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UNIFIED FACILITIES CRITERIA (UFC)

LOW IMPACT DEVELOPMENT

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UNIFIED FACILITIES CRITERIA (UFC)

LOW IMPACT DEVELOPMENT

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U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	1 Feb 2016	Updated Table B-4 to correct the description under "Soils" for "Bio-retention". Added “of underdrains.” to the end. The sentence should read in its entirety “ Soil limitations can be overcome with use of underdrains”.

This UFC supersedes UFC 3-210-10, dated 15 Novemeber 2010.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Refer to UFC 1-200-01, *General Building Requirements*, for implementation of new issuances on projects.

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-210-10, Low Impact Development

Superseding: This UFC supersedes UFC 3-210-10, dated 15 November 2010.

Description of changes: This revision clarifies applicability of Low Impact Development (LID) requirements to projects with various mixtures of facility types, clarifies project documentation requirements and designer responsibilities, and clarifies the relationship of Energy Independence and Security Act (EISA) requirements to Clean Water Act (CWA) requirements.

Reasons for changes: Several years of implementation experience identified the following issues:

- Ambiguity and inconsistency in applying LID requirements to projects with mixtures of building and pavement areas, particularly with regard to calculation of the applicable “footprint”.
- Unclear and/or infeasible documentation requirements.
- Unclear relationship between EISA requirements and CWA requirements, resulting in potential to inappropriately include LID design goals with CWA permits.

Impact: This change will improve:

- Objectivity and consistency in applying stormwater management requirements of EISA section 438 to DoD construction projects.
- Documentation of project LID goals and performance.
- Understanding of the relationship between EISA and CWA requirements to preclude inappropriate CWA permit stipulations.

Unification issues: None.

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND

Increased impervious area changes the natural flow of water and decreases the quantity of water that infiltrates into the ground. Increased runoff increases sediment transport and decreases water quality. Low impact Development (LID) seeks to restore pre-development infiltration rates at the project site through one or more LID Integrated Management Practices (IMPs).

In December 2007, Congress enacted the Energy Independence and Security Act (EISA) of 2007. This legislation established into law new stormwater design requirements for federal agencies to develop and redevelop applicable facilities in a manner that maintains or restores stormwater runoff to the Maximum Extent Technically Feasible (METF) with regard to the temperature, rate, volume, and duration of flow. In December of 2009, Environmental Protection Agency (EPA) issued EPA 841-B-09-001. EPA 841-B-09-001 provides technical guidance to assist federal agencies in implementing EISA Section 438 and was intended solely as guidance.

Deputy Under Secretary of Defense (Installations and Environment) memorandum of 19 January 2010 directs DoD components to implement EISA Section 438 using LID techniques in accordance with the methodology illustrated in Figure 2-1 and further described below. This policy directs DoD to implement EISA Section 438 EPA technical guidance in accordance with DoD Policy on Implementing EISA Section 438. Where DoD policy or the criteria provided in this UFC conflicts with EPA Technical Guidance, the DoD policy and UFC criteria govern. Individual Services may have more stringent implementation and applicability requirements relating to Low Impact Development.

1-2 PURPOSE AND SCOPE

This UFC provides technical criteria, technical requirements, and references for the planning and design of applicable DoD projects to comply with stormwater requirements under Section 438 of the Energy Independence and Security Act (EISA) enacted in December 2007 (hereafter referred to as EISA Section 438) and the Deputy Under Secretary of Defense DoD policy on implementation of stormwater requirements under EISA section 438.

1-3 DEFINITION OF LOW IMPACT DEVELOPMENT

LID is a stormwater management strategy designed to maintain site hydrology and mitigate the adverse impacts of stormwater runoff and nonpoint source pollution.

LID actively manages stormwater runoff by mimicking a project site's pre-development hydrology using design techniques that infiltrate, store, and evaporate runoff close to its source of origin. LID strategies provide decentralized hydrologic source control for stormwater runoff. In short, LID seeks to manage the rain, beginning at the point where

it falls. The LID features are distributed small scale controls that closely mimic hydrological behavior of the pre-project sites for a design storm event.

1-4 APPLICABILITY

The criteria and design standards in this UFC are required for the planning, design and construction of all Department of Defense (DoD) projects in the United States, United States Territories and Possessions of the United States that meet both of the following conditions:

1) The project includes construction or expansion of one or more buildings as part of its primary scope (i.e., primary facilities vice supporting facilities).

2) The "footprint" is greater than 5,000 gross square feet (464.5 square meters). "Footprint" consists of all new impervious surfaces associated with the building(s), including both building area and pavement area of associated supporting facilities (such as parking and sidewalks). "Footprint" does not include existing building area to be renovated, existing pavement area to be resurfaced, or new pavement area other than supporting facilities associated with the building(s).

For projects in the United States, United States Territories, and Possessions of the United States that do not meet the applicability requirements above, LID techniques apply to the extent practical.

1-5 GENERAL BUILDING REQUIREMENTS

UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, sustainability, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-6 REFERENCES

Appendix A contains the list of references used in this document.

CHAPTER 2 TECHNICAL REQUIREMENTS

2-1 DESIGN OBJECTIVE

2-1.1 Establishing Pre-Development Condition

The overall design objective for each applicable project is to maintain predevelopment hydrology and prevent any net increase in stormwater runoff. DoD defines "predevelopment hydrology" as the pre-project hydrologic conditions of temperature, rate, volume, and duration of stormwater flow from the project site. The analysis of the predevelopment hydrology must include site-specific factors (such as soil type, ground cover, and ground slope) and use modeling or other recognized tools to establish the design objective for the water volume to be managed from the project site. The Designer of Record (DOR) (hereafter referred to as the designer) must document the existing features that comprise the existing development condition.

Manage the increase in runoff between pre and post-development conditions on the project site, to the maximum extent technically feasible, through interception, infiltration, storage, or evapotranspiration processes. Other design requirements may need to be considered. Calculations must be performed by the designer indicating the difference between the post-development hydrology and pre-development hydrology for the design storm event. Calculations must demonstrate "No net increase" in stormwater runoff where technically feasible.

2-1.2 Design Storm Event

The design storm event is the 95th percentile rainfall depth and is based on the 24-hour (daily) rainfall depth averaged over a minimum of 10 years, ideally 30 years where 30 or more years of rainfall records are available. Appendix B contains a table of rainfall analysis for selected locations. Use the values in Appendix B or calculate the 95th percentile rainfall depth based on rainfall records. Rainfall records can be obtained from NOAA at http://cdo.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv=.

2-1.3 Maximum Extent Technically Feasible (METF)

Evaluate project site options to achieve the design objective to the maximum extent technically feasible. The "maximum extent technically feasible" criterion requires full employment of accepted and reasonable stormwater retention and reuse technologies subject to in-situ site conditions and applicable regulatory constraints (e.g., site size, soil types, vegetation, demand for recycled water, existing structural limitations and state or local prohibitions on water collection).

2-1.4 Technical Infeasibility

Cost alone should not be used as a constraint to justify technical infeasibility. Document all site-specific technical constraints that limit the full attainment of the design objective. If the design objective cannot be met within the project footprint, LID measures may be applied at nearby locations on DoD property (e.g., downstream from the project) within available resources. Document all applicable technical constraints if the design objective is infeasible due to technical constraints. In most cases, the designer should be able to document more than one technical constraint to demonstrate technical infeasibility. If the project meets the design objective, technical constraints do not need to be documented. Examples of technical constraints are as follows:

- Retaining stormwater on-site would adversely impact receiving water flows
- Site has shallow bedrock, contaminated soils, high groundwater table, underground facilities or utilities
- Soil infiltration capacity is limited
- Site is too small to infiltrate significant volume
- Non-potable water demand (i.e., irrigation, toilets, and wash-water) is too small to warrant water harvesting and reuse system
- Structural, plumbing, and other modifications to existing building to manage stormwater are infeasible
- State or local regulations restrict water harvesting
- State or local regulations restrict use of green infrastructure or LID.

2-2 POST-CONSTRUCTION ANALYSIS

The designer is required to conduct a post-construction site visit to assess the as-built LID features and validate if they have been constructed according to plans and specifications. If LID features were not constructed according to plans and specifications indicate the technical constraints that precluded meeting the design objective.

2-3 DOCUMENTATION

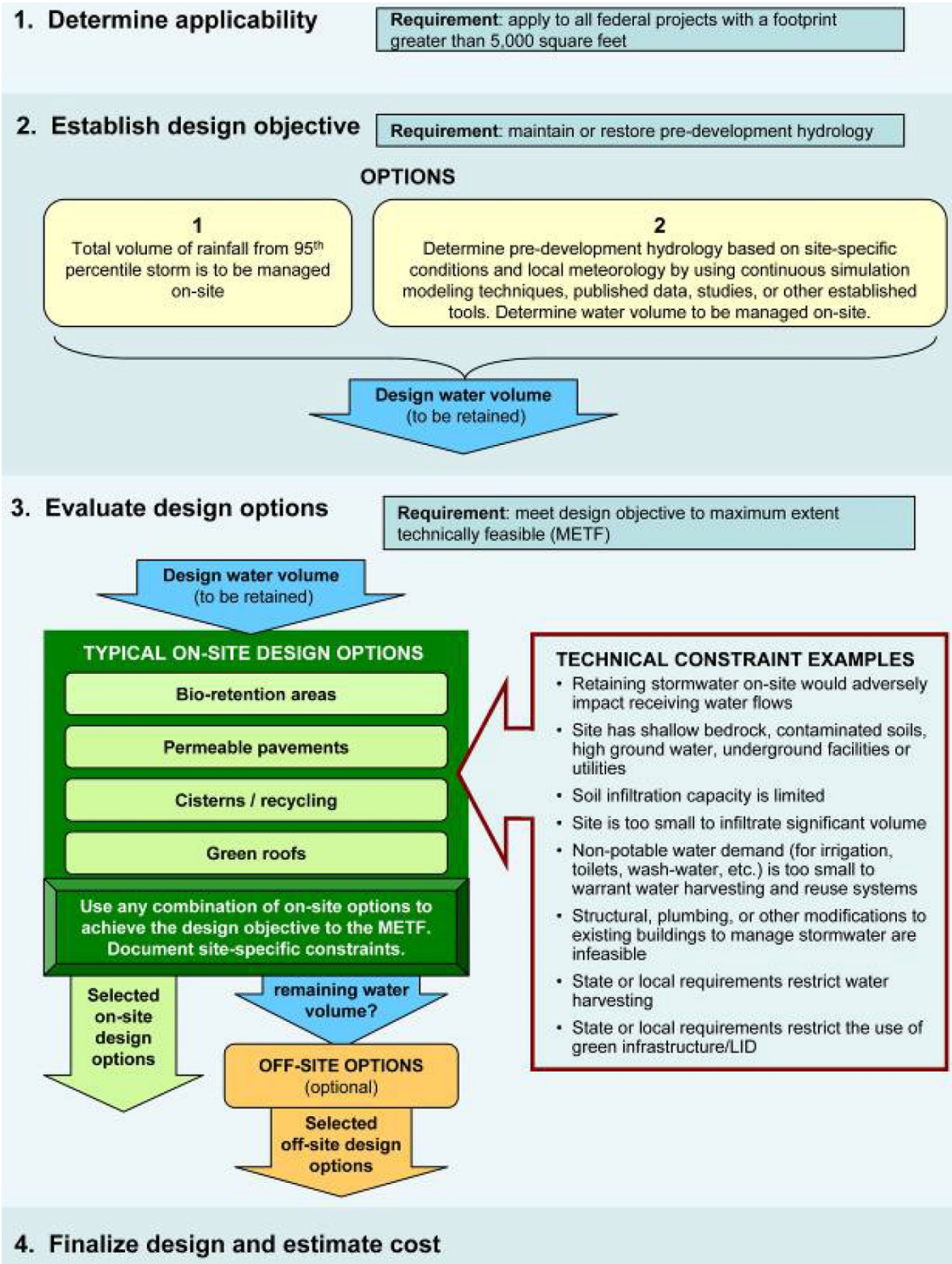
Provide the following documentation at the pre-final design stage:

- Pre-development condition (i.e., soil conditions, groundwater table of the project site, description of typical surrounding natural lands, and a brief history of existing development; including impervious area, lawns, meadows, forested area, wetlands, and water bodies)
- Calculations for pre-development and post-development runoff volumes and rates using the 95th percentile rainfall event to identify the volume of stormwater requiring management and the extent to which the design objective was met.
- Documentation of technical constraints, if applicable.
- Stormwater management practices used to meet the design objective and whether they were located on-site, off-site or both.
- Estimated construction cost to meet the design objective.

- Provide post-construction validation documentation indicating that the LID features have been constructed according to plans and specifications.

Update pre-final data at the final design stage, as applicable, and perform post construction analysis at the end of construction. Maintain this documentation as part of the project historical file.

Figure 2-1 Implementation of EISA Section 438



CHAPTER 3 PLANNING AND DESIGN

3-1 HYDROLOGIC ANALYSIS

DoD policy specifies that the designer is to determine pre-development hydrology based on site-specific conditions and local meteorology by using the 95th percentile storm. The designer must identify the pre-development condition of the site and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions. The post-construction rate, volume, duration and temperature of runoff must not exceed the pre-development rates. Replicate the pre-development hydrology through site design and other appropriate practices to the maximum extent technically feasible. Use infiltration, evapotranspiration, rainwater harvesting or other proven LID techniques. Defensible and consistent hydrological assessment tools should be used and documented.

When performing hydrologic analysis, the designer is required to have an understanding of the hydrologic methodology, the limitations of the methodology being used and a thorough understanding of the site specific hydrologic conditions. The results of the hydrologic analysis are only as good as the assumptions and site specific data used by the designer. Inappropriate assumptions or site data can affect the reliability of the results. The designer must be able to validate the design assumptions, site data and results to demonstrate that the design objective has been met.

3-1.1 Approved Methodologies

To control the stormwater volume in accordance with DoD policy, the use of TR-55, Chapter 2: “Estimating Runoff”, Curve Number Methodology is approved and recommended. Continuous simulation modeling may be used to complete the hydrologic analysis. Other approved methodologies are WinTR-20 and the Storm Water Management Model (SWMM) computer program developed by EPA. Computer programs that use the approved methodology are also approved.

3-1.2 Other Methodologies

Other methodologies may be submitted to the Government’s Civil Engineer for approval. Models developed for watershed nonpoint source analysis like EPA’s Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) should not be used for this type of hydrologic analysis.

3-2 TR-55 METHODOLOGY

TR-55 methodology is likely the most efficient and practical for designers to comply with EISA Section 438 requirements. Therefore, details of this methodology have been summarized in the following paragraphs.

3-2.1 Storm Event

During a storm event a portion of the precipitation is caught in the form of interception, depression storage, evaporation, transpiration, and infiltration. These losses are collectively referred to as *abstractions*. Only that part of the rainfall in excess of abstractions is defined as stormwater runoff.

The Soil Conservation Service (SCS 1986), now the Natural Resources Conservation Service (NRCS), presented an empirical method of determining initial abstraction based on the runoff curve number (CN) of the site and is given by:

EQUATION 1: Initial abstraction (inches), $I_a = 0.2 * S$

Where S = potential maximum retention after runoff begins (inches)

$$S = \frac{1000}{CN} - 10$$

The initial abstraction defined in Eq. 1 also represents the rainfall at which the direct runoff begins. Any rainfall over and above the initial abstraction results in direct surface runoff.

3-2.2 Total Depth

Calculate the runoff depth for both the pre and post-development conditions, and the difference will be the depth from which the volume to be retained on-site can be determined (for TR-55 methodology see equation 2 below).

EQUATION 2: Total depth of increase in runoff (inches),

$$D = \frac{(P - 0.2 * S')^2}{(P + 0.8 * S')} - \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)}$$

Where, P = design storm rainfall depth (inches)

S & S' = potential maximum retention after runoff begins (inches) during the pre- and post-development conditions, respectively

Note: Eq. 2 is valid if P > 0.2*S. Otherwise, the term calculating the runoff depth is:

$$\frac{(P - 0.2 * S)^2}{(P + 0.8 * S)} = 0$$

D= the depth of rainfall that becomes runoff

3-2.3 Design Storage

EQUATION 3: The design storage is:

$$V_{LID} = D * A$$

D = total depth of increase in stormwater runoff (inches)

A = drainage area or the area of the parcel being developed (square units)

Equation 3 indicates the volume of water to be managed to comply with the design objective.

Additional details on hydrologic analysis are located in Appendix B Best Practices, paragraph titled LID Design.

3-3 DESIGN OPTIONS FOR LID FEATURES

LID implementation is achieved by selecting a set of LID features that can closely maintain or replicate hydrological behavior of the pre-project site for the design storm event. Most LID features are distributed small-scale controls that increase rainfall interception and slow the time of concentration (T_c). Some LID features provide greater benefits (i.e. groundwater recharge, reduced T_c) than others. Give priority to those LID features that are proven in their regional area, provide the most benefits in relation to replicating pre-project hydrology and have the lowest lifecycle costs. LID features typically include natural features with low maintenance costs. Selecting appropriate LID features with the lowest Long-Term maintenance cost will extend the useful life of the LID features. Highly developed sites, sites with a high ratio of impervious to pervious area and (i.e., industrial sites) may require more costly, higher maintenance LID features in order to meet the design objective within the constraint of maximum extent technically feasible (see paragraph titled Maximum Extent Technically Feasible (METF) in Chapter 2). Provide a minimum 10 ft (3.05 m) offset from the LID feature to the face of the building.

Verify with the Installation the capability to maintain LID features prior to selecting for use on-site. LID features that cannot be maintained by the Installation with current capability and contract capacity may not be used.

LID features can generally be categorized into the following categories:

3-3.1 Engineered Natural Treatment

Engineered natural treatment provides depression storage, infiltration, and evapotranspiration. These design options are typically the least costly and easiest to accomplish if site availability, soils and groundwater table are conducive. Site features such as bioretention, vegetated swales, rain gardens, vegetated filter strips, downspout disconnection, reduced impervious area, tree preservation or re-vegetation using native

plants, soil amendments, and open space fall under this general category and are advisable due to lower lifecycle costs.

3-3.2 Engineered Subsurface Treatment

Engineered subsurface treatment provides infiltration and prevents concentrated flow. Site features may include permeable pavements and infiltration trenches. Engineered subsurface treatment may be the next most lifecycle cost effective method, as compared to engineered natural treatment, in meeting the design objective. These design options may be limited by wheel loading, traffic, ability to provide maintenance and foreign object debris (FOD) danger. Avoid locating infiltration trenches and similar features under pavements wherever possible. Refer to UFC 3-201-01 for additional criteria on permeable pavement.

3-3.3 Non-Potable Rainwater Harvesting

Rainwater harvesting systems store stormwater for non-potable uses, such as irrigation or toilet flushing. Site features may include LID features like cisterns and rain barrels. This design option may be used if adequate demands for reuse water exist. Certain types of facilities, such as a warehouse, may not have adequate water demand to make reuse lifecycle cost effective. Consider freeze protection for winter months.

3-3.4 Green (Vegetative) Roofs

Vegetative roofs decrease the T_c and increase seasonal evapotranspiration. They do not assist in infiltrating water into the ground at the source and have high initial and maintenance cost. Because of the high cost and limited technical advantages, vegetative roofs are the least preferred design option. Vegetative roofs are a design option where other design options do not meet the design objective. Vegetative roofs should be assessed with consideration of other benefits such as lower energy costs and noise reduction.

3-4 TIME OF CONCENTRATION FOR PRE- AND POST-DEVELOPMENT CONDITIONS

In order to mimic pre-project hydrologic patterns the site designer needs to provide features that limit the rate at which runoff leaves the site. To the maximum extent technically feasible, the post-development T_c must be equal to or greater than the pre-development T_c.

Maintaining T_c close to pre-development conditions is critical because the peak runoff rate, and thereby the volume of runoff from individual lots, is inversely proportional to T_c. Maintain T_c to the maximum extent technically feasible, by strategies such as reduction of impervious areas, maintaining natural vegetation, siting of impervious areas in poor draining soils, and disconnecting impervious areas.

3-4.1 Stormwater Flow Segments

TR-55 Curve Number Methodology is well documented and is used widely in engineering practice to determine the T_c. The method presumes that runoff from rainfall moves through a watershed as sheet flow, shallow concentrated flow, pipe flow, channel flow, or some combination of these. T_c is the sum of travel flow times calculated separately for the consecutive flow segments along the longest flow path. These three flow segments along with their implications on T_c are detailed in the TR-55 manual. The use of TR-55 is recommended for calculating T_c. Other methodologies in accordance with applicable State or local stormwater regulations and based on site specific conditions may also be used.

3-5 OFF-SITE OPTIONS

If the design objectives cannot be met within the project footprint, LID measures may be applied at nearby locations on DoD property (e.g., downstream from the project) to manage the remaining design water volume within available resources. Off-site options are generally less desirable than on-site options, as many of the benefits of managing the stormwater close to the source may be lost.

3-6 CLEAN WATER ACT PERMITS

Comply with applicable State and local requirements for stormwater management in addition to UFC requirements. Obtain State stormwater construction permits required under the Clean Water Act using the states approved methodology. Coordination of the design is the responsibility of the designer to insure that the criteria are met from both the regulatory and LID perspectives. Design the stormwater management (SWM) features to control all regulated storm events, as stipulated by State and Local regulations to handle the peak rate and volume of discharge for flood control purposes.

EISA Section 438 requirements are independent of stormwater requirements under the Clean Water Act and should not be included in permits for stormwater unless a state (or EPA) has promulgated regulations for certain EISA Section 438 requirements (i.e., temperature or heat criteria) that are applicable to all regulated entities under its Clean Water Act authority.

Compliance with applicable regulatory stormwater management requirements may satisfy all or part of the EISA Section 438 requirement for the project.

3-7 OTHER DESIGN REQUIREMENTS

Where State and Local standards for design of LID features to satisfy EISA Section 438 requirements do not exist, refer to *Low-Impact Development Design Strategies, An Integrated Design Approach and Low-Impact Development Hydrologic Analysis* prepared by Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division (PGDER). Follow applicable industry practice standards and local building codes (e.g., earthquake zones).

3-7.1 Sustainable Design

Incorporate sustainable development concepts to reduce energy consumption, O&M costs, reduce waste, and reduce pollution. Refer to UFC 1-200-02, for additional criteria.

3-7.2 Architectural Compatibility

Comply with DoD, and Activity requirements and provide LID features compatible with surrounding base architecture.

3-7.3 Base Design and Development Documents

Incorporate the intent of Installation Master Planning into designs. Follow published design guidelines that contain criteria relative to achieving, maintaining, and emphasizing a positive exterior visual environment applicable to military installations. Consult with the Government's Project Manager for direction in case of conflicts. Direction to deviate from these documents should be given in writing.

3-7.4 Anti-Terrorism (AT)

Comply with UFC 4-010-01 and UFC 4-010-02 when designing LID features. When conflicts arise between this document and UFC 4-010-01 or 4-010-02, UFCs 4-010-01 and UFC 4-010-02 govern.

3-7.5 Airfield Criteria

Where the criteria provided in this UFC conflicts with UFC 3-260-01, UFC 3-260-01 criteria governs.

APPENDIX A REFERENCES

DEPARTMENT OF DEFENSE

DODI 4165.14 Real Property Inventory and Forecasting

ENVIRONMENTAL PROTECTION AGENCY

http://www.wbdg.org/ccb/EPA/epa_841b09001.pdf

EPA 841-B-09-001, Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act, December 2009.

http://www2.epa.gov/water-research/storm-water-management-model-swmm?

SWMM, Storm Water Management Model, July 2010

http://water.epa.gov/polwaste/green/#guide

Low-Impact Development Design Strategies, An Integrated Design Approach

Low-Impact Development Hydrologic Analysis

NATURAL RESOURCES CONSERVATION SERVICE

http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

TR-55, Urban Hydrology for Small Watersheds June 1986

WinTR-20, Watershed Hydrology, March 2015

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 1-200-01, General Building Requirements

UFC 1-200-02, High Performance and Sustainable Building Requirements

UFC 3-201-01, Civil Engineering

UFC 3-260-01, Airfield and Heliport Planning and Design

UFC 4-010-01, DoD Minimum Antiterrorism Standards for Buildings

UFC 4-010-02, DoD Minimum Antiterrorism Standoff Distances for Buildings

APPENDIX B BEST PRACTICES

This Best Practices appendix provides additional detail and analysis supporting the criteria and builds process action steps in the Planning, Design, and post-construction stages of project development. In addition, the appendix gives a basic level of understanding for the rationale behind the UFC criteria hydrology and methods of calculation.

The UFC criteria are predicated on standard practices in the field of stormwater management. The design storm event is typically defined by the 95th percentile storm (see also section 3-4 of this UFC). By averaging all storm events that occur within 24 hours for several years, the designer can statistically predict the intensity of a storm that is equal to or less than 95 percent of all storms. The method of calculation for this is taken to be the Natural Resource Conservation Service (NRCS), formerly the Soil Conservation Service (SCS) TR-55 method. A site designer can easily hand calculate the necessary information for small sites using formulas given in the criteria. For larger sites, computer calculations and simulation modeling are encouraged.

By design, LID methods do not control runoff in excess of the pre-development condition, but are intended to bypass larger storm volumes to flood control measures as defined by the conventional stormwater management techniques. LID is in addition to the requirements of the stormwater permits required. There are other regulatory requirements that also affect the design of stormwater management, quality, and control that are specific to local regions and areas not covered in this document.

B-1 BACKGROUND

The use of LID was pioneered in the 1990s by Prince George's County, Maryland Department of Environmental Resources (PGDER) under a grant from the Environmental Protection Agency (EPA). Since 2004, LID techniques for controlling stormwater runoff have been considered for many projects based on site requirements and constraints. LID strategies provide a decentralized hydrologic source control for stormwater. LID implementation is based on selecting LID features that are distributed small scale controls that can closely maintain or replicate hydrological behavior of the pre-project site for a defined design storm event. These small scale practices are sometimes referred to as integrated management practices (IPMs)

LID differs from conventional SWM principles in that it does not store and release stormwater. LID uses filtration, infiltration, evaporation, plant transpiration, and reuse of rainwater to keep the additional stormwater generated due to the developed condition contained on-site.

The application of LID to infrastructure development program is practical and achievable, but it will require a change of thinking on the part of the site designer. The LID features fall into five categories, as follows:

1) Site Utilization: Begin the site process by reducing the impervious footprint if possible. Narrower streets, vertical construction, parking structures, and the removal of curb, gutter, and paved swales are a few of the ways to reduce impervious surfaces. It is crucial to mimic the pre-development hydrologic conditions in order for LID to be effective. Choose rougher surfaces, disconnect impervious areas, and increase the time of concentration (T_c). Retain as much of the natural tree cover as practical, and place the impervious structures in areas of the poorest soil types where possible.
2) Filtration: Include filtration practices in the site design. Vegetative buffers, filter strips, vegetative swales, check dams, sediment traps, and overland flow will provide natural water quality treatment and increase T_c.
3) Interception and Infiltration: The infiltration techniques of LID are the backbone of the runoff volume reduction. Depression storage, bio-infiltration, pervious pavements, open pavers, rain gardens, infiltration trenches, and tree boxes are gaining wide acceptance as tools in the SWM toolbox. Interception can also play a major role in reducing runoff volumes. Interception techniques include deep mulch beds, tree cover, and soil amendments.
4) Retention of Stormwater Volumes: Retention can play an important part in successful LID implementation. Retention seeks to hold runoff from localized impervious surfaces for subsequent treatment after the rainfall event. Rain barrels, cisterns, and parking lot storage that slowly infiltrates into the ground are examples of retention techniques.
5) Structural Solutions: Structural solutions represent the last line of defense in LID features. Structural solutions will increase the facility construction cost and must be balanced with mission requirements. In urban and industrial areas, sensitive environments, or known contaminated sites, structural solutions are often the only solution. These techniques are engineered solutions for the particular facility and can include green roofs, rainwater reuse systems, parking structures, and irrigation storage systems.

The site designer is encouraged to contact the Government's Civil and Environmental Engineer, as well as State and local regulatory officials to coordinate LID requirements with applicable stormwater programs. Table B-1 has useful links on stormwater topics which includes a link to NPDES state program statuses as granted by EPA.

Additional information may be found on the following link to the WBDG LID Resource Page: http://www.wbdg.org/resources/lidtech.php

Table B-1 U.S. EPA Websites related to Stormwater

U.S. Environmental Protection Agency

Low Impact Development (LID) is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treats stormwater as a resource rather than a waste product. Many practices have been used to adhere to these principles such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. Applied on a broad scale, LID can maintain or restore a watershed's hydrologic and ecological functions. LID has been characterized as a sustainable stormwater practice by the Water Environment Research Foundation and others.

Low Impact Development (LID)
http://www.epa.gov/nps/lid/

Stormwater Program
http://cfpub.epa.gov/npdes/home.cfm?program_id=6

Authorization Status for EPA's Stormwater Construction and Industrial Programs
http://cfpub.epa.gov/npdes/stormwater/authorizationstatus.cfm

State Program Status
http://cfpub.epa.gov/npdes/statestats.cfm?view=specific

Managing Wet Weather with Green Infrastructure
http://cfpub.epa.gov/npdes/home.cfm?program_id=298

B-2 PLANNING

B-2.1 The Planning Component

Successful implementation of LID begins during the planning process, which is one of the first steps. During the planning phase, the exact configuration of LID features and the ways in which LID will shape the site design is not expected to be determined. This section provides the organizational tools and steps to build upon in considering LID in the final project.

Each step progresses further into the details of the planning process. For example, budget planning at an early stage may only develop Step 1, then move on to Cost Analysis. Master Planning would necessarily move through Step 4, and preliminary design through Step 6.

B-2.1.1 Organizing the Planning Process and Timeline

Step 1: Define project objectives and goals at a macro-level

1) Identify the LID objectives and legal requirements for the project (e.g., stormwater permits, state erosion control and flood requirements, EISA Section 438). Estimate runoff volume, peak runoff rate, duration, frequency, and water quality.
2) Make assumptions on existing stormwater infrastructure in terms of how well it functions with respect to each of these aspects.
3) Evaluate the goals and feasibility for control of runoff volume, duration, and water quality, as well as on-site use of stormwater (e.g. irrigation, flushing toilets).
4) Prioritize and rank basic objectives.
5) Identify applicable local regulations or codes.
6) Determine typical LID features required to meet objectives as best as possible (i.e. infiltration, filtration, discharge frequency, volume of discharges, and groundwater recharge) taking into consideration available space, underground utilities, soil infiltration characteristics, slope, drainage patterns, groundwater table protected areas, setbacks, easements, topographic features, and other site features that should be protected such as floodplains, steep slopes, and wetlands.

Consider non-structural site planning techniques:

- Minimize total site impervious area.
- Use alternative roadway layouts that minimize imperviousness.
- Reduce road widths and drive aisles where safety considerations allow.
- Limit sidewalks to one side of roads.
- Reduce on-street parking
- Use permeable paving materials where it does not reduce the functionality and is permitted.

- Minimize directly connected impervious areas.
- Disconnect roof drains and direct drainage to vegetated areas.
- Site layout to direct flows from paved areas to stabilized vegetated areas.
- Site layout to break up flow directions from large paved surfaces.
- Site development to encourage sheet flow through vegetated areas.
- Locate impervious areas so that they drain to permeable areas.
- Maximize overland sheet flow.
- Maximize use of open swale systems.
- Increase (or augment) the amount of vegetation on the site.
- Use site fingerprinting. Restrict ground disturbance to the smallest possible area
- Reduce construction on highly permeable soils.
- Locate impervious areas to avoid removal of existing trees.
- Maintain existing topography and associated drainage divides to encourage dispersed flow paths.
- Locate new buildings, parking, and ponds in areas that have lower hydrologic function, such as clayey or disturbed soils.

LID Planning Steps:
Define Project Goals
Evaluate Site
Develop LID Strategies
Assume LID Concept Design
Target O&M Strategy

B-2.2 Cost Analysis

One of the most difficult challenges is to properly allocate resources for projects so that they are successful and fulfill the mission as programmed. LID requirements can add a new level of complexity to the project that must be addressed during planning. While it may be too early in the process to determine the configuration of LID features, a preliminary analysis is needed to determine the level of effort required to implement LID. (LID design is discussed in Appendix B, Chapter 4).

The three resources that must be addressed for LID are:

1. Implementation cost (may be less than traditional)
2. Operation & Maintenance costs (lifecycle)
3. Time impacts to design and permitting process

Information on the project mission must be gathered including; geographical location, site requirements, available sites, programmed space requirements related to increased impervious area, and the ability of the installation to maintain the LID feature. These set points will also help to determine the proper resource allocations to apply for the implementation of the LID site. LID features may be used in conjunction with conventional SWM will create a treatment train to hold, infiltrate, and filter the stormwater runoff. The LID site will contain less channelization of stormwater, less impervious pavement, more trees, more open ditches, less curb and gutter, and more

planting buffers. Many parameters must be weighed during the LID design process. Design must match the particular regional conditions.

Many of the following site conditions affect the design of LID features. Regional differences in weather patterns, soil types, groundwater conditions, existing development status, and current stormwater patterns will greatly influence the actual design and layout of the LID site and the choice of the LID features. However, one of the most important parameters will be the ratio of increased impervious surface area to the available land area or change in land cover.

Optimal LID implementation on a suitable site may result in a reduction in project cost. Classic LID design should reduce the amount of disturbed land, reduce impervious surface area, eliminate curb and gutter, reduce the size of pipes and holding ponds and increase the area planted in low maintenance tree cover. Building a large facility on a small site will increase the cost of implementing LID because the small site may require the selection of LID features that are structural in nature and are more expensive to build and maintain. On the other hand, a small building on the large site may use more natural LID features that are less costly and more easily maintained.

B-2.3 EPA LID Guidance

The following EPA manuals may be used as best practice resources: “Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices” and “Low Impact Development (LID) A Literature Review”. These manuals were based on “Low-Impact Development Design Strategies; An Integrated Design Approach”, and are geared toward general site development. Sites on military bases may have additional constraints that will influence which LID features may be used.

Other Federal Directives and Executive Orders that affect LID planning and design must be identified and considered.

B-3 STORMWATER MANAGEMENT

Human development increases impervious surfaces. Buildings, roads, sidewalks, and parking lots quickly shed rainwater and increase the percentage of rainfall that ends up as runoff. The resulting increase in runoff volume and the peak flows create negative consequences such as stream degradation and flooding risk. The principal objective of LID is to retain this increase in runoff on-site. LID techniques allow the developed site to mimic the pre-development hydrologic conditions.

LID builds on the conventional SWM philosophies and carries them a step further. LID processes begin at the point where the rain falls. Consideration for incorporating LID concepts, tools, and approaches requires assessment of the following at a minimum:

- Will the concept closely mimic the hydrology of pre-development condition?
- Will the concept mitigate adverse effects from increased stormwater runoff from the project?

- Can the drainage conveyance structures be optimized and reduce the overall cost of the project?
- What might be the hurdles for public acceptance? If required for the project to move forward, can these be reasonably achieved?

B-3.1 Hydrologic Cycle

Dr. David Maidment in his *Handbook of Hydrology* states:

> "The hydrologic cycle is the most fundamental principle of hydrology. Water evaporates from the oceans and the land surface, is carried over earth in atmospheric circulation as water vapor, precipitates again as rain or snow, is intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams, and ultimately, flows out into the oceans from which it will eventually evaporate once again. This immense water engine, fueled by solar energy, driven by gravity, proceeds endlessly in the presence or absence of human activity."

Of the total precipitation that occurs, a portion of it is lost through the following:

(i.) interception due to land cover
(ii.) evapotranspiration
(iii.) surface depression storage
(iv.) infiltration

Only the excess precipitation results in runoff that reaches receiving water bodies, such as streams and lakes. The process of infiltration is responsible for the largest portion of rainfall losses in pervious areas. LID techniques seek to mimic pre-development hydrologic condition in the post-development phase.

An understanding of the dynamics and inter-relationships in the hydrologic cycle is essential in preserving the pre-development hydrology. A comparison of pre-development and post-development hydrologic conditions is evaluated for four basic measures – runoff volume, peak rate of runoff, flow frequency and duration, and water quality. These four evaluation measures are discussed below:

Runoff Volume: LID techniques, if implemented properly into site design, will result in 'no net increase' in runoff for a specified design storm event.
Peak Rate of Runoff: LID is designed to maintain pre-development hydrologic conditions for all storms smaller than the design storm event. If additional controls are required, either to meet the state or local regulations and flooding issues for unusual storm events, conventional SWM facilities may be designed and implemented.

Flow Frequency and Duration: LID techniques mimic pre-development hydrologic conditions if implemented properly. The flow frequency and duration should be almost the same.

Water Quality: Because of the very nature of decentralized hydrologic source control, the nonpoint source pollution is greatly reduced, thereby, increasing the water quality of the receiving water bodies.

B-3.2 Conventional Stormwater Management Vs. LID

Conventional SWM facilities are primarily designed to temporarily store runoff, control flooding and downstream impacts due to increased runoff. These SWM facilities also provide water quality benefits. Whereas decentralized LID features include infiltration, increasing the length and time of flow over pervious areas, and disconnecting impervious areas that drain to stormwater collection systems. This helps to retain the increase in runoff from new development on-site.

Table B-2 contrasts conventional SWM methods that use “end-of-pipe” treatment and LID techniques that may reduce land requirements associated with conventional treatment. LID may reduce the overall costs of a project and reap benefits in protecting the environment and natural habitats.

Table B-2 Summary of Concepts of SWM and LID Techniques

Concepts of SWM	Concepts of LID Techniques
End-of-pipe stormwater treatment.	Stormwater is treated at or very close to the source.
Centralized collection system.	Decentralized system.
Reroute stormwater away from the site quickly and efficiently.	Mimics the pre-development hydrologic condition. The goal of LID is to retain the same amount of rainfall within the development site as that was retained on the site prior to the project.
Many of the stormwater management facilities are designed to control or attenuate peak runoff	LID techniques reduce the size of stormwater management facilities.
SWM facilities are designed to detain the first-flush (i.e. first ½ inch (13 mm) of runoff) from impervious areas of development.	LID techniques infiltrate stormwater on-site.

Table B-3 summarizes how conventional SWM and LID technology alter the hydrologic regime for on-site and off-site conditions.

Table B-3 Comparison of Conventional SWM and LID Technologies

Hydrologic Parameter	Conventional SWM	LID
	On-Site	
Impervious Cover	Encouraged to achieve effective drainage	Minimized to increase infiltration
Vegetation or Natural Cover	Reduced to provide or improve centralized drainage system	Maximized to maintain pre-development hydrology
Time of concentration (Tc)	Shortened, reduced as a by-product of drainage efficiency	Maintained or maximized to approximate pre-development conditions
Runoff Volume	Large increases in runoff volume not controlled	Controlled to pre-development conditions
Peak Discharge	Controlled to pre-development design storm event (i.e., 2 year, 10 year, 25 year)	Controlled to pre-development conditions for the 95 percentile storm event
Runoff Frequency	Greatly increased, especially for small, frequent storms	Reduced or minimized
Runoff Duration	Increased for all storms, because volume is not controlled	Controlled to pre-development conditions
Rainfall Abstractions (interception, infiltration, depression storage)	Large reduction in all elements	Maintained to pre-development conditions
Groundwater Recharge	Reduction in recharge	Maintained to pre-development conditions
	Off-Site	
Water Quality	Reduction in pollutant loadings but limited control of stormwater volume leaving site	Improved pollutant loading reductions, full volume control for the 95 percentile storm event
Receiving Streams	Severe impacts documented – channel erosion and degradation, sediment deposition, reduced base flow, and habitat suitability decreased, or eliminated	Stream ecology maintained to pre-development conditions for the 95 percentile storm event
Downstream Flooding	Peak discharge control reduces flooding immediately below control structure, but can increase flooding downstream through cumulative impacts and super positioning of hydrographs	Controlled to pre-development conditions for the 95 percentile storm event

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland.

B-3.3 Water Quality and Pollution Prevention

Use LID features that are distributed small-scale controls, closely maintaining or replicating the hydrology of pre-development site conditions. LID features may address additional regulatory requirements or other resource protection goals. Similarly, in meeting the regulatory requirements, BMPs can be designed to act as effective, practicable means of minimizing the impacts of development associated with water quality and quantity control.

Because of the very nature of decentralized hydrologic source control, the nonpoint source pollution is greatly reduced, thereby, increasing the water quality of the receiving water bodies.

B-3.4 Design Inputs

If possible, design inputs for successful implementation of LID techniques into a site development project obtain the following:

a. Detailed land cover and land-use information
b. Topographic contours, preferably at an interval that allows the flowpaths to be distinguished (Generally 1 ft (.25 m) interval contours minimum supplemented by spot elevations).
c. Soil borings, minimum of three borings, 15 ft (4.6 m) deep. These borings should reveal nature and condition of the shallow subsurface soils at this location, as well as defining the groundwater table, usability of on-site material for select fill, and through compositional analysis should determine both vertical and horizontal hydraulic conductivities.
d. Existing site drainage outfall conditions and characteristics including water level elevation and water quality
e. Watershed reports and master plans
f. Flooding issues, past or present
g. Installation Appearance Guide

B-3.5 Precipitation Data

The intensity-duration-frequency (IDF) curves for the United States were recently revised and published by the National Oceanic and Atmospheric Administration (NOAA), and are called Atlas-14 curves. These curves should be used when determining the precipitation depth and intensity for required duration and frequency. Other sources such as State drainage manuals have IDF curve data as well.

Long-term rainfall records for regional weather stations can be obtained from many sources, including the NOAA data center, at http://www.nesdis.noaa.gov. Table B-8 provides a summary of rainfall analysis for selected locations.

B-3.6 Low-Impact Design Elements for Stormwater Management

The LID concept encourages innovation and creativity in management of site planning impacts. As mentioned earlier, the implementation of LID techniques must be carefully evaluated for opportunities and constraints on a case-by-case basis. Many of the techniques are site-specific. Table B-4 summarizes the specific use of LID techniques, requirement, and applicability. Table B-5 summarizes hydrologic functions of LID practices.

Table B-4 \1\Summary of LID Techniques, Constraints, Requirements and Applicability/1/

	Maintenance	Max. depth	Proximity to building foundations	Water Table or Bedrock	Slopes	Soils	Space required
Bioretention	Low requirement, property owner can include in normal site landscape maintenance	2- to 4-ft (600 to 1200 mm) depth depending on soil type	Minimum distance of 10 ft (3 m) down gradient from buildings and foundations recommended	2- to 4-ft (600 to 1200 mm) clearance above water table or bedrock recommended	Usually not a limitation, but a design consideration.	Permeable soils with infiltration rates > 0.27 inches/hr (7 mm/hr) are recommended. Soil limitations can be overcome with use of underdrains.	Minimum surface area range: 50 to 200 ft^2 (4.6 to 18.6 m^2). Minimum length to width ratio 2:1
Dry Well	Low requirement	6- to 10-ft (1.8 to 3 m) depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft (600 to 1200 mm) clearance above water table or bedrock recommended	Usually not a limitation, but a design consideration. Must locate down gradient of building foundations.	Permeable soils with infiltration rates > 0.27 inches/hr (7 mm/hr) are recommended.	Minimum surface area range: 8 to 20 ft^2 (0.7 to 1.9 m^2). Minimum length to width ratio 2:1
Filter Buffer Strip	Low requirement, routine landscape maintenance	Not applicable	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Generally not a constraint.	Usually not a limitation, but a design consideration.	Permeable soils perform better, but soil not a limitation.	Minimum length of 15 to 20 ft (4.6 to 6.1 m^2).
Swales: Grass, Infiltration, Wet	Low requirement, routine landscape maintenance	Not applicable	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Generally not a constraint.	Swale side slopes: 3:1 or flatter. Longitudinal slope: 1.0% minimum; maximum based on permissible velocities.	Permeable soils provide better hydrologic performance, but soils not a limitation. Selection of type of swale, grassed, infiltration or wet is influenced by soils.	Bottom width: minimum 2 ft (600 mm), maximum 6 ft (1800 mm)
Rain Barrels	Low requirement	Not applicable	Not a factor	Generally not a constraint.	Usually not a limitation, but a design consideration.	Not a factor	Not a factor
Cistern					Not a factor	Not a factor	Not a factor
Infiltration Trench	Moderate to high	6- to 10-ft (1.8 to 3 m) depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft (600 to 1200 mm) clearance required	Usually not a limitation, but a design consideration. Must locate down gradient of building foundations.	Permeable soils with infiltration rates > 0.52 inches/hr (13 mm/hr) are recommended.	Minimum surface area range: 8 to 20 ft^2 (0.7 to 1.9 m^2). Minimum length to width ratio 2:1

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland

Table B-5 Summary of Hydrologic Functions of LID Practices

Hydrologic Functions	Bioretention	Dry Well	Filter or Buffer Strip	Swales: Grass, Infiltration, Wet Wells	Rain Barrels	Cistern	Infiltration Trench
Interception	High	None	High	Moderate	None	None	None
Depression Storage	High	None	High	High	None	None	Moderate
Infiltration	High	High	Moderate	Moderate	None	None	High
Ground Water Recharge	High	High	Moderate	Moderate	None	None	High
Runoff Volume	High	High	Moderate	Moderate	Low	Moderate	High
Peak Discharge	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Runoff Frequency	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Water Quality	High	High	High	High	Low	Low	High
Base Flow	Moderate	High	High	Moderate	Moderate	None	Low
Stream Quality	High	High	High	Moderate	None	Low	High

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland.

B-4 LID DESIGN

B-4.1 Introduction

LID strategies provide decentralized hydrologic source control for stormwater. LID implementation centers around selecting LID features which are distributed small-scale controls that can closely maintain or replicate hydrological behavior of the natural system for a design storm event.

The principal goal of designing LID features is to maintain existing pre-development hydrology. LID features will reduce runoff volume and T_c in order to mimic the pre-development hydrologic conditions. Standard BMPs may be used in conjunction with LID features, depending on site conditions, to handle the peak rate of discharge for flood control.

Follow published design criteria relative to achieving, maintaining, and emphasizing a positive exterior visual environment applicable to military installations.

B-4.2 Hydrologic Analysis

During a storm event, a portion of the precipitation is lost in the form of interception, depression storage, evaporation, transpiration, and infiltration. These losses are collectively referred to as abstractions. Only that part of the rainfall in excess of abstractions is realized as stormwater runoff. [1]

Table B-6 gives representative runoff curve numbers and the calculated initial abstractions for selected soil types. The runoff generated from a project site and the initial abstraction of the site does not have a linear relationship. For this reason, required design storage of LID features is calculated using Equation 2 and Equation 3 discussed in Chapter 3, TR-55 Methodology.

Runoff curve numbers are determined by land cover type, hydrologic condition, antecedent runoff condition (ARC), and hydrologic soil group (HSG). Curve numbers for various land covers based on an average ARC can be found in the TR-55 manual.

[1] Holding excess rainwater on-site that would ordinarily end up as runoff can be detrimental in some cases. Rainfall that is retained in excess of the initial abstraction can destabilize certain soils on slopes, impact sensitive coastal tidal zones, increase the need for mosquito control, and in certain riparian or usufructuary rights create an infringement. In many areas where shallow groundwater aquifers are used for water supply or irrigation, the designer must consider contamination issues.

Table B-6 Initial Abstraction for Indicated Soil Types

Existing Site Conditions	Curve Number (CN)	Initial Abstraction (inches)
Woods - good condition, HSG B	55	1.64
Woods - poor condition, HSG D	83	0.41
Pasture, grasslands - good condition, HSG B	61	1.28
Pasture, grasslands - fair condition, HSG C	79	0.53
Open space - lawns, park in fair condition, HSG B	69	0.90
Residential districts - 1/3 acre, 30% impervious, HSG B	72	0.78
Residential districts - 1/3 acre, 30% impervious, HSG C	81	0.47
Industrial area - 72% impervious, HSG B	88	0.27

B-4.2.1 Mimic Existing (Pre-Development) Hydrologic Conditions

From the preceding table, it can be seen that the hydrology of a naturally wooded environment in good condition provides a maximum retention that in turn increases the water quality treatment of stormwater runoff. For redevelopment, the site is not set at maximum retention, but to maintain pre-development levels. However, the typical site development project results in the following adverse environmental impacts:

- Changes to existing land-use and land cover
- Changes to natural drainage patterns
- Clear cutting of the native vegetation
- Soil compaction due to the use of heavy construction vehicles on-site
- Increase in impervious area
- Drainage systems that quickly move the water downstream.

As a result, the post-development hydrologic conditions are worsened, and in many cases, the damage becomes irreversible. For this reason, it is important to consider LID and mimic pre-development hydrologic conditions. The pre-development condition is the typical condition of the project site just prior to project. Apart from the potential increase in impervious area, the primary impacts due to human development are soil compaction, and increased efficiency of drainage patterns. The two land development conditions of concern are:

- Pre-Development Condition
- Post-Development Condition

It is recognized that there are very many different existing development conditions (including everything from leveling and fill, to existing conditions that bear no

resemblance to what came before). The goal, however, is to document a return to a realistic natural pre-development condition for the particular locale and setting.

LID techniques mimic the natural systems by capturing runoff in bio-infiltration practices (such as shown by Figure B-1 below), structural solutions, reuse or footprint reduction for a design storm event.

Figure B-1 Typical Bio-infiltration 'Rain Garden'

Note curb cut inlet. Design should be based on regional plants and growing conditions.

B-4.2.2 Time of Concentration for Pre- and Post-Development Conditions

In order to mimic natural hydrologic patterns the site designer needs to provide features that limit the rate at which runoff leaves the site. Maintaining T_c close to pre-development conditions is critical because the peak runoff rate and thereby the volume of runoff from individual lots, is inversely proportional to the T_c. Manage T_c by utilizing strategies such as reduction of impervious areas, maintaining natural vegetation, siting of impervious areas in poor draining soils, and disconnecting impervious areas.

Using traditional site planning techniques, the post-development T_c is invariably reduced. This is due to the curbs, channels, and pipes causing quicker drainage, resulting in higher peak flow rates. In order to mimic the natural hydrologic pattern the

site designer needs to provide features that slow down the runoff from the site. To maintain the T_c use the following site planning techniques:

- Maintaining or increasing pre-development sheet flow length
- Preserving natural vegetation
- Increasing surface roughness
- Detaining flows
- Disconnecting impervious areas
- Reducing longitudinal slopes of swales and ditches.

Achieving a T_c close to pre-development conditions is often an iterative process and requires analyzing different combinations of the appropriate techniques.

B-4.2.3 Design Storm Event Evaluation

Storm events are a complex natural phenomenon, and methods to predict and control their impacts rely upon empirical and mathematical modeling of the event. Three principal approaches were analyzed in selecting the 95th percentile design storm event. Those approaches are as follows:

B-4.2.3.1 Prince George's County Methodology

As previously mentioned any rainfall over and above the initial abstraction will result in direct surface runoff. It is prudent to design and implement LID features for the rainfall event that exceeds initial abstraction (Eq. 1) in the pre-development conditions. The design methodology would apply a modifying factor of 1.5 times the initial abstraction (as suggested in the Prince George's County LID manual) to serve as a practical approach to design LID features.

B-4.2.3.2 EPA Methodology

See EPA 841-B-09-001 for EPA methodology.

B-4.2.3.3 First-Flush Water Quality Volume

Many States and localities have adopted the conventional approach of collecting and treating the *first-flush* or *water-quality* depth of rainfall. These terms are defined by the local regulatory agency. In certain areas, this first flush depth is generally taken to be the first one inch of rainfall. In other localities with sensitive coastal or reservoir watersheds, the first-flush depth is generally taken to be the first 1.5 inches of rainfall. The water quality volume is equated to the volume of stormwater runoff generated by the first-flush rainfall depth. It may be practical to design LID features to handle the first-flush rainfall depth. Additionally, conventional SWM practices may be required to meet state or local regulations.

Most Local and State stormwater regulations include a first-flush or water quality depth for 2-, 5-, 10-, 25-, 50-, or 100-year regulated storm events.

B-4.2.3.4 Design Storage of LID Features

For the selected design storm event, the LID volume is equal to or greater than the total net increase in runoff from the pre- to post-development states. Typically, the total volume of stormwater runoff generated during the post-development conditions exceeds the total volume of stormwater runoff generated from the site during the pre-development conditions. The design storage volume of LID features would be the difference in total volume of stormwater runoff generated between pre- and post-development conditions. The design storage volume for LID features, calculated using Eq. 3 in Chapter 3, is compliant with DoD policy for maintaining pre-development hydrology.

Table B-7 illustrates the total depth of increase in stormwater runoff for a hypothetical representative site. The depth of increase in stormwater runoff calculated will be used in designing the LID features to handle all of the net increases in stormwater runoff generated from a parcel being developed (using Eq. 3).

B-4.3 Design Objective and Predevelopment Hydrology

The design storage volume of LID features, as calculated using Eq. 3, is a minimum requirement and must be followed for the design storm depth (using Eq. 2). This will assure the most practical solution and provide the maximum value for achieving an improved water quality discharge downstream. In certain geographical areas on optimal sites, the site designer will be able to improve the efficiency of the LID features to handle a portion of the flood control element of stormwater. For other rainfall events, which exceed normal intensities, the runoff will be collected and conveyed to the conventional SWM facilities. The conventional SWM facilities should be designed to discharge or outfall over a 24-hour period to reduce the peak flow rate below the pre-development outflow rate. Further, outfall water quality is improved through an additional treatment from conventional SWM facilities. To design the LID features for gross increases in stormwater runoff over a range of storm events, for less frequent or high return period storm events, would be impractical. Depending on site conditions, the use of conventional SWM facilities in conjunction with LID features may be required to handle unprecedented rainfall events and to avoid any downstream flooding of facilities and roadways that might become a life safety concern.

B-4.4 Design Considerations

A few of the most relevant design considerations are listed below. For a more detailed list, the reader is referred to published literature given in the References.

B-4.4.1 Develop LID control strategies

Use hydrology as a design element. In order to minimize the runoff potential of the development, the hydrologic evaluation should be an ongoing part of the design process. An understanding of site drainage can suggest locations for both green areas

and potential building sites. An open drainage system can help integrate the site with its natural features, creating a more aesthetically pleasing landscape.

a. Determine the State regulatory design storms. Regulatory requirements for design storms may also be stipulated in local ordinances, and these may limit or constrain the use of LID techniques or necessitate that structural controls be employed in conjunction with LID techniques.
b. Determine LID volumes using 95th percentile design storm and TR-55 Curve Number methodologies.
c. Evaluate current conditions. Analyze site with traditional hand methods or computer simulations. Use the results of modeling to estimate baseline values for the four evaluation measures: runoff volume, peak runoff rate, flow frequency and duration, and water quality.
d. Evaluate site planning benefits and compare with baseline values. The modeling analysis is used to evaluate the cumulative hydrologic benefit of the site planning process in terms of the four evaluation measures.
e. Evaluate the need for LID IMPs. If site planning is not sufficient to meet the site's LID objectives, additional hydrologic control needs may be addressed through the use of LID features. After LID features are selected for the site, a second-level hydrologic evaluation can be conducted that combines the LID IMPs with the controls provided by the planning techniques. Results of this hydrologic evaluation are compared with the baseline conditions to verify that the site LID objectives have been achieved. If not, additional LID features are located on the site to achieve the optimal condition.
f. Evaluate supplemental needs. If supplemental control for either volume or peak flow is still needed after the use of LID IMPs, selection of additional management techniques should be considered. For example, where flood control or flooding problems are key design objectives, or where site conditions, such as poor soils or a high groundwater table limit the use of LID features, additional conventional end-of-pipe methods, such as large detention ponds or constructed wetlands, should be considered. In some cases their capacity can be reduced significantly by the use of LID upstream. It may be helpful to evaluate several combinations of LID features and conventional stormwater facilities to determine which combination best meets the stated objectives. Use of hydrologic evaluations can assist in identifying the alternative solutions prior to detailed design and construction costs.
g. For residential areas, Prince George's County, Maryland, has developed a detailed illustration of an approach for conducting a hydrologic evaluation based on the TR-55 method. The effect of LID features should be reflected in the curve numbers and times of concentration selected for the analysis. A full description of this process is available from Prince George's County (*Low-Impact Development Hydrologic Analysis*)

B-4.4.2 LID Concept Design or Master Plan

1) Maximize the efficiency of the existing site. Place impervious areas in poorer soils and retain existing trees where practical.
2) Sketch a design concept that distributes the LID practices appropriately around the project site. Keep in mind the multifunctional capability of LID technologies (i.e., parking lot with detention facility underground).
3) Develop a master plan that identifies all key control issues (water quality, water quantity, water conservation) and implementation areas. Specify specific LID technologies and any connections they have to stormwater overflow units and sub-surface detention facilities.

B-4.4.3 Develop Landscaping Plans to Maximize Efficiency of LID Features and Reduce Maintenance

Use hardy, native plantings.

1) In areas where soils have low infiltration rates, as determined by percolation tests, average depth of bio-infiltration practices is determined such that the volume held would infiltrate within stated limits. For example, if the State criteria indicates 72 hours in soils with a low permeability rate (hydrologic soil group's C and D) of 0.05 inches/hour (1.3 mm/hr), the depth of infiltration basin = 72 hrs x 0.05 in/hr (1.3 mm/hr) = 3.6 inches (93.6 mm). Conservatively, the designer may opt to restrict this depth to 3.0 inches (75 mm) and provide a larger area to satisfy the LID volume requirement or may want to incorporate other LID practices, such as footprint reduction of impervious surfaces, and permeable pavers, in conjunction with sizing of bio-infiltration facilities. (Verify all actual design parameters with State BMP manual.)
2) Flood control is based on protecting life and property. Flood control criteria are ultimately determined locally based on drainage needs and flood risk of any particular area and may go beyond LID design criteria to achieve the necessary level of flood protection.
3) If project site has limited land area for bio-infiltration practices, in order to satisfy the LID volume criteria, a combination of structural practices such as rain barrels and cisterns may be employed in addition to bio-infiltration practices. At any time the outflow from the structural practices must be controlled to the sum total of assimilating capacity of bio-infiltration practices provided downstream. For example, if a downstream bio-retention facility is of size 600 sq.ft, in soil type C with an infiltration rate of 0.15 in/hr (3.8 mm/hr), then the cisterns or rain barrels provided on site will discharge into bio-retention facility at a rate = 0.15 in/hr * 600 sq.ft /(12 in/ft * 3600 sec/hr) = 0.0021 cfs.
4) LID features are to be incorporated into the site plan at locations as close as possible to the origin of surface runoff from impervious areas. For example, runoff from roof drains is to be collected around the building (depending on ATFP requirements, a minimum of 10 ft (3m) offset from the face of the building is required, refer to bio-retention design manuals for more details on specifications),

and runoff from parking lots will be held in traffic islands and all along the perimeter. The central idea is to mimic pre-development hydrology.

5) Plant bio-retention facilities with native vegetation; refer to local plant specialists and horticulturists.
6) Design positive overflow system to capture excess rainfall-runoff.

B-4.4.4 Develop Operation and Maintenance Procedures

Development of Operation and Maintenance Support Information documentation (OMSI) is critical to ensure LID features are properly maintained in order to function properly. LID features should be viewed as environmental systems that have specific maintenance requirements. O&M procedures for each of the LID practices implemented in the site plan should be developed as part of the OMSI documents. Different types of LID features will have different maintenance requirements, but some general principles will apply:

1) Keep LID features and flow paths clear of debris.
2) Regular trash pickup will be required.
3) Use native, drought-tolerant plantings that can tolerate periods of saturation. If required, water vegetation regularly during dry periods. Use special care in selecting plants in areas of tidal influence.
4) Consider impact on plants by road salts.
5) Grassed areas should be mowed regularly using a longer length cut.
6) Plantings should be pruned as needed.
7) Deep raking and tilling of depression storage should be done on a yearly basis or as indicated.

B-4.5 Gaining Acceptance of LID Options

LID projects will require a higher level of communication to keep stakeholders informed during the planning and design phase. From building tenant commands to O&M personnel, communicating intent and purpose is the key to successful LID implementation. In addition, for some period, feedback on implementation and program success will be required for all new facilities through the local Environmental Office.

B-4.6 Construction Permit Process

Conventional SWM is a patterned response to maximize the efficiency of site landscaping and site design to achieve a reduction in pollutant loading of rainfall that ends up as runoff due to human development. The EPA's CWA defined an appropriate level of SWM to help to keep our rivers, lakes, and shorelines clean. The CWA established the base guidelines for SWM, but for the most part turned the execution of those guidelines over to the local, state, or municipal regulatory agencies. The States then promulgated additional or clarifying requirements to a minimum level as the EPA requirements to meet the needs of the local geographic conditions. For example, SWM techniques suitable for Florida are not necessarily appropriate to the arid Southwest. Almost all projects will require Local or State construction permit in order to begin work.

As such, the LID requirements must be complementary to State and Local requirements for SWM. Without the regulatory acceptance and approval of the SWM plan, a project cannot be constructed.

B-4.7 Conclusions

The methods for calculating, modeling, and sizing stormwater runoff are based on the design storm. The design storm is a designation that defines a unit depth of rainfall in order to quantify the volume of rainfall generated for a given site. This data is needed in order to calculate the impact of development on a particular piece of land.

DoD has chosen to adopt the EPA's 95th percentile methodology to determine the design storm. Using the 95th percentile storm event as the LID design storm will result in a conservative design of LID features. Table B-7 compares the three analysis methods for a few sample locations, by soil and type. Table B-8 provides a summary of rainfall analysis for selected locations. Additional references for sources of rainfall data include NRCS TR-20 manual rainfall maps and Air Force 14th Weather Squadron rainfall data for installations.

Use the 95th percentile rainfall depth, as the design storm event when calculating the LID volumes. This will result in a practical and reasonable approach, as suggested by the EPA, in determining LID volumes. The design storm event is based on the regional 95th percentile, annual 24-hour rainfall depth averaged over several years (a minimum of 10-year daily, 24-hour precipitation events would be used). The 'design storm' will be used to calculate pre- and post-development LID volumes in order to determine the design objective. LID features will be used throughout the site design to manage the LID storage volume.

Table B-7 Analysis Method Comparison

Existing Site Conditions	Existing Site Composite CN	Method 1.	Method 2.	Method 3.	Selected Design Storm Rainfall Depth (inches)	Developed Conditions[2] Composite CN	Depth of increase in Stormwater Runoff (inches)
Woods - good condition, HSG B	55	2.45	1.63[a]	1.00	1.63	76.5	0.25
Woods - poor condition, HSG D	83	0.61	1.45[b]	1.00	1.45	90.5	0.32
Pasture, grasslands - good condition, HSG B	61	1.92	1.63[a]	1.00	1.63	79.5	0.32
Pasture, grasslands - fair condition, HSG C	79	0.80	1.45[b]	1.00	1.45	88.5	0.33
Open space - lawns, park in fair condition, HSG B	69	1.35	1.63[a]	1.00	1.63	83.5	0.37
Residential districts - 1/3 acre, 30% impervious, HSG B	72	1.17	1.63[a]	1.00	1.63	85.0	0.38
Residential districts - 1/3 acre, 30% impervious, HSG C	81	0.70	1.45[b]	1.00	1.45	89.5	0.33
Industrial area - 72% impervious, HSG B	88	0.41	1.63[a]	1.00	1.63	93.0	0.30

Method 1: Design Rainfall Depth Based on Initial Abstraction (inches)

Method 2: Region1 - 95 Percentile Rainfall Depth (inches);

Method 3: First-Flush Rainfall Depth (inches)

1. In this example, regional refers to: a - Norfolk region; b- Cincinnati Region.

2. The developed conditions composite curve number is calculated as equal to existing composite CN plus a 50% of maximum full development potential of the parcel. A full development potential is where the entire parcel is developed with impervious surface resulting in a composite curve number of 98. Here, it is assumed 50% of maximum full development and calculated as = existing CN+0.5*(98-existing CN).

Table B-8 Summary of Rainfall Analysis (1978-1997)

Description	State	Weather Station ID	Applicable Unit Identification Code						Annual Rainfall Depth (in)	99th Percentile	98th Percentile	95th Percentile	90th Percentile	75th Percentile	Rainy Days (>0.1")	Years of Available Record (1978-1997)
YUMA WSO AP	Arizona	029660	62974 (1 mi.)						3.38	2.20	1.46	0.98	0.73	0.43	8	17
BOULDER CREEK LOCAT RANCH	California	041005	44269 (mi.)						51.36	5.14	4.64	3.70	2.50	1.50	44	20
EL CENTRO 2 SSW	California	042713	45211 (1 mi.)						2.83	2.30	1.91	1.30	1.00	0.58	5	20
FAIRFIELD 3 NNE	California	042935	45653 (1 mi.)						21.55	3.26	2.48	1.80	1.30	0.90	31	20
FRESNO AIR TERMINAL	California	043257	44259 (27 mi.)						11.80	1.51	1.31	0.99	0.80	0.51	28	20
HETCH HETCHY	California	043939	64495 (36 mi.)						31.42	3.27	2.73	1.96	1.59	0.90	42	20
LOS ANGELES WSO ARPT	California	045114	44267 (17 mi.)	67399 (80 mi.)					13.95	2.56	2.30	1.64	1.23	0.77	23	20
MONTEREY NWSFO	California	045802	45210 (5 mi.)						20.10	1.70	1.47	1.37	1.14	0.85	31	2
SAN DIEGO WSO AIRPORT	California	047740	62473 (1 mi.)	00681 (30 mi)					11.69	1.74	1.58	1.28	1.01	0.60	23	20
VICTORVILLE PUMP PLANT	California	049325	3594A (60 mi.)	62204 (30 mi.)					6.47	1.73	1.60	1.12	0.90	0.60	12	19
COLORADO SPRINGS WSO AP	Colorado	051778	3455A (0 mi.)						17.06	2.11	1.59	1.12	0.85	0.48	37	20
JACKSONVILLE WSO AP	Florida	084358	57061 (18.75 mi.)	68931 (18 mi.)	68248 (25 mi.)	46134 (17.5 mi.)			52.35	3.46	2.86	2.12	1.59	0.87	74	20
KEY WEST WSO AIRPORT	Florida	084570	44222 (2 mi.)						39.68	3.76	2.95	1.92	1.41	0.76	59	20
MIAMI WSCMO AIRPORT	Florida	085663	30931 (2.5 mi.)						59.17	3.53	2.94	2.20	1.62	0.86	82	20
PANAMA CITY 5 NE	Florida	086842	44223 (9.5 mi.)	44224 (97 mi.)					56.51	4.24	3.30	2.40	1.80	1.10	63	20
TALLAHASSEE WSO AP	Florida	088758	67004 (83 mi.)						62.14	4.26	3.58	2.37	1.76	1.07	76	20
TAMPA WSO AIRPORT	Florida	088788	47030 (8 mi.)						46.24	3.22	2.70	1.92	1.48	0.88	66	20
SAVANNAH WSO AIRPORT	Georgia	097847	00263 (32 mi.)	44227 (35 mi.)					49.54	3.17	2.80	2.03	1.52	0.85	70	20
GUAM WSMO	Guam	914229	62395 (5 mi.)						95.12	4.24	3.27	2.20	1.45	0.70	143	14
HOKULOA 725.2	Hawaii	511540	44251 (mi.)						33.02	5.11	4.00	2.64	1.70	0.80	40	20
HONOLULU WSFO AP 703	Hawaii	511919	62742 (3 mi.)	47771 (9.5 mi.)					19.07	3.72	3.08	2.11	1.31	0.61	29	20
KEKAHA 944	Hawaii	514272	30614 (mi.)						20.08	4.83	3.86	2.80	1.91	0.90	24	20
CHICAGO OHARE WSO AP	Illinois	111549	65113 (23 mi.)						36.24	2.57	1.90	1.49	1.09	0.65	67	20
EVANSVILLE WSO AP	Indiana	122738	44204 (58 mi.)						43.72	2.78	2.16	1.74	1.25	0.78	71	20
NEW ORLEANS WSMO AIRPORT	Louisiana	166660	44218 (9 mi.)						65.10	4.38	3.33	2.48	1.81	1.06	77	20
SHREVEPORT AP	Louisiana	168440	45603 (11 mi.)						52.06	3.94	3.32	2.33	1.76	1.01	66	20
PORTLAND WSFO AP	Maine	176905	44214 (24 mi.)						42.49	2.88	2.23	1.55	1.17	0.71	71	20
BALTIMORE WSO ARPT	Maryland	180465	44201 (15.5 mi.)	0417A (14 mi.)					40.29	2.36	1.94	1.53	1.16	0.71	71	20
PATUXENT RIVER	Maryland	186915	00019 (0 mi.)	47370 (33 mi.)					24.97	2.90	2.58	1.80	1.30	0.80	36	20
BILOXI 9 WNW	Mississippi	220797	62604 (4 mi.)						60.53	5.64	4.04	2.74	2.07	1.20	59	9
TRENTON STATE COLLEGE	New Jersey	288880	3806A (30 mi.)						38.50	2.80	2.60	1.90	1.40	0.90	54	20
ALBUQUERQUE WSFO AIRPORT	New Mexico	290234	65460 (3 mi.)						9.74	1.15	1.06	0.88	0.65	0.39	25	20
MOREHEAD CITY	North Carolina	315830	00146 (16 mi.)	67001 (34 mi.)					38.57	4.10	3.30	2.40	1.70	1.00	46	20
HARRISBURG CAPITAL CITY	Pennsylvania	363699	68378 (6 mi.)						32.91	2.40	2.18	1.57	1.11	0.65	60	8
HARRISBURG WSO CITY OFFICE	Pennsylvania	363710	68378 (4.5 mi.)						30.58	2.05	1.84	1.32	1.08	0.70	56	8
MIDDLETOWN HARRISBURG INTL AP	Pennsylvania	365703	68378 (10 mi.)						34.91	2.46	2.25	1.39	1.10	0.69	62	7
PHILADELPHIA WSO AP	Pennsylvania	366889	45727 (2.5 mi.)						40.68	2.46	2.05	1.60	1.18	0.70	70	20
BLOCK ISLAND WSO AP	Rhode Island	370896	44210 (29 mi.)						33.37	2.54	2.08	1.52	1.23	0.74	56	16
NEWPORT ROSE	Rhode Island	375215	44211 (1.5 mi.)						32.86	2.80	2.30	1.79	1.30	0.80	46	20
CHARLESTON WSO AIRPORT	South Carolina	381544	69229 (4 mi.)						50.79	3.76	3.14	1.97	1.49	0.82	73	20
MEMPHIS WSFO	Tennessee	405954	44221 (18 mi.)						53.19	3.37	2.83	2.14	1.70	0.96	70	18
CORPUS CHRISTI WSO AP	Texas	412015	45974 (27 mi.)	68891 (11 mi.)	44215 (10 mi.)				32.44	4.40	3.42	2.50	1.73	0.91	42	20
NORFOLK WSO AIRPORT	Virginia	446139	62470 (5.7 mi.)						44.36	2.67	2.26	1.63	1.23	0.73	74	20
WASHINGTON NATL WSO AP	Virginia	448906	00025 (2.5 mi.)	00029 (1.5 mi.)	44252 (9.5 mi.)	44200 (22 mi.)	48429 (11 mi.)	45967 (25 mi.)	38.37	1.94	1.76	1.37	1.12	0.69	70	20
WILLIAMSBURG 2 N	Virginia	449151	44247 (11 mi.)						34.17	2.50	2.20	1.61	1.30	0.80	50	20
SEATTLE TACOMA AP WBAS	Washington	457473	44255 (17 mi.)						37.11	1.76	1.40	1.03	0.79	0.50	87	20
SEATTLE EMSU WSO	Washington	457458	44219 (mi.)						36.04	1.82	1.44	1.00	0.78	0.47	84	20
FRANKLIN 2 N	West Virginia	463215	31188 (5 mi.)						24.08	1.80	1.70	1.30	1.00	0.70	41	17

APPENDIX C GLOSSARY

C-1 ACRONYMS AND ABBREVIATIONS

Item	Definition
ARC	Antecedent Runoff Condition
AT	Anti-Terrorism
Bio	Biological
BMP	Best Management Practice
CN	Curve Number
CWA	Clean Water Act
DoD	Department of Defense
e.g.	for example
EISA	Energy Independence and Security Act
EPA	United States Environmental Protection Agency
Eq.	Equation
FC	Facilities Criteria
FOD	Foreign Object Debris
hr	hour
HSG	Hydrologic Soil Group
i.e.	Such as
I_a	Initial Abstraction
IMP	Integrated Management Practice
in/hr	inches per hour
LID	Low Impact Development
NPDES	National Pollutant Discharge Elimination System
NRCS	USDA Natural Resources Conservation Service (formerly SCS)
O&M	Operations and Maintenance
OMSI	Operation and Maintenance Support Information
PGDER	Prince George's County Department of Environmental Resources
SCS	USDA Soil Conservation Service
sec/hr	seconds per hour
SWM	Stormwater Management
T_c	Time of Concentration
TR-55	NRCS Technical Release 55
UFC	Unified Facilities Criteria
USDA	United States Department of Agriculture

C-2 DEFINITION OF TERMS

Building – DODI 4165.14, Enclosure 2, defines a building as: A roofed and floored facility enclosed by exterior walls and consisting of one or more levels that is suitable for single or multiple functions and that protects human beings and their properties from direct harsh effects of weather such as rain, wind, sun, etc.

Federal Facility - Section 401(8) of EISA states: The term “Federal facility” means any building that is constructed, renovated, leased, or purchased in part or in whole for use by the Federal Government.

Predevelopment – pre-project conditions that exist at the beginning of design. Where phased development occurs, the existing conditions at the time prior to the first phase being submitted will establish pre-development conditions.