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Low Impact Development (LID) and Transportation Stormwater Practices

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ABSTRACT

The proposed project is a combination of a research/design/best practices compilation and ranking in the format of a design decision tool that can be used by Region X transportation designers and other researchers with respect to current, and future climate change stormwater impacts. The compilation will focus on stormwater practices in the Pacific Northwest. The intent is to compile these practices with guidance as to how they may or may not fit into the Low Impact Development (LID) philosophy of mimicking natural hydrological processes in situ and how they might be applied for the most critical infrastructure needs. In addition, these lists will contain information on other associated benefits/concerns such as robustness with respect to anticipated climate change variations, urban heat island issues, constructability, maintenance, habitat etc. There are many groups and agencies already looking into LID practices which can be used as resources for information. Some examples are the Puget Sound LID Manual, the Prince George County LID manual, the DOD LID manual, the Portland LID Design Guide, etc. The practices in these references which can be related to DOT applications especially with respect to the unique issues of linear projects will provide information to aid in the development of this design decision tool. This project will have many benefits. It will serve as a clearinghouse to collect many of the LID and other beneficial environmental principles that are currently being developed by many groups within the region. It will also relate these to the benefits espoused by other guidance which might aid in focusing on practices which more economically serve various purposes, be they environmental, societal or agency missions. It may then serve as a springboard for future development of a Roadmap for comprehensive agency LID and climate change strategies so that future projects and operations can more readily address current and future environmental impacts.

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Section 1: Introduction

Low Impact Development (LID) is a concept that encourages development or redevelopment to include best management practices (BMPS) and other planning and design features that mimic the natural hydrologic processes and flows on a site as much as possible. These processes include decentralization, infiltration, filtration, storage, evaporation, interception and transpiration. LID approaches have emerged as the preferred method for managing stormwater in new developments in many regions of the country. LID approaches can be used to attain stormwater goals in many voluntary rating systems, including Leadership in Energy and Environmental Design (LEED™) and the Sustainable Sites Initiative (Haselbach 2010, SSI 2009*).* While LID is currently a voluntary or recommended approach for managing stormwater, it is anticipated that many regulatory agencies will be requiring LID, especially in watersheds that drain into sensitive waters. Washington State Department of Ecology (Ecology) is considering requiring LID to the maximum extent feasible when some of the state municipal National Point Discharge Elimination System (NPDES) permits are reissued (Ecology 2009). While LID design guidelines have emerged for residential and commercial developments, few focus on the unique needs of highway settings. With anticipated changes to NPDES municipal stormwater permits that may require LID to the maximum extent feasible, the need to implement LID approaches for DOTs has become an important issue to consider (NCHRP 2006, PCHB 2009).

The goal of this research project was to identify areas where LID could be integrated into the highway setting, specifically with respect to the Pacific Northwest DOT's: Oregon (ODOT), Washington (WSDOT), and Idaho (ITD). This task was completed with the following steps:

- Develop a Research Support Team – Individuals that could provide the researchers with background and supporting information as well as those who could serve on an advisory committee to provide additional expertise were identified.
- Outreach and Education – Throughout this research, project areas were identified where outreach and education of LID could be implemented, especially in a transportation setting.
- Review of Current Highway Stormwater Practices and Literature Search on LID – The current stormwater practices for the three Pacific Northwest DOTs and various national LID manuals, papers and syntheses were reviewed to understand how LID is currently represented.
- Identify Opportunities For Integrating LID into Current Stormwater Practices – Based on the evaluation of current DOT stormwater practices, areas where LID could be integrated into the current agency decision and design processes were identified.
- Evaluate Metrics for LID – Various LID manuals and papers were reviewed to determine the metrics used for evaluating LID practices, and a baseline metric that might be considered for highway settings was proposed, evaluated with a series of case studies, and received a preliminary expert scientific review.
- Consider Other Barriers and Benefits to LID – Throughout the research period, barriers to implementation of LID, both technical and procedural, were noted as were considerations of additional benefits from LID in support of other emergent agency priorities such as climate change mitigation.

The original scope also intended to provide an evaluation of the applicability of using emerging LID approaches in a highway setting. However, based on the assessment of DOTs stormwater practices, it was observed that many of the current design options include various aspects of the aforementioned LID processes and intentions, and that there are many opportunities to maximize the use of LID within the current DOT stormwater management practices without the addition of new technologies. Since LID approaches and technologies are numerous, rather than bring new technologies into the DOT stormwater guidance, this research focused on integrating currently available LID approaches more fully into existing stormwater management practices using common DOT BMPs and current practices. Once stormwater guidance has maximized the use of existing LID approaches, the need for other technologies could be evaluated.

Section 2: Background

Originally the focus of stormwater management was on maintaining safe driving conditions and protecting the roadway prism from any adverse impacts of runoff. Highway drainage designs focused on getting stormwater off and away from the highway. Once stormwater was away from the highway, considerations of the ecological impacts were secondary if they were considered at all (Landers 2010). The environmental awareness was in response to the 1987 amendment to the Clean Water Act that expanded the National Point Discharge Elimination System (NPDES) permit program to include stormwater discharges from urban roads and highways. This amendment required the use of best management practices (BMPs) to the maximum extent feasible to meet stormwater management requirements. The term BMPs quickly became a catch all term to describe every managerial and structural practice for stormwater management, and they include 'end of pipe' methods (i.e., highway stormwater that is then conveyed through storm drains to a detention or infiltration pond). Despite the reference, BMPs do not necessarily equally compensate for various aspects of the altered site hydrology (NCHRP 2006).

LID is a decentralized approach to stormwater management that has become a preferred option in many new developments. Prince George County Department of Environmental Resources formalized a set of LID standards with the goal of providing an innovative approach to stormwater management that decentralizes stormwater management and integrates it into the landscape (DER 1999). LID approaches minimize impacts to the environment by using the benefits of all the hydrological processes to manage the increased stormwater discharges as close to the source as possible The benefits of LID in new developments are well documented and design guidance is growing, including the 2005 Puget Sound LID Manual. (Hinman 2005). However, less research has been performed to consider the unique challenges of integrating LID approaches into a transportation setting that is linear in nature and constrained by the right of way (ROW) limits. More recently, groups such as the LID Center in Maryland are reviewing LID options for highway settings, and proposed rating systems, such as Greenroads, are recognizing the importance of stormwater management (LID Ctr 2006, Muench 2009). In addition, the American Society of Civil Engineers (ASCE) hosted the first green highway conference in Denver late in the fall of 2010 to share sustainable transportation ideas, including highway stormwater management approaches.

Section 3: Problem Statement

While the benefits of LID approaches are well documented and are slowly being accepted in residential and commercial developments, applying these same approaches in a highway setting is not as straight forward. For example, a primary LID approach in developments is to reduce impervious surfaces by modifying the roadway layout, narrowing roads, or reducing sidewalks to one side of the street (DER 1999). Reducing the impervious area is generally not an option for DOTs. Highway design guidance is based on FHWA guidelines which were developed to ensure safe conditions for drivers and pedestrians and include specific design criteria for the minimum roadway width as well as locating sidewalks. These operational and safety requirements will oftentimes supersede any modifications to highways that might reduce impervious surfaces. Stormwater management options from highway runoff are often limited due to the constraint of locating and maintaining facilities within the available ROW. In addition, DOTs often have limited control over pollutant sources entering the ROW which require robust stormwater management to address pollutants such as; oil and metal deposits from vehicle, sand and deicers due to winter maintenance practices, litter, and runoff from surrounding land uses (WSDOT 2008). Due to these and other limiting considerations, LID approaches commonly used in developments may not be similarly applicable in a highway setting.

Highways are linear in nature and constrained by the right of way (ROW). Since a highway can extend through an entire state, the soil conditions and hydrology are likely to change along the length of a project as well. Due to these variabilities and the novelty of LID approaches, DOTs have continued to use more traditional BMPs such as end of pipe solutions to manage stormwater. However, with anticipated regulatory requirements for LID practices to the maximum extent feasible, DOTs may have to justify why a preferred LID approach was not selected. In anticipation of these changes, DOTs such as Oregon and Washington have developed BMP selection processes that encourage the use of LID BMPs. However, due to the complexity and rapidly changing stormwater regulations and lack of design guidance and modeling tools, designers often revert back to more traditional BMPs. Guidance for integrating LID into current stormwater practices that is clear and simple would assist DOTs in developing future LID stormwater designs that are useable.

Section 4: Research Objectives and Methods of Approach

The primary objective of this research was to determine how LID approaches and technologies could be more fully integrated into stormwater practices for Pacific Northwest DOTs. The first step was to develop a research and advisory team for the project. Next, stormwater practices for the Pacific Northwest DOTs and LID manuals and syntheses were evaluated and compared including observation of current LID representation within the practices of these DOTs. Metrics for LID were also reviewed with the goal of proposing and validating baseline metrics for incorporation of LID into highway settings. Additionally, barriers to LID and how LID can support other emergent agency goals were considered. Outreach and educational opportunities were evaluated and implemented in support of understanding LID in a transportation setting. The remainder of this section summarizes the specific methods used to meet the research objectives and goals.

4.1: Team Development

Immediately after the proposal was accepted, a research and advisory team was assembled from Washington State University (WSU) and Washington State Department of Transportation (WSDOT). The majority of the research was performed by the team at WSU which included Associate Professor Liv Haselbach and graduate research assistant Aimee Navickis-Brasch, with assistance from other graduate and undergraduate students. WSDOT staff served as the advisory committee providing additional expertise, review, and comment throughout the research progression. This group consisted of engineers, planners, environmental and policy specialists, and maintenance personnel (See Appendix A for a comprehensive list of the team). The research team held 6 formal meetings. Multiple informal phone calls and email discussions as needed were also used to assist in the research progress.

4.2: Outreach and Education

One key to implementing LID is educating the public and practitioners about LID approaches. Agencies like the Prince George County, Department of Environmental Resources have dedicated an entire chapter in their LID design manual regarding outreach and education opportunities for the public (DER 1999). In addition, the Washington State Department of Ecology requires that WSDOT provide training for stormwater designers as part of the NPDES permit (Ecology 2010). In an effort to support LID, specifically in a transportation setting, outreach and educational opportunities were sought and implemented throughout this research project. Outreach included course work at WSU, and community and national activities.

4.3: Review of Current Stormwater Practices and Literature Search on LID

In order to determine the feasibility of integrating LID into transportation settings, the first objective was to understand current stormwater practices. While LID approaches nationwide were also considered, the focus was on Pacific Northwest DOTs specifically Idaho (IDT), Oregon (ODOT), and Washington (WSDOT). To develop an understanding of the DOT’s stormwater practices, an evaluation was performed in five specific parts as described in the following:

1. **Collect Stormwater Guidance** – Most of the three DOT's stormwater guidance's are summarized in manuals and electronic copies are available for download online. The primary DOT-related manuals collected consisted of; the WSDOT Highway Runoff Manual (HRM), ODOT Stormwater Management Program with an emphasis on Water Quality, ITD Stormwater Guidance and the Idaho Department of Environmental Quality (IDEQ) Stormwater: Catalog of Stormwater BMPs for Idaho Cities and Counties (WSDOT 2008, ODOT 2009, ITD 2010, IDEQ 2005).

2. **Review and Summarize** – The DOT manuals/guidance were reviewed with the goal of; becoming familiar with the general processes for stormwater management; understanding some common regulatory requirements, and identifying the audience that will interpret the manuals/guidance. The guidance for managing stormwater is extensive and can include planning, design, construction, and maintenance of BMP facilities. To narrow the review to a manageable level, specific areas were targeted for consideration as described below and summarized in a table located in Appendix C.

    - The Stormwater Guidance document title(s) along with the date of publication and a web link.
    - The primary contact information.
    - A general description of how the stormwater guidance is organized.
    - The date the NPDES municipal stormwater permit was issued/reissued.
    - Identification of what triggers stormwater management requirements and where these requirements can be found.
    - A summary of the overall BMP selection process, noting how this information is communicated to a designer and additional comments regarding BMPs.
    - The hydrology models and climate zone(s) in each state used to design BMPs.
    - A summary of runoff treatment and flow control requirements, including the design storm event along with any exemptions.
    - The manual user was identified
    - Comparison of each DOT's definition of LID (see Section 6.1 for a summary).

3. **Verify** – Next, the accuracy of the interpretation of each agency's online guidance was verified through correspondence via phone calls and emails and necessary adjustments were made. In addition to interviewing hydraulic/stormwater engineers from each agency, Idaho IDEQ staff and WSDOT Maintenance were also interviewed to help provide a more comprehensive representation of the stormwater management processes in each state.

4. **Correlate with a LID Literature Search** – Once the current stormwater practices were understood, the next step was to determine what LID approaches are currently being used. In order to do this a more comprehensive understanding of LID practices was required. Therefore, a literature search was conducted to determine how LID is implemented both on a national and local level at other agencies and to evaluate the feasibility of implementing recent LID research in a transportation setting.

5. **Include Maintenance Considerations** – Maintenance is essential to the future performance of runoff treatment and flow control BMPs (WSDOT 2010). An evaluation of current DOT stormwater practices was conducted by reviewing current BMP maintenance practices and interviewing WSDOT maintenance. The intent of this consideration was to better understanding how LID approaches could be maintained by considering:

    - Current maintenance of BMPs.
    - Barriers to maintaining BMPs.
    - Development of ideas to remove any barriers to BMP maintenance.

4.4: Identification of Areas to Incorporate LID

Once the current stormwater practices were understood, the next step was to determine what LID approaches are currently being used and where LID approaches could be more fully integrated into a highway setting. With a clear understanding of the unique highway settings, stormwater practices at DOTs, and various LID approaches, areas for incorporating LID were evaluated. After review of the practices at the three DOTs, the research focused on including additional modifications to the decision flow charts used for BMP feasibility evaluations at WSDOT in conjunction with the metrics as noted in Section 4.5.

4.5: Evaluation of Metrics for LID and Incorporation into the Decision Process

The information resources mentioned in Sections 4.3 and 4.4 were also reviewed to understand the various tools, evaluation methods and metrics used to determine the level of LID used in a design or development. These evaluations were not necessarily the same calculations as used for traditional BMP and hydrologic designs, but rather the criteria that the various agencies or manuals referred to specifically for identifying low impact development BMP practices. As previously mentioned, the review indicated that various site metrics such as percent impervious area, or percent disconnection of stormwater flowpaths were being adopted in settings such as new residential or commercial areas. These metrics were deemed not directly applicable to many highway settings, and thus the team re-evaluated the definition of low impact development, particularly within a highway seting, and a baseline metric based on this working definition was proposed. The metric was also included in a typical decision flow chart for selecting BMP designs (BMP feasibility evaluation), specifically modified to include additional steps that facilitated more fully incorporating LID priorities into the decision process.

Subsequent validation of the viability of the proposed metric and of the modified decision process was performed in the following manner during the research period. The metric was first used to evaluate some typical highway design scenarios in three case studies, and then the metric, the modified decision flow chart, and the case studies were presented for expert review. This expert review process included an anonymous review by three reviewers in a submittal to the Transportation Research Board (TRB). After incorporation of suggestions from the TRB review, the expert review process then included requests for review by members of the WSDOT team and an engineer from IDT and ODOT. The comments received were then incorporated into the draft metric and modified decision flow process proposed in this report.

4.6 Considerations of Barriers and other Benefits of LID

LID can also support other emergent agency goals such as adapting to climate change, and a demonstration of this was accomplished by first reviewing current sustainable transportation and climate change adaptation plans for DOTs with an emphasis on WSDOT and then evaluating a scenario where LID could support DOT goals. In addition, many barriers to incorporation of LID considerations were observed. Several of these were further evaluated, including consideration of maintenance issues, concerns for use of LID in areas with steep slopes, and aligning LID into other standard highway BMP designs. Resolving issues related to incorporating LID into sites with steep slopes were considered to be important next steps to more fully implementing LID practices into highway settings as determined by the research advisory team and is the focus of a current parallel research effort that has been included as part of the team meeting discussions throughout this research period.

Section 5: Results

5.1: Outreach

Since a key to implementing LID in any setting is educating the public and other professionals on the current status of this emerging technology and receiving feedback from other practitioners, outreach opportunities were constantly sought. This was completed in multiple ways including; incorporation into coursework, conveying knowledge of the unique requirements of linear projects to the LID community, and ongoing work that Liv Haselbach, the principal investigator, is involved in at the national level. Specific outreach completed during this research is described below.

- LID was more fully incorporated into the course and text book for Sustainability Engineering I (CE504) at WSU.
- Several of the graduate students in CE504 were advised on their course projects related to LID and green streets. One student developed a LID poster on Urban Green Street LID Practices in the Pacific Northwest, which was submitted to the poster competition,and awarded a prize at the Water and Land Use in the Pacific Northwest: Integrating Communities and Watersheds conference in Stevenson, WA . Another student helped with the development of the presentation entitled, “Introduction to Low Impact Development (LID)”, which was submitted to Carnegie Mellon University as part of the LID module Dr. Haselbach developed. This module was peer reviewed and uploaded onto the Center for Sustainable Engineering (CSE) website.
- Four other graduate students worked on projects which complemented another TransNow ongoing project (Online Training Course in Sustainable Transportation Infrastructure) by providing services for gathering information about sustainable transportation infrastructure and also reviewing course materials.
- Another undergraduate research assistant compiled a list of many national and regional LID guidance documents and references. These spreadsheets were shared with the design community at several venues including; The Water and Land Use in the Pacific Northwest: Integrating Communities and Watersheds conference in Stevenson, WA, 11/4-6/09; to the officers of the newly formed ASCE LID Green Streets Subcommittee for distribution via the web; and the ASCE LID Conference in San Francisco in April 2010.
- In addition, the findings and recommendations of this research project were presented at; The Green Streets and Highways Conference sponsored by ASCE in Denver in November 2010 and will be presented at The Transportation Research Board meeting in Washington D.C. in January 2011. This will serve as an opportunity to receive national feedback as well as share with others ways to integrate LID into a transportation setting.
- There was an exchange of current DOT BMP and LID approaches with all three agencies. This also helped the ITD to better understand current design requirements for BMPs commonly used in the northwest. ITD was invited to attend WSDOT stormwater courses but could not because of out of state travel restrictions.
- WSU students were included in WSDOT stormwater classes.

5.2: Comparison of Stormwater Practices

The stormwater practices at three Pacific Northwest DOTs were evaluated to understand current stormwater practices and identify how they are currently represented. Since stormwater management guidance can be extensive, key areas of focus were evaluated and are detailed in Appendix C.

<u>Similarities</u>

Overall, WSDOT and Oregon have the most similar processes in that both:

- Provide design guidance for both temporary and permanent BMPs that are comparable.
- Have a formal BMP selection process based on pollutant type
- Provide specific triggers for stormwater management requirements.
- Comply with NPDES stormwater permits that includes both temporary and permanent stormwater management guidance.
- Use single event models to design BMPs, although WSDOT also utilizes continuous modeling in Western Washington. In addition, both states have studied rainfall patterns and developed design storms that are specific to a location in the state.

Idaho's stormwater management processes differed from the other two states in that they:

- Only provide design guidance for temporary erosion and sediment controls (TESC).
- Permanent BMP guidance is not well defined. However, if necessary, the Idaho Department of Environmental Quality (IDEQ) manual can be used which provides BMP guidance specific to developments.
- The NPDES permit for ITD focuses on construction stormwater pollution prevention. However, ITD is working toward providing more specific permanent stormwater guidance when their NPDES municipal stormwater permit is renewed.
- The rational method is used to design BMPs for contributing basins under 100 acres. Larger basins require single event models.

There are also a few differences between the WSDOT and ODOT BMP selection process. For example at WSDOT, the designer determines the BMP requirements based on project specific/site specific conditions and stormwater requirements. Then, based on the pollutant removal requirements and flow attenuation requirements, a BMP selection process is followed to find a BMP that meets the stormwater requirements. At ODOT, pollutant type is identified by the stormwater office and then communicated to the designers who then select a BMP from a list of seven preferred options. These seven options are considered preferred because they were selected as part of a collaborative effort to streamline the permit process by various agencies. The agencies involved agreed that if one of the seven BMPS are selected, the requirements for each permit are met. Overall, the BMP selection process used by WSDOT and ODOT followed the same pattern, which is as follows:

- Determine stormwater requirements (flow control/runoff treatment).
- Select and conduct a preliminary design of BMP.
- Evaluate feasibility of constructing BMP within the ROW or whether additional ROW is required.
- Finalize BMP design or seek offsite options.

5.3: How LID is Represented at DOTs

Once the overall stormwater management approach was understood, the next steps was to determine where LID is mentioned in the DOT manuals and how LID processes are currently used by the designers. All three DOTs have a BMP selection process that supports some LID approaches. For example:

- <u>WSDOT</u> seeks to; 1) avoid and minimize impacts on hydrology and water quality, 2) consider compensating for altered hydrology and water quality by mimicking the natural process, 3) compensate for altered hydrology and water quality by using end-of-pipe solutions, and 4) recommends considering dispersion options first (WSDOT 2008).
- <u>ODOT</u> follows the NCHRP design strategies defined in the LID Design Manual, which is to; encourage sheet flow, maintain natural drainage, preserve natural vegetation, direct runoff to vegetated areas, utilize small scale stormwater features, and treat pollutants close to the source (ODOT 2009) (NCHRP 2006).

- ITD temporary BMP design guidance suggests preservation of existing vegetation or plant native vegetation in disturbed areas and preserve/maximize vegetation canopy, including shrubs and coniferous trees (ITD 2010).

The next question considered was how LID is communicated to the user which is generally an engineer and/or designer who actually develops the stormwater design. The following were observed:

- Define LID – ITD did not mention LID in their TESC stormwater guidance. ODOT, WSDOT, and IDEQ did include definitions of LID. However, the definitions were not consistent between the states and none represented all the processes of LID.
- LID in the BMP selection process – The overall permanent stormwater practices at both ODOT and WSDOT encourage using some LID approaches to manage stormwater. The BMP selection process for WSDOT actually recommends dispersion, which is a preferred LID approach (See Section 5.4), as a first choice whenever possible. Beyond that, with both DOT selection processes, it is not always clear which BMPs provide the most appropriate LID approaches for a given site.
- BMP Construction Feasibility – After a BMP is selected, the next step is to verify whether it is feasible for construction. A review of the feasibility evaluation for ODOT and WSDOT showed that, while LID approaches are indicated, it is not always clear or complete (WSDOT 2008, ODOT 2008). (Based on the WSDOT Engineering Economic Feasibility Checklist, a sample Feasibility Flow Chart that incorporates the LID metric approach as detailed in the next section was developed and is included in Appendix B.)

Based on the Pacific Northwest stormwater practices evaluation, means by which LID could be integrated in a highway setting were identified and will be demonstrated in the following sections. The main steps are:

- Development of a working definition of LID that includes all the hydrological processes.
- Development of simple metrics for assessing the LID performance in a highway setting.
- Identification of areas in the BMP feasibility evaluation for adding LID considerations.

5.4: Proposed Methodology for LID Incorporation and Associated Metrics

The development of a methodology for more formally introducing Low Impact Development concepts into the existing stormwater practices in the Pacific Northwest is the main objective of this research. However, it was important to first go through the aforementioned steps to more effectively propose a process that would consider not only environmental considerations, but regulatory and agency procedures and be compatible with accepted hydrologic and roadway designs. This section, Section 5.4, is organized into a typical paper format with an introduction, background literature search to substantiate the assumptions made, development of the metric and decision process and finally example applications in three case studies. This format allows for a concise overview of the proposed methodology and associated metrics to be pulled out of this research report for expert reviews or as a resource for other practitioners who might want to validate the applicability of the approach within their agency or design process.

Introduction

Low Impact Development (LID) best management practices (BMPs) for managing stormwater are becoming common in new developments and are considered part of sustainable development. Voluntary rating systems used to quantify sustainable practices, including Leadership in Energy and Environmental Design (LEED™) and the Sustainable Sites Initiative, encourage innovative practices to manage stormwater (Haselbach 2010, SSI 2009). Some regulatory agencies are requiring LID for stormwater management. Seattle Public Works Division has developed a Green Stormwater Infrastructure (GSI) system that requires LID practices be used for stormwater management to the Maximum Extent Feasible (MEF) (SPU 2009). The 'Green Infrastructure (GI) for Clean Water

Act', if passed, will fund projects that use LID, as well as set standards for LID BMPs (Udall 2010). Washington State Department of Ecology (Ecology) is considering requiring LID and justifying that the most appropriate LID approach for a given situation was selected when some of the state municipal National Point Discharge Elimination System (NPDES) permits are renewed (Ecology 2009).

It is anticipated that Departments of Transportation (DOTs) will soon be required to implement LID BMPs when feasible or be encouraged to use voluntary incentive programs like the proposed Greenroads for the sustainable design and construction of roads (Muench and Anderson 2009). However, incorporating LID approaches into a highway setting can present challenges due to the linear nature of the highway and practical limitations for locating and maintaining stormwater management within the right-of-way (ROW) (WSDOT 2008). Some of these challenges include changes in land uses, soil types, and/or climates over the length of the highway in addition to many unique traffic and safety requirements such as maintaining clear zones or designing for recoverable embankment slopes. To deal with these challenges, traditional end-of-pipe BMPs are often selected that collect stormwater and convey it to a single location. To encourage LID practices, DOTs such as Washington and Oregon are developing BMP selection processes that encourage LID BMP options (WSDOT 2008, ODOT 2008).

A solution to implementing LID in a highway setting may be as simple as clearly defining that a LID BMP is a BMP that uses as much of the full site hydrology as possible within the ROW. That is, to strive to disperse stormwater and mimic all of the natural hydrologic processes, including infiltration, filtration, storage, evaporation, interception and transpiration as much as possible. While many DOTs include definitions of LID in their manuals that mention mimicking the natural hydrologic cycle, it is not always clear to a designer how that may translate to the LID BMP selection process and many DOT stormwater design guidances focus on the infiltration capabilities of BMP options, excluding the other hydrologic processes. Furthermore, when a designer is attempting to select a BMP, most selection processes encourage all or nothing, meaning if a preferred LID BMP will not fit within the ROW, then another BMP is selected. So even if the selection process encourages and defines LID options, a more traditional end-of-pipe BMP may be selected if the LID BMP will not fit within the ROW.

To enable designers to understand and apply LID practices to stormwater management in a highway setting, a simple ranking system has been developed that could be readily used in combination with current DOT BMP selection processes. With this ranking system designers could determine what an appropriate LID BMP option is for any project site and justify their BMP selection. This will be presented by first defining full site hydrology (FSH), referencing research showing benefits of FSH, and explaining why this approach was selected over other models to demonstrate the benefits of FSH. Next, preferred LID BMPs, will then be defined as BMPs that maximize FSH aspects. These should be implemented first, or used in combination with other BMPs, referred to as alternative BMPs, when the ROW is limited. Next, proposed metrics for ranking of the BMP options will be presented along with a decision flow chart that could be integrated into any DOT selection process. Finally, three different case studies will be presented to demonstrate how the metrics can be used with currently available DOT BMP designs.

Full Site Hydrology

A LID approach attempts to mimic as much of the pre-developed hydrologic conditions as possible by taking advantage of the natural hydrologic cycle including; interception by vegetation, evaporation, transpiration, and infiltration (Haselbach 2010). For developments, a primary planning tool for an LID approach is to reduce the impervious area (DER 1999). While pervious pavement is under development for highway settings, it is not yet widely accepted and it is generally not practical to reduce the paved width of highways as part of the LID approach. So for a highway setting, the best way to maximize the natural hydrologic cycle may be to use the maximum amount of ROW possible to disperse flows and manage runoff close to where it originates (LID Ctr 2006). Simply put, FSH uses the LID approach to the maximum extent possible within the ROW of a highway project site. Highway runoff is conveyed via overland flow through as much area and vegetation as possible within the ROW, while giving priority to low maintenance practices and preserving, replacing, or adding trees for interception.

An FSH approach in the ROW distributes highway runoff for enhanced infiltration and evaporation, and interception of precipitation through vegetation allowing for the maximum use of the hydrologic cycle compared with traditional end-of-pipe BMPs such as ponds. Figure 5.1 illustrates how the benefits of the natural hydrologic cycle are maximized when flow is dispersed. For both cases depicted, precipitation will fall over both, the highway and the ROW, but the FSH approach assumes the highway runoff is dispersed over the ROW, and the end-of-pipe assumes this runoff is concentrated and conveyed to a pond. Total runoff from the paved roadway is calculated assuming that only 5% of rainfall is lost to interception and evaporation. The comparative pond option emphasizes infiltration, while FSH also includes increased evapotranspiration and interception (Lucas and Medina 2007). For the first few days after a precipitation event, infiltration and ponding are usually the dominant hydrologic processes for stormwater. However, once the storm event has dispersed or the field capacity of the soil is reached, evaporation and transpiration may become the dominant hydrologic processes (NCHRP 2006). Land areas may evapotranspirate as much as 64% of precipitation back to the atmosphere (Baumgartner and Reichel 1975). Florida studies have shown 50% evapotranspiration rates for sites with deep water-tables, shallow rooted vegetation, and sandy soils (Summer 1996). Other research studies estimated the total evaporation breakdown as; 52-48% from evapotranspiration, 36-28% from soil evaporation and 20-16% from tree canopy evaporation (Lawrence et al. 2007).

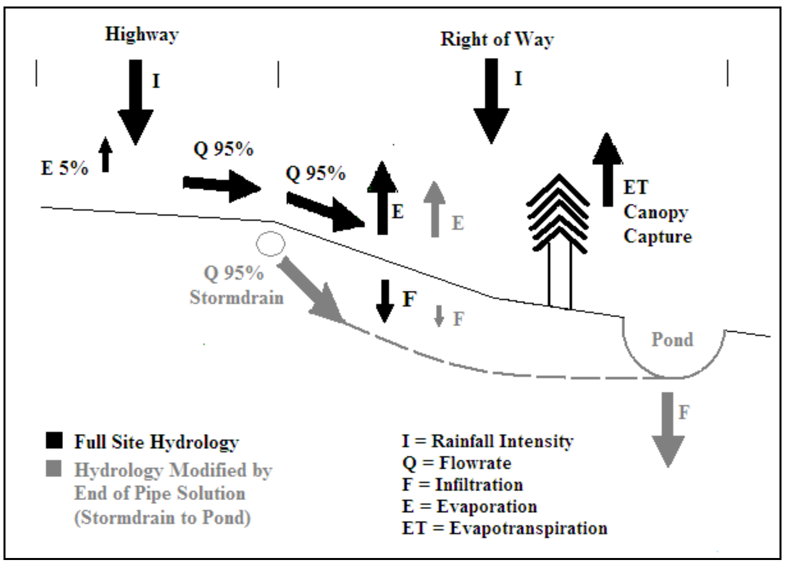

Figure 5.1: Full site hydrology of distributed highway runoff versus point discharged runoff

In addition to distributing runoff horizontally as much as possible within the ROW, the FSH approach prefers LID BMP designs that retain, replace, or plant trees or other vegetation to take advantage of vertical distribution of the rainwater. Trees contribute to a number of benefits in the hydrologic cycle including; interception of the rainfall by the canopy, evaporation, transpiration, and infiltration. In fact, some stormwater management practices like Green Street Infrastructure (SPU 2009) and the Kitsap County simplified sizing tool (Lancaster 2010) are recognizing the importance of the tree canopy in the hydrologic cycle and allow flow control credits for either retaining existing trees or planting new ones. Research estimates rainfall interception in a forest location at 15-40% for a coniferous forest and 10-20% for deciduous forests (Xiao et al. 2000). In Washington, Ecology acknowledges that 20-30% of precipitation may never reach the ground, and other research has documented that a tree canopy accounts for between 16-28% of the total site evapotranspiration (Ecology 2005, Whitehead et al. 1994). Another study documented that the deforestation of the Nigerian forest caused a decrease in infiltration rates by between 20-30% (Lal 1996). While extensive research has documented the benefits of trees, the actual value depends on many factors such as the type and size of the trees, the season of year, and the location of the tree. Programs such as iTree have been developed to estimate the benefit of maintaining or planting trees in an urban area (USFS 2010). Further benefits for canopy maximization include aesthetic enhancements (Susilo and Abe 2010).

Modeling Full Site Hydrology

Many BMPs are designed using a single event hydrologic model or the Rational Method, and while both of these methods are valuable, they have limitations when modeling LID. The Rational Method was developed to estimate the peak runoff from flood events (Peters 2010). The most common single event model uses a curve number (CN) to estimate the amount of precipitation a soil is able to retain (FHWA 2009). These CN values were originally developed based on relatively uniform agricultural landscapes as modified for soil group, cover type, and hydrologic condition. However, for highways with varying conditions over its length, a composite CN value may underestimate the runoff volume (Peters 2010). In addition, conventional approaches to stormwater management design typically include only precipitation, runoff conveyance and storage capacity, while LID design includes other components of the hydrologic cycle as well (Haselbach 2010).

Most single event methods consider the hydrologic process that occurred during the storm event, neglecting evapotranspiration, which may become the dominant hydrologic process later. Trees provide an interception that vertically disperses rainwater and slows the travel time (CWP 2008). Some of the intercepted precipitation will evaporate while the remainder will either become part of the stem flow or contribute to the site runoff and this may not be represented with many current models (Lucas and Medina 2007). To adequately model an LID approach the time between precipitation events should be included to also represent the changes in the soil moisture due to infiltration and evapotranspiration (Beyerlein 2010). The intent of this research effort is not to develop LID hydrology models, but to introduce LID metrics for decision making based on the aforementioned FSH processes being considered in the ROW.

Figure 5.2 illustrates the long term benefits of horizontal dispersion through evapotranspiration in Spokane, WA, a semi arid region. The average monthly precipitation is plotted against the potential evapotranspiration (PET) rates per month and per day. If a longer term, such as a month, were used as the model duration, the PET would exceed the precipitation rates for 7 months of the year. This is in contrast to a single event model based on one day with an average of 0.07 inches (1.8mm) per unit area. Figure 5.2 further supports the FSH concept of maximizing the ROW area used for runoff dispersion, since PET represents the average inches per area that could evapotranspirate, therefore the larger the area, the larger the PET. The precipitation and pan evaporation rates were obtained from the Spokane Storm Water Manual (Spokane 2008) and PET was estimated using the FAO Penman method and the pan evaporation rates (FAO 1998).

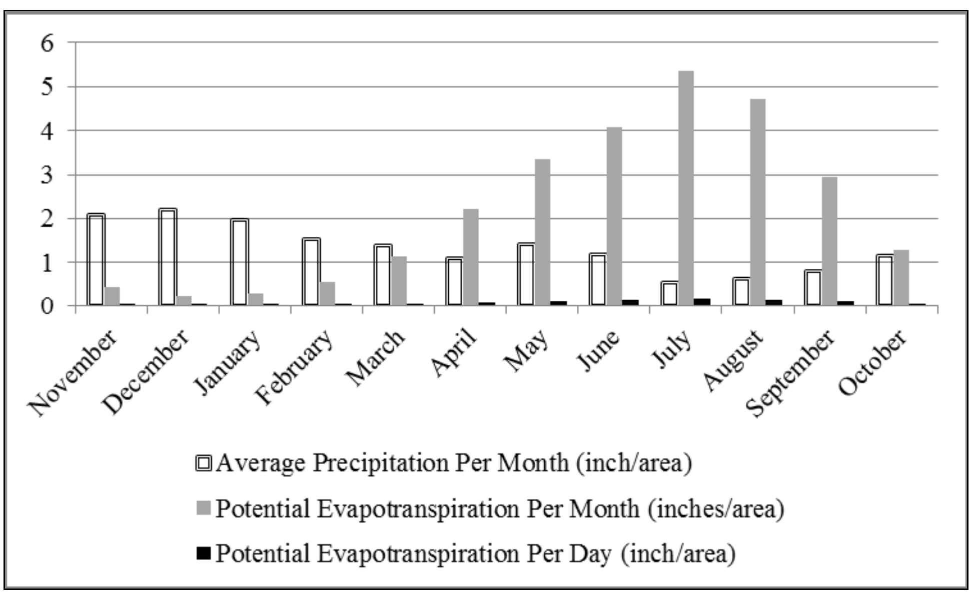

Figure 5.2: Average precipitation and estimated potential evapotranspiration (PET) rates for Spokane, WA

To apply the full site hydrology concept it is important to first understand the hierarchy of LID BMPs as well as to define the preferred and alternative BMPs. The definition of each individual BMP is based on the Highway Runoff Manual for Washington State DOT (WSDOT 2008).

Preferred LID BMPs use FSH processes as much as possible within the allowable ROW. Generally these are BMPs that keep runoff closer to the source and allow runoff to disperse over a wide area, and through vegetation. Then, if two options are considered equal, the option that includes trees is preferred because of the documented additional benefits. If a preferred BMP cannot fully fit within the ROW, preference is given to pairing preferred LID BMPs as extensively as possible in combination with an alternative BMP stormwater control to meet the full stormwater requirements. Using a paired LID BMP design is a newer concept in the BMP selection process, and is similar to the treatment train approach to runoff management which is commonly used when a dual function (both flow and water quality control) BMP is not applicable for the site (Wang et al. 2010). Finally, BMP preference should also consider the sustainability of an option that includes a long life cycle and lower maintenance cost (Clar 2010).

Preferred LID BMPs

Three preferred LID BMPs for highway settings are preliminarily recommended in this research; natural dispersion, engineered dispersion, and permeable pavement shoulders and walks paired with either natural or engineered dispersion as necessary. If any of these preferred LID BMPs can be used at a project site to fulfill all the stormwater requirements, they are automatically selected and no further analysis is necessary. Natural and engineered dispersion is the simplest method of managing stormwater flow control and pollutant removal. For both, highway runoff is dispersed through vegetation over a wide area next to the paved roadway, and infiltrated or evaporated. Natural dispersion is generally an area that existed prior to highway construction and is not modified as part of the project, whereas engineered dispersion is modified as part of the highway construction to provide an area for runoff dispersion. Both are generally easy to maintain and can allow trees to be retained or planted outside the highway clear zone (WSDOT 2008). The third preferred LID BMP are permeable pavements which are still under development for highway settings and only considered as a preferred option when used to provide a secondary purpose such as structural, level spreader, or runoff treatment. Permeable pavements, such as pervious concrete or porous asphalt, are pavements that allow stormwater to flow through the pavement, either infiltrating into the soils below or evaporating. Their use is being evaluated for implementation as highway shoulders for addressing stormwater needs while providing a structured area for vehicles. Particular interest is in the capability of these permeable pavements to also act as stormwater energy dissipaters, which may improve the effectiveness of the neighboring dispersion areas. However, their use is currently under development, and not yet fully included for application in most highway runoff design manuals.

Alternative BMPs

An alternative BMP is any BMP that is not a preferred LID BMP, but which still encourages some of the LID processes or has some LID features. While many of the alternative BMPs considered in this research promote the LID approach, they generally do not maximize FSH to the same extent as dispersion. Alternative BMPs also include more traditional approaches including end-of-pipe solutions. If a preferred LID BMP cannot be used for a project site to meet the full stormwater requirements, then it is recommended that pairing preferred and alternative BMP options is first considered and the choices ranked as described in the *Metrics Defined* Section of this report. Thus, paired BMPs as defined herein are simply a preferred BMP that has been paired with an alternative BMP to meet the stormwater requirements. (Whereas a dual function BMP is one that can provide both runoff treatment and flow control.) All three preferred LID BMPs are dual function. Some example alternative BMP definitions described in this research are:

- *Vegetated Filter Strip (VFS)*: Located adjacent to the highway, a VFS is a gradually sloped embankment that is well vegetated. This BMP is similar to dispersion, but flow control is not generally considered due to reduced infiltration rates. It is most often used as pretreatment in combination with other BMPs.

- *Media Filter Drain (MFD)*: MFDs have 3-4 parts; a gravel level spreader, a grass strip, a soil mix that provides treatment of stormwater and increases project infiltration rates, and an underdrain to convey runoff if the project site infiltration is too low. MFDs provide only runoff treatment. If flow control is also required they should be paired with a BMP that provides flow control.

- *Infiltration Pond*: This is a traditional end-of-pipe solution where stormwater is conveyed through storm drains or swales to a vegetated pond and can be dual function.

- *Bio-infiltration Swale*: This is similar to an infiltration pond, except longer and much shallower.

- *Infiltration Trench*: This is a long, narrow trench, usually filled with stone. The void spaces between the stones store runoff until runoff infiltrates. It is considered ideal for providing dual functionality where the ROW is limited. Pretreatment may also be provided with a VFS to extend its life.

Metrics Defined

When preferred LID BMPs will not fit within the ROW to adequately manage stormwater runoff, then preferred LID BMPs can be paired with other BMPs, and together evaluated and ranked based on two metrics, the FSH dispersion index (FSH_{dis}) and the FSH canopy index (FSH_{can}). These two metrics are used to estimate which BMPs, or combination of BMPs, maximize the natural hydrologic cycle within the available ROW by considering how much of the horizontal area of the ROW will be used to disperse flow and promote infiltration and evaporation (FSH_{dis}), and how much of the drip line of the tree canopy (vertical interception area in the ROW) is retained (FSH_{can}) within the ROW.

First, commonly used DOT BMPs are designed using accepted models to demonstrate that full stormwater requirements can be met, both runoff treatment and flow control. Next, the equivalent width of each BMP is calculated over the ROW (where the equivalent width is the BMP area per length of highway) and the percent of the equivalent ROW available for runoff to disperse is estimated with FSH_{dis} by dividing the sum of the equivalent widths of the BMPs (W_{BMP-T}) by the total ROW equivalent width (W_T). (For paired LID BMPs, the equivalent width is determined for each BMP and added to obtain the numerator for the FSH_{dis} index.)

$$FSH_{dis} = W_{BMP-T}/W_T$$

For project sites where a tree canopy is retained or restored, FSH_{CAN} is also calculated using an equivalent width based on the canopy drip line area in the ROW (W_{CAN}), but the denominator is modified by subtracting out the clear zone from the equivalent ROW width (W_{T-CZ}). The option with the largest FSH_{dis} is generally the approach that uses LID to the maximum extent feasible. In the case of a tie for dispersion in the ROW, preference is given to the designs with the maximum FSH_{CAN}.

$$FSH_{CAN} = W_{CAN}/W_{T-CZ}$$

Figure 5.3 provides an example logic diagram for applying the metrics within current DOT highway runoff design decision processes (See also Appendix B.). Priority is given to BMPs that fit in the ROW. First, the preferred LID BMPs are chosen for design. If the preferred LID BMP design does not fit within the ROW, then the preferred LID BMPs are paired with alternative BMPs, and FSH_{dis} is maximized (maximum horizontal infiltration and evaporation) for various combinations. Then the preferred paired options are evaluated for maximizing the canopy index (maximum vertical interception, evaporation, etc.) using the land in the ROW. Finally, alternative BMPs are similarly evaluated for both indices for designs that fit within the ROW if pairing with preferred LID BMPs is found not to be feasible. If none of the aforementioned options meet the stormwater requirements within the ROW, then the designers will need to explore options that include land outside of the ROW. Extension of the proposed logic is not fully presented herein for designs outside of the ROW, but it is intended that similar logic loops and maximization of the indices will be included in those decision processes such as through Step 5 in Figure 5.3.

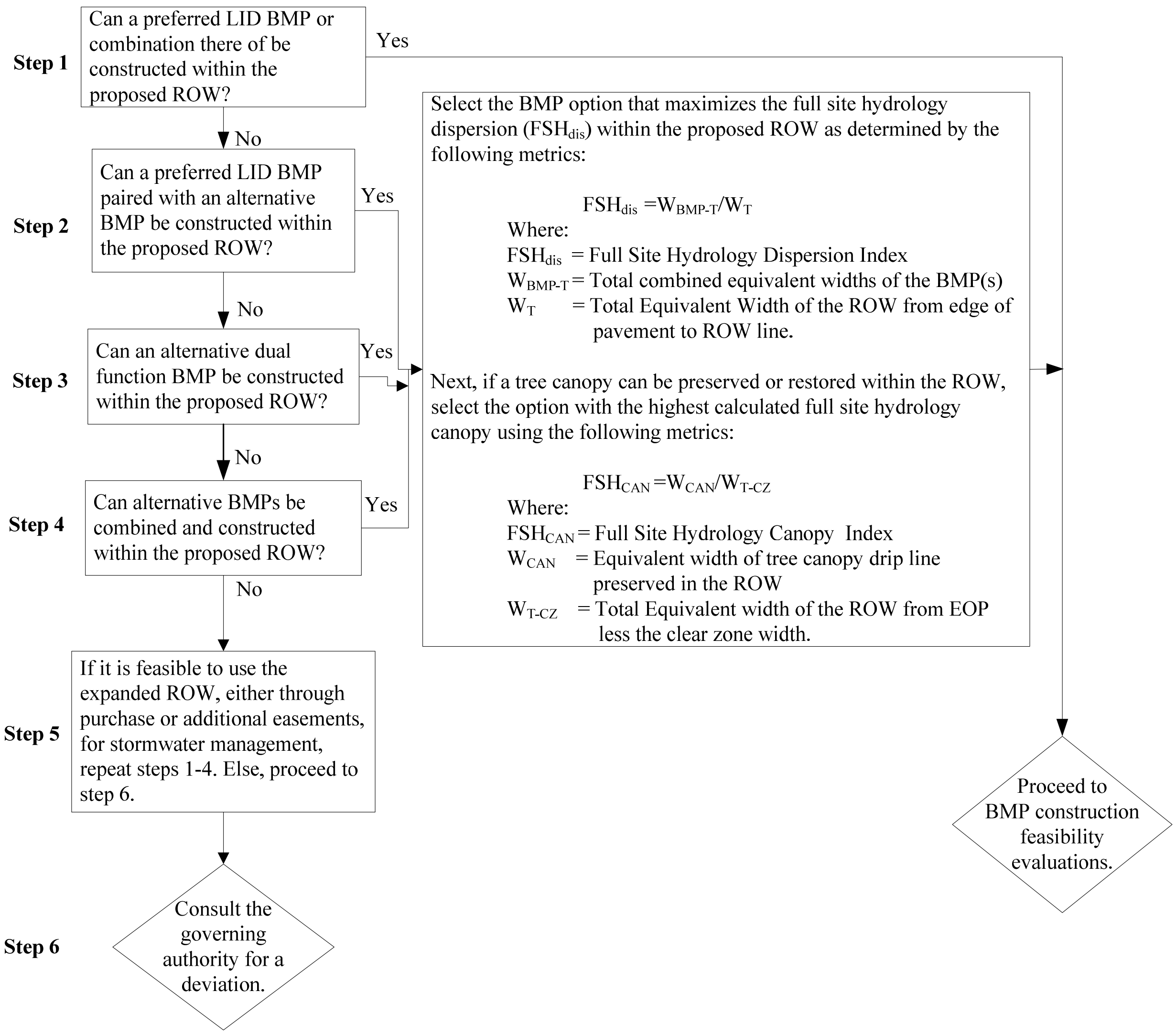

Figure 5.3: Full site hydrology metrics decision loops

[Additional BMP construction feasibility evaluations are then furthered considered in the WSDOT Highway Runoff Manual such as archaeological sites, impacts to wetlands, etc.(WSDOT 2008)]

Ecology in Washington acknowledges the challenge of keeping up with increasingly more complex stormwater regulations for staff involved in stormwater facility design (Ecology 2010). Considering this complexity, simple metrics such as those proposed, may help designers readily demonstrate that a LID approach is used to the maximum extent feasible. Also, since common DOT BMPs are used in the proposed decision loops, the metrics can be easily integrated into most established DOT selection processes. These metrics can be enhanced and expanded for other applications and additional considerations. They are best suited for the majority of highways that are located in rural settings, although case studies presented in this document may also apply to urban areas.

Metrics Demonstrated with Case Studies

The first case study is in a rural location with no area restrictions for BMP selection, the second is an urban location with limited ROW, and the third is a mountainous, rural area with ROW only available in the median area for stormwater management. Unless otherwise noted, each BMP was designed to meet the full stormwater requirements for both runoff treatment and flow control following the WSDOT Highway Runoff Manual (WSDOT 2008). At each site it was assumed that the infiltration rate was 1 in/hr (2.54 cm/hr) and site conditions were acceptable for infiltration.

Case Study 1 – Rural Setting

- Contributing width of highway pavement = 36 feet (11m)

- Available ROW = 31 feet (9.5m)

- Equivalent width of tree canopy within ROW = 7.5 feet (2.3m)

- Project length = 5280 feet (1,610m)

For this site in Figure 5.4, there was adequate area in the ROW for dispersion. However to demonstrate how the metrics compare to other BMP options, alternative BMPs were also evaluated independently of a preferred LID BMP option as shown in Table 5.1. Note that if dispersion was not an option, the second best option without pairing would be a media filter drain however this option is only approved to meet the runoff treatment requirements and would have to be paired with another BMP such as an infiltration pond to meet the full stormwater requirements.

Figure 5.4: Rural highway setting

TABLE 5.1 Rural Setting Metrics

	% of Stormwater Requirements Met		Preferred LID BMP			Alternative BMPs			Metrics		
BMPs	Flow Control	Runoff Treatment	Design Width	Design Length	Equiv. Width	Design Width	Design Length	Equiv. Width	Sum of Equiv. Widths	FSH_{DIS}	FSH_{CAN}
Natural Dispersion[1]	100	100	14	5280	--	--	--	--	14	0.451	0.36
Storm drain to Infiltration Pond	100	100	--	--	--	67	120	1.52	1.52	0.05	0
Bio-infiltration Pond	100	100	--	--	--	34.5	276	1.8	1.8	0.06	0.36
Media Filter Drain (MFD)[2]	0	100	--	--	--	8	5280	8	8	0.26	0.36

Units are given in feet, 1 foot = 0.305 meters

1. Since a preferred LID BMP will fit within the ROW, it is not necessary to evaluate alternative or paired BMPs. However, the other options were ranked to provide a comparison of the metrics.
2. If flow control is required for this site, the MFD will have to be combined with another BMP to meet full flow control requirements.

Case Study 2 – Urban Setting

- Contributing width of highway pavement = 44 feet (13.4m)
- Available ROW = 7 feet (2.1m)
- Existing equivalent width of tree canopy within ROW = none
- Project length = 464 feet (142m)

The second case study in Figure 5.5 is located at a signalized intersection where a state highway overlaps with a city street. For safety, curb and gutter will be installed although curb cuts can be used along with energy dissipaters to allow runoff to disperse in the 7 foot (2.1 m) available ROW located between the highway and the sidewalk. In this case it is estimated that 17 feet (5.2 m) of dispersion is required to meet the stormwater requirements. Since there is not enough room for the dispersion area, the designer would proceed to Steps 2-4 in Figure 5.3 and evaluate pairing with other BMP options to determine which combinations would maximize the full site hydrology within the ROW. If a BMP option extends beyond the ROW, the FSH_{dis} is disregarded until all other options within the ROW are exhausted. For this case study two options yielded an FSH_{dis} of 1, pairing engineered dispersion with a bio-infiltration swale or with an infiltration trench. However since planting trees in the swale is an option but not with the infiltration trench, the preference is given to pairing engineered dispersion with a bio-infiltration swale based on the second index. Some alternative BMPs are also evaluated singly for comparison. The results are tabulated in Table 5.2.

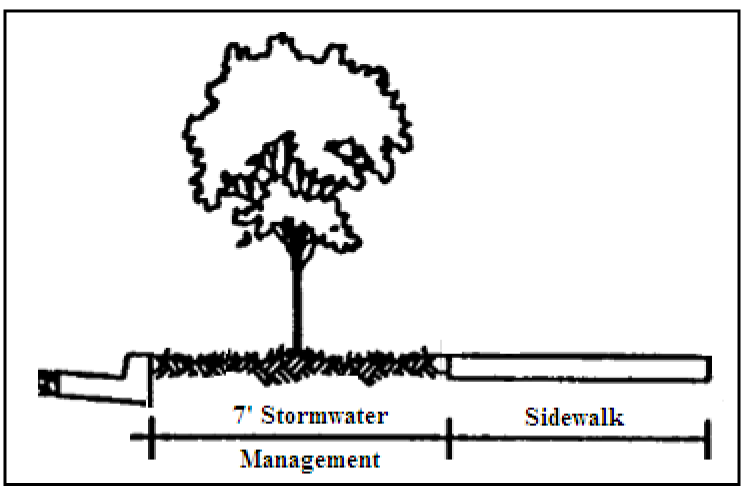

Figure 5.5: Urban setting with limited ROW

Table 5.2 - Urban Setting Metrics

	% Stormwater Requirements Met		Preferred LID BMP			Alternative BMPs			Calculations		
BMPs	Flow Control	Runoff Treatment	Design Width	Design Length	Equiv. Width	Design Width	Design Length	Equiv. Width	Sum of Equiv. Widths	FSH_{DIS}	FSH_{CAN}
Engineered Dispersion	41	41	17	465	17	--	--	--	17	N/A [1]	>0[2]
Bio-infiltration Pond	100	100	--	--	--	7	262	4	4	0.64	>0[2]
Paired Engineered Dispersion &	21	21	7	232	3.5				7	1	>0[2]
Bio-Infiltration Pond	79	79				3.5	232	3.5			
Infiltration Trench[3]	100	100	--	--	--	7	465	7	7	1	0

Units are given in feet, 1 foot = 0.305 meters

1. Not applicable since the design width exceeds available ROW.
2. These options could allow for trees
3. The infiltration trench was designed using CALTrans standards.

Case Study 3 – Mountainous Rural Location

- Contributing width of highway pavement (both sides) = 80 feet (24.4m)
- Available ROW = 24 feet (7.3m) in the median
- Existing equivalent width of tree canopy within ROW = none
- Project length = 2000 feet (610m)

In this mountainous rural setting as shown in Figure 5.6, a divided 6 lane highway is constrained by a mountain area on one side and a surface body of water on the other side. The only available ROW is in the median and to accommodate this situation the highway was designed to slope toward the median. For this site natural dispersion will not fit alone, however when paired with a a bio-infiltration swale, the stormwater requirements are met as noted in Table 5.3. Another option is to use MFD to meet runoff treatment requirements and an infiltration pond off site for flow control, however since the full stormwater requirements cannot be met within the proposed ROW the FSH is listed as N/A. So for the mountain setting, the most appropriate LID approach would be pairing natural dispersion with a biofiltration pond.

Figure 5.6: Mountainous rural location

Table 5.3 – Mountainous Rural Setting Metrics

	% Stormwater Requirements Met		Preferred LID BMP			Alternative BMPs			Metric		
BMPs	Flow Control	Runoff Treatment	Design Width	Design Length	Equiv. Width	Design Width	Design Length	Equiv. Width	Sum of Equiv. Widths	FSH_{DIS}	FSH_{CAN}
Natural Dispersion	80	80	30	2000	30	--	--	--	30	N/A[1]	N/A
Bio-infiltration Pond	100	100	--	--	--	24	520	6.22	6.22	0.26	>0[2]
Pair Natural Dispersion &	76	76	24	1900	22.8				24	1	>0[2]
Bio-infiltration Pond	24	24				24	125	0.2			
Paired Media Filter Drain &	0	100	--	--	--	16	2000	16	16	N/A[3]	>0[2]
Infiltration Pond	100	0	--	--	--	120	120	N/A[3]			

Units are given in feet, 1 foot = 0.305 meters

1. Not applicable since the design width exceeds the width of available ROW.
2. If trees were present they could be retained or added in the median area as appropriate considering safety.
3. Requires additional land outside of ROW.

Metrics Conclusion

The selection of a list of preferred LID BMPS for highway applications will provide designers with a simple decision method to maximize LID principles when there is adequate ROW for these designs. The decision tree with FSH loops for ranking BMP options presents a simple addition to incorporating enhanced LID characteristics into existing DOT BMP selection processes when the preferred options cannot be fully met within the ROW. Both the preferred LID BMP and alternative BMPs should still be designed in accordance with regulatory requirements.

The FSH_{dis} metric represents a basic concept of dispersing stormwater for enhancing most LID processes. Just as the concept of reducing the 'effective' percent of impervious area is a commonly used metric for LID design in subdivisions and urban developments, the FSH_{dis} metric represents a basic concept covering most LID processes in a linear setting. The full site hydrology approach is further enhanced with the addition of the canopy index (FSH_{CAN}), similar to the encouraged use of vegetative LID practices for urban developments.

It is intended that these concepts will be further refined for additional highway applications or circumstances with additional loops and submetrics. For example, additional loops using these two metrics might be applied to stormwater practices outside of the ROW or adapted to non-linear projects by maximizing the ratio areas used for dispersion based on the area outside of the development foot print (the building footprint plus the hardscape) and then further maximizing the canopy area. In addition, if tabulated and evaluated based on the overall lengths of highways or lanes, these indices can be adapted to evaluate the advancement of LID into the overall program of a highway department or state.

5.5: Consideration of Barriers and Other Benefits

There are many barriers and also benefits to including low impact development practices to a higher degree in highway designs. Some of the barriers or concerns relate to additional maintenance considerations. It is also important to align the design of LID BMPs to be compatible with standard highway practices. Finally some additional benefits may be related to the possibility of a lower carbon footprint with certain stormwater practices.

Maintenance Considerations

To better understand the actual maintenance practices and procedures for BMPs, a meeting was scheduled with WSDOT maintenance on May 11, 2010 in Olympia, Washington. While WSDOT provides specific maintenance requirements for BMPs, and BMP maintenance is prioritized by the type of fix needed. The order of priority is given as follows; emergency fixes, invasive species management, and maintenance of the clear zone for the purpose of safety. The focus of this interview was to understand how BMP maintenance is prioritized and to identify any barriers to LID BMP maintenance.

Priority BMP Maintenance

- Emergency fixes – are identified when a BMP is visually not operating. For example infiltration ponds not infiltrating or a storm drain overflowing.
- Invasive species management- is a state requirement that discourages and eliminates invasive plant species as part of the integrated vegetation management (IVM) plan. Each county has a list of invasive species that must be managed. Practices associated with managing invasive species include: selective spraying with herbicides, releasing weed eating insects, and encouraging the growth of native plants (WSDOT 2009).
- Maintenance of the clear zone for the purpose of safety - the recovery zone is also part of the IVM, which requires visually clear areas adjacent to the highway and proper sight distance. As part of roadside maintenance practices in the clear zone, for example, no vegetation shall be over 4' tall and nothing with a diameter greater than 4 inches shall be located in Zone 2 as shown in Figure 5.7.

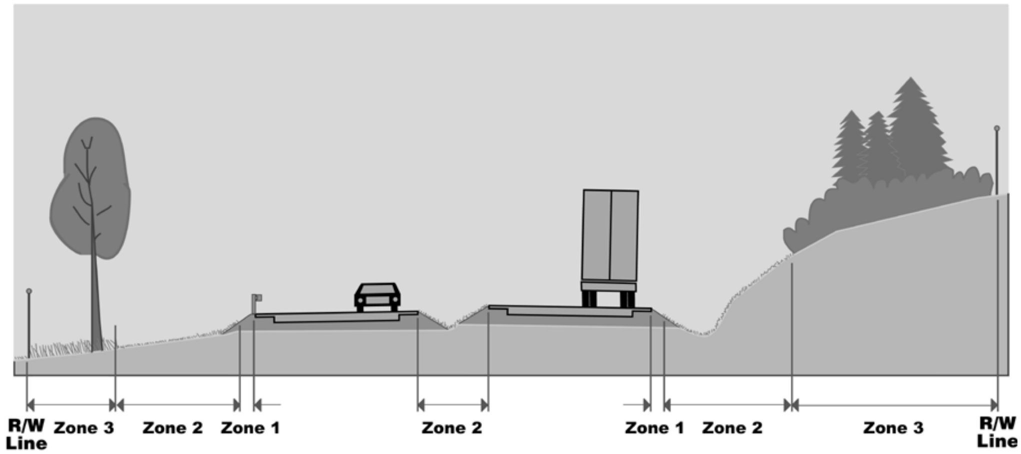

Figure 5.7: Example of Roadside Maintenance Zones (WSDOT 2009)

Barriers to BMP Maintenance

Barriers to proper BMP maintenance include maintenance practices that are contrary to IVM or require specialized equipment and training for maintenance staff. Some examples are noted below:

- When BMPs are newly installed, it is not always communicated to maintenance what the specific maintenance requirements are.
- Some BMPs have mowing requirements. The equipment currently owned by WSDOT maintenance is 8 feet at the narrowest and 21 feet at the widest and generally only one pass is completed. If the BMP is wider than the mower arm or steeper than permitted for safe mower operation, this creates a barrier to mowing part or all of the BMP. Also, the riding lawn mower can only cuts grass 8" high and since BMPs such as biofiltration swales are designed for shorter grass, the swales have to be manually mowed. See Figure 5.8.

Figure 5.8: Example of Roadside Mowing Practices (courtesy of WSDOT Maintenance)

- The current media filter drain (MFD) design requires a 1 to 3 foot no vegetation zone. However, without native vegetation in this zone, invasive species can grow creating a need for removal. The most common removal method would be spraying with herbicide but this could contaminate the MFD material that is intended to provide runoff treatment of the stormwater. WSDOT is considering a different BMP design for MFD to align with maintenance practices.

- Some BMPs require a 1' gravel spreader located immediately adjacent to the highway. While the level spreader is essential to the proper operation of some BMPs, vegetation can grow in this area and if the vegetation height grows over 4', as part of the IVM the vegetation will have to be cut and/or removed in the case of invasive species.
- Any BMP that is located within the first 0-2 foot no vegetation zone (shown as Zone 1 in Figure 5.7) is located in the 'no vegetation zone' that maintenance requires to: reduce fire potential, prevent pavement breakup by invasive species, provide sight distance at intersections, and prevent build up of winter sand at the pavement edge.

Aligning Maintenance Procedures with LID Practices

An important consideration is to modify the design requirements of the LID BMP to align with maintenance practices. As mentioned previously, it would be beneficial to design BMPs so that they can be mowed in as few passes as feasible. One other example of this is the provision of a level spreader feature at the edge of pavement prior to discharge of stormwater through natural or engineered dispersion. The following are some ideas for consideration of how level spreaders might be modified to align with maintenance practices, but these ideas are not fully tested and it is recommended that future research is to determine their efficacy and sustainability.

- Where gravel level spreaders are the only option, consider replacing the current 1 ¼" base course with a larger aggregate.
- Evaluate replacing the gravel level spreader with a rolled shoulder, beveled edge or pervious pavement. See Figure 5.9 for example of a rolled shoulder.

Figure 5.9: Example of Rolled Shoulder (provided by WSDOT maintenance)

Align BMP Design with Highway Design

Another consideration for integrating LID into a highway setting is to align the design criteria of BMPs with highway designs. As mentioned in Section 2: Background, the concept of managing stormwater to protect the environment has grown since the Clean Water Act was expanded in 1987 to include stormwater discharges from urban municipal separate storm sewer systems (which includes runoff from roads and highways). However many

BMP design criteria are not specific to the BMP in a highway setting. One example relates to the current vegetated filter strip's design criteria which are largely based on research specific to biofiltration swales. This section will focus on the design criteria for VFS to illustrate how research specific to this BMP, along with consideration of the highway design, can enhance LID as well as reduce construction costs.

A common BMP used to provide runoff treatment of highway stormwater are vegetative filter strips (VFS) which are essentially vegetated embankments located adjacent to the road, as illustrated in Figure 5.10. A primary goal of VFS is to remove total suspended solids (TSS) when highway runoff sheet flows through vegetation where velocities are slowed and sediment is trapped (WSDOT 2008). Currently, many DOTs constrain roadway embankments constructed as a VFS to a 15% slope or flatter. In addition, some DOTs also require, "a minimum residence time of 9 minutes" for full removal of 80% TSS (WSDOT 2008). Since many existing highway embankments are constructed at a 25% slope, when the embankments are used as a BMP the side slopes are flattened and the roadway footprint is expanded to meet the VFS design criteria which may result in the purchase of additional right of way (ROW) and increase the limits of disturbance. To keep highway construction cost down and minimize the limits of disturbance, it is desirable to have the design criteria for VFS align with the design criteria for most highways.

Figure 5.10: Vegetative Filter Strip

It is not entirely clear where the 15% slope limit originated, but this limit is widely used by DOTs including WSDOT and ODOT. The logic for the slope limit in DOT BMP design manuals is to ensure that runoff enters VFS as sheet flow and the concern is steeper slopes could encourage concentrated flow as evidenced by erosion on embankments. A detailed literature review for research that recommended this limit could not be found. However, based on a recommendation from a 2005 swale study performed in Texas, it may simply be for safety of the traveling public. The Texas study monitored biofiltration swales located in the highway median for 5 years with the goal of recommending design guidance of VFSs. In the final recommendation, embankment slopes used as part of a biofiltration swale were limited to 15% for safety (Lantin and Barrett 2005). Safety is also a justification for a 25% slope when embankments are used as part of roadside and or median channels as defined in Hydraulic Engineering Circular (HEC) 22 (FHWA 2009). In both the Texas study and HEC, the swale side slopes are the embankments and function the same as VFSs that receive highway runoff as sheet flow.

This criterion is consistent with the WSDOT limit of 25% to allow for recovery of errant vehicles on embankments. However, there are sometimes other site factors such as speed and ADT which may require a flatter slope. This may account for the 15% limit recommended by the Texas study (WSDOT 2008). Since there are highway setting that permit the 25% embankment slope, it is desireable to have the VFS design criteria align with this limit when 25% is also safe for errant vehicles.

In an attempt to align VFS with the highway design criteria, WSDOT is currently working on research connected with this project that considers the factors that lead to the success and/or failure of VFS on slopes steeper than 15%. Since highway embankments have been used indirectly as VFS since long before the Clean Water Act, there are many existing vegetated embankments with slopes steeper than 15%. In the steep slope study, a total of 46 sites were visited, with and without erosion, and site conditions were documented. One goal of the steep slope research is to revise the current design criterion for BMPs to allow for 25% slopes when appropriate.

The other design criterion of interest is the 9 minute residence time. This requirement is based on research performed on biofiltration swales that was extended to VFS. While the two BMPs are similar in that both use biofiltration to remove TSS, there are differences in the shape, operation, and runoff design depth. A biofiltration swale is a vegetated channel that allows runoff to flow at a maximum of 3 inches in depth whereas VFS are sloped embankments designed to accept runoff traveling as sheet flow at a maximum of ½ inch in depth (MMS 1992). The swale study did not provide any justification for applying channel flow research to a sheet flow application. However, one of the original researchers was contacted and indicated VFS were assumed to be a very wide swale.

In the case of VFS it may be a conservative assumption to use swale research in order to establish VFS design criteria. For example, consider the purpose of both BMPs which is to remove of 80% of TSS and, based on the swale study, requires a 9 minute residence time. Using Newton's first law of motion, a theoretical scenario can be considered to compare a VFS to a swale when determining the settling velocity and time required for sediment to settle in runoff. The settling velocity in both BMPs would be nearly equal since it is a function of the diameter of sediment, specific gravity of the particle, and a drag coefficient (Lindeburg 2006). However, the time to settle is a function of the height sediment has to fall and the settling velocity and, since the depth of runoff is 6 times higher in a swale than a VFS, it is unlikely that sediment will require the same amount of time to settle in a VFS as it would for a swale. Since the original 9 minutes was based on a swale, it is possible that applying the 9 minutes to a VFS will result in a wider design width (i.e., length of flow path) than necessary.

Climate Change Benefits

Currently many DOTs are striving to develop sustainable transportation systems and one of the goals is to reduce their carbon footprint as part of an increased policy to support climate change mitigation strategies. WSDOT is required to document CO_2e (Carbon dioxide equivalents of emissions to global warming potential) as part of an environmental impact statement (EIS) for a proposed major highway improvement project. Currently, only major contributors of CO_2e are considered which includes vehicle users and construction activities for the highway. However, in order to meet requirements such as Governor Christine Gregoire's Washington Climate Change Challenge, which calls for an overall reduction in green house gases to 1990 levels by 2020, it is expected that additional strategies will need to be considered (Gregoire 2008).

In an effort to illustrate the reduced carbon footprint that a preferred LID BMP may have as compared to some other traditional stormwater management practices, a life cycle analysis (LCA) of the green house gases (GHG) produced from dispersion as well as from a storm drain and infiltration pond (end of pipe) design scenario were compared. The comparison required the following steps:

- Preliminary design of both BMPs assuming a 36' wide by 1 mile long highway section.
- An estimated cost estimate using the WSDOT Unit Bid Analysis.
- Segregation of the life of the BMPs into several phases (embodied, construction and maintenance)
- Using the cost estimate, a carbon dioxide equivalent (CO_2e) for each BMP was calculated using Economic Input Output Life Cycle Cost Analysis (EIOLCA 2008).

This comparison will first provide a brief description of the different sources of CO_2e emissions as well as possible sequestration benefits. Next, the CO_2e calculations are reviewed and then the two BMPs compared with their carbon footprint

A carbon source is anything that releases more carbon than it absorbs. Sources of carbon emissions from BMPs are either; embodied, construction, operational, or demolition (however demolition is not being considered in this particular analysis). Embodied emissions are released from the extraction, processing, and energy required for the conversion of materials into a useable form. These activities occur prior to construction and are generally referred to as the 'cradle to gate' emissions. Construction emissions are released due to activities used to construct the BMP such as fuel burned through the use of construction equipment. When embodied and construction emissions are considered together, they are referred to as 'cradle to consumer'. Operational emissions are released after construction and are generally due to maintenance activities. Demolition emissions are activities used to decommission a BMP. When all four of these sources are considered it is generally referred to as a 'cradle to grave' emissions. For this comparison, only the carbon emissions from cradle to consumer were considered, although some maintenance activities that might contribute to the carbon footprint of the options are listed in Table 5.4 along with examples of the embodied and construction items.

Table 5.4. Example Breakdown of Items Considered for each BMP

	Embodied	**Construction**	**Operational (Maintenance)**
Storm drain Infiltration Pond	Catch Basin Grate Inlet Storm drain pipe Hydroseed Gravel Backfill Activities associated w/ BMP design	Clearing and grubbing Excavation of pond and trench Install gravel, storm drain, and hydroseed Testing pipe	Remove trash and sediment Erosion repair Vegetation replaced Repair grate and pipe Remove vegetation in catch basin
Engineered Dispersion	Hydroseed Compost Activities associated w/ BMP design	Clearing and grubbing Grading Install hydroseed/compost	Remove trash and sediment Erosion repair Vegetation replaced Remove sand and debris accumulation along pavement edge.

A carbon sink is anything that absorbs more carbon, than releases it. There are many natural sinks in the environment that remove and store carbon from the atmosphere including; plant photosynthesis, water bodies, and soils. For the storm drain and infiltration pond BMP, the predominant sink is the vegetated pond area, whereas, the entire engineered dispersion area as designed in this scenario is covered with vegetation, which will be an additional benefit to the dispersion option. Comparisons of these sinks are not included in the following analyses, as only the 'cradle to consumer' portion is being evaluated and the science for evaluating these sinks is not well evolved.

A life cycle analysis is used to estimate and compare the CO_2e emissions released during the life of a product. For the two BMPs considered, an input-output model called EIOLCA was used to estimate the CO_2e (EIOLCA 2008). It is based on average industry emissions used to make or perform each of the items as listed in Table 5.4 The model requires the user to select the industry of interest and then provides further options for the sector. For this BMP evaluation 7 industries were selected with different sectors as noted in Table 5.5. Based on the industry and sector selection, the entire supply chain for producing and constructing the BMPs are represented in the CO_2e per $1,000,000. To convert this value to align with the project, an estimated cost of all material and labor cost are required. This is done by developing a bill of materials with take offs for each item and estimated cost separated by material and labor. Costs were determined using the WSDOT Unit Bid Analysis, which provides the material and construction cost combined. Because the unit bid analysis provides only the total cost of an item and the EIOLCA requires that costs be broken down into material and labor, some estimating of the breakdown in cost was performed and also noted in Table 5.5.

Table 5.5. Material and Labor Cost Breakdown Using WSDOT Unit Bid Analysis and Industry/Sector in EIO/LCA for Each Item

Item	Material Or Labor	% Material	% Labor	Industry	Sector
Concrete Catch basin and storm drain	M	33	67	Plastic, Rubber and Non-metallic Mineral Products	Concrete Pipe Manufacturing
Plastic pipe	M	33	67	Plastic, Rubber and Non-metallic Mineral Products	Plastic pipe, fittings, and profile shapes
Corrugated metal	M	33	67	Ferrous and Nonferrous Metal Production	Iron, steel pipe and tube from purchased steel
Gravel backfill	M	33	67	Mining and Utilities	Sand, gravel, clay, and refractory mining
Hydroseed and compost	M	33	67	Agricultural, Livestock, Forestry, and Fisheries	Greenhouse and nursery production
Soil testing and Surveying	M	0	100	Professional and Technical Services	Architectural and engineering services
All Labor – Construction	L		100	Construction	Highway, street, bridge, and tunnel construction

Based on the cost estimate and the industries selected, the carbon footprint from ‘cradle to consumer’ were estimated in metric tons (mt) for each design scenario and are summarized in the bar graphs in Figures 5.11 and 5.12. As expected, the storm drain and infiltration pond BMP produced the highest CO2e. This was primarily due to the concrete storm drain pipe and catchbasin, although excavation and backfilling activities were also significant. For the engineered dispersion area, the highest contributors of CO2e were providing the compost, and grading, primarily due to fossil fuel emissions for the equipment.

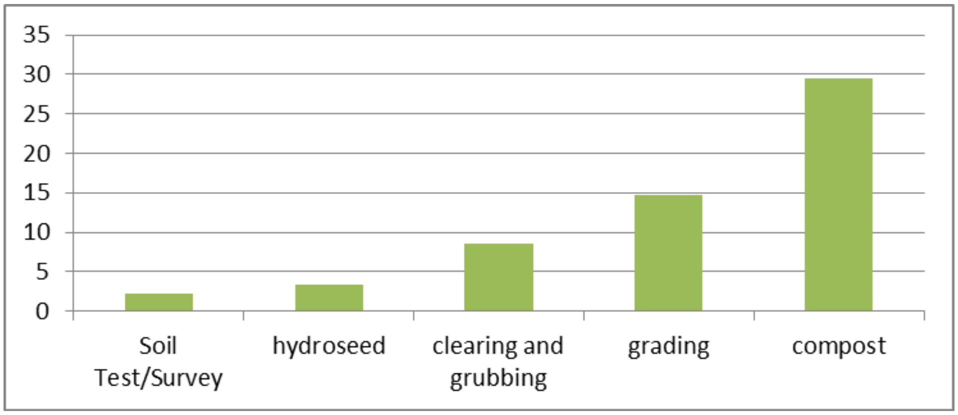

Figure 5.11: CO_2e (mt) for Engineered Dispersion

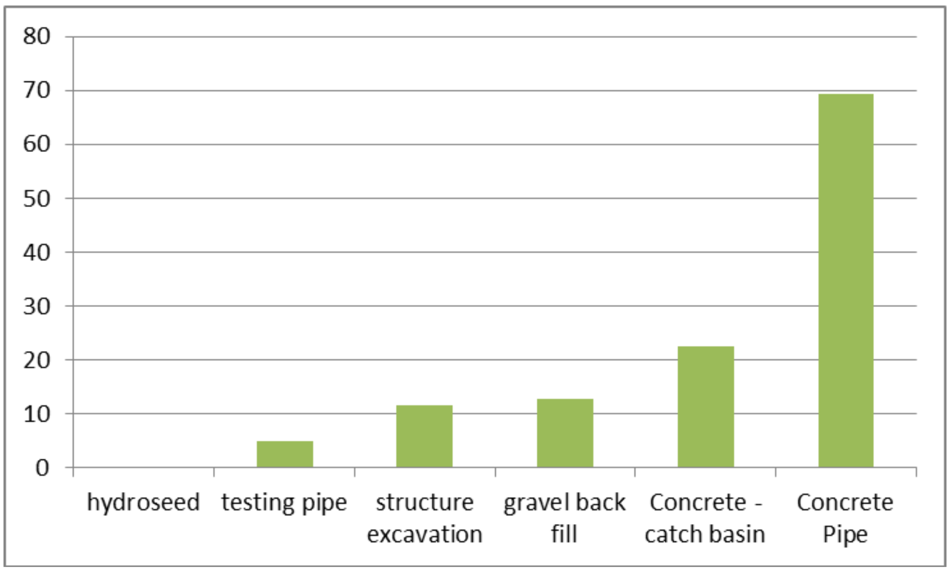

Figure 5.12: Storm Drain and Infiltration Pond CO_2e (mt)

Section 6: Recommendations

Based on the observations described in Section 5: Results, specific areas where LID could easily be integrated into the current processes where identified and include:

- Providing a clear, working definition of LID.
- Developing simple metrics to assist designers in selecting the most appropriate LID approach for a given project and empower designers to justify their selection.
- Integrating LID approaches into BMP selection processes.
- Highlighting maintenance considerations in the BMP selection, design, and constructability process in support of sustainable highway programs.
- Aligning the BMP design criteria with highway design criteria.
- Considering benefit of LID approaches to help DOTs reduce CO2e in support of climate change.

6.1: Provide a Working Definition of LID

During the review of the Idaho, Oregon, and Washington manuals, it was observed that ITD stormwater guidance does not mention LID, and while IDEQ, ODOT, and WSDOT all provided a definition or description of LID approaches, the definitions were not consistent and none defined all of the processes that represent LID approaches. A review of stormwater guidances from other local and national agencies showed that this pattern of inconsistency was not specific to Pacific Northwest DOTs. Some local jurisdictions did not mention LID as an approach to stormwater management. Most local jurisdictions provided a definition of LID, but it was generally not consistent with other agencies. Considering the history of BMPs and LID, it is not completely surprising to see this pattern since LID is a newer concept in stormwater management and is rapidly changing to keep up with regulatory requirements. Agencies like Washington Department of Ecology (Ecology) have acknowledged the need for a consistent LID definition and have responded by working with some NPDES municipal stormwater permittees via LID advisory committees to develop a consistent LID definition. The committees' overall charge was to advise Ecology on low impact development standards intended to assist permittees in implementing LID on a wider scale in response to more stringent policies that will require LID approaches to manage stormwater (Ecology 2009).

For DOTs, the need for a consistent definition that includes all applicable LID processes is important so that design criteria can be set so that BMPs can be more readily chosen that meet not only the site requirements, but also incorporate LID to the maxium extent feasible. In order to develop this working definition of LID, stormwater practices were evaluated throughout the Pacific Northwest and the nation. In the end, a combination of definitions from the WSDOT HRM, LID Technical Committee, and the research design team were used to develop a proposed definition.

HRM defines LID as "*an evolving approach to land development and stormwater management that uses a site's natural features and specially designed BMPs to manage stormwater; it involves assessing and understanding the site, protecting native vegetation and soils, and minimizing and managing stormwater at the source. LID practices are appropriate for a variety of development types*" (WSDOT 2008).

While this definition does represent many LID approaches, the definition could be enhanced by incorporating a description of the natural hydrologic cycle benefits as described in the Puget Sound LID Technical Committee definition which states, [LID] "…*strives to mimic pre-disturbance hydrologic processes of infiltration, filtration, storage, evaporation and transpiration*…" (Ecology 2009).

Finally, the research team evaluated the definition compared to the approach and recommended the following additions; since LID is not just a permanent stormwater practice, it can also be used in temporary settings'…*for construction staging and limits of disturbance, and sediment control...*'

The final definition used for this research and recommended for DOT's adoption is as follows:

> *An evolving approach to land development and stormwater management that uses a site's natural features and specially designed BMPs to manage stormwater; it involves assessing and understanding the site, construction staging, limits of disturbance, and sediment control, protecting native vegetation and soils, and minimizing and managing stormwater at the source. <u>LID strives to mimic pre-disturbance hydrologic processes of infiltration, filtration, storage, evaporation and transpiration</u>. LID practices are appropriate for a variety of development types.*

6.2: Metrics for Assessing LID Performance in a Highway Setting

To enable designers to understand and apply LID in a transportation setting, a simple set of metrics was developed that could readily be used within a DOT BMP selection process. This process assumes that the stormwater management requirements are first ***fully met and followed*** as defined by local jurisdiction, and then the LID decision metrics are applied in the BMP selection process.

The methodology and metrics which are being proposed as a basis for future consideration by DOTs as detailed in the Results Section 5.4 focus on an LID approach which attempts to mimic the pre-developed hydrologic conditions by taking advantage of the natural hydrologic cycle including: vegetation, interception, evaporation, transpiration, and infiltration. In a highway setting a possible way to maximize the natural hydrologic cycle is to use the maximum amount of ROW available to disperse flows and manage runoff as close to where it originates as possible. This concept is referred to as Full Site Hydrology (FSH) for the purpose of the metrics and research is referenced that demonstrates the benefits of FSH. Research and the goal of keeping the metric simples is also used to explain why the FSH approach was selected over other more complicated models that are being developed or are currently used for LID approaches.

Given the concept of FSH and the proposed LID definition in Section 6.1, a hierarchy of stormwater practices for highway settings was defined. The first choices are called preferred LID BMPs which are BMPs that use as much FSH as possible within the allowable ROW. Some examples of a listing of preferred LID BMPs are given in Section 5.4, but each DOT would need to evaluate which BMPs would be in this preferred list depending on the state or local regulatory requirements, regional conditions, climate, etc. The intention of having preferred LID BMPs are to have a short list of options which can be chosen from that the regulators and agencies have agreed upon to be considered as practices that adhere most fully to the principles of LID. When preferred LID BMPs, either singly, or paired with other preferred LID BMP choices, fulfill the flow and pollution control requirements by accepted hydrologic design, and are considered feasible based on other considerations such as maintenance, economic or archeologic constraints, then they may be used for the project without further analysis with the LID FSH metrics.

If a set of preferred LID BMPs cannot be implemented to meet the full stormwater requirements, the next recommended step in the decision process is to pair a preferred BMP with an alternative BMP. An alternative BMP is any BMP that is not on the preferred list. The final option is to solely use alternative BMPs. In either of these alternate scenarios, the LID FSH metrics would be used to rank the choices amongst those which meet the full stormwater requirements and other feasibility constraints. The preferred options would deal with the stormwaters close to the source and over a large area so that these waters are distributed for both infiltration and evaporation processes, particularly in conjunction with vegetation. Finally, options that also retain or restore tree canopy would also rank higher due to increased interception and evapotranspiration.To further enable designers to understand and apply LID practices to stormwater management in a highway setting, this simple metric system has been developed that is being considered for further refinement and possible use in combination with current DOT BMP selection processes. The intention of the metrics are so that designers might be able to determine what an appropriate LID BMP option is for any project site and justify their BMP selection. The metric first considered how much ROW is available compared to how much area in the ROW is used for BMP dispersion. The goal is to select the BMP with the highest score because as much of the FSH in the ROW will be utilized to disperse both infiltration and evaporation. The second metric emphasizes the benefits of the tree canopy to intercept stormwater by placing a priority on sites that can preserve or replace the existing tree.

In the future it is expected that there will be additional factors that could be added to the metrics to further refine their applicability. In addition, it is again emphasized that the metrics be used in combination with construction feasibility, and other environmental, maintenance and life cycle considerations of the BMP. It is recommended that WSDOT and other DOTs consider these metrics, modify them to meet specific needs, analyze if they might readily fit into their stormwater design processes, and finally include an expert analysis and research to determine their efficacy.

6.3: Include LID Considerations in BMP Feasibility Evaluations

The WSDOT Highway Runoff Manual (HRM) contains a BMP feasibility evaluation called the Engineering and Economic Feasibility (EEF) checklist that breaks the feasibility evaluation into five specific areas that could prevent locating a BMP within or adjacent to the available ROW including; infrastructure limitations, geographic/geological limitations, environmental/health limitations, hydraulic limitations, and cost limitations. To illustrate how LID approaches could be integrated into feasibility evaluations, a BMP decision flowchart that represents the current EEF checklist has been developed, aligned with the proposed LID metrics. The flowchart was first developed to be consistent with the EEF checklist and then areas for incorporating LID approaches were 'redlined' into the process. In addition, maintenance is a very important consideration for LID BMPs, and while maintenance is a consideration in most DOTs' stormwater guidance, presenting it as part of the feasibility evaluation will highlight the priority of this consideration to the designer during the BMP selection and design process. A draft LID BMP decision flowchart and proposed maintenance decision loop addition that might be included in the BMP decision making process are provided in Section 5.4 and Appendix B.

6.4: Other Barriers and Benefits to LID

Maintenance Considerations

Based on a review of current BMP maintenance requirements, along with results of the interview with WSDOT maintenance, the following is recommended:

- BMP maintenance requirements should align with other highway maintenance requirements/practices as much as possible.
- Written Maintenance plans for newly constructed BMPs should be developed.
- Maintenance practices should be considered in the design and feasibility analysis of BMPs (see proposed Maintenance Feasibility in Appendix B.

Aligning LID BMP Practices with Highway Design Practices

As noted in the VFS example in Section 5.5, it may be important to perform additional research into the assumptions and calculations used in the designs of BMPs so that they might more effectively align with highway design practices and more efficiently use DOT resources such as available ROW. This is particularly important with respect to maximum slope requirements.

Climate Change Adaption and LID Benefits

Considering the LID approach and the increasing demand to reduce CO2e, it is recommended that primary LID BMPs be chosen which may also offer opportunities to reduce the carbon footprint during highway construction projects. LID approaches strive to mimic natural processes and reduce the overall impact of stormwater on a site. In a highway setting dispersion is typically a preferred LID BMP and essentially uses a vegetated area to allow runoff to sheet flow and disperse (infiltrate and evaporate). There are several ways that LID approaches, such as natural dispersion, could help DOTs reduce CO_2e and develop more sustainable transportation systems such as:

- Maximizing the use of vegetation within the ROW which might increase carbon sequestration.
- Ensuring BMPs will function for their designed life by verifying the feasibility of proper maintenance.
- Reducing CO_2e by using approaches such as natural dispersion compared to a more traditional end of pipe BMP approach such as storm drains discharging into a pond as this decreases construction activities and the use of external materials.

Section 7: Conclusions and Goals for Future Research

The primary objective of this research was to determine how LID approaches and technologies could be integrated into stormwater practices for the Pacific Northwest DOTs Based on evaluations of the DOT's'stormwater practices it was determined that there are many ways to maximize LID within the current practice. Recommendations for using LID to the maximum extent feasible are summarized below:

- The development of a working definition of LID that may be used by the DOTs to further understand the goals of LID. (An example definition has been provided in Section 6.1.)
- The development of simple metrics for assessing the LID performance in a highway setting. (Suggested metrics have been provided and evaluated with case studies in Section 5.4.)
- Defining a hierarchy of BMPs and combination of BMPs that help assist a designer in choosing the most appropriate LID for a given project. (A suggested hierarchy has been provided in Section 5.4.)
- Identification of areas in the BMP feasibility and selection process for more fully evaluating LID considerations. (A prototype modified LID BMP decision flowchart has been provided in Appendix B.)
- An emphasis on maintenance considerations especially during the design feasibility evaluation. (An additional prototype loop for maintenance considerations in a LID BMP decision flowchart process has been provided in Appendix B.)
- Recommendations that BMP design align with highway design. (A common DOT BMP, Vegetative Filter Strips (VFS), was used as an example to demonstrate this, and the importance of considering how steep slopes in the ROW impact both LID and highway design was also emphasized .)

It is recommended that the ideas for implementing LID in this paper be used as a foundation to help DOT agencies implement LID to the maximum extent feasible within their own stormwater process. This would include additional expert analyses of the proposed methodology for decision making and the associated full site hydrology (FSH) metrics for refinement, further case studies for feasibility of implementing the methods to meet agency goals, and finally research into whether this methodology will result in designs and practices that incorporate LID more fully into highway designs.

During this research, other ideas for implementing LID were also considered, but extended beyond the original research scope, and as previously noted, many additional barriers and benefits to LID implementation were briefly mentioned. These have been compiled into the following list of suggestions for future research that could further enhance LID and improve overall stormwater management.

- Test BMP performance in a highway setting to not only meet the requirements of the NPDES municipal stormwater permit, but also to integrate with DOT highway design standards, such as:
  a) Consideration of various methods of insitu soil testing that is not only representative of the surface infiltration rates, but also feasible to use in support of BMPs such as VFS and dispersion.
  b) Further evaluation of pervious pavements for use as level spreaders to enhance runoff treatment of VFS and other sheet flow BMPs.
  c) Identification of the necessary widths of VFS to meet TSS removal goals and also VFS contributions to infiltration and evaporation.
  d) Development of a model that can more accurately estimate the benefits of LID compared to the single event model, rational method, or continuous simulation model.
  e) Further consideration of maintenance budget restrictions and how effective BMPs might be under various maintenance scenarios.
  f) Research into the alignment of design slopes in the highway ROW with LID BMP design and the efficacy of various sloped areas in combination with soil and climate conditions to effectively also provide space for preferred and alternative BMPs

Resolving issues related to incorporating LID into sites with steep slopes were considered to be important next steps to more fully implementing LID practices into highway settings as determined by the research advisory team and is the focus of a current parallel research effort. It is recommended that continuation of the steep slope research be a priority, as many of the LID options require use of extensive sloped areas of the ROW.

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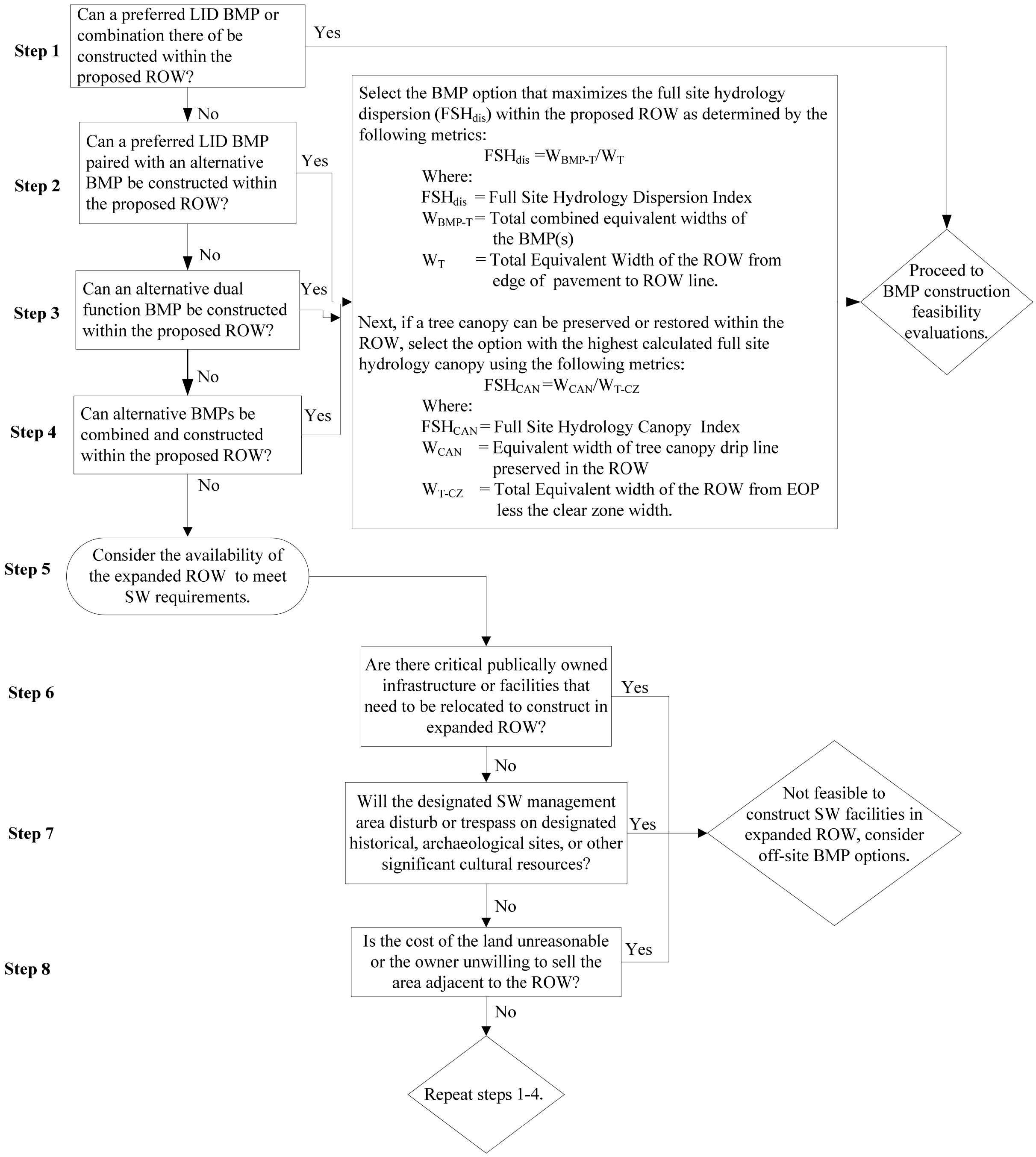
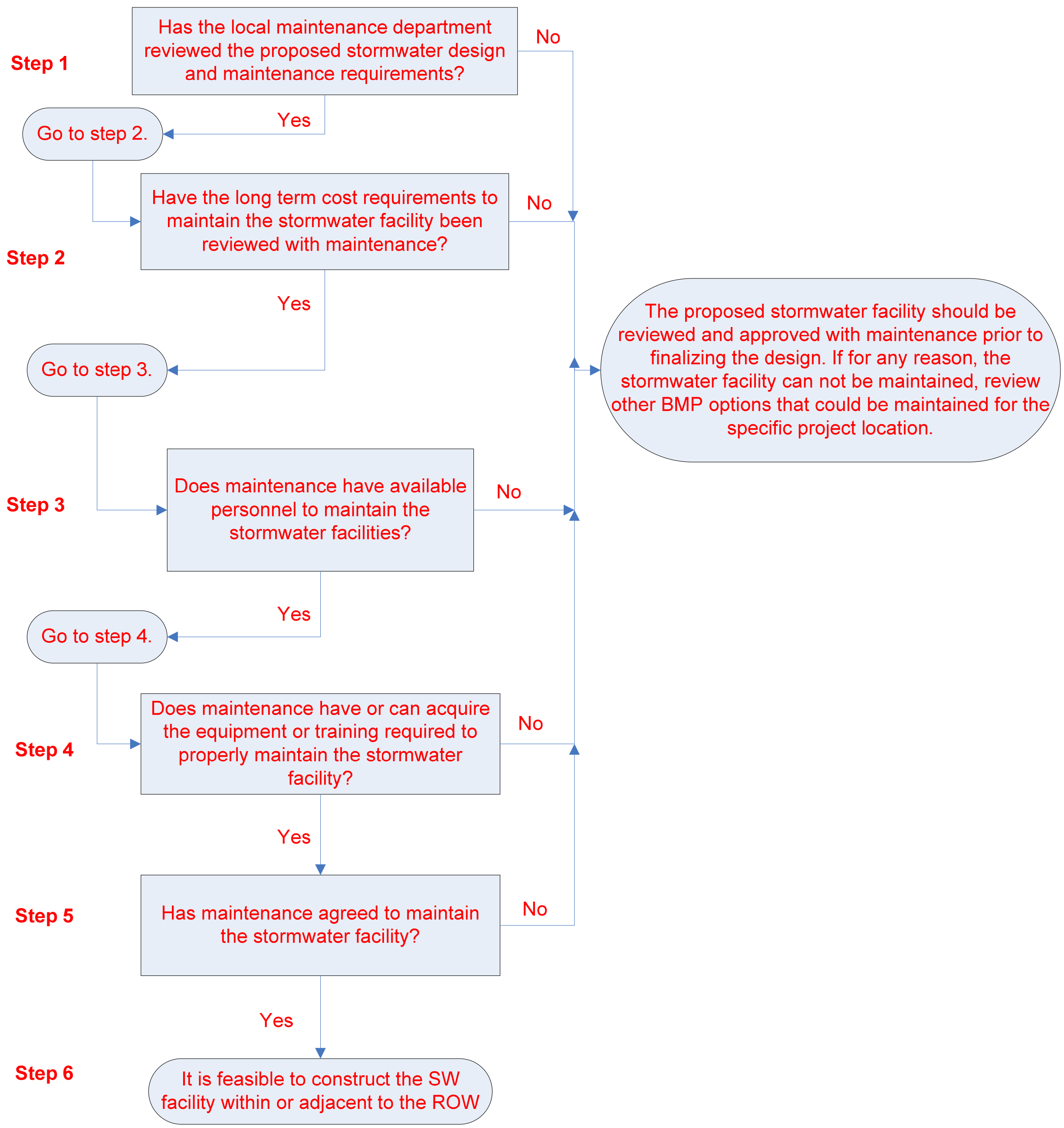
ER Eastern Region
SWR Southwest Region
NWR Northwest Region

Appendix B: LID Modified Decision Flow Chart (BMP Feasibility Evaluation)



Proposed - EEF 2A-2.2 Infrastructure Limitations to Construction Feasibility

[Additional BMP construction feasibility evaluations are then furthered considered in the WSDOT Highway Runoff Manual such as archaeological sites, impacts to wetlands, etc. (WSDOT 2008)]



NEW - EEF 2A-2.7 Maintenance Limitations to Construction Feasibility

Appendix C: Comparison of Stormwater Practices at Northwest DOTs

State	WSDOT	ODOT	ITD
Manual Title	Highway Runoff Manual (HRM)	ODOT Hydraulics Manual Appendix 14 - Water Quality	Best Management Practices Erosion and Sediment Control *(For permanent BMPs IDEQ Storm Water Best Management Practices Catalog)*
Date of publication/ most recent revision	2008	2009	• 2008 another manual due out in April 2010 that focuses on construction stormwater responsibilities • 2005 – IDEQ Manual was published
NPDES municipal stormwater permit issued/ reissued	WSDOT issued their own permit in 2009	General permit~ 10 years ago	• 2008 – general permit • Focuses on construction discharges and stormwater pollution prevention plan. • The web site indicated runoff treatment is also required for: a section 401 or 404 Certification or for stream alterations.
Contact for Manual	Mark Maurer	William Fletcher	Brad Wolfinger
Phone	(360)705-7260	(503) 986-3509	(208) 334-8163
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Web Links	http://www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm	http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/storm_management_program.shtml	http://itd.idaho.gov/manuals/Online_Manuals/BMP/
General Format Description for Stormwater Guidance	One manual with references to the Hydraulics Manual. Contains guidelines for what triggers stormwater, hydrologic guidance, BMP selection, and design, BMP maintenance, and temporary erosion and sediment control.	Actual BMP design guidance is located in Appendix 14 of the Hydraulics Manual. Guidance for what triggers stormwater management, flow control, and design storms is located on the web site.	• BMP manual - ESC mostly construction • ITD does not specify triggers for stormwater or specify min. requirements • IDEQ manual (for developments) used for permanent RT & FC BMPs
Triggers for SW Management	Chapter 3 (HRM) lists the 9 Minimum Requirements and Figure(s) 3.1, 3.2, 3.3 illustrate the applicability. Triggers for these requirements are site specific and based on: amount of impervious surface added, roadway specifics such as ADT, exemptions, runoff treatment and flow control requirements, etc.	Web page lists triggers: • a change in impervious surface area • a change in basin area contributing runoff managed by the project • change in stormwater drainage • replacement or enlargement of stream crossing structures • reconstruction of roadway & projects with 404 permits	• Only construction triggers are listed in the BMP manual. • The web site indicated runoff treatment is also required when: a section 401 or 404 Certification is required, or for stream alterations. • IDEQ Manual implies that local requirements and permits dictate requirements.

BMP selection strategy	• Step 1: Avoid and minimize impacts on hydrology and water quality. • Step 2: Compensate for altered hydrology and water quality by mimicking natural processes. • Step 3: Compensate for altered hydrology and water quality by using end-of-pipe solutions.	ODOT follows NCHRP design strategies in LID Design Manual, which basically states: • encourage sheet flow • maintain natural drainage • preserve natural vegetation • direct runoff to vegetated areas • small scale stormwater features • treat pollutants close to source	• Construction ESC (ITD) • Local requirements/permits dictate the type of pollutant remove required. • IDEQ also has suggestions for developments and the following criteria: ✓ preserve existing or plant native vegetation in disturbed areas ✓ Preserve and maximize vegetation canopy, shrubs, & coniferous trees.
BMP selection and format	A flow chart in Chapter 5, lists BMPs for flow control and then runoff treatment and in order of preference based on strategy noted in above box.	BMP Selection Tool Matrix - lists BMPs, pollutants, and treatment mechanisms. • Infiltration Pond • Bioretention • Bioslope • Grass Swale (soil amended) • Filter Strip (soil amended)	• None found in ITD documents and in interviews with ITD employees, no one was aware of any. • IDEQ has a BMP Selection Matrix (Table 4.1). The table lists all BMPs, the target pollutants, and physical constraints for each BMP
Additional BMP comments	• No source control BMPs are provided in the HRM, instead designers should consult the Ecology manuals. • BMP options include flow control and runoff treatment (some are combination BMPs which are generally preferred)	Regulatory agencies have agreed that if one of the 5 preferred BMPs is used, the permit requirements are met. If not, a treatment train may be used to remove the highest pollutants (as identified by the Environmental Office) and approval by another regulatory agency may be required.	• None specified in ITD documents • For IDEQ the design should use BMP matrix along with the target pollutants specified and site constraints to select the BMP that best fits the project. • IDEQ recommends source control first, then treatment trains
Climate Zones	6 defined	9 defined	9 defined per - IDF curves For ADT <20,000 use 10 year MRI For ADT >20,000 use 25 year MRI
Hydrology Methods	• For WWA continuous simulation is used. • For EWA single event model.	Rational Method and SCS	• Rational Method for basins < 100 AC • TR-55 for basins > 100 AC
Runoff Treatment Design Event	Depends on location of project (EWA or WWA) and if volume or flow based: • WWA flow based 91% of average runoff, volume based 91% of 24 hr • EWA 6 month 3 hour for flow based and 6 month 24 hour volume based.	Treatment facilities must be designed to handle the volume and peak flow for 50% of the cumulative rainfall from the 2 year, 24 hour project site (with a few % differences based on climate zones)	• None specified in ITD documents • IDEQ recommends either 'first flush event' that is runoff from the first ½"-1" of a storm event be used to design the treatment BMP or a percentage removal of a pollutant (for example 80% TSS)
Runoff Treatment Exemptions	Smaller projects, some water bodies have dissolved metals treatment exemptions.	None specified	None specified

Flow Control Design Concept	Prevent increases in the stream channel erosion rates beyond those characteristics of natural or reestablished conditions. The intent is to prevent cumulative future impacts, where possible. Infiltration is preferred.	The primary criteria for flow control for channel protection is to maintain the duration and frequency of discharges from the project for flow resulting from the range of flow control design storms.	Follows 2004 EPA requirements to protect channel from (accelerated) erosion and habitat protection. Need to match pre-projectflows.
Lower Discharge Point	50% of 2 year	42-56% of 2 year 24 hour	Match 2 year (EPA 2004 requirement)
Upper Discharge Point	Match 25 year for EWA and 50 year for WWA. Check for impact of 100 year event.	minimally incised channel - channel bank over topping event, Incised streams - 10 year, 24 hour storm event	Match 10 year and detain the difference, check for impact with 100 year.
Flow Control Exemptions	Exemptions are detailed depending on site conditions and receiving water body characteristics.	1) Receiving water is a large river, reservoir, lake, or estuary. 2) Less than 0.5 cfs increase in discharge from the 10 year, 24 hour event.	None specified

EWA Eastern Washington Areas
WWA Western Washington Areas