Retrieved July 15, 2006 from http://www.roofmeadow.com/technical/publications.shtml.

Roofscapes, Inc. (n.d.). Green roof stormwater performance simulation. Viewed January 15, 2007 at http://www.roofmeadow.com/services/stormwatersim.shtml.

Rozzelle, R. (2004). Path to a water quality ordinance using LID: the Huntersville experience – moving from conferences to codes. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Schueler, T. R. (1995). *Site planning for urban stream protection*. Washington, D.C.: Department of Environmental Programs Metropolitan Washington Council of Governments.

Schueler, T.R. (2000a). Why stormwater matters. In T. R. Schueler & H.K. Holland (Eds.), *The Practice of Watershed Protection* (pp. 365-370). Ellicott City, MD: Center for Watershed Protection.

Schueler, T.R. (2000b). The architecture of urban stream buffers. In T. R. Schueler & H.K. Holland (Eds.), *The Practice of Watershed Protection* (pp. 225- 233). Ellicott City, MD: Center for Watershed Protection.

Schueler, T.R., & Caraco, D.S. (2001). Prospects for low impact development at watershed level. In Urbonas, B. R. (Ed.), *Linking stormwater BMPs designs and performance to receiving water impact mitigation* (pp. 196-209). Reston, VA: American Society of Civil Engineers.

Seattle Public Utilities (2005). *Pinehurst green grid natural drainage system* (Ordinance 121660, PW# 2005-030). Seattle, WA: City of Seattle, Department of Executive Administration.

Seattle Public Utilities (n.d.) *Street edge alternatives (SEA Streets) project*. (electronic resource). Viewed October 30, 2006 at http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Street_Edge_Alternatives/index.asp.

Shared Strategy for Puget Sound (SSPS). (2005). *Draft Puget Sound salmon recovery plan (Revised December, 2005)*. Seattle, WA: Shared Strategy for Puget Sound.

Smart Growth Network. (2002). *Getting to smart growth: 100 policies for implementation*. Retrieved July 25, 2006 from http://www.smartgrowth.org/library/articles.asp?art=870.

Smart Growth Network. (2003). *Getting to smart growth II: 100 more policies for implementation*. Retrieved July 25, 2006 from http://www.smartgrowth.org/library/articles.asp?art=870.

Spokane Aquifer Joint Board (SAJB). (2004). The Spokane Valley-Rathdum Paririe aquifer atlas (2004 update). Spokane, WA: Author.

Spokane County. (1979). *Spokane Aquifer water quality management plan: final report and water quality management framework recommendations for policies and actions to preserve the quality of the Spokane – Rathdrum Aquifer*. Spokane, WA: Office of County Engineers.

Spokane County. (1998). *Guidelines for stormwater management (as amended through August 2003)*. Spokane, WA: Spokane County Public Works, Division of Engineering and Roads.

Spokane County. (2004). *Spokane Valley – Rathdrum Prairie Aquifer water quality report for the period January 1, 2003 – December 31, 2003*. Spokane, WA: Public Works Department Division of Utilities.

Spokane County. (2005a). *Watershed management plan: water resource inventory area 55 – Little Spokane River & water resource inventory area 57 – Middle Spokane River* (Draft 03). Spokane, WA: Little Spokane River and Middle Spokane River Planning Unit.

Spokane County, City of Spokane, & City of Spokane Valley. (2005). *Spokane regional stormwater manual*. (2005 Public Review Draft). Spokane, WA: Spokane County.

Spokane County Conservation District (SCCD). (2005a). *The Hangman (Latah) Creek water resources management plan*. Spokane, WA: The Hangman (Latah) Creek Watershed Planning Unit WRIA 56.

Spokane County Conservation District (SCCD). (2005b). *The Hangman (Latah) Creek water sampling data summary*. Spokane, WA: The Hangman (Latah) Creek Watershed Planning Unit WRIA 56.

Spokane County Conservation District (SCCD). (2005c). *Spokane County proper functioning condition stream inventory and assessment*. Spokane, WA: Author.

Staeheli, P. (2004). The integration of natural drainage in an urban subdivision. In *Putting the LID on Stormwater Management: Proceedings of the 2004 Low Impact Development Conference*. College Park, MD., September 21-22, 2004. Retrieved February 25, 2006 from http://www.mwcog.org/environment/LIDconference/.

Stephens, K.A., Graham, P., & Reid, D. (2002). *Stormwater planning: a guidebook for British Columbia*. Vancouver, B.C. Canada: British Columbia Ministry of Water, Land, and Air Protection.

Strecker, E.W. (2001). Low-impact development (LID) is it really low or just lower? In Urbonas, B. R. (Ed.), *Linking stormwater BMPs designs and performance to receiving water impact mitigation* (pp. 210-222). Reston, VA: American Society of Civil Engineers.

Stuart, D. (2001). *On-site runoff mitigation with rooftop rainwater collection and use*. Seattle, WA: King County Department of Natural Resources, Water and Land Resources Division.

Terrell, M.D. (n.d.). *Drip irrigation*. Spokane, WA: Washington State University, Spokane County Cooperative Extension.

Texas Water Development Board. (2005). *The Texas manual on rainwater harvesting, third edition*. Austin, TX: Author.

University of New Hampshire Stormwater Center. (2005). *2005 Data report*. Retrieved August 30, 2006 from http://ciceet.unh.edu/news/releases/stormwater_report_05/.

U.S. Fish and Wildlife Service (USFWS). (2006). *ESA basics: 30 years of protecting endangered species*. Arlington, VA: Endangered Species Program.

Virginia Department of Conservation and Recreation (1992). *Virginia erosion and sediment control handbook, third edition*. Richmond, VA: Division of Soil and Water Conservation.

Walesh, S.G. (2001). Urban watershed trends: looking over the divide. In Urbonas, B. R. (Ed.), *Linking stormwater BMPs designs and performance to receiving water impact mitigation* (pp. 9-23). Reston, VA: American Society of Civil Engineers.

Washington Department of Fish and Wildlife (WDFW). (n.d.). *Hydraulic project approvals (HPA)*. Retrieved June 18, 2006 from http://wdfw.wa.gov/hab/hpapage.htm.

Washington State Department of Community, Trade, and Economic Development (WSDCTED). (2002). *Citations of recommended sources of best available science for designating and protecting critical areas*. Olympia, WA: Author.

Washington State Department of Community, Trade, and Economic Development (WSDCTED) (2003b). *Critical areas assistance handbook: protecting critical areas within the framework of the Washington Growth Management Act.* Olympia, WA: Growth Management Services.

Washington State Department of Community, Trade, and Economic Development (WSDCTED) (2003c). *Watershed planning: the link between growth management and watershed planning.* Retrieved June 20, 2006 from http://www.cted.wa.gov/portal/alias__CTED/lang__en/tabID__420/DesktopDefault.aspx.

Washington State Department of Community, Trade, and Economic Development (WSDCTED) (2005). *Comprehensive plan checklist: a technical assistance tool from Growth Management Services.* Retrieved June 21, 2006 from http://www.cted.wa.gov/portal/alias__CTED/lang__en/tabID__420/DesktopDefault.aspx.

Washington State Department of Ecology (WSDOE). (1999). *Spokane River dissolved metals total maximum daily load submittal report.* (Publication No. 99-49-WQ). Olympia, WA: Author.

Washington State Department of Ecology (WSDOE). (2004a). *Stormwater management manual for Eastern Washington.* (Ecology publication number 04-10-076). Olympia, WA: Water Quality Program.

Washington State Department of Ecology (WSDOE). (2004b). *Spokane River Dissolved Oxygen Water Quality Improvement Project*. Viewed July 12, 2006 at http://www.ecy.wa.gov/programs/wq/tmdl/spokaneriver/dissolved_oxygen/problem.html.

Washington State Department of Ecology (WSDOE). (2004c). *Spokane River and Lake Spokane (Long Lake) pollutant loading assessment for protecting dissolved oxygen*. (Publication No. 04-03-006). Olympia, WA: Author.

Washington State Department of Ecology (WSDOE). (2005a). *Assessment of total dissolved gas in the Spokane River at Upriver and Little Falls dams.* (Ecology publication number 05-03-010). Olympia, WA: Author.

Washington State Department of Ecology (WSDOE). (2005b).*Construction stormwater general permit, national pollutant discharge elimination system (NPDES and state waste discharge general permit for stormwater discharges associated construction activity.* Olympia, WA: Water Quality Program.

Washington State Department of Ecology (WSDOE). (2005c).*Ecology's statewide data sets* (Rivers, Washington State Base Map, Water Resource Inventory Areas). Retrieved June 10, 2006 from http://www.ecy.wa.gov/services/gis/data/data.htm.

Washington State Department of Ecology (WSDOE). (2006a). *Fact sheet for National Pollutant Discharge Elimination System and State Waste General Permit for discharges from large and medium municipal separate storm sewers*. Olympia, WA: Washington State Department of Ecology.

Washington State Department of Ecology (WSDOE). (2006b). *Water cleanup plans (TMDLs) by Ecology region: Eastern Region*. Viewed May 10, 2006 at http://www.ecy.wa.gov/programs/wq/tmdl/watershed/tmdl_info-ero.html.

Washington State Department of Ecology (WSDOE). (2006c). *Guidance for UIC wells that manage stormwater* (Draft). (Publication Number 05-10-067). Olympia, WA: Water Quality Program.

Washington State Department of Ecology (WSDOE). (2006d). *Focus on cost reimbursement, water resources* (Publication Number 05-11-016). Olympia, WA: Washington State Department of Ecology, Water Resources Program.

Washington State Department of Ecology (WSDOE). (2007a). *Eastern Washington phase II municipal stormwater permit.* Olympia, WA: Washington State Department of Ecology.

Washington State Department of Ecology (WSDOE). (2007b). *Phase I municipal stormwater permit.* Olympia, WA: Washington State Department of Ecology.

Washington State Office of the Attorney General. (2000). *Introduction to Washington water law*. Olympia, WA: Author.

Washington State University [WSU] Pierce County Extension and AHBL, Inc. (2005). *Maintenance of low impact development facilities*. Retrieved September 18, 2006 from http://www.psat.wa.gov/Programs/LID/assistance/LID_assistance.htm, listed under "Maintenance Specifications".

Wayland, R.H. & Hanlon, J.A. (2002, Nov. 22). *Establishing total maximum daily load (TMDL) wasteload allocations (WLAs) for storm water sources and NPDES permit requirements based on those WLAs*. (EPA memorandum to regional Waste Division Directors). Retrieved March 20, 2006 from http://www.epa.gov/owow/tmdl/policy.html.

Whalen, J. (2005). *Draft Spokane River subbasin summary*. Portland, OR: Columbia Basin Fish and Wildlife Authority.

Yake, Mike. Senior Engineer. City of Spokane Wastewater Management Department. Personal communication, January 9, 2007.

Zarecor, Matt. P.E. Section Manager Land Development Services. Spokane County Public Works. Personal communication, December 14, 2006.