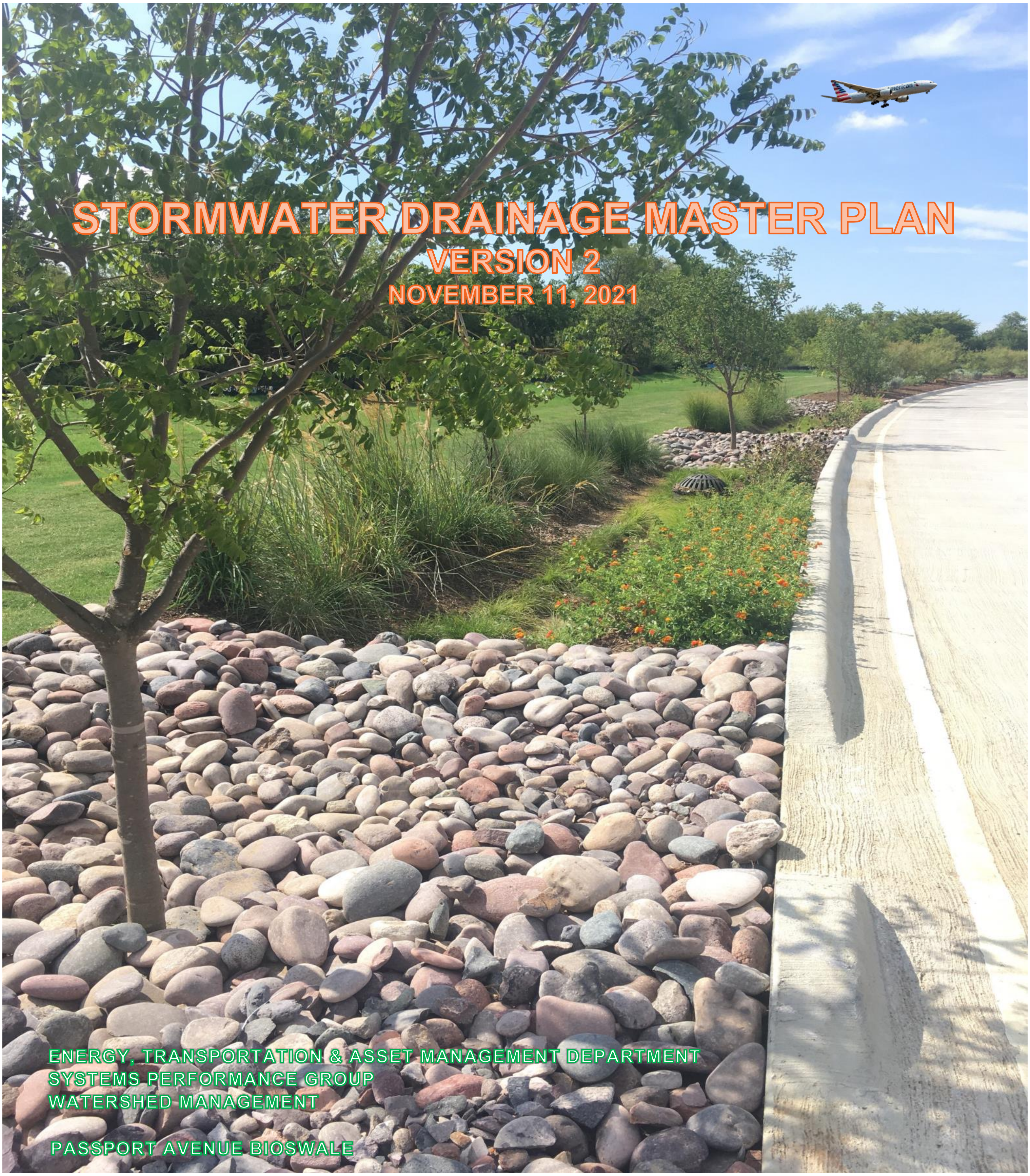
DFW

STORMWATER DRAINAGE MASTER PLAN

VERSION 2

NOVEMBER 11, 2021



ENERGY, TRANSPORTATION & ASSET MANAGEMENT DEPARTMENT
SYSTEMS PERFORMANCE GROUP
WATERSHED MANAGEMENT

PASSPORT AVENUE BIOSWALE

November 11, 2021

RE: Stormwater Drainage Master Plan

The Systems Performance Group (SPG) of the Energy, Transportation and Asset Management Department (ETAM) embarked in 2017 on the development of an airport Stormwater Drainage Master Plan (SDMP) that would properly and effectively manage current and projected storm water drainage throughout the airport property.

The first edition of the SDMP was published in December 2018 to comply with the "Pollution Prevention/Good Housekeeping for Municipal Operations #11" under the TPDES General Permit No. TXR040000 – Small Municipal Separate Storm Sewer Systems, which committed DFW International Airport (DFW) to develop a Stormwater Drainage Master Plan.

This second edition of the SDMP expanded the comprehensive plan and included a program that would meet TPDES MS4 Permit requirements, provide watershed stormwater H&H models, introduce stormwater sustainability practices, and compliment the DFW Design Criteria Manual Section 334 – Storm Drainage Utilities.

This SDMP also addresses flood control, watershed stormwater drainage management, conveyance and channel deficiencies and maintenance, stormwater quality, while accommodating future development and land uses that will meet the overall sustainability principles of DFW through the implementation of Low Impact Development (LID) and Green Stormwater Infrastructure (GSI) strategies as well as address Climate Change impacts to stormwater management.

The SDMP consists of the following sections:

Understanding that stormwater management, LID/GSI strategies and technologies, and sustainable practices will advance over time and H&H models updated based on existing and future developments, new versions of the SDMP will be periodically published.

The development of the SDMP would not have been possible without the support of DFW and ETAM executive management, the SPG Watershed Management Team, Ada Inda – Quality Engineer, Alana Stewart – Systems Performance Analyst and Razak Albarqaawee – Systems Performance Analyst as well as Stefan Hildebrand – Senior Geospatial Analyst. Additional critical support was provided by the Environmental Affairs Department

led by Asciatu Whiteside (Environmental Program Manager) and Merritt Kendall (Environmental Project Manager), and Mano Pydipelly (Project Manager) from the Design, Code and Construction Department and other DFW stakeholders from the Commercial Development Department and Planning Department.

CDM Smith was retained in 2018 to develop the first and second editions of the SDMP. Brian Hall, Seth Nehrke and Mike Schultz with CDM Smith and Rob Armstrong with Huitt-Zollars comprised the core project management team with the support of subconsultants 2M Associates, Salcedo & Associates, IEA, LTRA Associates, CCA Landscape Architects and UWRI.

Finally, it should be noted that Candace Reed Pearson initially managed the SDMP project for CDM Smith and was instrumental in expediting the preparation of the first edition of the SDMP publication in December 2018 to meet the MS4 requirement. Candace also was involved in the development of the DFW Utility Master Plan in 2009 and the development of the 2014 Sustainability Management Plan for EAD. Candace will always be remembered for her interest in and dedication towards DFW.

If there are any questions or further clarification is needed on the SDMP, please do not hesitate to contact Ada Inda or myself.

Nov 11, 2021

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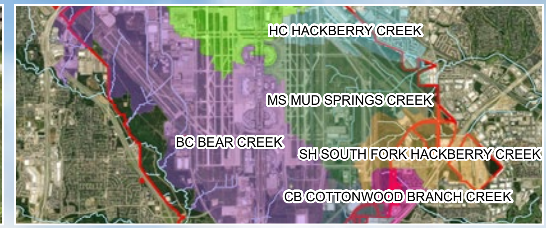

STORMWATER DRAINAGE MASTER PLAN

DFW
DALLAS
FORT WORTH
INTERNATIONAL
AIRPORT

July 2021
Final Submittal

CDM Smith

Huitt-Zollars | UWRI | Salcedo & Associates | IEA | 2M Associates
LTRA Associates | CCA Landscape Architects

Signature and Certification

Prepared under the responsible charge of:

7-31-2021

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This Dallas Fort Worth International Airport (DFWIA) Stormwater Drainage Master Plan report was prepared for DFWIA in accordance with the professional services agreement, Stormwater Drainage Master Plan Professional Services, Contract No. 8500349. The material in it reflects CDM Smith's best judgement in light of the information available at the time of preparation. Any use of or reliance on this information by a third party is at the sole discretion and responsibility of said third party. CDM Smith explicitly disclaims all liability for damages, if any, suffered by any third part as a result of any third party's reliance on the information contained therein, or for decisions made or actions taken by any third party based on this report.

Acknowledgments

The Stormwater Drainage Master Plan was developed by the

Energy, Transportation, and Asset Management Department

Systems Performance Group/Watershed Management

In collaboration with the:

Environmental Affairs Department

Commercial Development Department

Planning Department

Design, Code, & Construction Department

Authored By:

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Salcedo & Assoc | IEA
2M Assoc | LTRA Assoc
CCA Landscape Architects

In memory of Candace Reed Pearson, P.E., for her leadership and expertise which contributed to the success of this project. Candace was a consummate engineer and a good friend.

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Table of Contents

List of Figures

List of Tables

Appendices

Acronyms

A/E	Architect Engineering
ACROS	Airport Climate Risk Operational Screening
ACRP	Airport Cooperative Research Program
ALP	Airport Layout Plan
AOA	Airport Operations Area
ARFF	Aircraft Rescue and Fire Fighting Road
BMP	Best Management Practices
CAD	Computer-Aided Design
CBOD	Carbonaceous Biochemical Oxygen Demand
CIP	Capital Improvement Program
CWA	Clean Water Act
DCM	Design Criteria Manual
DFWIA	Dallas Fort Worth International Airport
EAD	Environmental Affairs Department
EISA	Energy Independence and Security Act
EMC	Event Mean Concentrations
EPA	United States Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FIS	Flood Insurance Study
fps	Foot per Second
FHA	Federal Highway Administration

GCM	Global Climate Models
GSI	Green Stormwater Infrastructure
H&H	Hydrologic and Hydraulic
HEC	Hydrologic Engineering Center
HVAC	Heating, Ventilation, and Air Conditioning
IDDE	Illicit Discharge Detection and Elimination
iSWM	Integrated Stormwater Management by NCTCOG
LID	Low-Impact Development
LiDAR	Light Detection and Ranging
LOMR	Letter of Map Revision
LOS	Level of Service
MCM	Minimum Control Measure
MSGP	Multi-Sector General Permit
MS4	Municipal Separate Storm Sewer System
NAVD88	North American Vertical Datum of 1988
NCTCOG	North Central Texas Council of Governments
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination Systems
NRCS	Natural Resources Conservation Service
O&M	Operation and Maintenance
PSMS	Primary Stormwater Management System
RAS	River Analysis System
SDMP	Stormwater Drainage Master Plan
SOP	Standard Operating Procedures
SWMM	EPA Stormwater Management Model
SWMP	Stormwater Management Program
SWP3	Stormwater Pollution Prevention Plan
SWPTP	DFWIA Stormwater Pretreatment Plant
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollutant Discharge Elimination System
TPH	Total Petroleum Hydrocarbons
TxDOT	Texas Department of Transportation
UNT	University of North Texas
USACE	U.S. Army Corps of Engineers
USDA SCS	United States Department of Agriculture Soil Conservation Service
WOTUS	Waters of the United States
WQ_V	Water Quality Volume

Section 1

Background and Purpose

1.1 Introduction

Dallas Fort Worth International Airport (DFWIA) is located in north-central Texas on the border of Tarrant and Dallas Counties, as shown in **Figure 1-1**. Its land parcel covers more than 17,000 acres, within the cities of Grapevine, Irving, Euless, Coppell, and Fort Worth. As one of the busiest airports in the world and an important economic engine for the North Texas Region, DFWIA is committed to being one of the most sustainable airports in the United States. DFWIA became the first carbon-neutral airport in the Americas and is working continuously to improve sustainability, including stormwater management. DFWIA's Sustainability Management Plan was developed in 2014 and updated in 2018 (DFWIA 2014).

Part of the strategic approach to sustainability includes development of a formalized Stormwater Drainage Master Plan (SDMP), which is also an MS4 requirement. This allows for a proactive approach to managing stormwater quantity and quality issues and preserves existing floodplains and ecosystems. In 2014, stormwater low-impact development (LID) design guidelines were implemented to manage the impact of new impervious surfaces on the watersheds within DFWIA's jurisdiction, with these guidelines being updated as part of the SDMP. Stormwater management aspects such as water quality, watershed management, flood mitigation, streambank protection and conveyance currently are addressed informally under the current stormwater management program and will be formalized as part of the SDMP.

The purpose of this Stormwater Drainage Master Plan (the Plan) is to address flood control, watershed management, conveyance deficiencies, and maintenance, water quality, habitat protection, recreation, and ecosystem enhancements while preparing for future development and land uses. Moreover, the approach presented here is intended to further DFWIA's sustainability principles by focusing on the implementation of guidelines and best management practices (BMPs) in various forms per applicable Airport Cooperative Research Program (ACRP) Reports and Federal Aviation Administration (FAA) controls, including LID and Green Stormwater Infrastructure (GSI) strategies.

1.2 SDMP Goals and Objectives

The SDMP has two major components: this Stormwater Master Plan (the Plan) and the Stormwater Maintenance Management Program (the Program). The Program will provide data transfer protocols, operations and maintenance information, regulatory changes, and/or organizational priorities so the Plan can be updated periodically, moving from a monitor and react strategy to a proactive management plan.

The Plan will develop the principles and practices that guide stormwater management at DFWIA. It will define existing regulatory criteria, establish detailed watershed models that will define existing levels of service and act to guide future operations and planning activities.

The Program, provided under separate cover, will establish the policies, procedures, and practices for advancing and updating the Plan's guidelines and recommendations. The Program will include the following:

- A formalized process for compiling, submitting, and updating data associated with stormwater management (including GIS spatial data, design documents, and hydrologic and hydraulic [H&H] model data sets.).
- An outline for selecting improvement projects for capital improvement programs (CIPs).
- An integrated approach for the operation and maintenance (O&M) of the drainage system components

O&M practices established by the Program integrate existing O&M elements with those developed according to the Plan guidelines and recommendations, including stormwater collection, conveyance, and storage (including the first flush system), owned and/or operated stormwater controls (quantity and quality), and management of third-party-owned and/or operated stormwater controls (quantity or quality).

The foundation for the SDMP comprises watershed-level studies, the ongoing stormwater management and compliance programs associated with MS4 requirements, an updated geodatabase of the stormwater system components, and DFWIA's sustainability principles and BMPs (**Figure 1-2**). The Plan and Program are intended to be consistent with DFWIA's Sustainability Master Plan (2014), Stormwater Management Program (SWMP), and Stormwater Pollution Prevention Plan (SWP3), which were developed to satisfy current TCEQ Texas Pollutant Discharge Elimination System (TPDES) General Permit requirements, as well as Federal and State Guidelines such as ACRP reports and FAA regulations.

DFWIA SDMP
Figure 1-1
Location Map

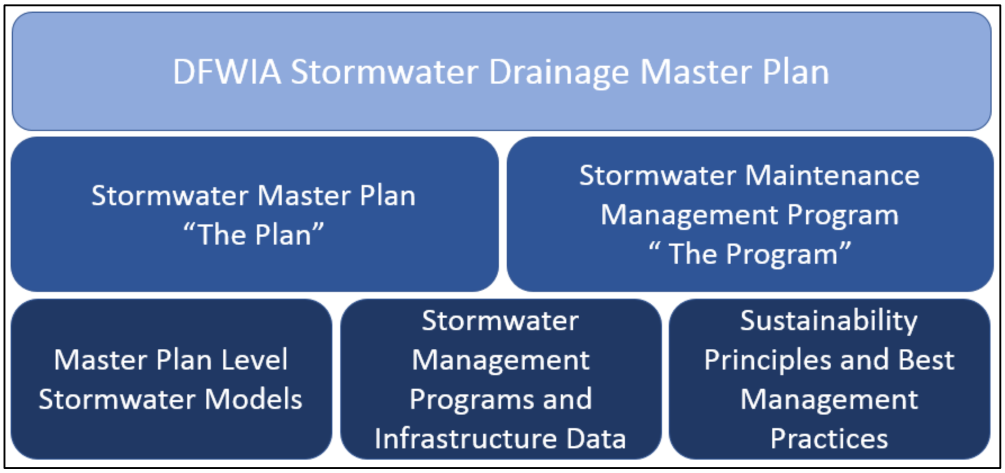


Figure 1-2
DFWIA Stormwater Management Initiative

The main objectives of the Stormwater Drainage Master Plan Initiative are as follows:

- Utilize and refine the stormwater spatial information and data management framework to support the upkeep of the Plan and the execution of the Program.
- Develop and manage stormwater models for the DFWIA property using consistent modeling methodology to increase level of detail and accuracy.
- Identify stormwater management alternatives to resolve flooding and erosion problems and equitably manage new development.
- Administer guidance documents to regulate future development at DFWIA to manage both water quantity and water quality issues based on potential problems predicted in the stormwater models.
- Manage procedures and practices that serve as a framework to implement, advance, and maintain this SDMP.

1.3 Facility Description

DFWIA is governed by the DFWIA Board (the Board), comprised of city council members and representatives from Dallas and Fort Worth, and created in 1968. The Board is responsible for all day-to-day operations and compliance with all permits and regulations, including those promulgated by, FAA, TCEQ and others.

The airport operations area (AOA), commonly referred to as the airside, comprises passenger terminals and gates, which service multiple national and international airlines; two major cargo areas; northeast cargo and west cargo, which serve several cargo companies; and all runways, taxiways, and aprons. The landside area includes all property outside the AOA.

More than 70% of tenants who lease facilities within the DFWIA property are related to air transportation or cargo industries and include the airlines, cargo companies, ground-support equipment providers, and air fueling companies. The remaining tenants include recreational/hospitality facilities, restaurants, warehousing, light industrial facilities, and natural gas drilling and exploration.

A shift in tenant demographics is ongoing, with strategic expansions on landside areas for retail, light industrial, office, hospitality, and mixed-use commercial development. **Figure 1-3** provides a layout of the airport within the county and city limits.

1.4 Report Organization

The remainder of this report is organized into the following sections:

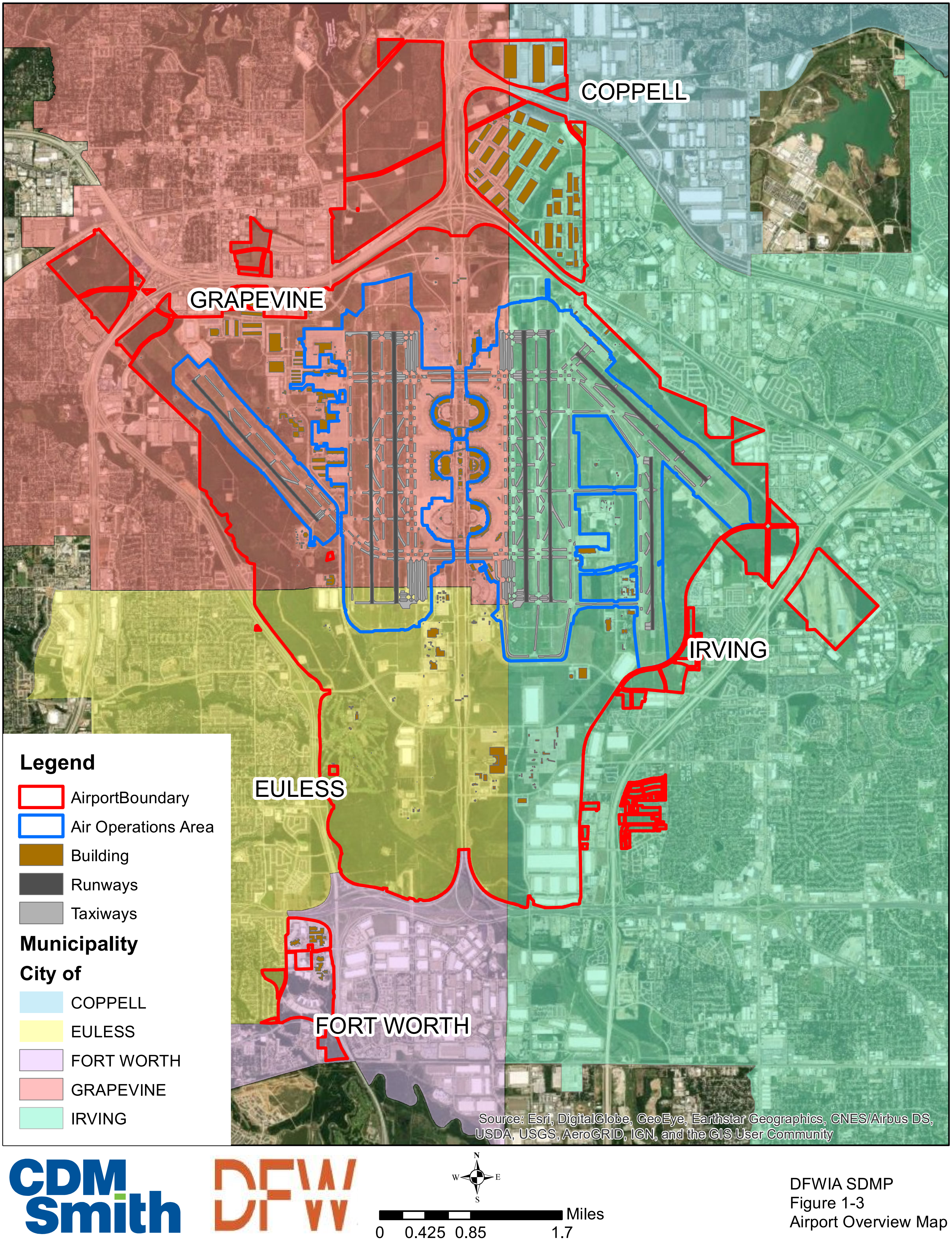
Section 2 – Stormwater Planning and Data Management – **Section 2** provides an overview of regulations, ordinances, policies, and programs that frame and implement stormwater compliance efforts, along with data management strategies to maximize these efforts.

Section 3 – Data and Model Collection and Evaluation – **Section 3** summarizes available data and defines strategies for leveraging the data for maximum effectiveness.

Section 4 – Model Development and Existing System Evaluation – **Section 4** defines the processes for development of the watershed models and outlines the methodologies for analyzing and evaluating the results.

Section 5 – Alternatives Development and Evaluation – **Section 5** outlines innovative, holistic solutions to address current and ongoing needs and quantifies the level of service improvements.

Section 6 – Mitigation Strategies for Model Identified Drainage Issues – **Section 6** quantifies achievable benefits while plotting a path for implementation.



DFWIA SDMP
Figure 1-3
Airport Overview Map

Section 2

Stormwater Planning and Data Management Criteria

2.1 Stormwater Infrastructure System

Stormwater collection, storage, treatment, and outfall systems operated at the airport also receive flows from and discharges into stormwater systems operated by neighboring municipalities (e.g., Fort Worth, Euless, Grapevine, Irving). The majority of stormwater runoff eventually discharges into local creeks and waterways. Waters of the U.S. either originating on or traversing airport property include the following: Grapevine Creek (GC), Cottonwood Creek (CC), Hackberry Creek (HC), South Fork Hackberry Creek (SH), Mud Springs Creek (MS), Estelle Creek (EC), Cottonwood Branch Creek (CB), Bear Creek (BC), Big Bear Creek (BB), Little Bear Creek (LB), and their associated tributaries.

Drainage areas from stormwater outfalls can be categorized into permitted industrial and non-industrial discharges. **Figure 2-1** presents the stormwater and first flush systems, including components and piping, permitted outfall locations, monitoring locations, property boundaries, surface water bodies, and the existing stream network. The first flush system consists of a series of inlets, fuel separators, and pipes that convey flows to the first flush system stormwater treatment plant where it receives advanced treatment to remove fuel, oil, and grease, prior to discharge into the TRA Sanitary Sewer interceptor. Further information on the location and classification of the outfalls is provided in the DFWIA Stormwater Pollution Prevention Plan (DFWIA 2016b).

2.1.1 Primary Stormwater Management System

The primary stormwater management system (PSMS) includes pipes, open channels, storage areas, permitted outfalls, basins, pumps, and several collection systems that discharge to surrounding waterways without treatment. Areas where stormflows may encounter high-pollutant loads related to airport industrial activities are collected by the first flush system. This runoff then is treated as detailed in **Section 2.1.2** before discharge to the TRA interceptor and the Hackberry Creek watershed in the case of East Cargo Ramp system, which is not connected to the main FFS.

Stormwater flows originating from runway and taxiway areas discharge to the areas receiving waters via the stormwater collection and conveyance systems. Likewise, storm drain inlets supporting roadways, the public side of terminal areas, general parking areas, offices, municipal buildings, most tenant leaseholds, recreational facilities, and the Rental Car Center complex discharge directly to the PSMS, which discharges to the nearest receiving water or Municipal Separate Storm Sewer System (MS4). Some maintenance facilities and tenant facilities are constructed with stormwater structural controls designed specifically to treat first flush stormwater as well as control the release of stormwater before runoff discharges into tributaries or downstream waters.

There are stormwater outfalls that drain either the AOA or Board-operated facilities associated with industrial activity. Drainage from the north is discharged into Grapevine Creek and Cottonwood Creek; Hackberry Creek receives the northeast and east drainage including a confluence with Mud Springs Creek; South Fork Hackberry, Cottonwood Branch, and Estelle Creeks receive the southeast drainage; and Bear Creek receives the central, west and southwest drainage.

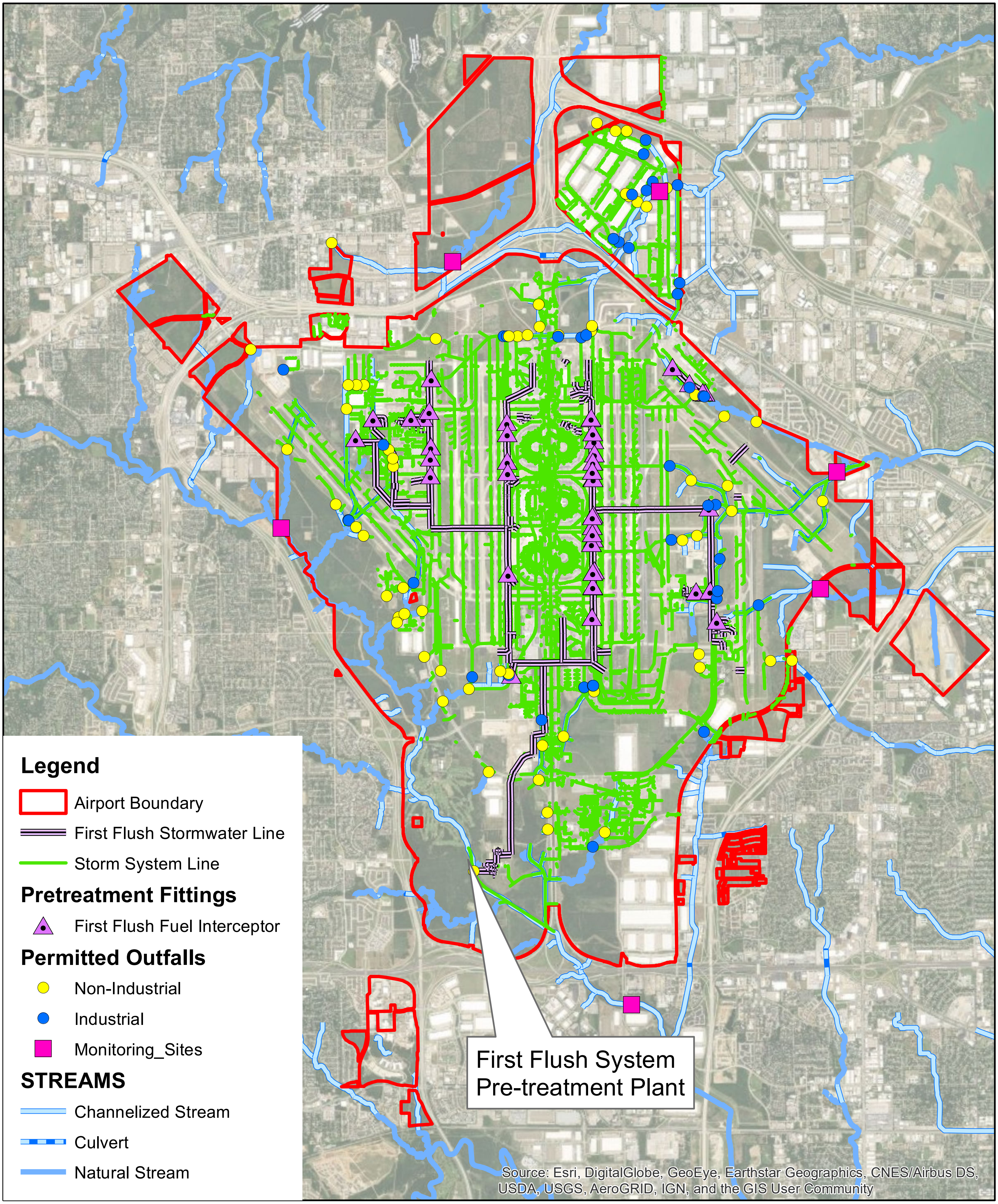
2.1.2 First Flush System

In addition to the PSMS, a first flush system (FFS) is in place to collect first flush stormwater runoff. The first flush system is composed of terminal and air cargo ramp inlets, fuel separators, and piping that convey first flush stormwater to the DFWIA Stormwater Treatment Plant (SWTP). First flush stormwater (treated) is authorized for discharge from Outfall 001 under TPDES Wastewater Permit No. WQ0001441000, however, it is currently only discharging to the TRA Sanitary Sewer Interceptor.

Ramp storm drain inlets contain a baffle to maintain a water level designed as a vapor trap to prevent vapors from the fuel separators from venting close to aircraft. The fuel separators collect drainage from these inlets to capture fuel residue, oil and grease as first flush while discharging the stormwater beyond the first flush to PSMS. The fuel separators direct first flush discharges to the SWTP. Fuel separators and stormwater inlets associated with the first flush system are inspected quarterly and cleaned annually as necessary. The Terminal D ramp has underground pretreatment detention structures that are inspected and cleaned annually.

First flush discharges from the terminals (airside), Allied Aviation fuel farm, UPS cargo facility (ramp/apron area), west cargo (ramp/apron areas), and the former U.S. Mail cargo facility are discharged through fuel separators to the SWTP. The East Cargo Ramp FFS discharges into Hackberry Creek after flowing into an additional underground treatment structure or stormwater treatment unit.

Modeling of the first flush system shows a composite capture of approximately 0.25 inches over the area served by the first flush collection system. A technical memorandum detailing the model conversion, aggregation, and analysis is included in **Appendix A**.



DFWIA SDMP
Figure 2-1
Stormwater And First Flush System

2.2 Stormwater Quantity Criteria

Multiple agencies and jurisdictions have developed criteria for flood control which apply to DFWIA. These various criteria are summarized in the following sections.

2.2.1 Federal Requirements and Regulations

2.2.1.1 Federal Aviation Administration

The FAA has developed an Advisory Circular, AC 150/53205, *Airport Drainage Design*, for the design and maintenance of large hub airport surface drainage systems. This Advisory Circular combines existing surface drainage topics covered in different agency manuals into one Unified Facilities Criteria Surface Drainage Design document. The Advisory Circular establishes general concepts and procedures for the hydrologic design of surface structures. FAA sets minimum standards in the Advisory Circular; however, each facility may be designed to a higher standard as required by DFWIA's Design Criteria Manual Section 334 – Storm Drainage Design. **Table 2-1** summarizes the FAA design storm requirements.

Table 2-1 FAA Minimum Surface Drainage Standards[1]

Facility Type	Design Storm Return Period (years)	Design Storm Duration (hours)	Notes
Taxiway and Runway Pavement	5	24	No ponding encroaching on edge of pavement A ponding limit of 4 inches around apron inlets
Runway, Taxiway, and Helipad Centerlines	10	24	Center 50% free from ponding
Landside Areas	10	24	Landside areas at DFWIA are governed by the DFWIA DCM
Depressed Pavement Sections and Underpasses	50	24	

Note:
1. For areas other than airfields and heliports, check the appropriate local regulatory agency for guidance on design storm requirements.

2.2.1.1.1 Other Design Criteria

- AC 150/5320-5 requires that conduits or channels greater than 96 square inches passing through or beneath security fences have security barriers.
- Traverse and longitudinal grades within the runway or taxiway safety area outside of the shoulders will be as required by AC 150/5300-13, Airport Design.

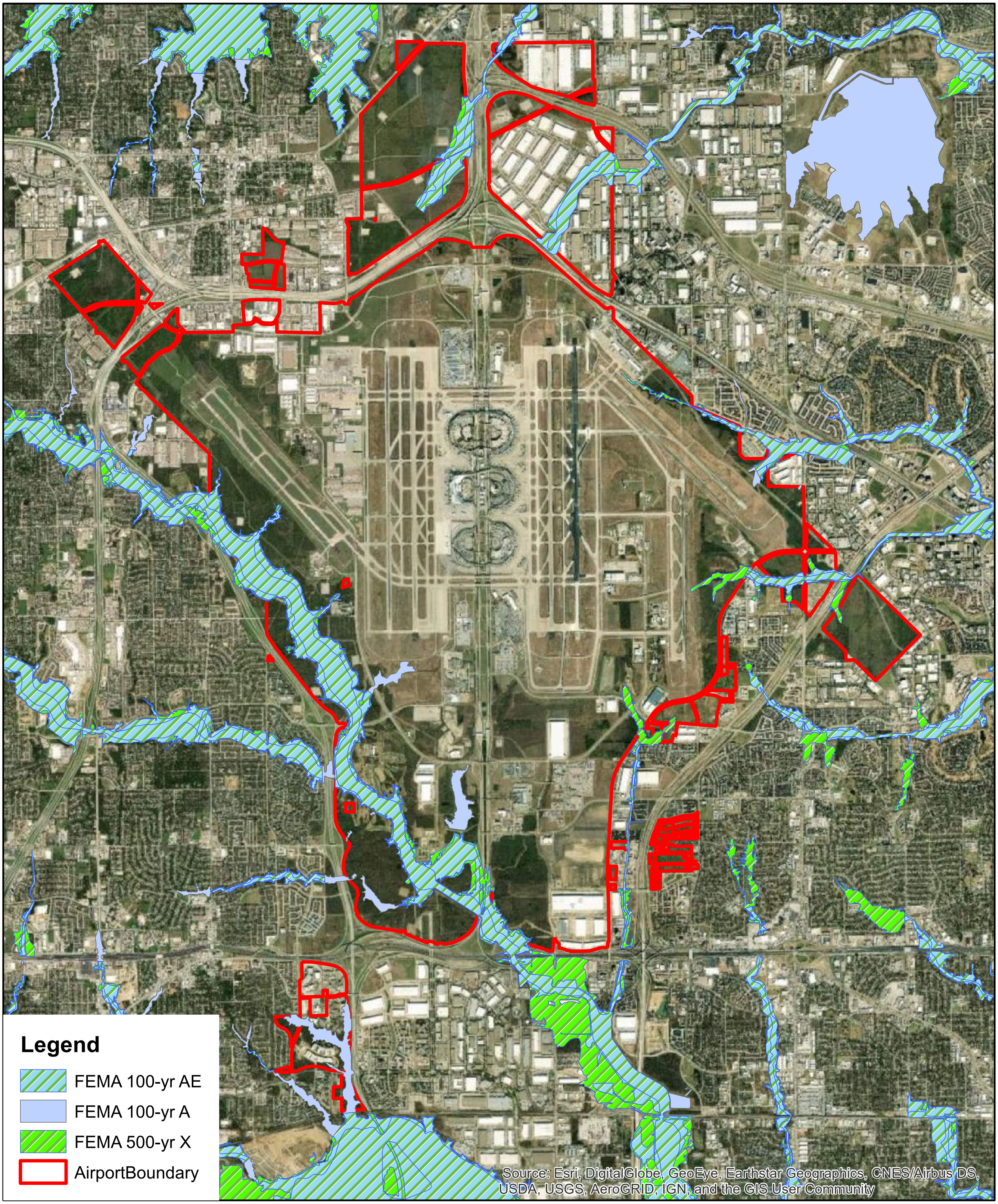
Aviation facilities also have restrictions on surface storage of water because of the potential development of fog and attraction of wildlife, especially waterfowl. FAA recommends a separation distance of 10,000 feet from the end of the nearest runaway to a stormwater detention pond. FAA Advisory Circular, AC 150/52000-33C, *Hazardous Wildlife Attractants* on or *Near Airports*, documents the land use practices that potentially attract wildlife. FAA also recommends a distance of 5 statute miles between the furthest edge of operating area and the wildlife attractant, if the attractant could cause hazardous wildlife movement into or across the approach, departure, or circling airspace. However, if a detention pond drains within 48 hours of the end of the storm event, the distance restrictions are relaxed. All detention ponds at

DFWIA are regulated more stringently and are required to drain within 24 hours after the end of a storm event per DCM Section 334 – Storm Drainage Design.

2.2.1.2 Federal Emergency Management Agency

Federal Emergency Management Agency (FEMA) determines floodplain elevations and boundaries based on H&H modeling. FEMA's Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) present these results and flood risk areas. Floodplain boundaries are presented on the FIRMs, and FEMA-regulated floodplain areas as provided by DFWIA are depicted on **Figure 2-2**. The FEMA database appears to show some relic floodplain boundaries extending across elevated runway-taxiway areas of DFWIA that are clearly no longer within the floodplain, as shown on **Figure 2-3**, where the floodplain extends across runway 13R/31L. DFWIA will be submitting a Letter of Map Revision (LOMR) to FEMA to update the maps for these areas , which will be based on watershed drainage study results.

On-site flood inundation maps have been developed as part of this SDMP and are presented as part of each watershed study. The DFWIA SDMP design event inundation maps do not replace the FEMA FIRMs as the effective regulatory floodplain document with respect to elevations and areas. They are intended to identify problem areas and assist with identification of flood reduction benefits for mitigative measures. These inundation maps may be used as a guide by DFWIA to advance or limit development of the two boundaries where the SDMP models show higher flood stages and greater areas of inundation.



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DFWIA SDMP
Figure 2-2
Airport FEMA Coverage

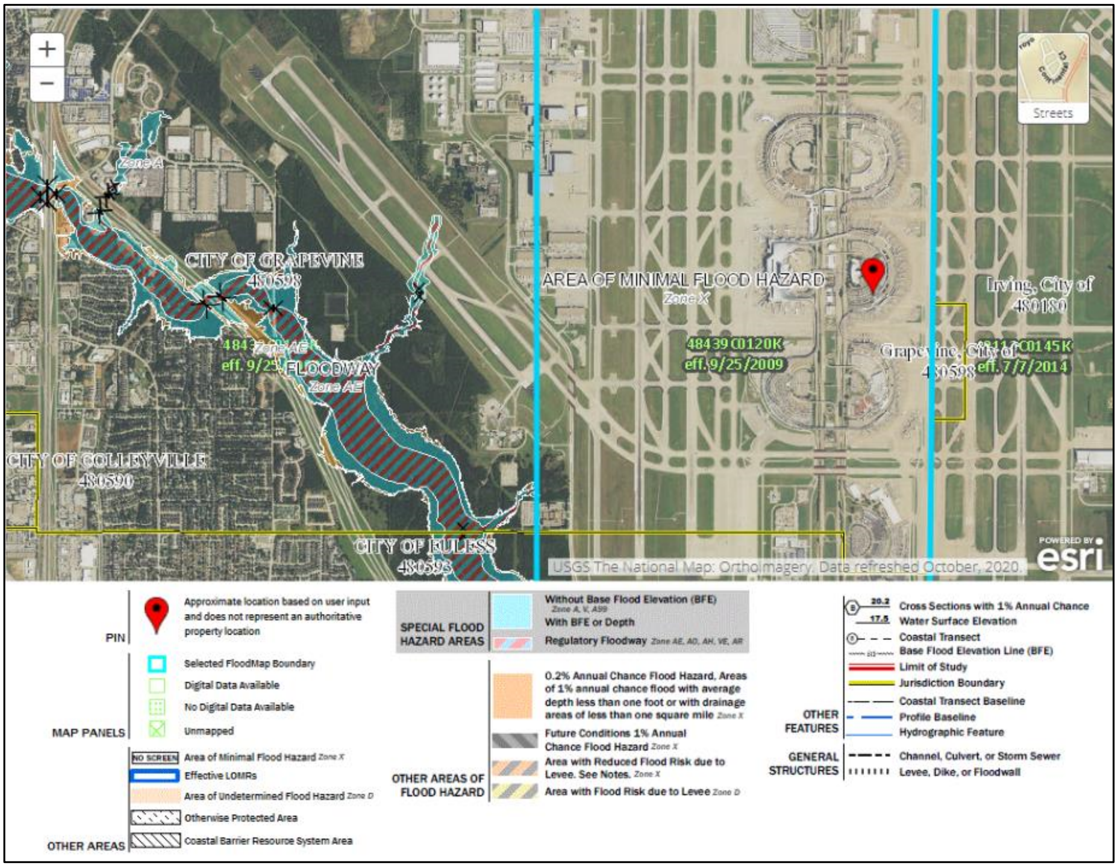

Figure 2-3
FEMA Floodplain Coverage (FEMA Map Service Center)

2.2.2 NCTCOG Regional Stormwater Strategy

The North Central Texas Council of Governments (NCTCOG) has developed the integrated Stormwater Management (iSWM), a regional program that provides guidance and a framework to develop and implement a strategy to address regional water quality issues. The goals of this regional program are to:

- Protect the health and welfare of citizens and the environment;
- Effectively address state and federal regulations;
- Share professional knowledge and experience; and
- Train government staff and the development community.

The iSWM provides four types of documentation—criteria, technical, tools, and program guidance—for each project phase, from planning through design, construction, and maintenance.

NCTCOG developed iSWM to help cities or other entities with jurisdictional responsibility implement more environmentally friendly approaches to stormwater management. The program is intended to provide guidance for all development and redevelopment related to stormwater activities.

The iSWM Criteria Manual recommends that a stormwater management system be designed for the four storm events listed in **Table 2.2.**

Table 2-2 Dallas iSWM Storm Events

Name	Focus	Description
Water Quality	Remove pollutants in stormwater runoff to protect water quality.	Criteria based on a volume of 1.5 inches of rainfall, not storm frequency
Streambank Protection	Regulate discharge from site to minimize downstream bank and channel erosion.	1-year, 24-hour storm event
Conveyance	Control runoff within and from the site to minimize flood risk to people and properties for the conveyance as well as the 100-year storm.	5-year, 24-hour storm event
Flood Mitigation		100-year, 24-hour storm event

A downstream assessment for 1-, 5-, and 100-year events is required to protect downstream properties by determining the extent of necessary improvements for two focus areas: streambank protection and flood mitigation.

Once the assessment of necessary improvements is complete, the following questions at each determined junction downstream must be answered to determine the necessity, type, and size of nonstructural and structural controls to be placed on-site or downstream of the proposed development:

1. Are post-development discharges greater than predevelopment discharges?
2. Are post-development velocities greater than predevelopment velocities?
3. Are post-development velocities greater than velocities allowed by the receiving systems?
4. Are post-development flood heights more than 0.1 feet above the predevelopment flood heights?

Should undesirable downstream impacts be found, iSWM states the general options available for the two focus areas. These are shown in **Table 2.3**.

Table 2-3 iSWM Mitigation Options

Design Focus Area	Design Options
Streambank Protection	Option 1: Reinforce/stabilize downstream conditions.
	Option 2: Install stormwater controls to maintain or improve existing downstream protection.
	Option 3: Provide on-site controlled release of the 1-year, 24-hour storm event over a period of 24 hours.
Flood Mitigation and Conveyance	**Flood Mitigation**
	Option 1: Provide adequate downstream conveyance systems.
	Option 2: Install stormwater controls on-site to maintain or improve existing downstream conditions.
	Option 3: In lieu of a downstream assessment, maintain existing on-site runoff conditions.
	Conveyance
	Minimize localized site flooding of streets, sidewalks, and properties using a combination of on-site stormwater controls and conveyance systems.

DFWIA requires implementation of Option 1, 2 and/or 3 for Streambank Protection and Option 3 only for Flood Mitigation.

The iSWM Criteria Manual is intended for redevelopment and development projects meeting common thresholds, and as a guide for other projects. Several options are presented as design alternatives addressing water quality.

The recommended criterion in the iSWM is to treat the first 1.5 inches of rainfall. **Table 2-4** summarizes the water quality design focus areas of iSWM.

Table 2-4 Design Focus Area Options – Water Quality

Design Focus Area	Design Options
Water Quality Protection	Option 1: Use integrated site design practices to conserve natural features, reduce impervious cover, and use natural drainage systems.
	Option 2: Treat the water quality protection volume (WQv) by reducing total suspended solids from the development site for runoff resulting from rainfall events up to 1.5 inches.
	Option 3: Assist in implementing off-site community SWP3 as designated in an approved master plan or TPDES stormwater permit.

DFWIA currently requires the implementation of Option 2 for Water Quality Protection with the WQv based on 0.25 inches of rainfall on impervious pavements as the first flush.

Recommended iSWM stormwater control practices to help reduce pollution and improve water quality, which are applicable to DFWIA, include:

- Bioretention (This can be a variant of a swale and may have landside redevelopment applications.)
- Enhanced Swales (Widely used at DFWIA and are consistent with FAA and iSWM requirements.)
- Detention (Dry detention is widely used at DFWIA and is consistent with FAA requirements for fog and bird-attractant land uses.)
- Filter Strips (These can be used similar to swales and are widely used at DFWIA.)

- Sand Filters, Filter Boxes, etc. (These can remove suspended solids, especially for systems that dry out on a regular basis.)
- Proprietary Systems (These are various oil-water separators and vortex for first flush treatment systems, which are most effective as offline systems that allow a bypass for large events.)

The iSWM Criteria Manual contains a number of checklists for planning and detailed designs intended for new development. All of these criteria, however, are not applicable for use at DFWIA as noted.

2.2.3 Municipal Requirements and Collaboration

DFWIA is surrounded by a number of cities that are directly involved in stormwater management by either contributing to or receiving flows from the DFWIA PSMS. Cities directly affected include Irving, Coppell, Grapevine, Euless, and Fort Worth. Each of these municipalities has their own stormwater rules and regulations that need to be accounted for when establishing development criteria in areas coincident to the municipality and DFWIA. However, DCM Section 334 requires any new discharges to tributaries on or off airport property from new developments must meet existing conditions for the 1, 25 and 100 year design events.

2.2.4 DFWIA Design Criteria

Formal policies contained in the Design Criteria Manual (DCM) (DFWIA latest edition) and existing practices that have developed through implementation of the DCM are discussed in this section. The practices will be standardized in the Plan and incorporated into the DCM as appropriate during the next revision. The DCM outlines the formal design criteria for all proposed airport projects. All projects that alter the runoff characteristics from an area greater than 1 acre are required to prepare a drainage study that, at a minimum, describes the H&H analyses conducted to demonstrate compliance with storm drainage criteria set forth in the iSWM design criteria developed by the NCTCOG. The four primary iSWM criteria are as follows:

1. Stormwater quality
2. Streambank protection
3. Conveyance
4. Flood mitigation

The stormwater drainage design required under the DCM must include a sufficient hydrologic analysis to determine the existing and proposed drainage conditions. All calculations associated with the determination of runoff characteristics and coefficients, volume of runoff, time of concentration, velocities, inlet size, hydraulic gradient, and any other items pertinent to the drainage design must include:

- Stormwater drainage analysis for the 1-, 25-, and 100-year, 24-hour design storms.
- Consideration of stormwater management alternatives and recommended facilities.
- Description of measures taken for velocity dissipation to ensure non-erosive velocities at points of discharge for each design storm.

- Additional practices that are in use, include providing the following items in the drainage design:
  - Comparison point tables for pre- and post-development conditions.
  - Detention staging tables and level versus time hydrographs.
  - Discharge hydrographs delineating drainage time.

The DCM establishes that the total capacity of a closed storm drainage system must be designed in accordance with iSWM criteria for conveyance piping. The total capacity of the drainage facility must be equal to or greater than the runoff of a storm of 100-year design frequency. If the 100-year storm runoff exceeds the capacity of the design, then the closed storm system will be designed based on a minimum 25-year frequency, or larger, which must include a 100-year emergency overflow system. Storm drains must be designed to meet a minimum mean velocity and not exceed velocities specified in the DCM. Current practice encourages use of vegetated channels throughout the airport and discourages generation of flows with high velocities.

The use of GSI strategies as an aid to meet predevelopment conditions is included in the DCM. GSI strategies currently recommended in the manual include infiltration trenches, rain gardens, bioswales, permeable pavements, filter strips, and rainwater harvesting. This Plan/Program will include the evaluation of additional green stormwater strategies for use by developers.

Care should be taken to ensure that the published version of the DCM is utilized for reference.

2.2.5 SDMP-Recommended Stormwater Quantity Criteria

Watershed management is subject to federal and state requirements. Existing and future conditions must be considered in any planned development. This section summarizes the stormwater quantity criteria that take these variations into consideration and that are used in developing alternatives for the Plan.

The water quantity (conveyance, flood control, and erosion mitigation) criteria standards may be summarized by separating property into airside and landside areas.

2.2.5.1 General

The stormwater drainage system should safely collect, store, and convey the 100-year frequency flow. The following methods should be considered to accommodate these flows.

- Only dry detention or underground systems may be applied for the airport and the surrounding neighborhoods up to 10,000 feet from the airport boundary. No BMPs that may be considered wildlife or fog attractants are allowed within this range. All dry detention areas must be designed according to ACRP Research Report 174 (ACRP, 2017), iSWM, FAA Advisory Circulars and DCM parameters. Any conflicts or alternatives must be resolved through the DCM variance process.
- Future building construction or major renovations should be checked against the 100-year storm event to confirm system capacity and no adverse impacts. It is also recommended that the full range of storms be checked to confirm that the system will perform across a wide range of storm events.

2.2.5.2 Airside Areas

Criteria as provided in FAA Advisory Circular 150/5320-5, Airport Drainage Design, will be followed such that no runway or taxiway shoulders shall be encroached upon during the 5-year, 24-hour storm event.

Hydraulic design should follow criteria and guidelines as presented in the DCM.

The 100-year, 24-hour design storm will be used as a check storm versus runway and taxiway elevations to determine stages at runway-taxiway crown elevations.

The maximum ponding at apron inlets should be no greater than 4 inches for the 5-year storm.

Temporary storage of stormwater between runways, taxiways, and aprons should be considered, proving it drains within 24 hours. Note, while the drawdown criteria in AC 150 is 48 hours, DFWIA maintains more conservative criteria with a 24 hour drawdown requirement.

Uncovered surface detention structures will not be allowed in the airfield.

2.2.5.3 Landside Areas

Hydraulic design should follow criteria and guidelines as presented in the DCM.

Future development/redevelopment plans are required to evaluate and implement on-site measures published in the DFWIA Development Design Guidelines (DFWIA, 2020) to confirm that proposed runoff does not exceed existing peak discharges to the receiving system.

For multilane roadways the permissible spread of water into the street shall be as defined in the DFWIA DCM.

For all other roads within, or immediately adjacent to, the airport boundary, peak flooding will meet the more stringent of local municipality or TXDOT standards.

Detention structures must be sized to capture the 100-year design storm and drain within 24 hours per the current DCM.

It is the responsibility of the developer to confirm all references provided within this document to confirm that they are still applicable as compared to the latest release of the reference document.

2.2.5.4 Off-site Areas

Runoff must be collected and attenuated so that peak discharges and stages do not increase for neighboring areas, velocities do not create erosion problems, and water quality is maintained. The intent is that any and all discharges from airport property are maintained at or below existing levels.

2.2.5.5 Summary

This section is a summary guide for allowable water quantity criteria for flood levels versus design storms. The criteria that cover airside areas apply for existing as well as future conditions. Alternative BMPs will be considered to mitigate problem areas for which criteria are not being met. The criteria for landside areas allow for GSI collection, storage, and treatment features to mitigate any potential building flooding, manage road flooding, where applicable, and provide for water quality. The off-site area criteria cover future development, including the alternative designs for on-site mitigation.

2.3 Stormwater Quality Criteria

As a separate public entity, DFWIA does not fall under the municipal authority of the cities of Dallas or Fort Worth and is considered a small MS4. As such, DFWIA is subject to TPDES General Permit TXR040000 and, therefore, is required to comply with various programs administered under the TPDES program. Compliance with TPDES Multi-Sector General Permit (MSGP) TXR050000 is also required, because of the discharge of stormwater associated with industrial activity. A SWMP (DFWIA 2016a) and a SWP3 (DFWIA 2016b) were developed by the DFWIA Environmental Affairs Department to satisfy these requirements.

DFWIA is a Level 2 MS4 under TPDES General Permit TXR040000. The primary driver for this plan is compliance with water quality requirements. Other goals include providing support for watershed management, habitat protection, recreation, ecosystem enhancements, and flood control requirements, as outlined in BMP #11 (SWMP). In addition, the water quality efforts consider the requirements and regulations described subsequently.

Compliance with TPDES MSGP TXR050000 is required because of the classification of airports as dischargers of stormwater associated with industrial activity. This MSGP requires the permittee to have a SWP3 (DFWIA 2016b) that describes efforts to mitigate against potential stormwater discharges from industrial activities. Although the impacts of the industrial discharges are considered part of the water quality assessment and modeling in this plan, mitigation of these discharges is addressed under that SWP3.

In addition to these permits, several other regulations should be review for compliance. Two FAA Advisory Circulars provide standards for drainage design and requirements for the prevention of wildlife attractants:

- AC 150/5200-33, *Hazardous Wildlife Attractants on or near Airports,*
- AC 150/5320-5, *Airport Drainage Design.*

Section 438 of the Energy Independence and Security Act (EISA) for federal facilities requires federal agencies to reduce stormwater runoff from federal development projects to protect water resources. It includes technical guidance for reducing stormwater runoff and pollution to comply with this Act. ACRP Research Report 174 (ACRP, 2017) provides guidelines for implementing green stormwater infrastructure at airports in the United States.

Because of the natural hydrologic processes that provide important functionality to GSI practices, the FAA Advisory Circulars and related federal stormwater management criteria are critical to the success of the GSI effort. The guidelines and criteria are relative to the SDMP and are discussed subsequently.

The Implementation Plan for Seventeen *Total Maximum Daily Loads for Bacteria in the Greater Trinity River Region* (NCTCOG 2013) establishes a path to address indicator bacteria in impaired streams in North Central Texas. Coordination with other stakeholders, under NCTCOG's implementation plan, helps contribute to monitoring efforts for indicator bacteria. Multiple watershed segments are included under this monitoring plan, including stream sections that cross through airport land, encompassing segments 0822A (Cottonwood Branch Creek), 0822B (Grapevine Creek), and 0841 (Bear Creek, Big Bear Creek, and Trigg Lake). The design of GSI takes these impairments into consideration.

Review of the Texas Commission on Environmental Quality (TCEQ) Surface Water Quality Viewer (https://www.tceq.texas.gov/gis/segments-viewer) shows the following stream segment bacteria impairments on or adjacent to DFWIA property:

- 0822B Grapevine Creek.
- 0822A Cottonwood Branch.
- 0841B Bear Creek.
- 0841J Estelle Creek.

All impaired segments are viewable on TCEQ's website (https://www.tceq.texas.gov/waterquality/tmdl/nav/tmdlsegments).

A summary of water quality monitoring is accessible through the Surface Water Quality Web Reporting Tool (https://www80.tceq.texas.gov/SwqmisPublic/index.htm).

2.3.1 Water Quality Overview

Potential pollutants have been identified that may enter stormwater through on-site operations. The Illicit discharge detection and elimination (IDDE) program concentrates on identifying illicit discharges or connections and finding solutions to correct or eliminate those discharges. The Environmental Affairs Department has created standard operating procedures (SOPs) to provide guidance to all operators that are part of the MS4 program. These SOPs are available from DFWIA upon request.

BMPs have been enacted for all Board-owned and tenant facilities with the intent to minimize the release of pollutants to the environment. Good housekeeping techniques are stressed to employees during training sessions and minimum acceptable protocols are defined in the SWP3.

BMPs can include nonstructural (measures or activities taken to minimize pollution) and structural controls. They are intended to eliminate or minimize the impact of environmental pollutants. A BMP Guidance Document (DFWIA 2018A) educates tenants on the various control measures that should be incorporated into their daily activities to prevent or reduce stormwater pollution. The BMP Guidance Document provides a list of common BMPs that can be implemented. All operators and tenants are expected to become familiar with the BMPs applicable to their on-site activities.

Structural controls are the physical features incorporated into the construction of a facility, infrastructure or system that are designed to reduce or eliminate environmental pollution of a specific collection system or increase safety. Common structural controls currently in use to provide treatment include the following:

- Oil/water separators
- Runway-taxiway swales
- Stormwater systems and drain filters (or similar systems designed to treat stormwater runoff)
- Rainwater harvesting

- Spill containment systems and ponds
    - Diversion valves and shut-off valves
    - Secondary containment structures

DFWIA monitors water quality and quantity of the MS4 through visual inspections and sampling from representative outfalls and monitoring locations shown in the SWMP. Outfalls are sampled for a wide range of parameters that include the following:

- pH
- Temperature
- Flow
- Dissolved oxygen (DO)
- Conductivity
- Chlorine
- Ammonia
- Surfactants
- Total petroleum hydrocarbons (TPH)
- Carbonaceous biochemical oxygen demand (CBOD)
- Bacteria (E. coli)
- Oil and grease
- Copper
- Zinc

Sampling results are reviewed and provided to TCEQ as part of DFWIA's Annual Report.

Tenants operating under the shared SWP3 are required to conduct all applicable hazardous metal effluent sampling for their respective leasehold if the tenant does not qualify for a hazardous metals waiver. Tenants operating under individual SWP3s are required to conduct all required benchmark, effluent, and visual monitoring identified in the MSGP for their respective leasehold or primary areas of operation.

2.3.2 MS4 Program History

To address water pollution, Congress enacted the Clean Water Act (CWA) amendments of 1987, which requires the United States Environmental Protection Agency (EPA) to develop a two-phase comprehensive regulatory program aimed at reducing water pollution produced from stormwater discharges. On November 16, 1990, EPA promulgated Phase I of these published regulations, which authorizes stormwater discharges under the NPDES. The Phase I NPDES program addresses stormwater discharges associated with medium and large municipalities.

Phase II of the NPDES program was promulgated on December 8, 1999 and expands the previous regulatory program by requiring permit authorization from small municipalities.

The TCEQ was delegated authority from EPA to administer the NPDES stormwater program on September 14, 1998; therefore, after September 29, 2000, when all NPDES permits expired, all industries covered under the NPDES program were required to apply for TPDES permit coverage through the TCEQ.

On August 13, 2007, TCEQ issued TPDES TXR040000, authorizing stormwater discharge to the state's surface waters from MS4s located in urbanized areas.

2.3.3 DFWIA Stormwater Program

DFWIA is a registered level 2 MS4 under the regulated number RN105481485. The Board (CN601700610) holds permit number TXR040044 for the small MS4, which is managed by DFWIA Environmental Affairs Department (EAD). As part of compliance, a SWMP was enacted to outline efforts for compliance with state and federal regulations. The SWMP outlines BMPs implemented or to be adopted to meet the following five minimum control measures (MCMs) developed by TCEQ:

1. Public education, outreach, and involvement.
2. Illicit discharge detection and elimination.
3. Construction site stormwater runoff control.
4. Post-construction stormwater management in new development and redevelopment.
5. Pollution prevention and good housekeeping for municipal operations.

Stormwater programs have been enacted to map, control, and monitor stormwater runoff from DFWIA. Adoption of stormwater ordinances and policies with legal authority to impose fines or similar penalties has been developed considering the following several factors:

- Flood control
- Watershed management
- Conveyance deficiencies and maintenance
- Water quality
- Habitat protection
- Recreation
- Ecosystem enhancements

DFWIA's Code of Rules and Regulations, Chapter 6A, Stormwater (DFWIA Rules, 2012), establishes uniform requirements and methods to control the introduction of pollutants into the airport municipal separate storm sewer system (MS4) to comply with the requirements of the TPDES permits. Article II of the regulation lists the only non-stormwater discharges permitted to the MS4. Permit years run from October 1 through September 30.

A benthic macroinvertebrate bioassessment was performed in and around the airport by the University of North Texas (UNT 2017a). The purpose of this multiyear monitoring study was to collect data that could be used to characterize water quality and biological conditions, identify significant long-term trends, and evaluate the effectiveness of programs designed to protect water resources within its watershed. Overall, benthic macroinvertebrate communities present in the MS4 receiving waters revealed a high aquatic life use, especially considering the urban setting of these streams. The bioassessment found that water quality programs implemented at DFWIA were protective of the habitat, especially in riparian areas of Bear Creek and Trigg Lake. Focused efforts on Bear Creek riparian areas have been established because of the potential to improve water quality. Efforts include mapping and researching environmentally sensitive areas, including endangered species and wetlands within the Waters of the United States (WOTUS) rule. Applicable regulations are monitored for habitat protection based on TCEQ, Texas Parks and Wildlife, and other pertinent regulatory entities.

In the past, two projects have impacted or removed natural wetlands within the boundary of the airport. In 1993, the construction of parallel runway 17L/35R on the east side of the property was approved, which impacted 4.25 acres of wetlands and 4.11 acres of other WOTUS. To alleviate this loss, a mitigation plan was created to replace the lost functions of water quality enhancement and wildlife protection. This mitigation included protection and enhancement of 2.9 acres of existing wetlands and the creation of 10.5 acres of new wetlands. The project was completed in 1996. In 2008, approval by TCEQ was obtained to rescind the watershed deed restriction within the MS4 to allow for the construction of a gas pad, drilling of gas wells, and the construction of a lateral gas line to service the wells located near the east runways. Construction was completed in 2008 and annual compliance reports were submitted to determine whether the development activities within the watershed were negatively affecting the function of the wetland mitigation area or the quantity/quality of water entering the wetland mitigation area. Within the 5 years documented, no quantity or quality changes were documented, and construction activities did not appear to impact the wetland mitigation area.

2.3.3.1 Stormwater Monitoring and Sampling

The Stormwater Sampling and Monitoring Plan (DFWIA 2016c) provides information on the quality of stormwater runoff. The stormwater analytical data obtained during the monitoring program is used to identify the types and sources of pollutants and to provide a means for evaluating potential environmental risks.

Stormwater monitoring and sampling efforts are identified in the MS4 and MSGP stormwater permits. The MS4 permit requires monitoring and sampling for those outfalls not covered under an individual permit. Tenants subject to MSGP requirements are also required to monitor stormwater quality.

2.3.3.2 Illicit Discharge Monitoring

As part of the IDDE monitoring program, all outfalls are inspected at least once a year. Reasonable attempts are made to collect background information regarding the drainage area for the outfall being inspected. Examples include stormwater system maps, as-built drawings, and similar resources referring to facilities and upstream areas the outfall supports. During site visits, outfalls are evaluated for structural and erosion problems and to determine if flow is present during dry conditions.

If flow is observed at outfall locations, a sample is taken and tested for general parameters. Visual assessments are performed to look at sheen, color, odor, and foam to determine the origin of the discharge. Should the discharge be deemed non-stormwater-related, samples are provided to a lab for testing, which may track the source of the illicit discharge. Photos are taken during inspection, and any structural or erosion problems found are reported for further evaluation.

2.3.2.3 Channel Inspections

Separate from illicit discharge efforts, airport channels and controls are monitored and maintained. Maintenance includes inspection and cleaning of trash and debris, control of vegetation, and general upkeep of the channels. Channels on the landside are monitored and maintained periodically. All channels are inspected at least once per permit term, and channels on the airside are monitored on a continuous basis.

Channel inspections are performed throughout the MS4, including areas around outfalls reported to have structural or erosion problems. These inspections are outlined in the SOP titled *Storm Water Drainage System Management,* which is geared toward monitoring and restoring channels, but it is also used to document other drainage issues found. Inspection criteria include slope instability and erosion factors, pipe submergence and blockages, location and placement near infrastructure, appearance of illicit discharge sheens or debris, and overall status of the channel.

2.3.3.4 First Flush System

DFWIA operates a first flush system that serves the airport by collecting runoff from the terminal and air cargo ramps and conveying it to the stormwater treatment plant. Additional detail can be found in **Section 2.1.2** and the technical memorandum detailing the analysis performed in **Appendix A.**

2.3.3.5 Green Stormwater Infrastructure

In addition to the structural BMPs implemented in the SWMP (DFWIA 2016a), Section 334 of the DCM requires GSI to be implemented for new and redevelopment projects for both airside and landside. GSI enhances natural hydrologic processes for water quality treatment and provides some mitigation for quantity. The 2014 Low Impact Development Design Guideline Report (DFWIA, 2014) has been replaced by the GSI guidance document developed as part of this SDMP and contained in **Appendix B.**

2.3.4 Water Quality Criteria Conclusions and Recommendations

Unless otherwise stated, the criteria set forth in this section applies primarily to new development on the DFWIA property, whether performed by the airport or by airport tenants, and for development adjacent to the airport property that is a result of airport water quantity or water quality mitigation performed by the airport.

There are DFWIA, municipal, TCEQ, and federal requirements for water quality that will require retrofit of redevelopment parcels to capture runoff and reduce pollutant loads. While iSWM recommends a static 1.5-inch water quality capture goal, a continuous hydrologic simulation based on a capture rate of 80% of average annual runoff was performed in support of the development of the Green Infrastructure Guidance Manual contained in **Appendix B**. The results of the simulation are shown in **Figure 2-4** with the water quality depth expressed in inches as a function of the percent impervious and the design drain time.

Potential changes in effluent guidelines and changes due to new construction require DFWIA to continue efforts to properly collect, store, and dispose of aircraft and pavement deicing chemicals for the 60% collection tier.

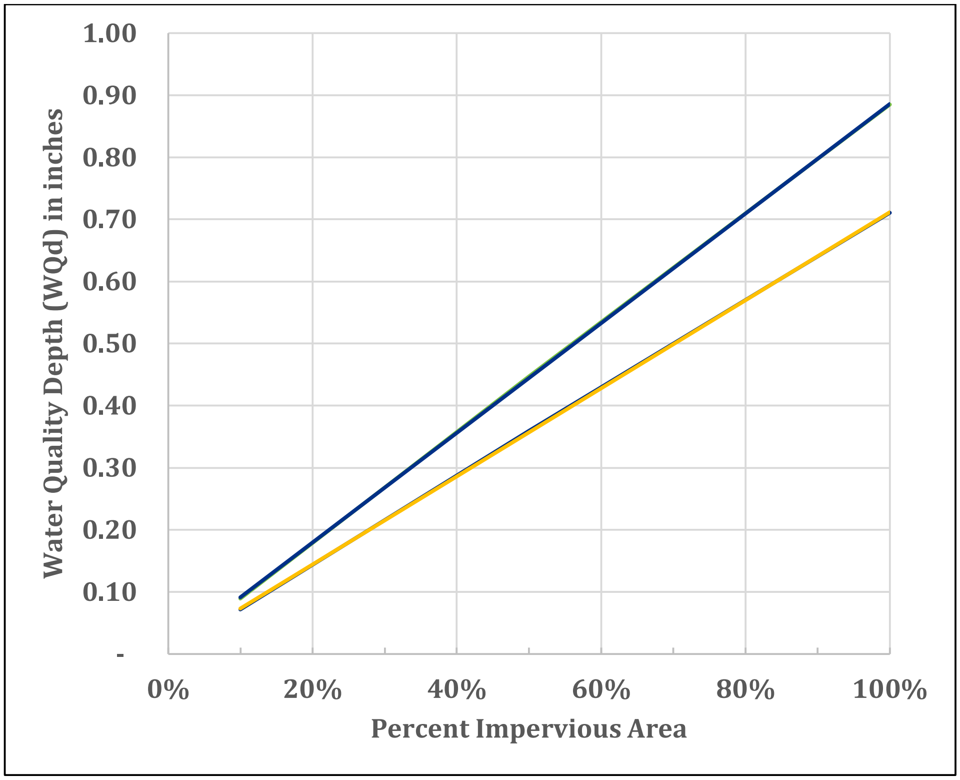

Figure 2-4
Water Quality Depth (in watershed inches) for 80-Percent Capture of Average Runoff Volume (UWRI 2020)

2.4 Data Collection, Inventory, and Management Criteria

Data from DFWIA-owned GIS data, design documents, the 2010 DFWIA Hydrology Gap Analysis, and supplemental GIS data sets covering areas outside airport property developed by third parties–NCTCOG and Texas Department of Transportation (TxDOT) were inventoried with descriptions in the Stormwater Geospatial Data Management Review technical memorandum (**Appendix C**).

The following information is utilized in the Plan:

- NCTCOG:
  - Topographic LiDAR
  - Landuse (for areas outside DFWIA coverage)
  - Soils (based on the Natural Resources Conservation Service, published January, 2007 as the Soil Survey Geographic (SSURGO) database)

- FEMA:
  - Existing regulatory flood hazard boundaries
  - Existing FEMA Letter of Map Revision (LOMR) information
  - Existing FEMA regulatory model information:
    - Cross Sections
    - Structures
    - Basins
    - Flow Paths

Additionally, approximately 12,000 pages of as-built drawings supplements the data collection. The drawings provide locations of stormwater infrastructure and invert elevations.

Current data archiving practices for as-builts files (stored as PDFs) include file server storage and cataloging using contract numbers. Corresponding contract numbers are associated with digital stormwater infrastructure data, though no dynamic link exists.

2.4.1 DFWIA Underground Utilities Geodatabase

Spatial data is maintained by the DFWIA Energy, Transportation, and Asset Management (ETAM) Department in a series of file geodatabases. These data are updated as needed at the feature level and outside of an ESRI Enterprise environment. Planned migration to an enterprise GIS environment will allow for multi-user editing, a formalized and controlled quality review process, and version control.

Additionally, DFWIA continues converting existing and new underground utilities computer-aided design (CAD) data into GIS. These data will be added to the master, stormwater database where appropriate.

DFWIA ETAM has deployed the following Esri suite to support GIS tasks:

- ArcGIS 10.3 for desktop system requirements
- Enterprise/SDE
- ArcGIS Online to supporting web/mobile applications

2.4.1.1 Geographic Information Systems

A record of GIS-based data has been updated and developed to support the Plan and help guide future developments. GIS data provide an inventory of assets, allows assessment of important system components and constraints, and identifies potential locations for implementing BMPs.

Information in GIS format is made available to developers with the purpose of assisting in the process of planning and designing new projects. Geospatial data on drainage infrastructure, floodplains, drainage basins, topography, soils, environmentally sensitive areas, land use, streamflow, rain gauges, and watershed monitoring sites, among others, will be made available to developers to facilitate a comprehensive evaluation of stormwater management strategies.

To this purpose, an intranet GIS application is maintained to facilitate internal access to updated geospatial data pertaining to stormwater management.

2.4.1.2 Survey

The only area where surveying was conducted was within the Cottonwood Creek watershed, as detailed in the watershed report contained in **Appendix E**. The remainder of the airport's topographical information used to inform the development of the watershed drainage models was derived from the 2007/2015/2017 Lidar, geodatabase, as-builts, or previous work performed by DFWIA.

2.4.2 Local, State, and Regional Data Sources

Additional data were acquired as need from the following outside entities:

- NCTCOG
  - Light detection and radar (LiDAR)
  - Land use/land cover
- TxDOT
  - As-builts–bridges/structures
- FEMA
  - U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center–River Analysis System (HEC-RAS), Hydrologic Engineering Center-2 (HEC-2) riverine models
- U.S. Department of Agriculture
  - Soils

2.4.3 Plan Refinement

To support the modeling efforts and future needs that will rely on an accurate and complete GIS, invert elevations to stormwater infrastructure of 36 inches and greater were used in the development of the watershed models as detailed in the individual watershed reports contained within Appendix E. These data were obtained from scanned as-builts will continually be field verified and geo-referenced to improve the accuracy of the hydraulic models developed for the Plan.

DFWIA ETAM will continue to convert and maintain stormwater infrastructure within the Esri Stormwater Utility Data Model with the associated geometric properties, such as inverts, populated. This data model represents the industry standard, provides standardized naming conventions, and allows inclusion of Esri's tools/functionality seamlessly. Esri tools support inventory maintenance, inspections, and the use of mobile devices for field crews. In addition, the stormwater data model can be used to identify core NPDES information and can be extended to support local regulations. Data specific to DFWIA's stormwater system (such as contract IDs) are stored and maintained within the stormwater model without affecting core functionality.

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Section 3

Model Data Collection and Evaluation

A significant amount of as-built information is available on the DFWIA stormwater system. This section of the report discusses the steps to gather data for the evaluation and assessment of the existing stormwater system and proposed improvements.

The project approach was to gather and assess existing data on the DFWIA stormwater system, including previous studies, reports, and modeling efforts. DFWIA provided a robust GIS database of existing stormwater infrastructure, which was used to establish an initial plan and to inform the development of the models.

Data collection is required to compile the necessary information for the modeling of the H&H elements of the existing stormwater system.

DFWIA was the major source of the data, though data were also collected and reviewed from state and federal agencies. A description of the data obtained, its role in the modeling effort, and where applicable, the necessary modifications required, were used in the stormwater system evaluation.

3.1 Stormwater Models

A variety of stormwater models have been applied at and around DFWIA over the years, including the following:

- USACE HEC-1, HEC-2, Hydrologic Modeling System (HMS), and RAS models as developed by FEMA and its contractors for FISs and FIRMs.
- An existing Stormwater Management Model (SWMM) representation of the first flush system developed by Halff Associates, Inc.
- Multiple small models on various platforms that were developed to support the design and analysis of the existing DFWIA stormwater system.

Various existing and available modeling tools for the Plan were evaluated. Based on this evaluation, the EPA SWMM version 5 was selected for the Plan because SWMM met the following criteria:

- Consistent with the DFWIA SDMP goals and redevelopment needs (e.g., levels of detail, model updating, permitting).
- Model credibility and acceptance.
  - Technically correct with demonstrated performance of stormwater master plans; accepted by FEMA and EPA.
- Public domain program with access to the source code.
  - Models can be exchanged freely and applied by various architect/engineering (A/E) teams as part of ongoing development at DFWIA.

- The model engine and graphical user interface (GUI) may be downloaded from the EPA website (EPA SWMM)).

- User-friendly within the limits of data constraints.
  - Regularly available training.
  - GUI to aid in data entry and results interpretation.
  - Readily coordinated with GIS data.
  - Quality of documentation.
- Flexible and adaptable to specific DFWIA needs.
  - Uses existing DFWIA and the cities' databases.
  - Represents key elements of stormwater management system (closed conduits, control structures and outfalls, irregular and/or regular cross sections, above- and belowground storage elements, boundary conditions).
  - Calculates flows, velocities, and water surface elevations.
  - Considers backwater and surcharged pipe flow conditions.
  - Simulates flow reversals and interconnections.
  - Represents small basins (tens of acres) and large basins (hundreds to thousands of acres).
- Maintenance and support of model by developers and users.
  - User groups and help manuals may be found on the same website (https://www.epa.gov/water-research/storm-water-management-model-swmm), and SWMM user groups are available on the internet for discussion topics (www.openswmm.org).
  - Model is updated and enhanced periodically.

3.2 Rainfall and Design Storms

For previous studies, rainfall distributions were generated for six recurrence intervals (1-, 2-, 5-, 10-, 25-, and 100-year events) of 24-hour duration design storms for each of the eight modeled watersheds. The National Oceanic and Atmospheric Administration (NOAA) finalized its Atlas 14-point precipitation frequency estimates for Texas in 2018. These values are used as the new standard for rainfall estimates. For all design storms, the U.S. Department of Agriculture Natural Resources Conservation Service's (NRCS, formerly Soil Conservation Service [SCS]) Type II 24-hour hyetographs are used with Atlas 14 storm volumes.

3.3 Soils and Geotechnical Data

Soils data for the airport property were obtained from NCTCOG, for which data originate from, NRCS's Soil Survey Geographic database, published in January 2007.

The hydrologic model within SWMM uses both soil storage and infiltration rates to determine the volume of surface water runoff and infiltration in pervious land areas. Soil capacity (or soil storage) is a measure of the amount of storage (in inches) available in the soil type for a given antecedent moisture condition. An average antecedent moisture condition is used for all design storm analyses. Soil capacities are estimated based on the NCTCOG iSWM Hydrology manual as shown in **Table 3-1**.

Table 3-1 Global Horton Infiltration Parameters

Hydrologic Soil Group	Maximum Infiltration Rate (in./h)	Minimum Infiltration Rate (in./h)	Decay Rate (1/h)	Drying Time (days)	Maximum Soil Storage (in.)
A	9.0	0.50	2.0016	2.1	5.00
B	6.0	0.25	2.0016	2.1	3.80
C	4.0	0.10	2.0016	2.1	1.40
D	2.0	0.05	2.0016	2.1	1.0

3.4 Land Use and Impervious Areas

Examination of the Land Use GIS shapefile reveals 16 different land uses. The land use codes within DFWIA were aggregated into 10 land use classes as detailed in the Stormwater Modeling Methodology contained within **Appendix D**. Each land use class has unique parameters for percent impervious, percent of directly and nondirectly connected impervious areas (DCIA and NDCIA, respectively), and pervious and impervious cover roughness factors. For airside areas, the actual percent imperviousness was measured, with the remaining portion classified as "Forest, Open, & Park." Additional details regarding land use and impervious areas within each watershed can be found in the individual watershed reports contained in **Appendix E**.

For areas outside DFWIA, the NCTCOG GIS land use files were used. Gaps within this coverage for roadway areas were assigned conservatively as "light industrial" land use, because they are composed of a mix of impervious and grassed areas.

3.4.1 Existing Conditions

For this study, existing land use is defined as year 2017, derived from DFWIA land use data collected on May 31st, 2017, and provided as part of the airport geodatabase for that year.

3.4.2 Future Conditions (Airport Layout Plan)

Future conditions were not evaluated as part of this initial Plan development. The existing conditions watershed models developed will be updated based on the DFWIA Airport Layout Plan (ALP) to allow for analysis and refinements to the ALP as appropriate.

3.5 Topography

Topographic data define the hydrologic boundaries, overland flow slopes, channel floodplains, critical flood elevations, and stage-storage area relationships and is provided from the following four major sources:

- Existing survey data
- 2007, 2015, and 2017 LiDAR survey by NCTCOG:
    - Coppell (2015)

- Euless (2007)
- Grapevine (2015)
- Irving (2017)
- Fort Worth (2015)

- As-built plans for landside and airside construction, upgraded roadway crossings, and improvements to the PSMS (obtained from both DFWIA as well as the surrounding municipalities and TxDOT).
- Site-specific topographic survey.

3.6 Stormwater Facilities, Inventory, and Geodatabase

The DFWIA PSMS consists of streams, culverts, bridges, control structures, underground pipe networks, vaults, a first flush system, and detention ponds. Field investigations have and can continue to assist in updating the definition of the hydraulic network.

As part of the development of the Plan, additional field surveys provided for cross sections and structures to augment the previous work. A survey was collected referencing the North American Vertical Datum of 1988 (NAVD88) in accordance with FEMA Data Capture Standards.

3.6.1 Survey, As-Built, and GIS Inventory

DFWIA Geodatabases are noted as the best available data as detailed in the Stormwater Geospatial Data Management Review Technical Memorandum contained in **Appendix C**. These data represent the complete GIS database of DFWIA and include data that will not be used in the final stormwater geodatabase. The stormwater geodatabase will be compiled largely from data gathered from the utilities and environmental geodatabases. Other geodatabases contain useful reference information but are not expected to contribute data to the final stormwater geodatabase.

Review of the data revealed more than 15,000 features compromising approximately 154 miles of conveyance piping ranging in size from 1” to 264” were contained within the “storm line” coverage, none of which contained invert elevations. 12,000 pages of as-built drawings were used to extract invert elevations, georeferencing the applicable sheets within GIS, and using the information to populate the inverts of the “storm line” coverage for pipes equal to or greater than 24 inches in diameter. The as-built plans also were used to inform the development of the individual watershed models with respect to the coding of existing stormwater infrastructure.

3.6.2 PSMS

PSMS modeling was performed using SWMM. This modeling effort assessed underlying causes of flooding and erosion issues in the system and predicted areas of concerns, preventing further issues from occurring. Because of the immense amount of data received, a comprehensive review of the existing stormwater system determined that pipes 36 inches and larger would be modeled to represent the PSMS, to represent the stormwater system accurately at a masterplan level of detail. In multiple locations, pipes smaller than 36 inches were modeled to allow for better definition of complex systems and to ensure all areas within each watershed were represented accurately.

3.7 Water Quality Data

DFWIA has ongoing water quality goals along with modeling, monitoring, and reporting information. The airport has an existing water quality initiative and is actively seeking opportunities to improve the quality of water discharged from DFWIA to the area receiving waters. Additional details on existing and proposed water quality initiatives are contained within the Green Stormwater Infrastructure Manual developed as part of this Plan and is contained within **Appendix B.**

3.8 Lakes and Wetlands Data

There are wetlands present within DFWIA proper, with approximately 30 acres within the overall area covered by the eight watershed models. In accordance with FAA guidelines, DFWIA does not allow the use of wet detention structures and prohibits standing water to minimize the risk associated with fog and animal attractants.

3.8.1 Trigg Lake

Trigg Lake, located south of South Airfield Drive within the Big Bear Creek watershed, is approximately 41 acres. It was constructed in 1981 to provide irrigation for Bear Creek Golf Club. It has been classified as an intermediate-sized, significant hazard dam by TCEQ, and assigned inventory number TX05801.

Dam breach analyses and drainage studies and reports relating to Trigg Lake and its spillway were used to define discharge parameters in the Bear Creek watershed model.

3.8.2 Wetlands

Because the fog and wildlife prohibitions associated with the airport wetlands are very limited within the DFWIA watersheds, there is a 3.4-acre wetland located in the northwest portion of the Big Bear Creek watershed, just southeast of Ira E. Woods Avenue. The only other known wetland spans 27 acres at the downstream end of the Cottonwood Creek watershed, in the southeast corner of the intersection of W. Bethel Road and TX State Highway 121. These wetlands developed either naturally or were constructed as mitigation requirements.

3.9 Studies and Reports

In the past, H&H modeling studies, mainly utilizing HEC-HMS and HEC-RAS, of the stormwater infrastructure and portions of contributing watersheds have been developed on a project-level-of-detail basis. The scope and extent of these individual studies vary depending on the issues that were assessed and the different studies' objectives (i.e., development, design, floodplain delineation, performance evaluations, etc.).

These previous studies are useful as groundwork and reference for the comprehensive planning purposes of this initiative. When FEMA model(s) are available, relevant information will be used to inform development of the SWMM models and model validation.

Previous studies and reports, along with existing FEMA models, were used to inform the development of the existing conditions watershed reports contained in **Appendix E**.

3.10 Known Problem Areas

Major flooding has not been a significant issue in the past at DFWIA. In **Section 2**, **Figure 2-2** provides a 100-year floodplain map for the airport and surrounding area. Modeling of DFWIA watersheds focused on delineating the constraints to determine causes and provide options for resolving potential flooding issues. Figures detailing existing areas of inundation for the full range of storm events are contained within each individual watershed report. FEMA FIRMs establish the effective regulatory elevations and areas by jurisdiction. The DFWIA SDMP design event inundation maps do not replace the FEMA FIRMs as the effective regulatory floodplain document with respect to elevations and areas but are used as boundary conditions for the development of the event inundation maps on DFWIA property. They are intended to identify problem areas and assist with the identification of flood reduction benefits for mitigative measures. These inundation maps provide development and/or design guidance in locations not covered by FEMA FIRMs or where the SDMP models show higher flood stages and greater areas of inundation.

Existing conditions watershed models revealed some areas of flooding, both landside and airside. Several of these areas are confirmation of known flooding issues while others are new and warrant additional investigation moving forward. Additionally, widespread erosion was noted during watershed field investigations and corroborated through rapid screening procedures as part of the watershed modeling efforts. The detailed watershed analyses for each of the eight watersheds is contained in **Appendix E**.

As discussed in **Section 2.3.2**, periodic channel inspections aid in tracking and monitoring erosion and drainage problems. To establish risk, areas are graded based on the severity of the following aspects:

- Structural condition of outfalls
- Sediment buildup
- Plant growth/debris accumulation
- Ponding
- Erosion and general channel integrity
- Animal activity
- Bank plant coverage
- Dam conditions (if applicable)
- Riparian buffers
- Environmentally sensitive areas

A ranking system classifies the risk of an area. The higher the risk factor, the higher the score assigned for that aspect. Criteria scores are added together and multiplied by a scaling factor to prioritize areas on the airside or those that threaten the structural integrity of infrastructure. Priority sites chosen through this ranking system are being used to develop erosion control and stream restoration projects. Information from these inspections provide approximate conditions of the PSMS to better predict drainage concerns before they risk the integrity of key infrastructure.

In addition to these inspections, the watershed models were used to identify potential areas at risk for erosion. Open channels with velocities in excess of 3 feet per second (fps) for the 1-year storm event were flagged as being potentially erosive. Additional details can be found within the individual watershed reports in **Appendix E**.

3.11 Climate Change

DFWIA is committed to pursuing resiliency in the face of global climate change. The foundation of this pursuit is to understand the best available science regarding anticipated impacts to climate in the area. ACRP Research Report 147 provides guidance to understanding the impacts climate change may have upon DFWIA.

ACRP Research Report 147 provides valuable insight on the risks that may result from anticipated changes in temperature. The average number of hot days and humid days per year are expected to significantly increase. These increases are expected to adversely impact pavement integrity; increase heating, ventilation, and air conditioning (HVAC) demand and duration; potentially impact the electrical grid resulting in higher utility costs; and increase building maintenance needs.

While impacts resulting from increased temperature are more easily quantified, potential impacts to precipitation and, therefore, design rainfall depths, are significantly less certain. The Airport Climate Risk Operational Screening (ACROS) precipitation projection tool shows no significant variation in the rainfall depths and provides no prediction on rainfall intensities from climate change in the airport area. A detailed climate change report has been developed as part of the master planning effort and is contained in **Appendix F**.

The Global Climate Models (GCMs) used in the U.S. National Climate Assessment show significant agreement that temperatures are expected to increase as a result of climate change. However, the models reveal significant uncertainty in the impact that the increased temperatures may have upon precipitation in Texas. Regardless of this uncertainty, EPA has developed a tool that allows users to estimate future rainfall probabilities by averaging the results of the various GCMs. This tool, SWMM-CAT, is available on the SWMM website (EPA SWMM).

The watershed models developed as part of the Plan include an assessment of the potential impact of climate change. The upper bound of the 90% confidence interval for the 100-yr 24-hour storm is 12.5 inches. This value is within 4% of the 500-yr value of 12.0 inches, therefore the 500-yr rainfall depth was increased to 12.5 (within the 90% confidence bounds of 8.01-17.1) to represent both the 500-yr event as well as the 100-yr event inclusive of climate change. While this method does not explicitly incorporate climate change predictions, it facilitates resiliency against extreme events through proven statistical methods to reduce uncertainty in design storm estimates. The Plan requires this approach for appropriate design criteria to protect critical infrastructure from stormwater impact.

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Section 4

Model Development and Existing System Evaluation

4.1 Hydrologic & Hydraulic Model Development

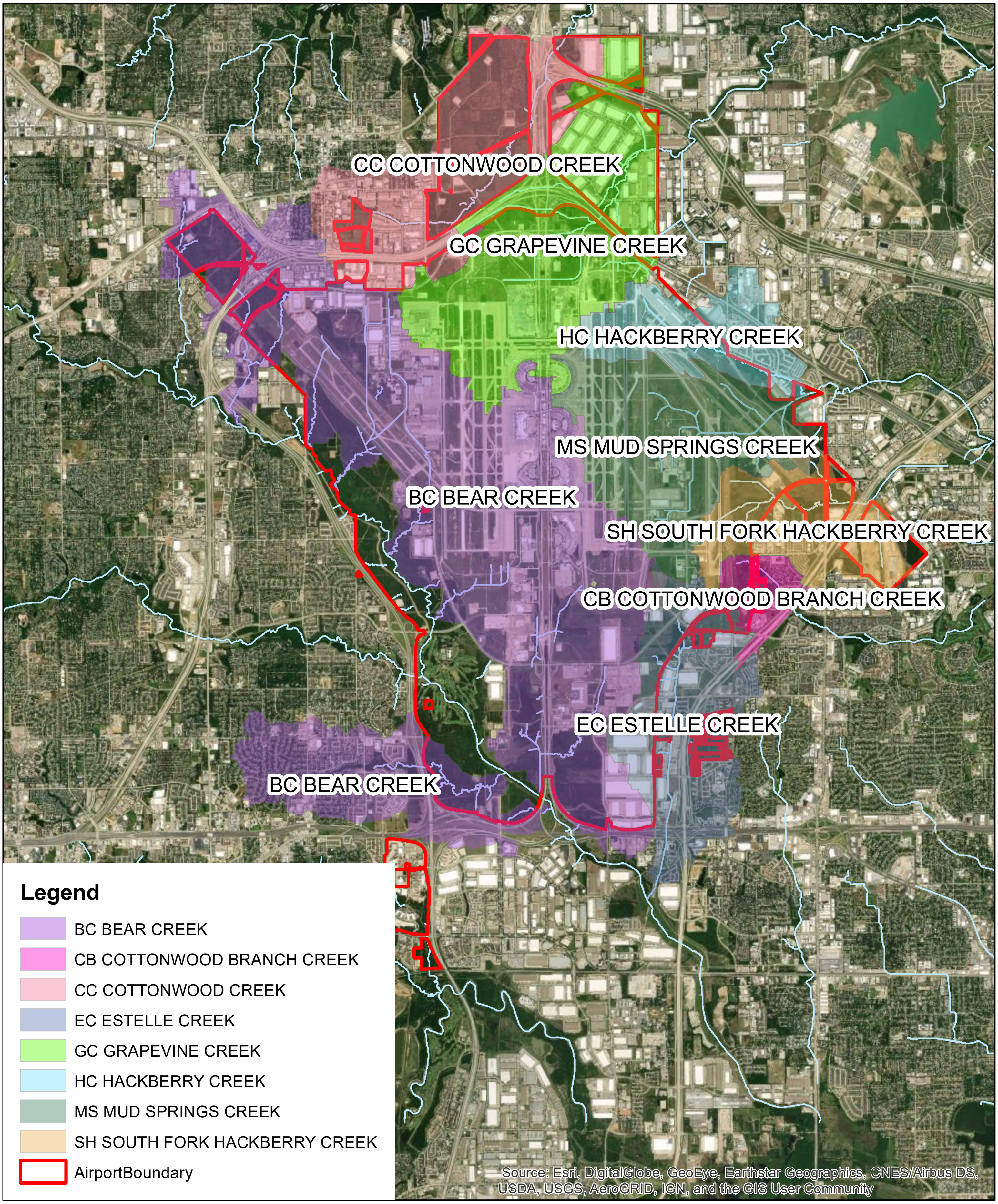
The stormwater system at DFWIA, including its contributing watersheds, were evaluated by developing H&H models to facilitate the analysis of conveyance and water quality issues. The modeling of the PSMS was performed using SWMM. This modeling effort assessed underlying causes of flooding and erosion issues in the system and predicted areas of concern, preventing further issues from occurring. Models were built to simulate existing land use conditions representative of May 2017 for all eight major watersheds contributing to DFWIA. Detailed watershed reports were developed for Cottonwood Creek, Grapevine Creek, Hackberry Creek, South Fork Hackberry Creek, Mud Springs Creek, Estelle Creek, Bear Creek, and Cottonwood Branch Creek, as shown in **Figure 4-1** and **Appendix E**. The overall watershed boundaries shown in **Appendix E** are representative of the watershed boundaries prior to the watershed analyses being performed. **Figure 4-1** shows the updated watershed boundaries that were developed individually during the detailed modeling of each watershed.

The developed models represent the PSMS and were used to accomplish the following:

- Determine baseline hydrology and hydraulic conditions for the basins.
- Assess the system's drainage characteristics for established design storm events.
- Provide sufficient level of detail for FEMA floodplain delineation requirements (not performed as part of this masterplan effort).
- Identify possible causes of existing flooding and erosion problems.
- Determine and conceptually size system components.
- Analyze stormwater management approaches such as GSI strategies.

The evaluations also consider other system aspects that may place constraints on future development.

Proper evaluation of existing stormwater facilities (conveyance and storage) is critical in effectively managing flood and erosion risk, capital improvements, water quality issues, and future development. As part of establishing a comprehensive approach for managing stormwater, models of the H&H for the eight major contributing watersheds are necessary. These models provide the foundation and necessary framework to address water quantity and water quality concerns. The models provide the ability to evaluate opportunities for improvement and resolve other issues associated with future development.



N W E S

0 0.5 1 2 Miles

DFWIA SDMP
Figure 4-1
Major Watersheds
Final Modeled Boundaries

4.1.1 Hydrologic Parameters

Hydrologic features can be characterized using parameters that represent a simplified version of the stormwater system to better understand and predict its behavior. The following hydrologic parameters were defined in each of the watershed models:

- Topographic Data – These data were used to define hydrologic boundaries, overland flow slopes, channel floodplains, critical flood elevations, and stage-storage area relationships.
- Hydrologic Units – These units are natural physical features or constructed stormwater management systems that control and direct stormwater runoff to a common outfall.
- Rainfall Intensities and Quantities – NOAA Atlas 14, volume 11, version 2 was used to determine rainfall depths for six recurrence intervals of 24-hour duration design storms as shown in **Table 4-1.**

Table 4-1 NOAA Atlas 14 Rainfall Depths

24-hour Storm (in.)	1-year	5-year	10-year	25-year	100-year	500-year
	3.3	5.0	5.9	7.1	9.2	12.0

Additional details with respect to other hydrologic parameters such as land use and impervious area, soil types and characteristics, surface roughness, and depression storage can be found in the modeling methodology in **Appendix D**.

4.1.2 Hydraulic Parameters

As previously noted, models are simpler, easier to understand, and easier to modify than the system they represent. Even though they can never represent reality perfectly, they must be similar enough to accurately replicate or predict the system's performance. The level of simplification adopted by modelers when constructing a model greatly depends on the objectives and scale of the modeling exercise. For instance, models used for design support often are more detailed, with most of the system's infrastructure elements represented. Models used in planning studies usually are less detailed, preserving only those characteristics of the system that are essential for assessing performance and aiding in the decision-making process.

SWMM H&H models use a node/link representation of the PSMS. The nodes are located at places of significance, from a modeling perspective. For example, nodes can be located at points along a pipe system where there is a change in material, size, flow direction, or a significant inflow; upstream and downstream from bridges and structures; stream intersections; gauge locations; problem areas; or potential future development connections. Links represent the linear elements that move water from one node to another in the conveyance system, such as pipes and channels. For the Plan, only pipes with diameters greater than or equal to 36 inches are modeled.

H&H boundary conditions provide for accurately simulated peak stages and flows throughout the system. Existing FEMA models provide for boundary conditions where available. In locations where FEMA information does not exist, local stream gauges were used; in cases where neither exist, engineering judgement established the model boundary conditions.

Additional details with respect to hydraulic data used in analyzing each of the DFWIA watersheds can be found in the modeling methodology in **Appendix D.**

4.2 Model Results

After the watershed models were developed, they were run for the full range of storm events, to allow for the analysis of the existing infrastructure. Results from each storm were used as follows:

- 1-year – Peak velocities from the 1-year event are evaluated to identify areas potentially at risk for erosion, identified as open channels with velocities greater than 3 fps.
- 5-year – Airside peak stages from the 5-year event were reviewed to identify areas of potential flooding onto the edge of taxiways and runways per FAA criteria.
- 10-year – Airside peak stages were reviewed to confirm that the center 50% of runways, taxiways, and helipads were free from ponding per FAA criteria.
- 25-year – The 25-year peak discharges were established as a baseline against which future development will be measured. While the 25-year storm may be the regulatory storm of record, it is recommended that the entire range of storms be reviewed to confirm that post-development peak discharges do not exceed those of predevelopment.
- 100-year – The 100-year event was simulated to allow for the development of inundation maps to use in comparing with the regulatory FEMA floodplains, and to provide a baseline for protection in areas not covered by FEMA.
- 500-year – The 500-year event was simulated to evaluate overall system performance under extreme precipitation.

Results of all the storms simulated are contained within the individual watershed reports in **Appendix E**.

4.3 Problem Areas

4.3.1 Existing System Assessments

Stormwater system assessments address water quality, quantity, flood, and erosion issues. These assessments document current flooding issues, streambank issues, and stormwater features that are deficient in meeting stormwater requirements, structures, developments within flood-prone areas, channels that have ponding, and erosion issues.

The assessments also evaluate compliance with environmental aspects of the system such as water quality, wildlife, wetlands, riparian zones, and endangered species and constraints these aspects place on future developments.

The watersheds were evaluated against the criteria identified in **Section 2** to confirm known problem areas and identify additional areas potentially at risk for flooding and/or erosion. A complete summary of all identified problem areas is in the individual watershed reports in **Appendix E**.

Section 5

Alternatives Development and Evaluation

This section summarizes the process used to develop and screen conceptual alternatives to meet level of service (LOS), assess the viability of these alternatives, and identify alternatives for future implementation.

5.1 Identification of Alternatives

Improvements to the stormwater drainage system typically are identified based on deficiencies observed during scheduled channel inspections and day-to-day-operations. Priority is given to those issues that impact airfield operations or threaten the structural integrity of key infrastructure elements. Historically, improvements have been reactionary, namely, rehabilitating faulty infrastructure or serious erosion problems in the systems channels.

A more proactive approach to the management of the drainage system is being implemented, which takes advantage of collaborative initiatives between projects and overall improvements to the system. Watershed models were developed to identify potential flooding, erosion, and water quality issues to develop sound solutions. Channel improvement projects will not only work to repair heavily eroded areas but restore open channel hydraulic and ecological functions.

Although GSI strategies already have been introduced into the planning process, the Plan focuses on formalizing the implementation of these strategies into the planning, design, operation, and maintenance of future development. These strategies not only address water quantity but also water quality issues associated with development, strengthening compliance programs and improving the quality of biological systems inside and outside the airport.

Finally, the Program (see **Section 1**) will provide not only the means to execute recommendations but also will establish the processes for the periodical revision of the Plan and other Program components (including design criteria and O&M procedures). In this manner, stormwater management remains dynamic and continues to improve in response to new information, changes in regulation, and/or organizational priorities.

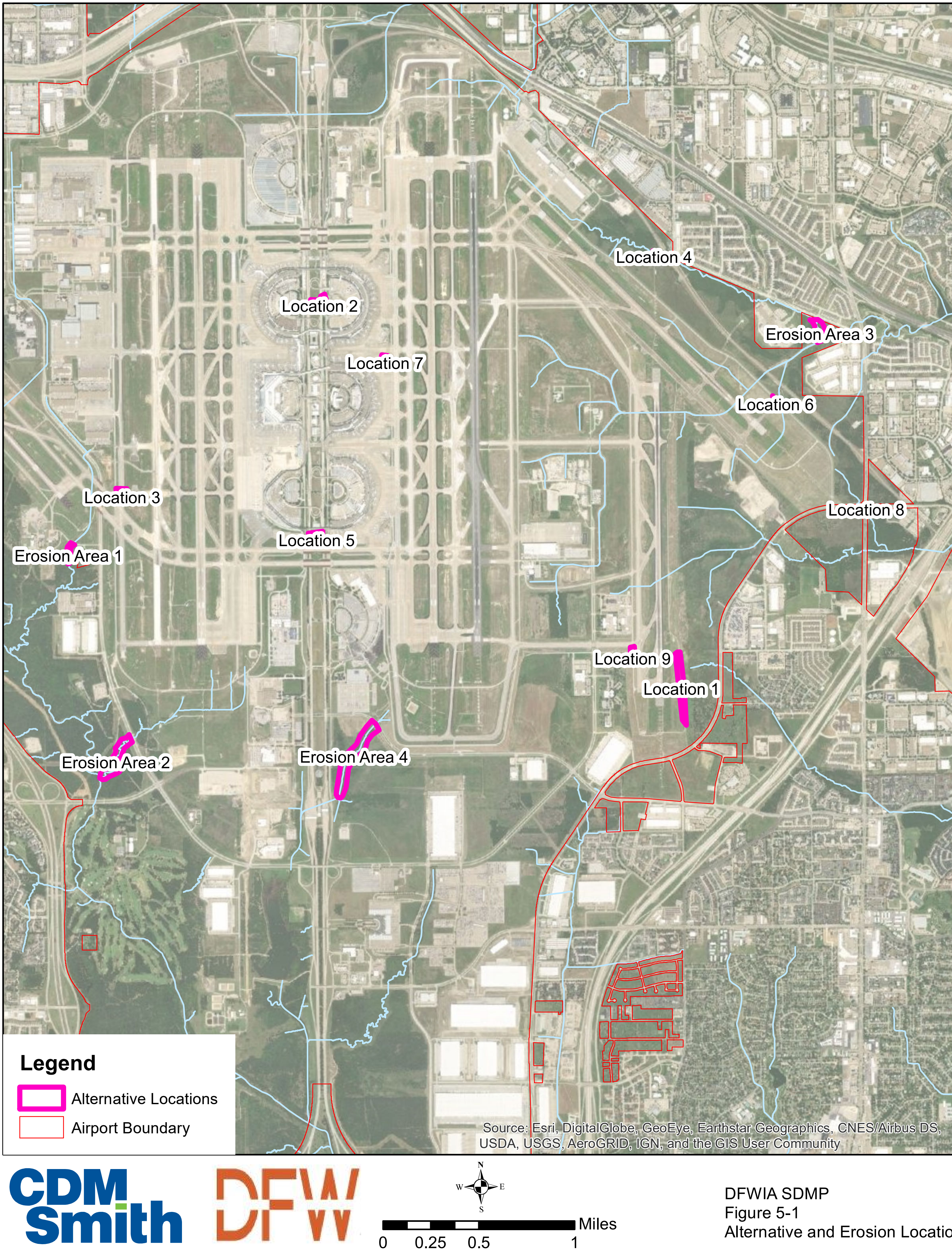
The initial screening criteria to identify areas for alternative improvement analysis was the FAA surface drainage standards presented previously in **Section 2** and repeated here in **Table 5-1**. The individual watershed models evaluated the existing systems and areas that potentially do not meet FAA standards were flagged. Additional areas that exhibited flooding also were presented for inclusion in the alternatives evaluation.

Table 5-1 FAA Minimum Surface Drainage Standards[1]

Facility Type	Design Storm Return Period (years)	Design Storm Duration (hours)	Notes
Taxiway and Runway Pavement	5	24	No ponding encroaching on edge of pavement A ponding limit of 4 inches around apron inlets
Runway, Taxiway, and Helipad Centerlines	10	24	Center 50% free from ponding
Landside Areas	10	24	
Depressed Pavement Sections and Underpasses	50	24	

Notes:
1. Based on FAA Advisory Circular 150/5320-5 Airport Drainage Design. For areas other than airfields and heliports, check the appropriate local regulatory agency for guidance on design storm requirements.

Nine flooding improvement areas and four channel erosion locations were identified as shown in **Figure 5-1** for areas requiring further analysis and inspection after appropriate storm events.



DFWIA SDMP
Figure 5-1
Alternative and Erosion Locations

5.1.1 Improvement Alternative Location 1 (Tier 3)

Location 1, found within the Cottonwood Branch Creek watershed, is located along the existing Aircraft Rescue and Fire Fighting (ARFF) Road that runs parallel to the southern end of Runway 35R. ARFF Road exhibits flooding for the 5-year, 24-hour design storm event as shown in **Figure 5-2**.

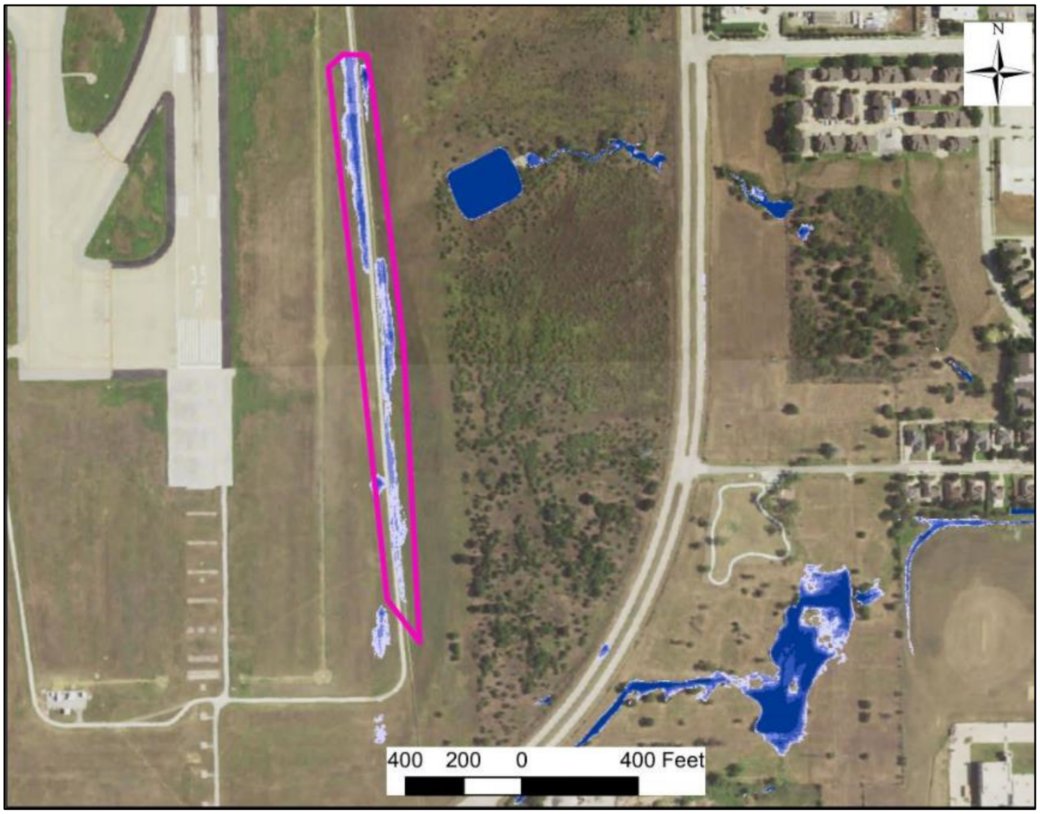


Figure 5-2
Flooding for 5-yr Storm along ARFF Road Adjacent to Taxiway 35R

There is a roadside ditch on either side of the ARFF road. The ditches are not well defined by LiDAR on southern half of this area, particularly on the east side of the road. Review of the existing watershed model suggests the ditches have near 5-year design storm capacity and the water levels during the 5-year design storm are at the edge of road. North of the outfall, the ditches are larger and better defined by LiDAR. These ditches are flowing north, carrying runoff from Cottonwood Branch Creek into South Fork Hackberry Creek. In the west ditch there is approximately 1,500 linear feet between the last inlet at the north end of Cottonwood Branch and the first inlet at the south end of South Fork Hackberry and it is here, in the northern end of Cottonwood Branch that there is the greatest potential for road overflow.

The improvement evaluation includes adding an inlet in the west ditch, along with a 24” RCP flowing north into the South Fork Hackberry system and connecting to the existing inlet and 39” RCP, as shown in **Figure 5-3**, effectively expanding the South Fork Hackberry storm drain network further to the south. This would break up the 1500 LF of ditch into two sections joined by an inlet. It will also be necessary during the detailed design phase to modify grades in the existing ditch to convey runoff to the new inlet. This will reduce the potential for road overtopping by pulling surface runoff into the storm network where there is greater capacity, providing a 5-yr level of service for the ARFF Road.

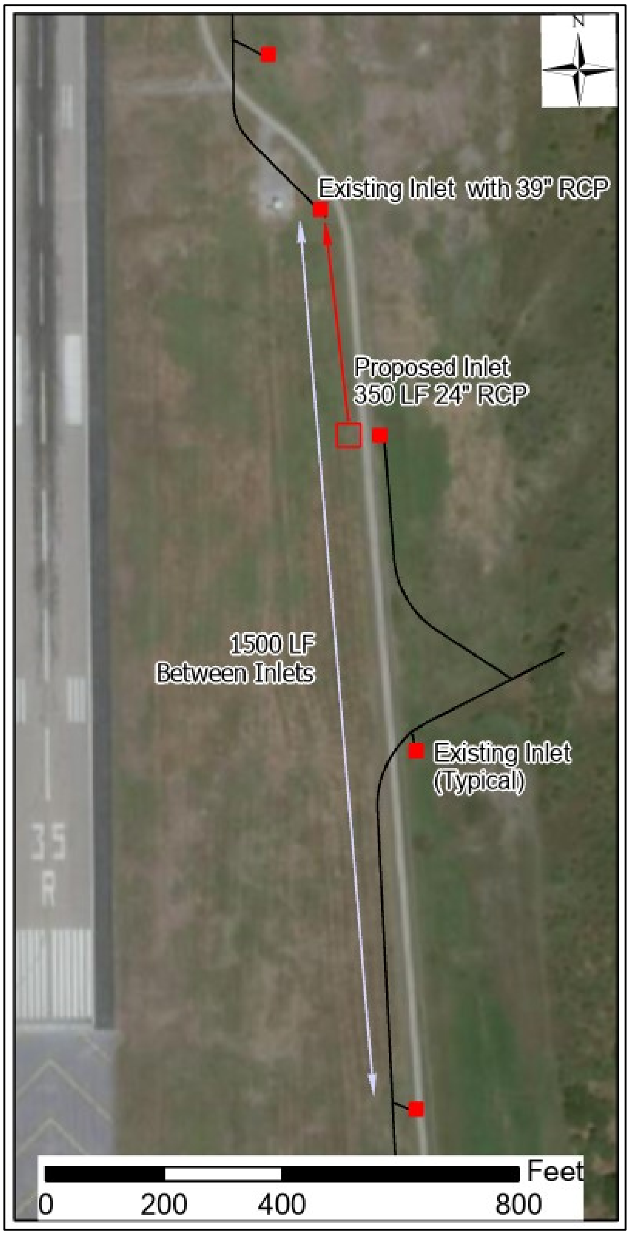


Figure 5-3
Additional Inlet and Storm Drain along ARFF Road Adjacent to Taxiway 35R

Being on the upper end of South Fork Hackberry's storm drain network there is greater benefit continuing this line to the north, following the existing drainage pattern, than connecting the proposed inlet to the existing inlet in the east ditch, which is already near capacity. Conceptual stormwater infrastructure quantities are shown in **Table 5-2**.

Table 5-2 Alternative Location 1 Conceptual Quantities

Description	Units	Quantity
New Catch Basin	EA	1
Install 24" RCP	LF	350

5.1.2 Improvement Alternative Location 2 (Tier 3)

Location 2, found within the Grapevine Creek watershed, is located on the existing Terminal B to Terminal A Road. Crossunder Road No. 2 exhibits flooding for the 100-year, 24-hour design storm event as shown in **Figure 5-4.**

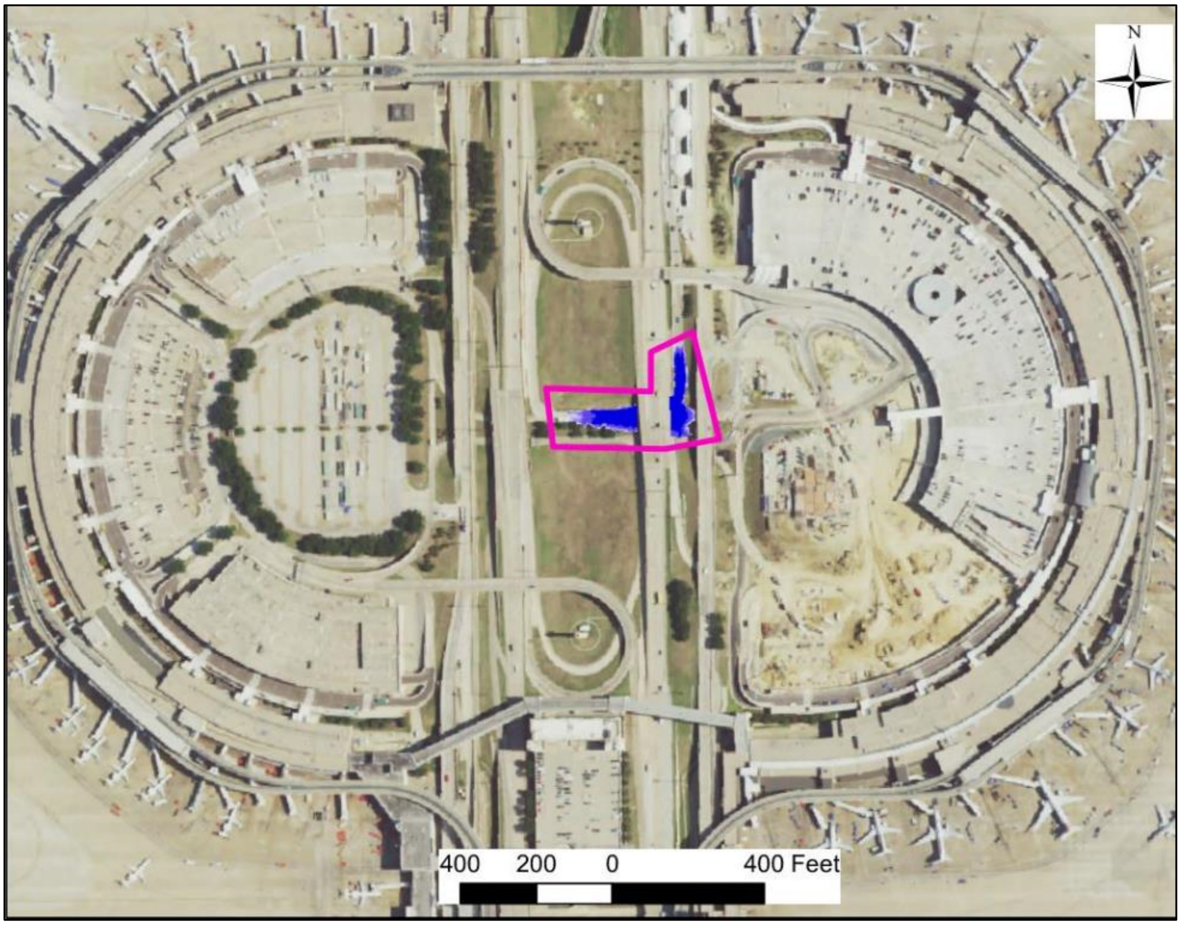


Figure 5-4
Flooding for 100-yr Storm along Crossunder Road No. 2 between Terminals A and B

The storm drain geodatabase shows runoff flowing from a 27" RCP into a 21" RCP into a 45" RCP. However, the 21" RCP (model link GC-AB-38010S) is also called out to be 45" in other provided documentation. The watershed model, which conservatively characterized this pipe as a 21" bottleneck, was modified to determine the sensitivity this pipe size had on the flooding of concern (model node GC-AB-38020). This showed the change in pipe size to have minimal impact in flooding depth and area, but a significant impact in duration of flooding as shown in **Table 5-3.**

Table 5-3 GC-AB-38010S Pipe Size Sensitivity

SWMM Node	Ground Elevation (ft NAVD)	45" RCP Peak HGL (ft NAVD88)
GC-AB-35040	592.7	571.4
GC-AB-38005	575.7	571.5
GC-AB-38010	571.6	571.6
GC-AB-38015	569.2	571.4
GC-AB-38020	569.2	571.4
Duration of Flooding		43 min

The lowest road elevation of the Crossunder Road (model node GC-AB-38020) appears to be 568.2 feet. Based on the 45" line, the road experiences approximately 43-minutes of flooding with a maximum depth of approximately 3.2 feet during the 100-year design storm event.

Based on the model results for the storm drain network, with a 45" RCP in place, it is the pipe capacity downstream of this underpass, not the pipes in this area that are having the larger impact on the flooding of concern.

The impacts of various downstream pipe size improvements on the duration of flooding for the area of concern can be found in **Table 5-4** and shown in **Figure 5-5.**

Table 5-4 Downstream Pipe Size Improvements[1]

SWMM Node	Existing (51" & 48")	60" & 54"	66" & 60"	66" & 66"
GC-AB-29010	567.2	567.3	567.4	567.4
GC-AB-35010	568.3	567.9	567.8	567.9
GC-AB-38010	571.6	570.7	570.1	569.9
GC-AB-38020	571.4	570.7	570.3	570.1
Duration of Flooding	43 min	32 min	26 min	24 min

Note 1: All elevations shown are referenced to NAVD88

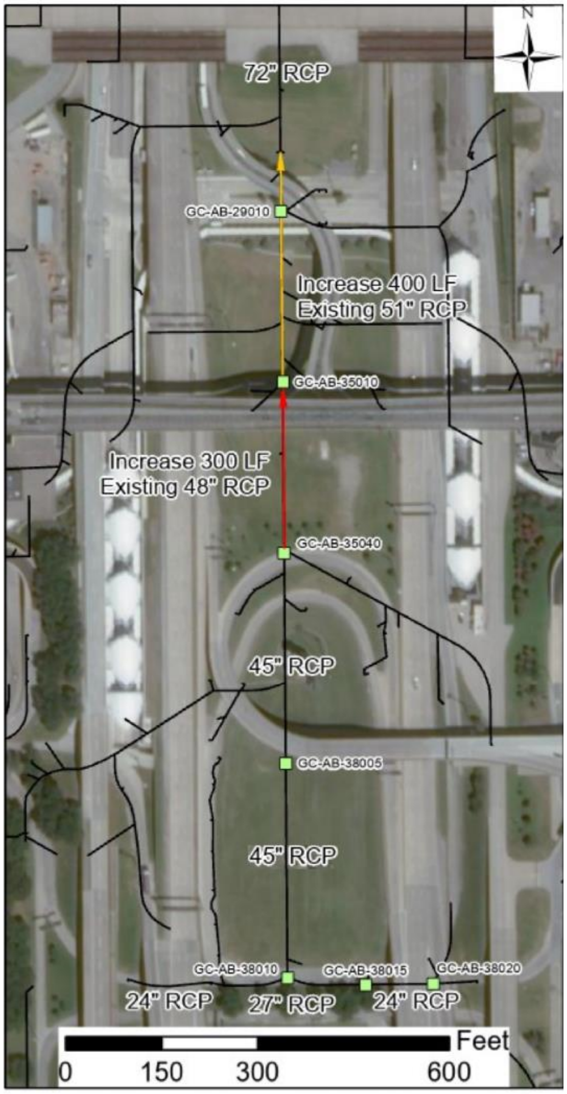


Figure 5-5
Pipe Size Improvements

Adding surface storage below edge of road is not feasible in this location. The areas on either side of the underpass are higher in elevation and thus would require significant regrading. This would also potentially reduce cover over the existing 45" RCP to an unsafe level. Conceptual stormwater infrastructure quantities are shown in **Table 5-5**.

Table 5-5 Alternative Location 2 Conceptual Quantities

Description	Units	Quantity
Demo 48" RCP & Install 66" RCP	LF	300
Demo 51" RCP & Install 66" RCP	LF	400

5.1.3 Improvement Alternative Location 3 (Tier 2)

Location 3, found within the Bear Creek watershed, is located at the Taxiway WM/C intersection. The Taxiways exhibit flooding for the 5-year, 24-hour design storm event as shown in **Figure 5-6**.

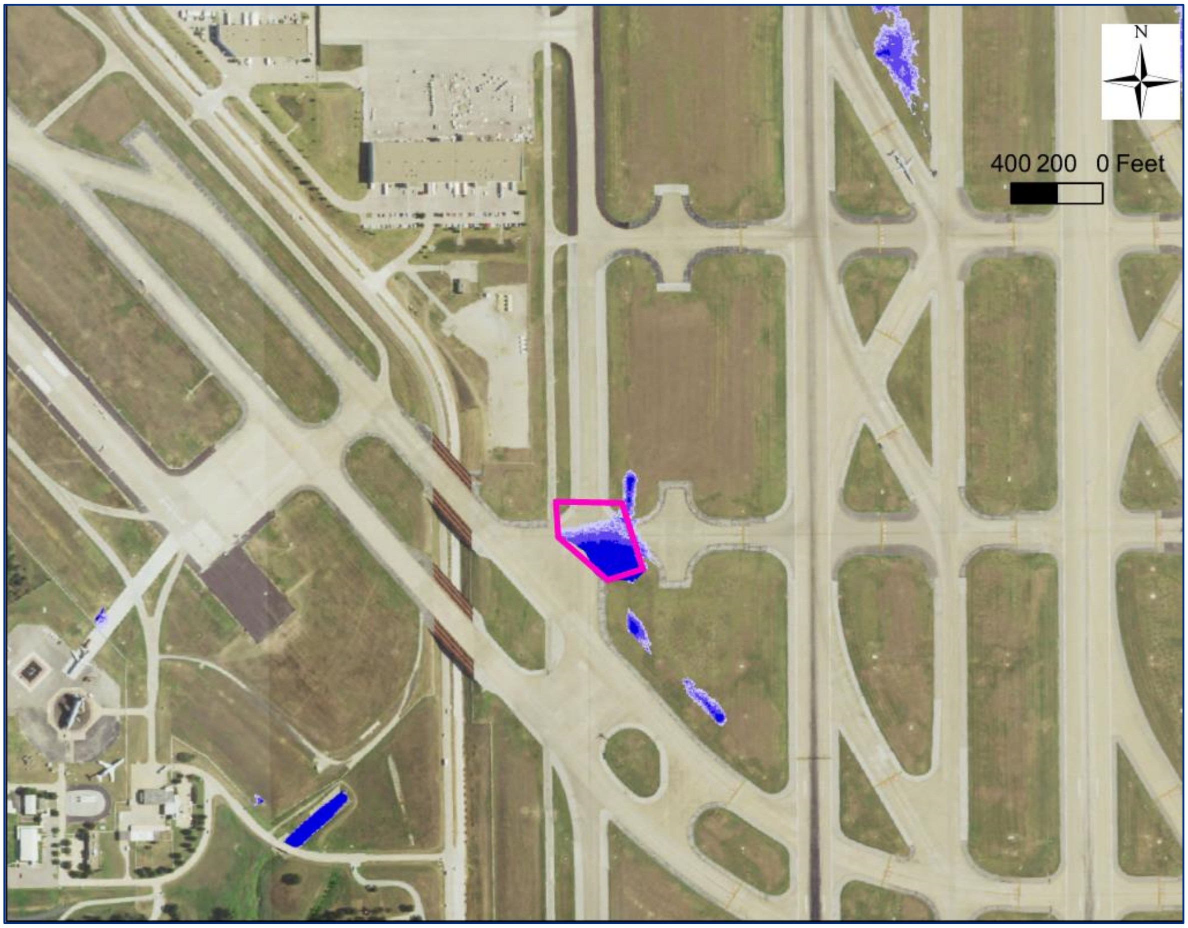


Figure 5-6
Flooding for 5-yr Storm along Taxiway WM/C

Review of the existing topography in the area reveals that there is room to add above-ground system storage in the area north of the flooding to create additional flood storage capacity. Increasing the available storage at an elevation of 578.5 to approximately 149,500 square feet will be sufficient to prevent the 5-year design storm from encroaching onto the taxiway. With the proposed grading, the new 5-year design storm will have a water surface elevation of 578.8 with the existing edge of pavement being 579.0. The area of proposed grading is shown in **Figure 5-7**, and the modified stage-area relationship is shown in **Table 5-6**. Alternatively, in lieu of excavation, increasing the size of the pipes connecting the existing inlets to the primary stormwater system will reduce stages below the edge of runway as shown highlighted in green in Figure 5-7. Conceptual analysis showed that increasing only the eastern pipe from a 24” RCP to a 48” RCP reduced inundation to the edge of pavement. Replacement of only the eastern pipe would be preferential, as it connects to the primary system within the grassed area, therefore no disturbance to the taxiway would be needed. Replacement of both pipes shown in Figure 5-7 from 24” RCP to 48” RCP reduces stages well below the edge of pavement, but the western pipe connects to the primary system underneath the existing pavement.

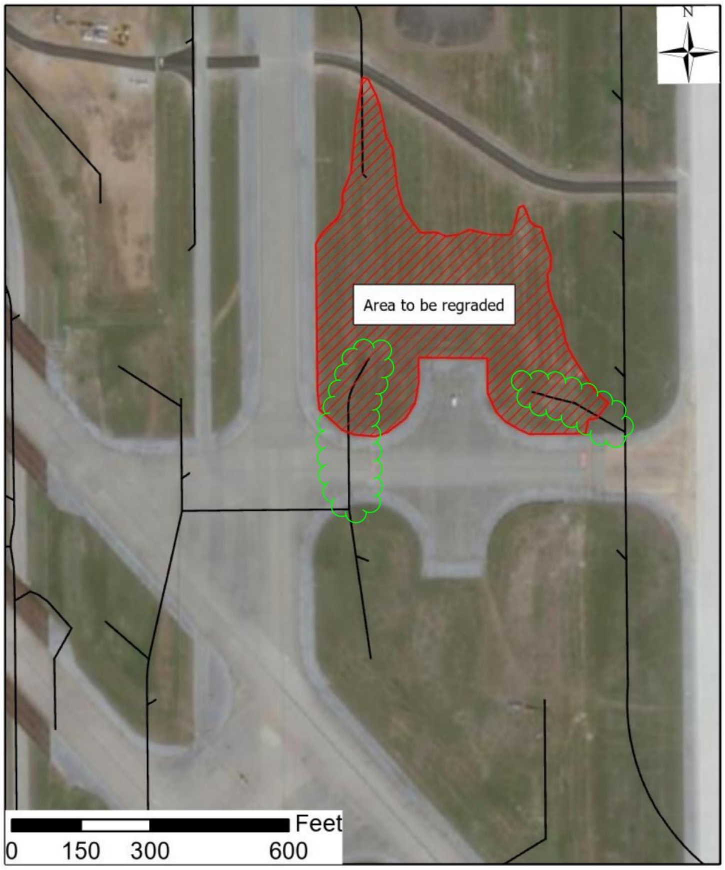


Figure 5-7
Area to be Regraded for Additional Storage

Table 5-6 Additional Flood Storage at Alternative Location 3

Elevation (ft NAVD88)	Existing Storage (square feet)	Proposed Storage (square feet)	Delta Storage (square feet)
578.0	112	112	0
578.5	1,936	149,500	+147,564
579.0	7,654	146,476	+138,821
579.5	24,144	152,287	+128,143
580.0	37,101	154,565	+117,464
580.5	49,921	156,707	+106,786
581.0	63,104	159,211	+96,107
581.5	80,982	166,410	+85,429
582.0	100,910	175,660	+74,750
582.5	126,153	190,225	+64,071
583.0	160,456	213,849	+53,393
583.5	194,225	236,939	+42,714
584.0	225,710	257,746	+32,036
584.5	258,369	279,727	+21,357
585.0	301,300	311,979	+10,679

Elevation (ft NAVD88)	Existing Storage (square feet)	Proposed Storage (square feet)	Delta Storage (square feet)
585.5	340,740	340,740	0
586.0	388,147	388,147	0

Conceptual stormwater infrastructure quantities are shown in **Table 5-7**. It should be noted that conceptual analysis shows that either excavation or upsizing of the existing laterals will reduce the level of flooding within the area to below the edge of pavement for the 5-yr design storm. All improvements that contain the addition of a storage element must be designed such that there is no introduction of standing water that could potentially violate the DFWIA 24-hour drain time regulations.

Table 5-7 Alternative Location 3 Conceptual Quantities

Description	Units	Quantity
Excavate Additional Storage	CY	20,750
Demo 24" RCP & Install 48" RCP (eastern pipe)	LF	220
Demo 24" RCP & Install 48" RCP (western pipe)	LF	328

All improvements that contain the addition of a storage element must be designed such that there is no introduction of standing water that could potentially violate the DFWIA 24-hour drain time regulations.

5.1.4 Improvement Alternative Location 4 (Tier 2)

Location 4, found within the Hackberry Creek watershed, is located where 17L Navaid Road crosses Hackberry Creek, immediately upstream of the railroad bridge in the vicinity of the intersection of Esters Blvd and Cabell Dr. The road is overtopped for the 10-year, 24-hour design storm event as shown in **Figure 5-8**.

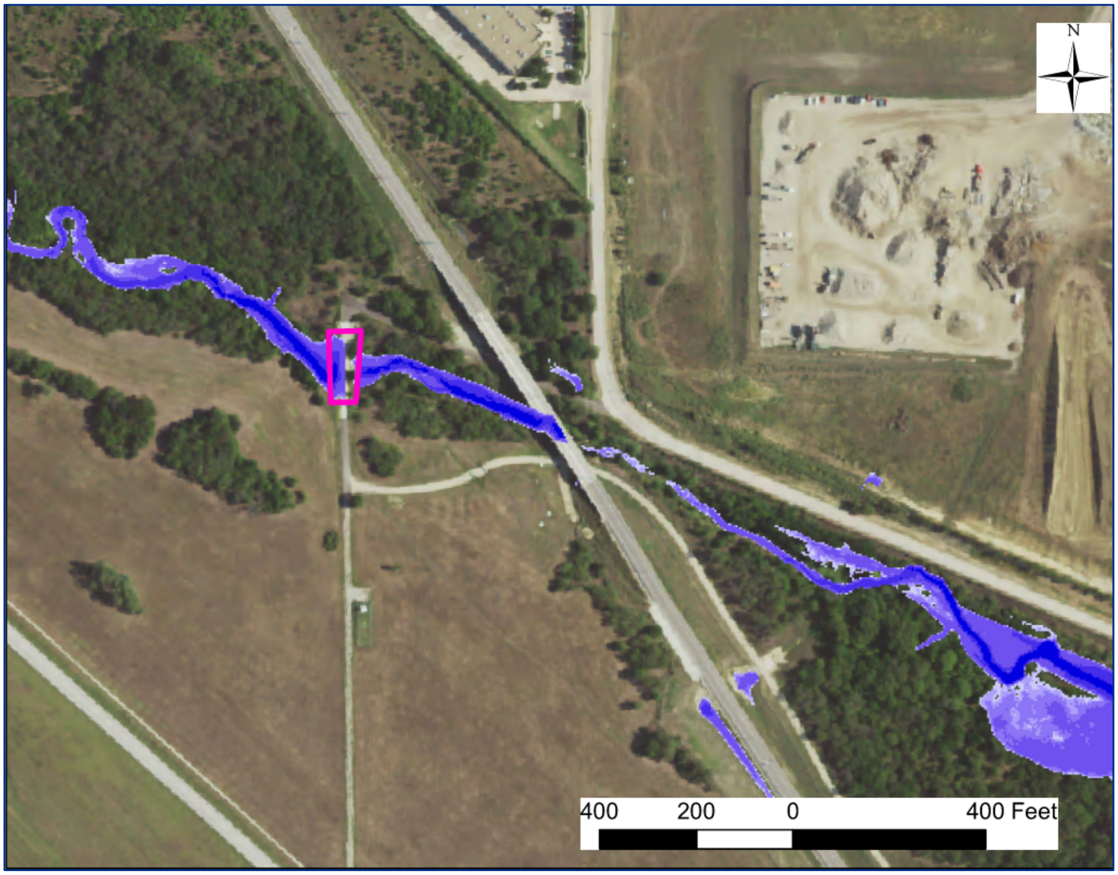


Figure 5-8
Flooding for 10-yr Storm on 17L Navaid Rd

Additionally, significant erosion is occurring at the interface between the existing concrete and the adjacent riprap as shown in **Figure 5-9**.

Figure 5-9
Flooding for 10-yr Storm on 17L Navaid Rd

Review of existing topography reveals that the access road has a sag elevation of approximately 499.8 feet. The peak water surface elevation for the 10-year design storm at the upstream side of the existing culverts is 501.8. This elevation is a result of the normal depth elevation in the creek, not from a capacity issue created by undersized culverts. A sensitivity analysis was performed looking at increasing the existing conveyance capacity by replacing the three existing 42” pipes with five 60” pipes, resulting in only a 0.25’ reduction in peak stages, which would still result in overtopping of the road. Additionally, space constraints would prohibit significantly increasing the size of the conveyance pipes due to the size of the existing channel both upstream and downstream of the culverts. Review of the existing watershed models show that this road is predicted to be overtopped for the 1-yr design storm, which exhibits a peak stage of 501.2 at the upstream end, resulting in greater than a foot of overtopping. Therefore, for the road to be outside the 10-year design storm area of inundation, the road will need to be raised above the existing peak stage elevation of 501.8. Regardless of whether the road is elevated, the ongoing erosion should be addressed to provide additional resiliency and prolong the life of the roadway. And design changes should be checked for velocity increases, and mitigation measures installed as needed. Conceptual stormwater infrastructure quantities are shown in **Table 5-8**.

Table 5-8 Alternative Location 4 Conceptual Quantities

Description	Units	Quantity
Raise Road	LF	140
Remove Sediment	LS	1
Realign Approach Channel	LS	1

Field investigations also showed that the conveyance capacity downstream of the existing pipes is partially impeded by sediment deposition that currently has a small tree growing in it as shown in **Figure 10**.

Figure 5-10
Sediment Deposition Downstream of 17L Navaid Rd

The sediment deposition and tree should be removed, and the as-built drawings for the road should be reviewed and the design lines and grades downstream of the pipes restored.

5.1.5 Improvement Alternative Location 5 (Tier 3)

Location 5, found within the Bear Creek watershed, is located on the existing Terminal E to Terminal F Crossunder Road No. 5. The Crossunder Road exhibits flooding for the 5-year, 24-hour design storm event as shown in **Figure 5-11**.

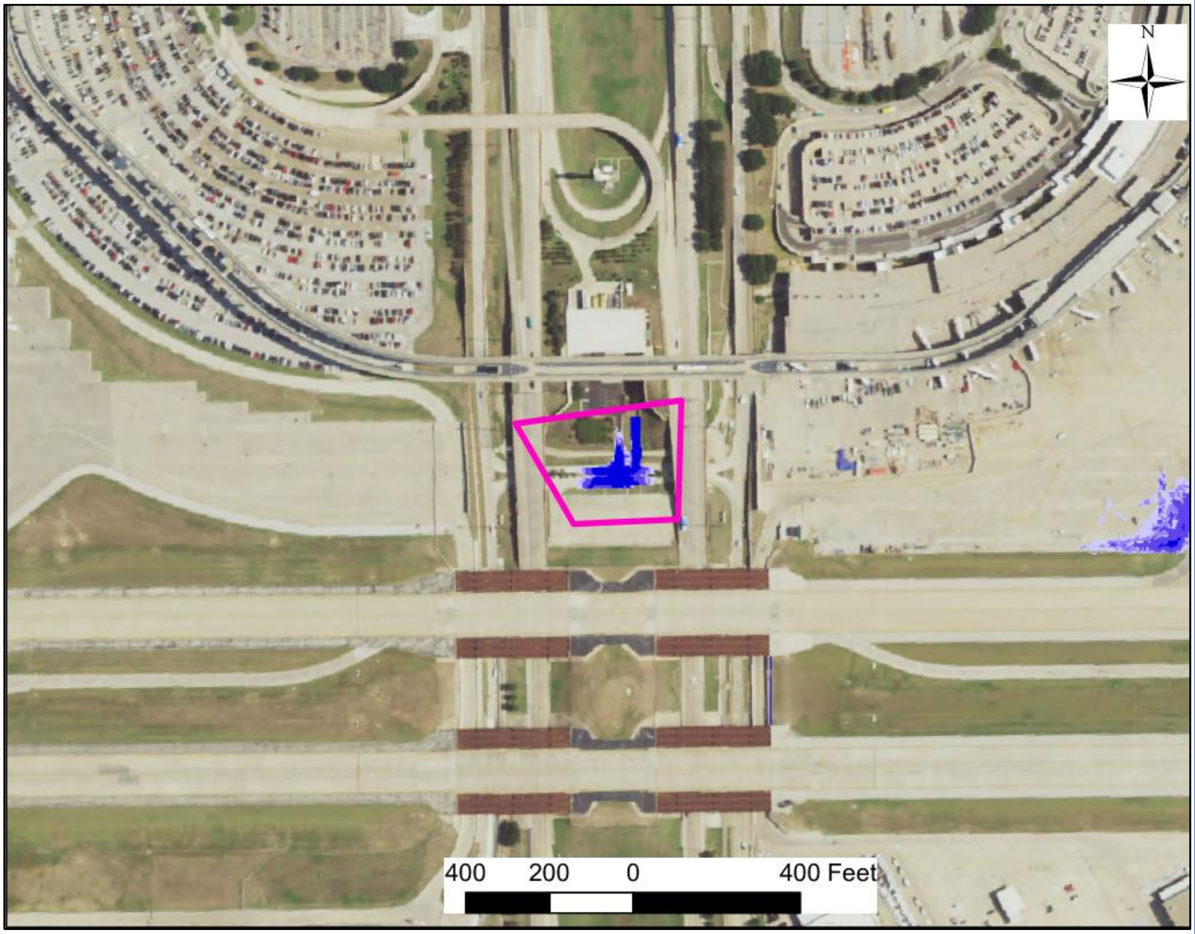


Figure 5-11
Flooding for 5-yr Storm along Crossunder No. 5

The minimum road elevation for this crossunder road is approximately 549.5 feet. The peak modeled water surface elevation for the 5-year design storm is 551.7 feet. Based on the 5-year watershed model, this underpass experiences flooding for 15 minutes with a maximum depth of 2.2 feet.

This crossunder is in a heavily developed, low-lying area with no space in which to add surface storage. The parking lot to the south slopes up to an elevation of 566.5 feet, and the grassy area further to the south increases rapidly up to 588.0 feet. Therefore, increasing the pipe size to match the next larger size downstream, replacing 1400 feet of 96" RCP with 108" RCP, is the most viable improvement.

Runoff from this area is conveyed south and increasing approximately 1400 feet of 96" RCP with 108" RCP as shown in **Figure 5-12** will reduce the length of predicted flooding to 10-minutes for the 5-year design storm, with a maximum flood depth of 1.6 feet. This will also increase capacity for the larger rain events. Alternatively, rather than removing and replacing the existing 96" RCP the installation of a parallel pipe to increase conveyance capacity should be investigated as part of the detailed design process.

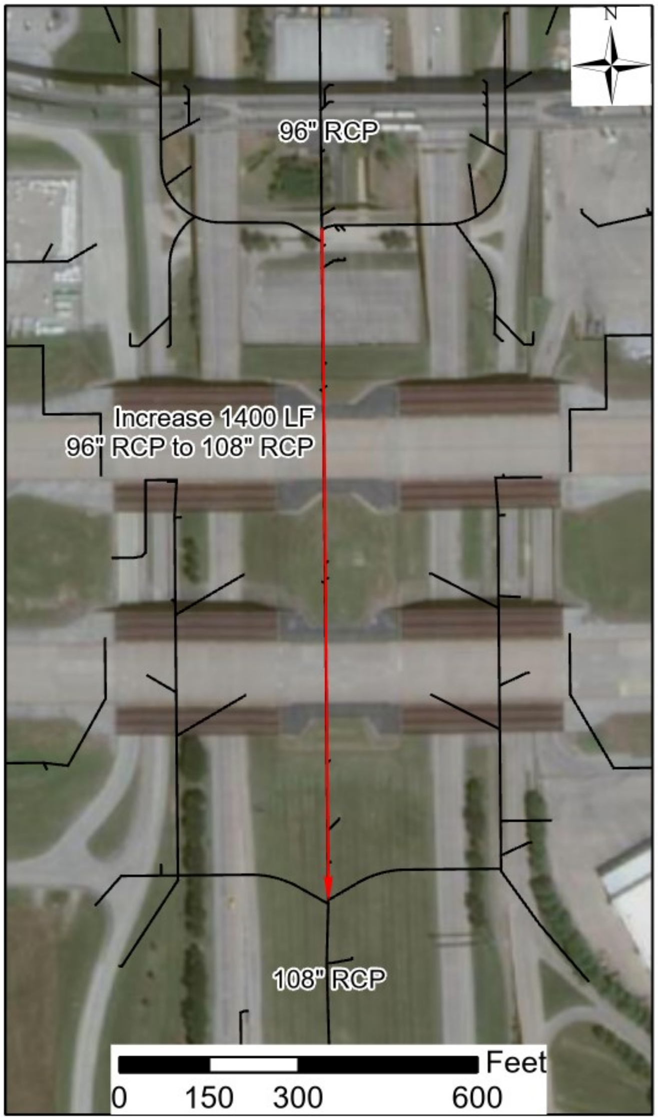


Figure 5-12
Increasing conveyance from 96" RCP to 108" RCP

Conceptual stormwater infrastructure quantities are shown in **Table 5-9**.

Table 5-9 Alternative Location 5 Conceptual Quantities

Description	Units	Quantity
Demo 96" RCP & Install 108" RCP	LF	1,400

5.1.6 Improvement Alternative Location 6 (Tier 3)

Location 6, found within the Mud Springs watershed, is located along the existing ARFF Road southwest of Runway 13L. ARFF Road exhibits flooding for the 100-year, 24-hour design storm event as shown in **Figure 5-13**.

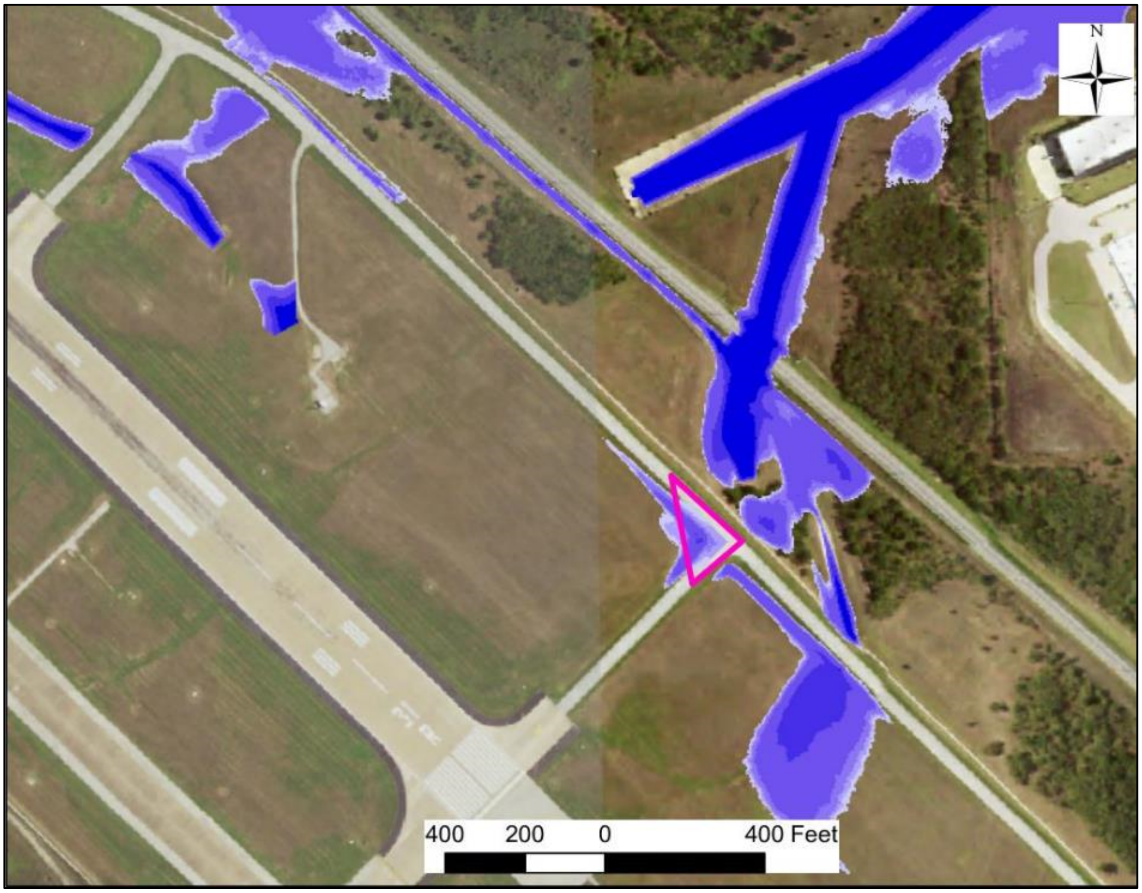


Figure 5-13
Flooding for 100-yr Storm along ARFF Road SW of Runway 13L

In the area of concern, the edge of road has an elevation of approximately 499.0. The upstream end of the existing 36" RCP Culvert has a predicted peak stage of 499.6, whereas the downstream end has a concurrent peak stage of 497.6. This large difference implies the problem is a lack of conveyance capacity in the pipe. It should be noted that the pipe of interest was not in the geodatabase provided and as-built plans were not available. The 36" size was conservatively set based on LiDAR and aerial photogrammetry. Prior to initiating improvements the pipe size should be verified. Replacing the existing 36" RCP with 2 – 4'H x 3'W box culverts will remove the bottleneck and alleviate the roadway flooding. Based on the LiDAR, the existing 36" RCP already has limited cover; therefore it is not feasible to install a pipe taller than the existing 36" RCP without further compromising the limited cover. Replacement of the pipe alone will reduce the predicted duration of flooding in the area of concern from 113 minutes to 15 minutes. In addition to the dual 4'x3' box culverts, increasing the existing flood storage at elevation 497.0 feet to 15,000 square feet will reduce the peak flood stages to below the edge of road. The area of proposed grading is shown in **Figure 5-14**, and the modified stage-area relationship is shown in **Table 5-10**. All improvements that contain the addition of a storage element must be designed such that there is no introduction of standing water that could potentially violate the DFWIA 24-hour drain time regulations.

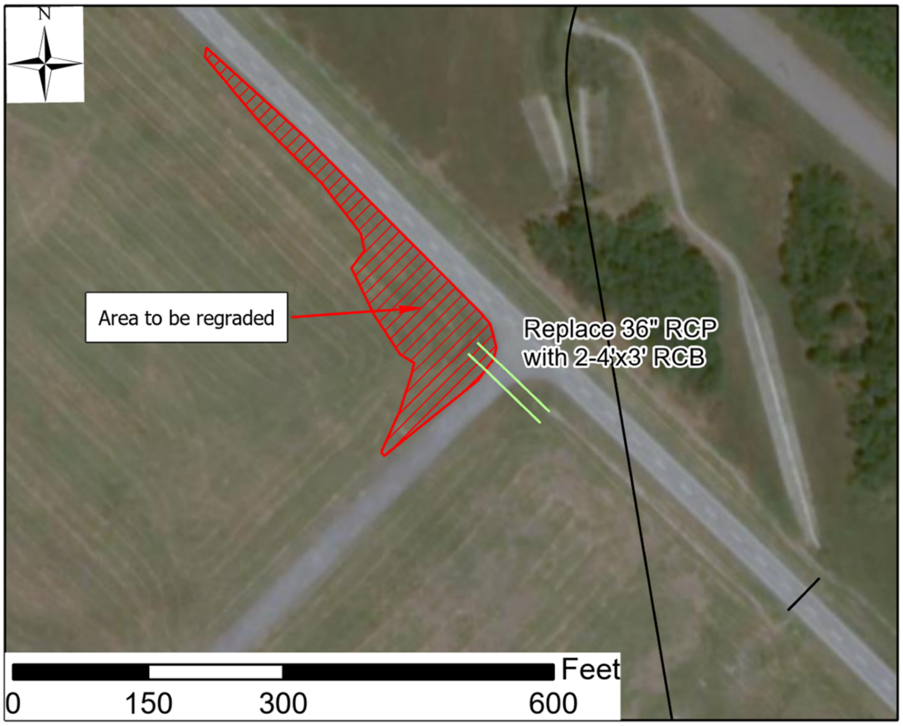


Figure 5-14 Area of Proposed Additional Flood Storage

Table 5-10 Additional Flood Storage at Alternative Location 6

Elevation (ft NAVD88)	Existing Storage (square feet)	Proposed Storage (square feet)	Delta Storage (square feet)
496.3	100	100	0
497.0	626	15,000	+14,374
498.0	3,232	17,172	+13,940
499.0	10,137	27,215	+17,078
500.0	33,322	33,322	0

Conceptual stormwater infrastructure quantities are shown in **Table 5-11**.

Table 5-11 Alternative Location 6 Conceptual Quantities

Description	Units	Quantity
Demo 36” RCP & Install (2) 4’x3’ RCBC	LF	160
Excavate Additional Storage	CY	1,680

5.1.7 Improvement Alternative Location 7 (Tier 2)

Location 7, found within the Mud Springs watershed, is located on the northeast side of the apron along Terminal C. The apron exhibits flooding for the 10-year, 24-hour design storm event as shown in **Figure 5-15**.

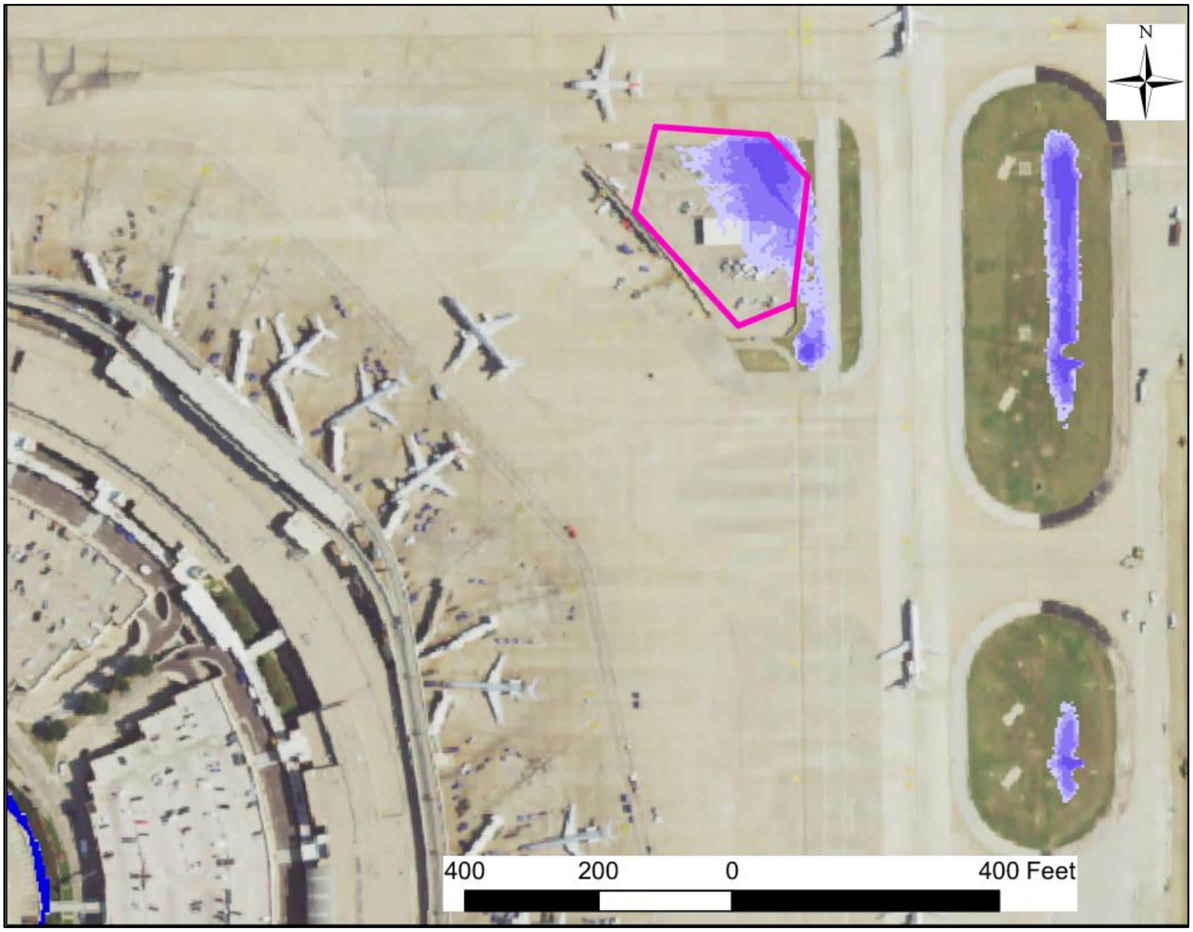


Figure 5-15
Flooding for 10-yr Storm Apron NE of Terminal C

The area of concern has very little available surface storage. The critical elevation at the edge of pavement is 569.2 feet, and the water surface elevation for the 10-year design storm is 570.7 feet. The analysis evaluated installing a new 36" RCP connecting the collection system in the area of concern to the existing pipe system in the swale to the east, matching crown elevations. While the existing system to the east has additional capacity, to completely alleviate flooding in the area for the 10-yr storm the existing swale should be regraded, increasing the available storage to 35,000 square feet at elevation 563 feet, and to 50,000 square feet at elevation 564 feet as shown in **Figure 5-16** and **Table 5-12.** This will eliminate the flooding of concern during the 10-year design storm, and the eastern system will have capacity to continue to hold the 100-year design storm off of the runway. All improvements that contain the addition of a storage element must be designed such that there is no introduction of standing water that could potentially violate the DFWIA 24-hour drain time regulations.

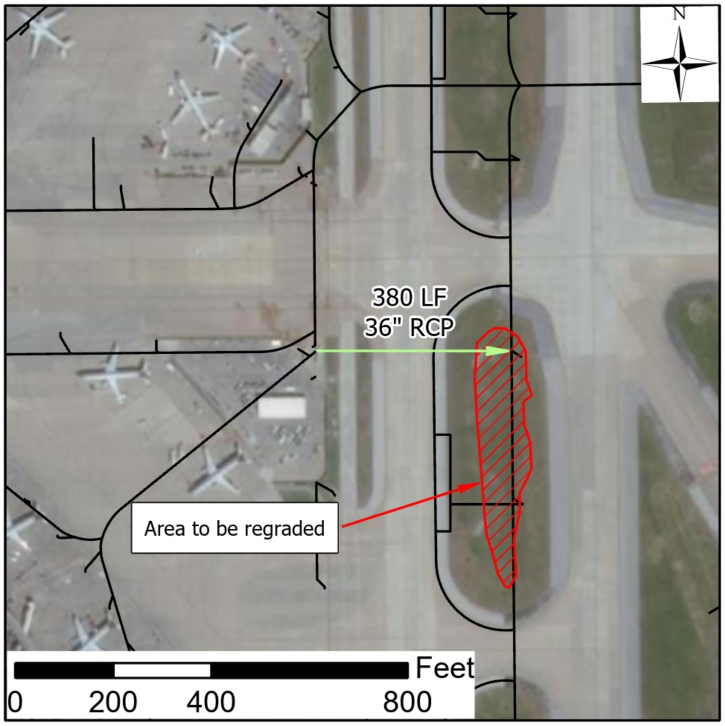


Figure 5-16
Proposed Regrading & 380 Linear Feet of New 36" RCP

Table 5-12 Additional Flood Storage at Alternative Location 7

Elevation (ft NAVD88)	Existing Storage (square feet)	Proposed Storage (square feet)	Delta Storage (square feet)
562.7	100	100	0
563.0	166	35,000	+34,834
564.0	8,116	50,000	+41,884
565.0	28,180	54,051	+25,871
566.0	58,101	58,101	0

Conceptual stormwater infrastructure quantities are shown in **Table 5-13**.

Table 5-13 Alternative Location 7 Conceptual Quantities

Description	Units	Quantity
Install 36" RCP	LF	380
Excavate Additional Storage	CY	3,800

5.1.8 Improvement Alternative Location 8

Location 8, found within the South Fork Hackberry Creek watershed, is located at the intersection of Valley View Drive and North Belt Line Road. The intersection exhibits flooding for the 5-year, 24-hour design storm event as shown in **Figure 5-17**.

Figure 5-17
Flooding for 5-yr Storm at Intersection of Valley View Lane and N. Belt Line Road

The east side of the intersection of Valley View Lane and Beltline Road does not have a cross culvert and based on original documentation it was assumed that the water surface flows over Valley View to a South Fork Hackberry branch in the southeast corner of the intersection.

After a closer investigation and additional documentation from the City of Irving, it was determined that a local storm drain network exists rather than the aforementioned culvert that would connect the area to a tributary to South Fork Hackberry Creek. With the model updated to include this additional data, the flooding of concern disappeared for the 5-year storm as shown in **Figure 5-18.**

Figure 5-18
Revised Inundation for 5-yr Storm at Intersection of Valley View Lane and N. Belt Line Road

5.1.9 Improvement Alternative Location 9 (Tier 2)

Location 9, found within the South Fork Hackberry Creek watershed, is located along the existing ARFF Road near the intersection of Runway 17L and Taxiway ER. RFF Road exhibits flooding for the 100-year, 24-hour design storm event as shown in **Figure 5-19**.

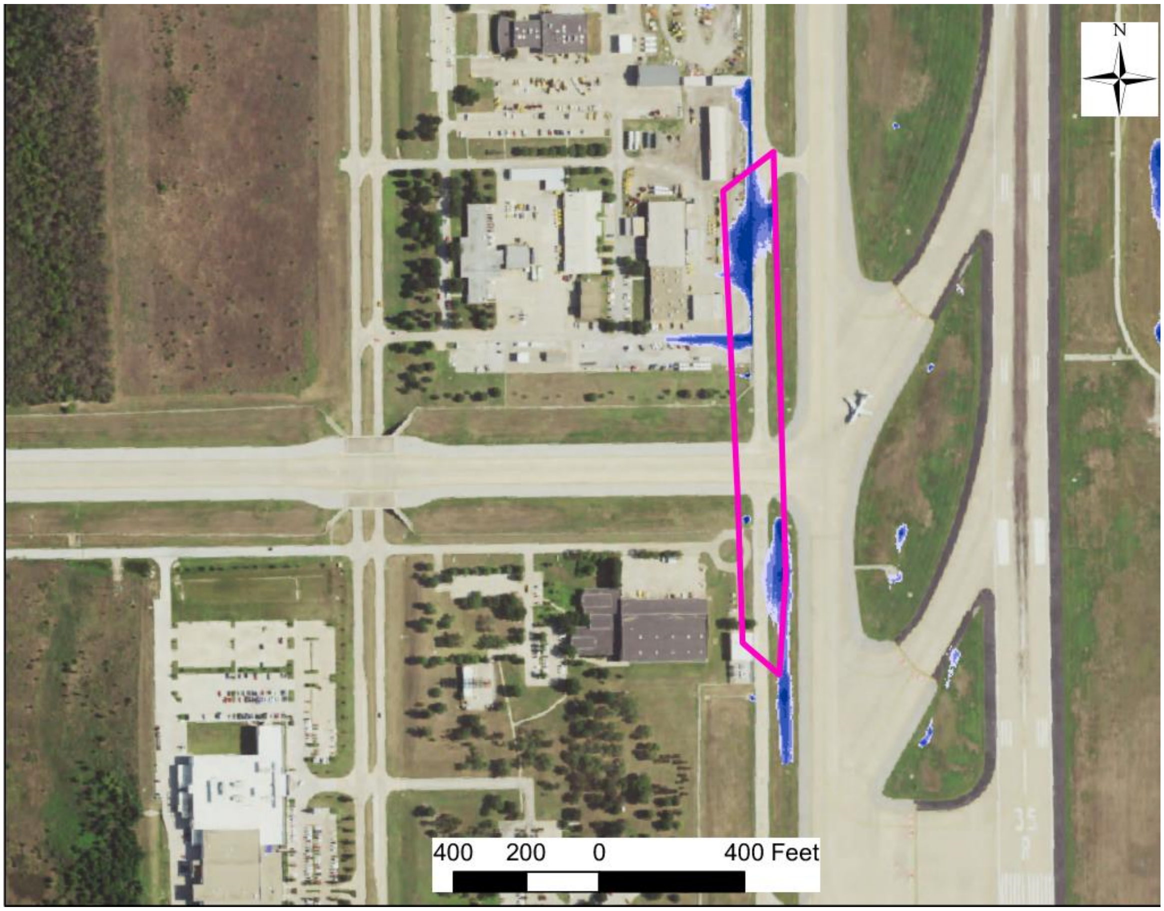


Figure 5-19
Flooding for 100-yr Storm along ARFF Road near the Intersection of Runway 17L and Taxiway ER

To alleviate the roadway flooding south of the taxiway increasing the conveyance capacity and upsizing the existing pipe servicing the area of concern from a 42" RCP to a 48" RCP was investigated. This will reduce flooding in the swale such that the 100-year design storm no longer encroaches on the road, as shown in **Figure 5-19.**

North of the taxiway, the runway is several feet higher than the ARFF road. Flooding over the road in this area is approximately one foot deep, with a duration of approximately 25 minutes. The runoff from the runway flows west, down to a small swale along the ARFF road. The west ARFF swale is lower in elevation than the eastern swale, and it is this western swale that is overflowing onto the ARFF road. As the west swale is lower in elevation, we investigated adding an inlet between the existing inlets to increase conveyance in the area and reduce the total amount of water in the swale as shown in Figure 5-19, keeping the roadway clear for the 100-yr storm.

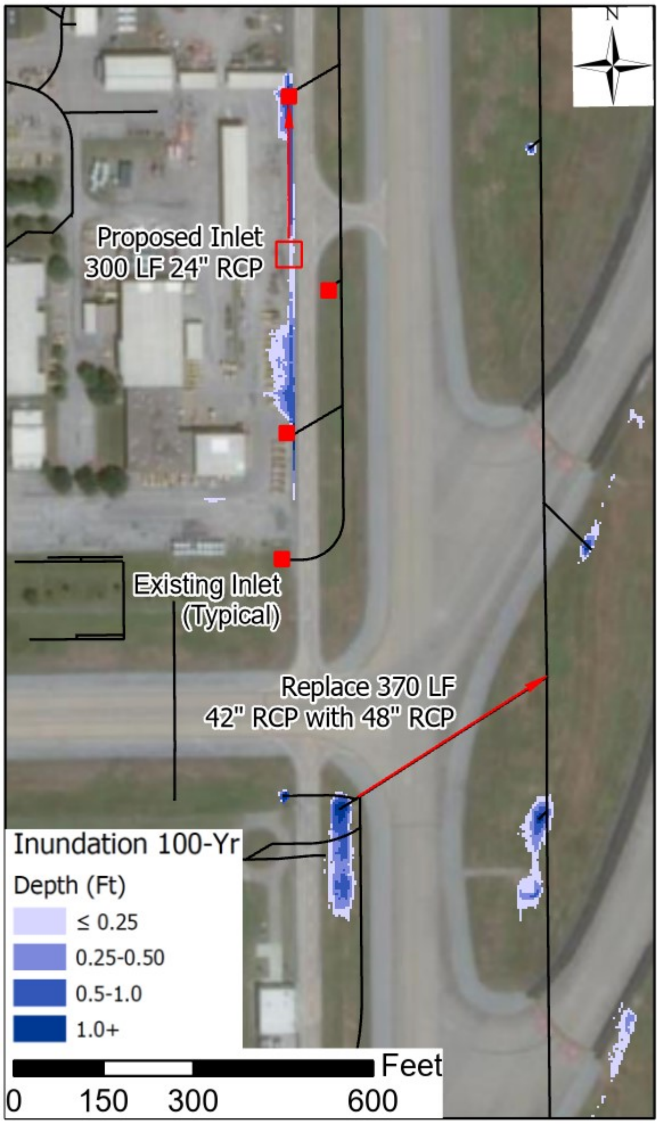


Figure 5-19
Conceptual Improvements near the Intersection of Runway 17L and Taxiway ER

Conceptual stormwater infrastructure quantities are shown in **Table 5-14**.

Table 5-14 Alternative Location 9 Conceptual Quantities

Description	Units	Quantity
New Catch Basin	EA	1
Install 24” RCP	LF	300
Demo 42” RCP & Install 48” RCP	LF	370

5.2 Alternatives Evaluation - Erosion

While the alternatives analysis focused mainly on flooding problems, erosion issues were also investigated, along with riprap sizing and the establishment of stable channel sections.

Per discussions with DFWIA four sites experiencing erosion issues were selected for additional investigation. Three locations are within the Bear Creek watershed, and the fourth is at the very downstream of the Hackberry Creek watershed at the intersection with the Mud Springs Creek channel. The following sections provide additional detail and analysis for each location.

5.2.1 Erosion Location 1 (Tier 3)

Erosion location one is within the Bear Creek watershed on channel BB-E, located downstream of West 27th St, west of West Airfield Dr as shown in **Figure 5-20**.

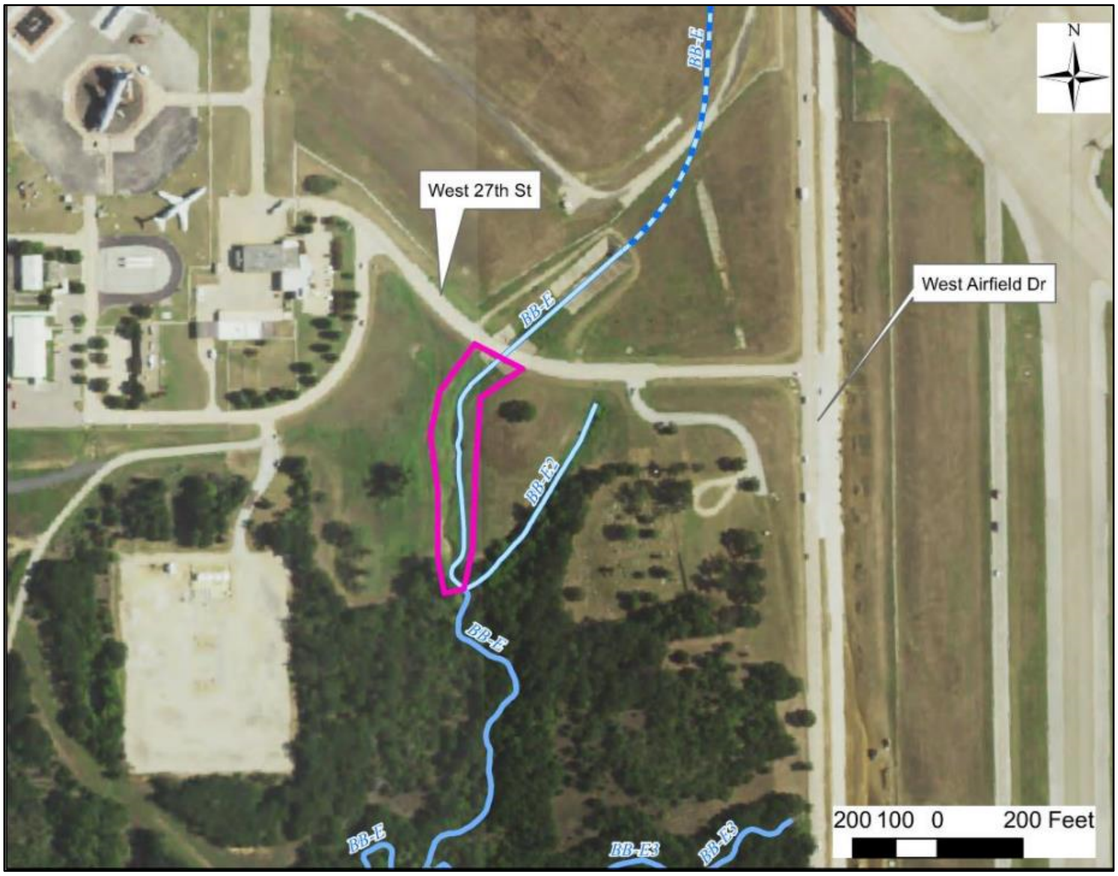


Figure 5-20
Erosion location 1 within the Bear Creek Watershed

Review of the watershed modeling for Bear Creek showed that link BC-BB-E-11090A was represented as a natural irregular channel as shown in **Figure 5-21**. The channel has a longitudinal slope of approximately 2.2%, and during the 1-yr 24-hour design storm simulation had a peak velocity of 8.1 ft/sec.

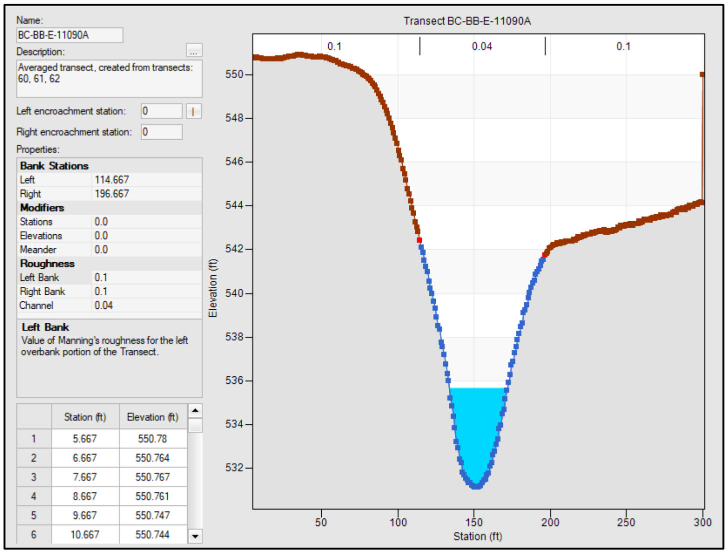


Figure 5-21Transect BC-BB-E-11090A located D/S of West 27th Dr

The eroding channel is located directly downstream of a paved trapezoidal channel that conveys flows under West 27th Dr as shown in **Figure 5-22**.

Figure 5-22
Erosion Area 1 - Paved Channel under West 27th Dr

Field observations revealed that the riprap that was installed at the downstream end of the paved channel has failed and migrated downstream as shown in **Figure 5-23** and **Figure 5-24**. While some of the riprap is still spanning the channel, it is likely not providing nearly the energy dissipation that it was designed to provide.

Figure 5-23
Erosion Area 1 - Failed Riprap Downstream of West 27th Dr

Figure 5-24
Erosion Area 1 - Failed Riprap Downstream of West 27th Dr

The high velocities coming off the paved channel section have displaced the riprap resulting in a local scour hole as seen in Figures 13 and 14. The resulting instabilities and elevated velocities have also caused lateral erosion of the western bank as seen in **Figure 5-25**.

Figure 5-25
Erosion Area 1 - Erosion and Lateral Bank Migration Downstream of West 27th Dr

It is recommended that the riprap sizing calculations that were originally performed be revisited and revised to reflect updated flows. It is recommended that the peak velocities in the channel for both the 25-yr and 100-yr design storms be considered when sizing the replacement riprap. Review of the Bear Creek watershed model reveals these velocities to be 10.0 ft/sec and 10.5 ft/sec, respectively. It is imperative that the riprap be sized to withstand these velocities. Additional survey of the channel cross sections in the immediate area, both upstream and downstream of the erosion area, should be obtained and the model should be updated and rerun to confirm design velocities.

Additionally, to address the downstream bank erosion it is recommended that a geomorphological analysis be performed to determine the root cause of the erosion, as it could be attributed to misaligned channel geometry, unstable sinuosity, or a number of other factors. The eroded bank should also be stabilized. If space permits it is recommended that the slope be graded to reestablish a natural slope and stabilized with an appropriate engineering methodology, both of which will be determined during the detailed design analysis. For conceptual planning purposes a slope of 4:1 (H:V) can be used, and a slope treatment such as vegetated riprap covered in native grasses can be considered as shown in **Figure 5-26**.

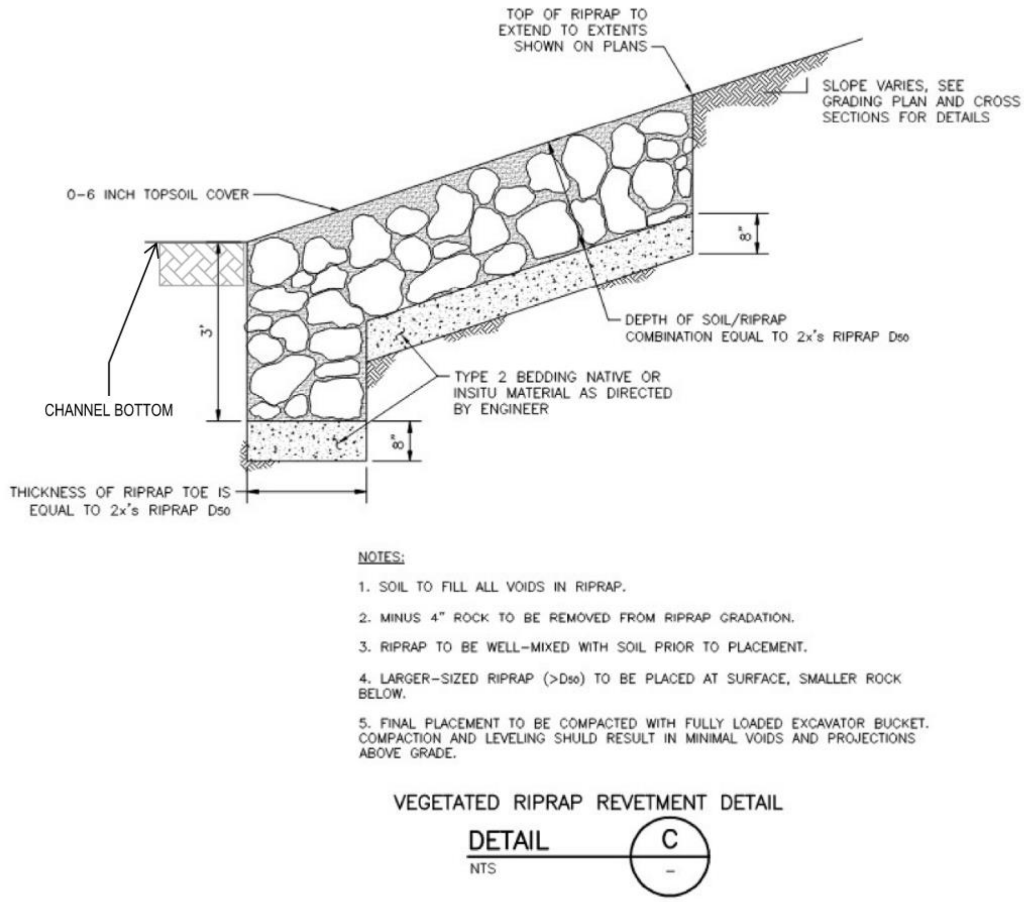


Figure 5-26
Erosion Location 1 - Conceptual Bank Stabilization Section

5.2.2 Erosion Location 2 (Tier 2)

Erosion location two is within the Bear Creek watershed on channel BB-F3, located downstream of West Airfield Drive, north of East Mid Cities Blvd as shown in **Figure 5-27**.

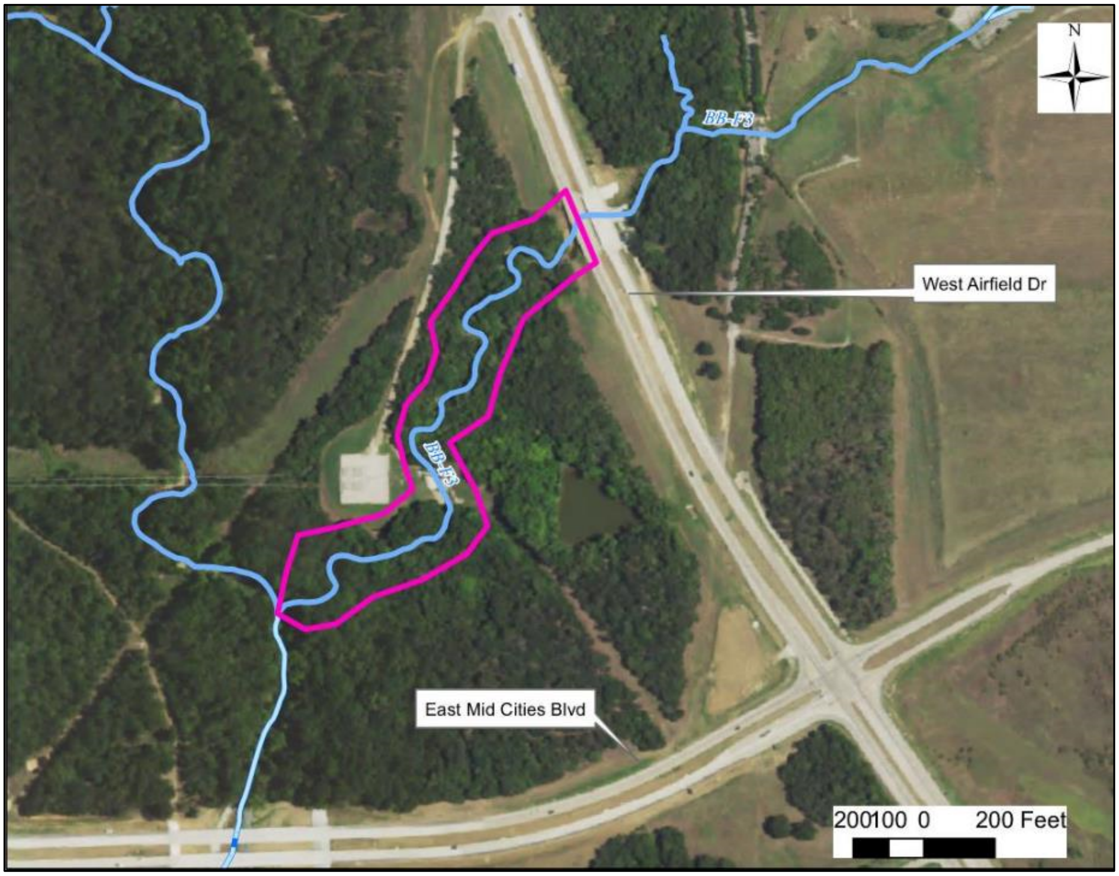


Figure 5-27
Erosion Location 2 within the Bear Creek Watershed

Review of the watershed modeling for Bear Creek showed that link BC-BB-F3-11000A was represented as a natural irregular channel as shown in **Figure 5-28**. The channel has a longitudinal slope of approximately 0.1%, and during the 1-yr 24-hour design storm simulation had a peak velocity of 4.1 ft/sec.

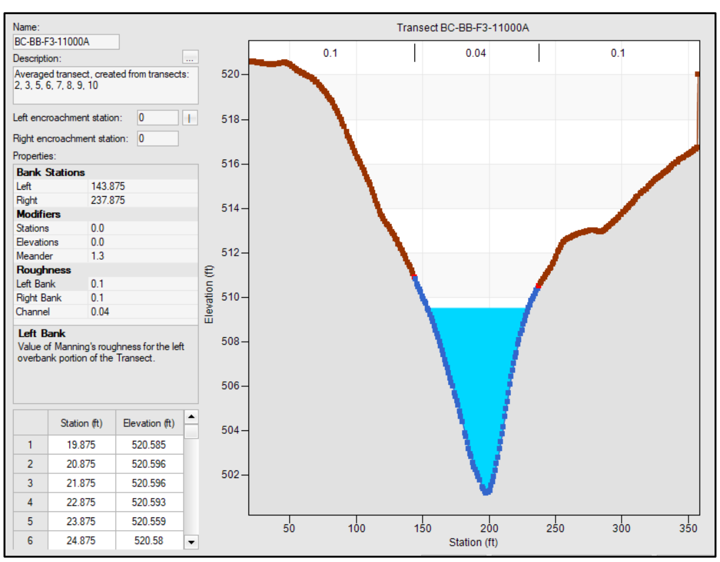


Figure 5-28
Transect BC-BB-F3-11000A Located D/S of West Airfield Dr

The eroding channel is located directly downstream of a triple span bridge with two bridge piers that carries traffic on West Airfield Dr over BB-F3 as shown in **Figure 5-29**.

Figure 5-29
Erosion Area 2 - Looking upstream at West Airfield Dr

Field observations revealed that riprap that was installed under the bridge has migrated downstream as shown in **Figure 5-30** and **Figure 5-31**. While some of the riprap is still present in the center of the channel, the upper level appears to have washed out. Figure 5-31 also shows the severe erosion that has occurred along the left bank of the channel.

Figure 5-30
Erosion Area 2 - Riprap Underneath West Airfield Dr Bridge

Figure 5-31
Erosion Area 2 - Riprap Washed Downstream of West Airfield Dr Bridge

There is a significant difference in channel morphology above and below the bridge, as the upstream channel is significantly smaller and while riprapped, it appears to be stable in both the vertical and horizontal directions as seen in **Figure 5-32**.

Figure 5-32
Erosion Area 2 - Existing Channel Upstream of West Airfield Dr Bridge

It is recommended that the riprap sizing calculations that were originally performed be revisited and revised to reflect updated flows. It is recommended that the peak velocities in the channel for both the 25-yr and 100-yr design storms be considered when sizing the replacement riprap. Review of the Bear Creek watershed model reveals these velocities to be 5.4 ft/sec and 5.7 ft/sec, respectively. It is imperative that the riprap be sized to withstand these velocities. Additional survey of the channel cross sections in the immediate area, both upstream and downstream of the erosion area, should be obtained and the model should be updated and rerun to confirm design velocities.

Additionally, to address the downstream bank erosion it is recommended that a geomorphological analysis be performed to determine the root cause of the erosion, as it could be attributed to misaligned channel geometry, unstable sinuosity, or a number of other factors. Based on the disconnect between the channel forms upstream of the bridge as compared to downstream of the bridge it is recommended that any analysis include a detailed study of the flow mechanics related to the bridge hydraulics. It is necessary to determine if a downstream knickpoint has migrated up to the bridge, or if the bridge hydraulics are resulting in hydraulic instabilities that have propagated erosion downstream.

The heavily eroded left bank should also be stabilized. If space permits it is recommended that the slope be graded back to reestablish a natural slope and stabilized with an appropriate engineering methodology, both of which will be determined during the detailed design analysis. However, as seen in Figure 5-21 there are a number of large trees immediately along the left top of bank, many with exposed roots. Rather than grading this slope back and removing the trees it is likely a better solution to restore the natural bank geometry, filling the slope and then installing a hardened face to resist re-eroding the area. A similar treatment could be applied to the right bank, as it is also heavily eroded as seen in Figure 5-19 (note that Figure 5-19 is looking upstream, so river-right is on the left side of the photo). It should also be noted that this erosion is not localized to the area around the bridge, field investigation revealed that it has propagated downstream as well as shown in **Figure 5-33**. Due to the complex nature of the river mechanics in play at erosion location 2 it is recommended that a detailed study be completed by a multidisciplinary team inclusive of hydraulics experts as well as geomorphologists to determine the root cause of the erosion and to develop a comprehensive solution that will address the issues now and into the future.

Figure 5-33
Erosion Progressing Downstream Along Bear Creek

5.2.3 Erosion Location 3 (Tier 2)

Erosion location three is located on the main stem of Hackberry Creek, located southwest of Cabell Drive, immediately upstream of the confluence with Mud Springs Creek as shown in **Figure 5-34**.

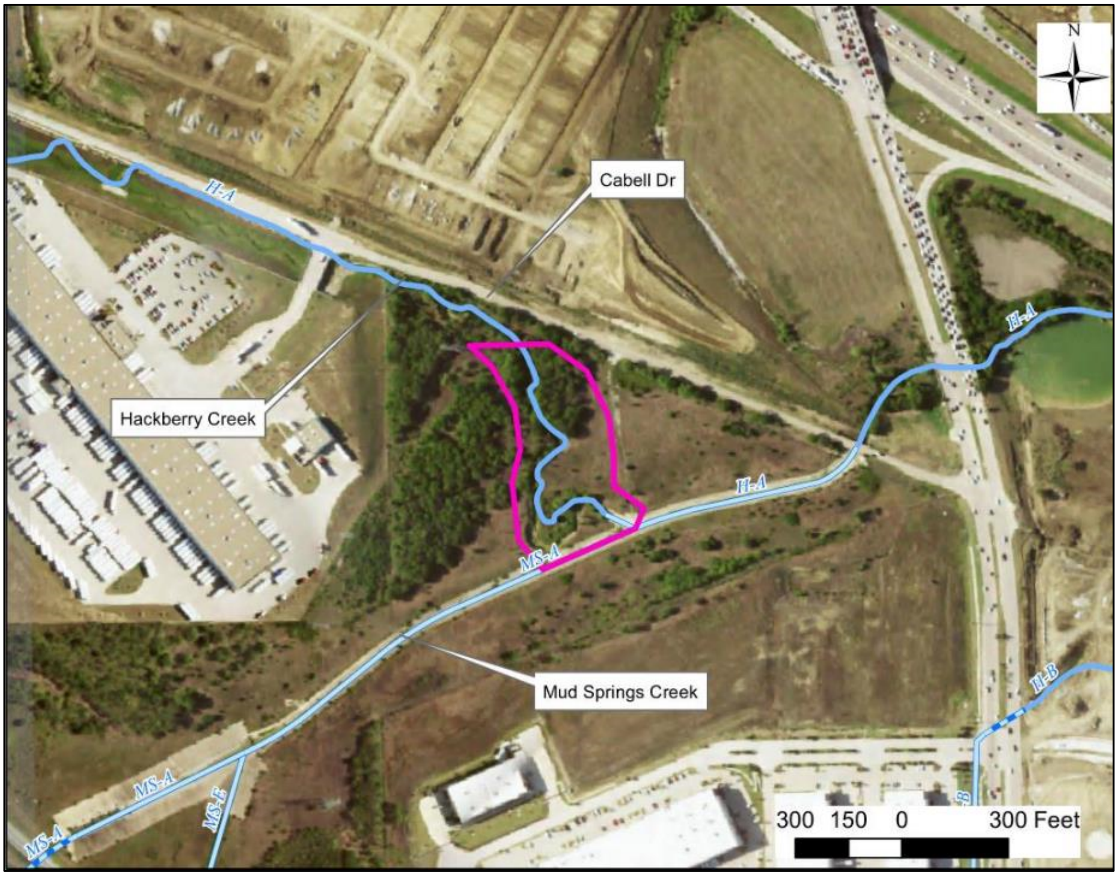


Figure 5-34
Erosion Location 3 within the Hackberry Creek Watershed

Review of the watershed modeling for Hackberry Creek showed that link HB100003A was represented as a natural irregular channel as shown in **Figure 5-35**. The channel has a longitudinal slope of approximately 0.3%, and during the 1-yr 24-hour design storm simulation had a peak velocity of 1.1 ft/sec.

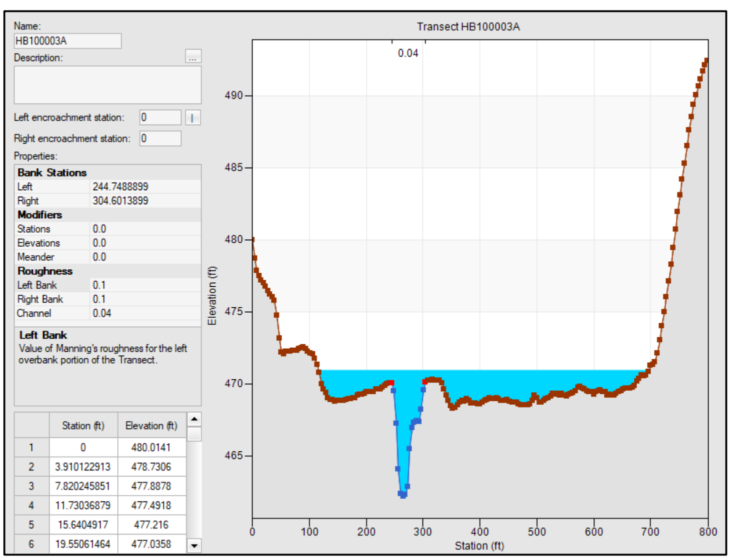


Figure 5-35
Transect HB100003A Located U/S of Confluence with Mud Springs Creek

The eroding channel is located immediately upstream of the confluence with Mud Springs Creek and is encroaching on the north side of the concrete channel that conveys Mud Springs Creek as shown in **Figure 5-36**.

Figure 5-36
Erosion Area 3 - Encroachment on Mud Springs Creek Channel

Field observations revealed that the channel has been experiencing severe lateral migration occurring on the outside of the meander, resulting in the near vertical slope that can be seen in **Figure 5-37.**

Figure 5-37
Erosion Area 3 - Riprap underneath West Airfield Dr Bridge

Review of historic aerial imagery in Google from 2001 to present clearly shows the lateral migration resulting in the channel shifting south and encroaching on the concrete channel conveying Mud Springs Creek as shown in **Figures 5-38 through 5-42**.

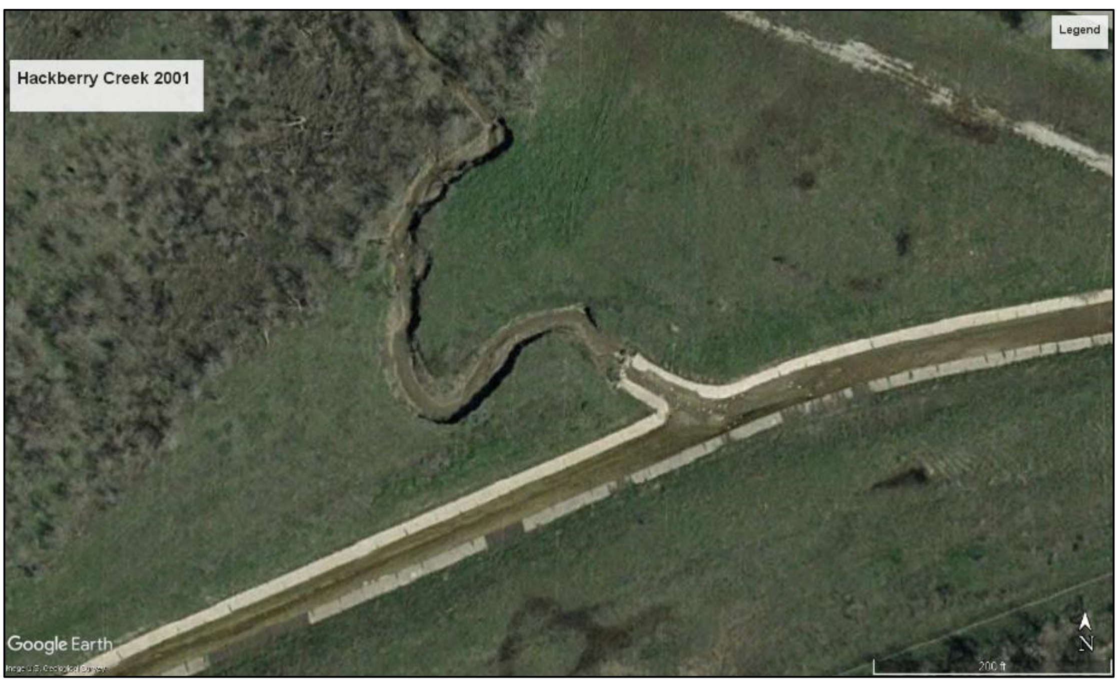


Figure 5-38 Hackberry Creek Channel Upstream of Mud Springs Confluence – 2001

Figure 5-39
Hackberry Creek Channel Upstream of Mud Springs Confluence - 2005

Figure 5-40
Hackberry Creek Channel Upstream of Mud Springs Confluence - 2011

Figure 5-41
Hackberry Creek Channel Upstream of Mud Springs Confluence - 2015

Figure 5-42
Hackberry Creek Channel Upstream of Mud Springs Confluence - 2020

Review of these aerial images shows that by 2015 the right bank of Hackberry Creek was right against the back side of the concrete channel that conveys Mud Springs Creek. DFWIA staff have witnessed flows overtopping the bank and spilling into Mud Springs Creek at this location, which is clearly evidenced by the staining in the photographs.

Two potential alternatives for rectifying this situation are presented below.

Alternative 1: Restoration of Historic Channel Geometry

One alternative solution would involve review of historic aerial photos to establish and restore the historic channel planform and geometry. Geomorphological calculations would also need to be performed to establish a stable meander geometry based on the flow regime as compared to the material comprising the channel bed and banks. The recent lateral instability exhibited by the channel would require the installation of bank stabilization measures to prevent the channel from migrating back into the current location where it is threatening the Mud Springs Creek channel. Bank stabilization measures would include a mixture of vegetation and hardening, with riprap or another "hard" stabilization technique being required along the outside (southern) side of the bend that has shifted as well as along the outside of the final meander as conceptually shown in **Figure 5-43**. It should be noted that Figure 5-43 is based on the 2001 aerial photo, as Google images prior to this point were blurry and did not accurately portray the area.

Figure 5-43
Erosion Area 3 - Conceptual Channel Reinforcement

Several challenges are associated with this alternative. Relocating the channel will require close regulatory coordination, as Hackberry Creek is classified as Waters of the US, and any work in the stream would need to receive the appropriate regulatory review and approval. Another challenge associated with this approach is that it addresses the problem, not the cause. The channel, even with stabilization in place, is likely going to strive to migrate south towards the concrete channel unless changes are made throughout the watershed to establish a more stable flow regime.

Alternative 2: Implementation of an Overflow Weir

A second alternative consists of leaving the channel where it currently resides and installing a low-level overflow weir along the concrete channel conveying flows from Mud Springs Creek. This alternative would involve lowering the top of the existing concrete channel along Hackberry Creek to establish a dedicated discharge point. An angled cutoff wall would also need to be installed along this stretch to reduce hydraulic losses and prevent flow from Hackberry Creek from further undermining the backside of the existing concrete channel as shown in **Figure 5-44**.

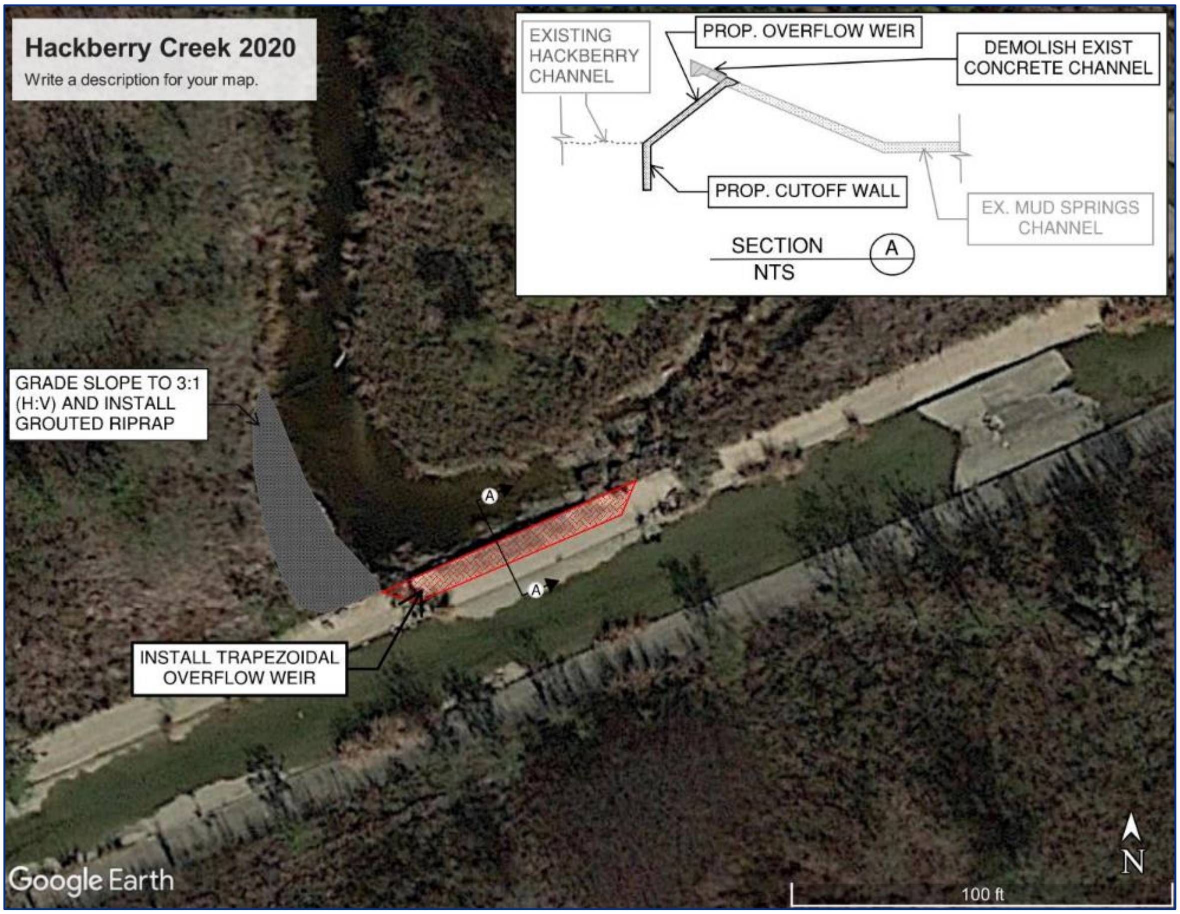


Figure 5-44
Erosion Area 3 - Conceptual Overflow Weir

Calculations will need to be performed during the detailed design process to determine project requirements such as the overflow elevation, the optimal width and shape of the overflow weir, the extents of lateral stabilization required, and the depth and extent of the cutoff wall to prevent undermining of the channel. While permits for work within Waters of the US would likely be required, the permitting process will likely be more streamlined than that of relocating the channel.

Regardless of the improvement alternative selected it is recommended that changes within the watershed be analyzed to determine the root cause of the channel instability. Once the cause(s) are determined then measures can be employed to stabilize the Hackberry Creek flow regime.

5.2.4 Erosion Location 4 (Tier 2)

Erosion location four is within the Bear Creek watershed on channel T-A, located downstream of West Walnut Hill Lane, east of International Parkway as shown in **Figure 5-45**.

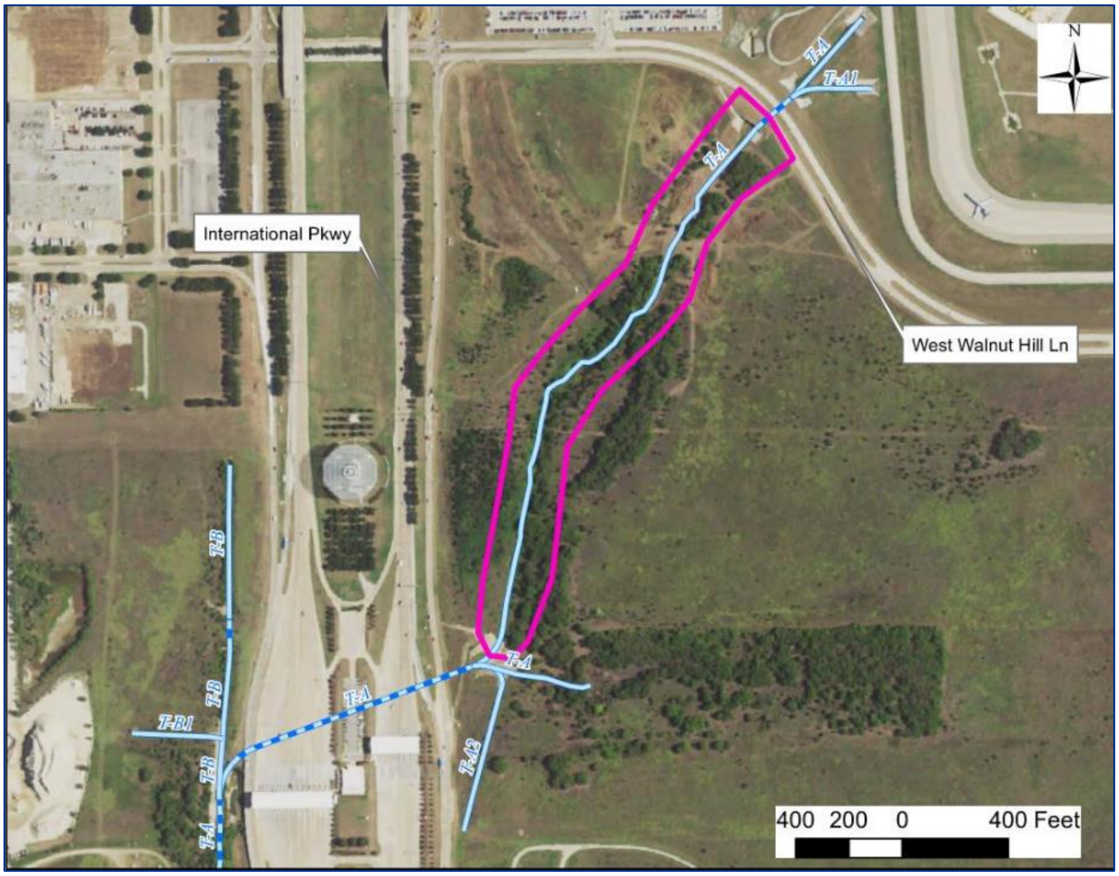


Figure 5-45
Erosion Location 4 within the Bear Creek Watershed

Review of the watershed modeling for Bear Creek showed that this stretch is divided into two links BC-T-A-15005A representing the upstream portion, and BC-T-A-15000S representing the downstream stretch. Both sections were represented as natural irregular channels as shown in **Figure 5-46** and **Figure 5-47,** respectively. Both channels have a longitudinal slope of approximately 0.3%, and during the 1-yr 24-hour design storm simulation had peak velocities of 5.2 ft/sec and 4.4 ft/sec respectively.

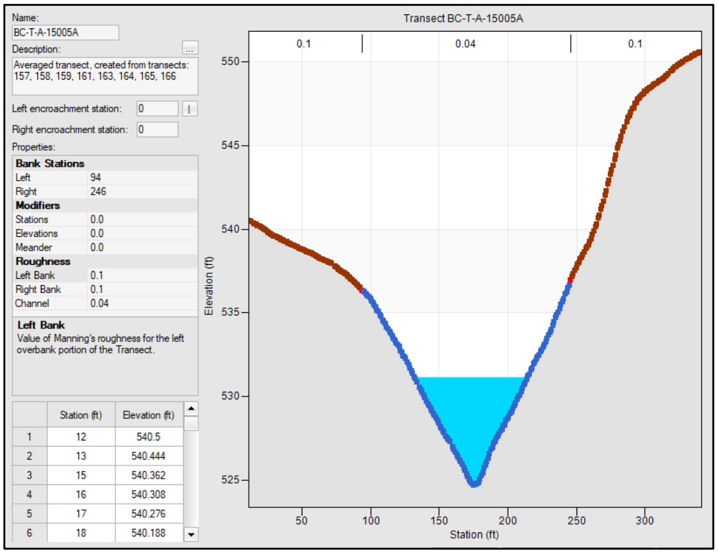


Figure 5-46
Transect BC-T-A-15005A Located D/S of West Walnut Hill Lane (upstream portion)

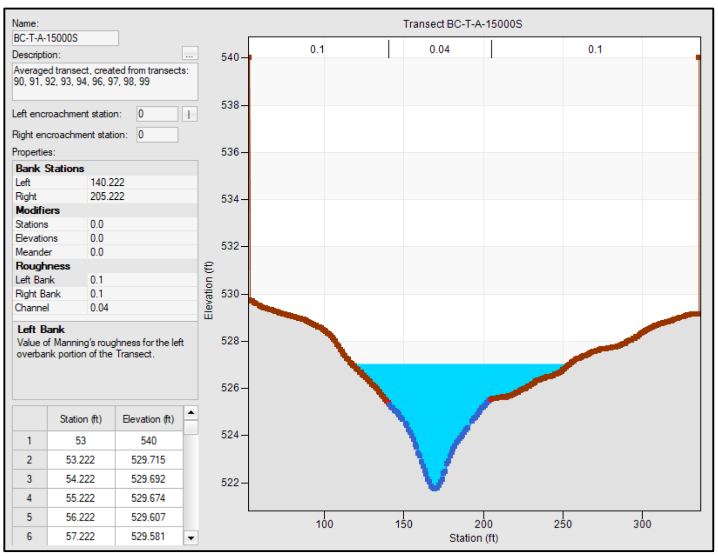


Figure 5-47
Transect BC-T-A-15000S Located D/S of West Walnut Hill Lane (downstream portion)

While minor incision is occurring along the entire stretch, the area of greatest concern is at the downstream end of the natural channel where it intersects with the existing concrete lined portion immediately upstream of the International Parkway crossing as shown in **Figure 5-48**.

Figure 5-48
Erosion Area 4 - Looking Upstream at the Interface between the Lined and Natural Channel

The main concern regarding the vertical erosion at the channel/concrete interface is that water appears to be getting underneath the concrete, and the hydrostatic uplift has resulted in cracking of the concrete as shown in **Figure 5-49** and **Figure 5-50**.

Figure 5-49
Erosion Area 4 - Looking Upstream at Damage to Lined Channel

Figure 5-50
Erosion Area 4 - Looking South at Damage to Channel

A comprehensive solution would involve restoring the channel design lines and grades upstream of the interface with the existing lined channel to reestablish an uninterrupted longitudinal profile. A channel geomorphic analysis would be performed to determine the best means of stabilizing the channel to inhibit vertical incision in the future. At the same time the existing concrete lined portions of the channel that are damaged would be replaced, and a hydraulic cutoff wall would be installed at the upstream end of the concrete channel at the interface with the natural channel to prohibit water from flowing underneath the concrete section. Options for providing additional vertical channel stability to prevent incision should be investigated as part of the detailed design process. Additionally a review of the upstream watershed would be performed to determine factors contributing to the erosion that has been seen in the natural channel, and mitigative measures would be employed to reduce velocities within the channel to below 3 ft/sec for the 1-yr 24-hr storm event.

A near-term solution focused on minimizing continued damage to the existing concrete channel would focus on preventing flows from undermining the concrete and the associated uplift damage. This could be accomplished by installing a hydraulic cutoff wall at the upstream end of the existing concrete channel. The area would need to be dewatered and any existing undermining would need to be addressed, likely with flowable fill. It is recommended that the hydraulic cutoff wall be installed at an angle to allow for a smoother transition to bridge the vertical disconnect that exists between the existing earthen channel and the concrete lined portion as shown in **Figure 5-51**.

Figure 5-51
Erosion Loction 4 – Conceptual Cutoff Wall

5.3 Alternatives Evaluation - Riprap

During field investigations at DFWIA, there were multiple instances observed where riprap was washed out and displaced downstream, as shown in **Figure 5-52**, which is typically a result of poor installation or undersized rock.

Figure 5-52
Displaced Riprap within the Bear Creek Watershed

There are numerous methodologies for designing and sizing riprap, including the NCTCOG iSWM method that refers back to USDA SCS nomographs from circa 1975. While these design methods are sound, it is recommended that designers also cross-check the size of riprap using the Federal Highway Administration (FHA) riprap sizing guidance (FHA 1989) as well as the TxDOT Hydraulic Design Manual (TxDOT 2019). In locations subject to frequent high velocities in excess of what traditional riprap is designed to withstand, the use of grouted riprap, gabions, or concrete channel sections with appropriate energy dissipation can be used. Using these conservative design methodologies and requiring thorough inspections during construction should result in longer-lasting, more efficient energy dissipation throughout DFWIA.

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Section 6

Mitigation Strategies for Model Identified Drainage Issues

6.1 Stormwater Drainage Master Plan

This section presents the assessment of the alternatives analyzed as part of this SDMP as well as overall recommendations for improvements at DFWIA.

6.1.1 Summary of Alternatives

As detailed in section 5, of the nine flooding locations investigated full restoration of the desired LOS was achievable at six locations. At two locations the improvements investigated were able to significantly reduce the depth and duration of flooding, and at one location it was discovered that a City of Irving local storm sewer is in place and appears able to provide for a 5-year level of service.

Conceptual solutions to specific erosion locations were developed, and are presented in section 5.2, and guidance for riprap sizing is provided in section 5.3. It should be noted that all of the alternative solutions investigated are conceptual in nature, and detailed analysis and design needs to be undertaken prior to initiating any remedial actions.

6.1.2 Capital Costs

Based on the current volatility in the construction market with respect to labor and materials pricing capital improvement costs for the alternatives analyzed were not developed. Conceptual quantities are provided in section 5.1 to support future planning. These quantities will be refined as part of the detailed analysis and design process.

6.1.3 Operations and Maintenance Costs

Operation and maintenance costs and considerations for various types of stormwater infrastructure at DFWIA are defined under separate cover in the Program.

6.1.4 Phasing Considerations

In developing a phased approach to the implementation of the improvement alternatives analyzed top priority was assigned to issues that could potentially result in loss of life or catastrophic damage to property. Airside issues that could potentially result in a violation of FAA criteria were prioritized over landside issues. The remainder of the issues were ranked based on frequency of impact, and the potential reduction in DFWIA required LOS. A tiered phasing matrix has been developed to aid in the planning of potential alternatives to proceed into the detailed design phase as shown in **Table 6-1**.

Table 6-1 Alternative Improvement Phasing[1]

Phasing Tier	Timeframe for Implementation	Alternative Location	Notes
Tier 1 Improvements	Tier 1 Improvements should be implemented as soon as possible to limit risk to life and/or property	None identified	Based on the analysis performed as part of this SDMP no catastrophic threats to life and/or property were discovered
Tier 2 Improvements	Tier 2 Improvements should be implemented as soon as possible after Tier 1 has been addressed as they do not meet FAA criteria for ponding and/or pose an immediate threat to infrastructure	Flooding Location #3	Flooding located airside
		Flooding Location #4	Requires elevating road
		Flooding Location #7	Flooding located airside
		Flooding Location #9	Flooding located airside
		Erosion Location #2	Additional study recommended
		Erosion Location #3	Imminent risk to concrete channel
		Erosion Location #4	Imminent risk to concrete channel
Tier 3 Improvements	Tier 3 Improvements should be implemented as funding becomes available to rectify loss in LOS	Flooding Location #1	Flooding located airside
		Flooding Location #2	Crossunder flooding
		Flooding Location #5	Crossunder flooding
		Flooding Location #6	Flooding located airside
		Erosion Location #1	Additional study recommended

Note:
1. It should be noted that the recommendations in Table 6-1 are subject to revision, and all alternative locations should continue to be monitored for changing and potentially worsening field conditions.

6.1.5 Implementation Plan

A phased plan will be implemented to address the flooding and erosion issues identified and investigated. Airside issues that could potentially result in a violation of FAA criteria or a reduction in DFWIA desired LOS will be addressed as soon as possible. The remainder of the landside issues should be addressed as funding allows. The implementation process will be:

1. Review the Plan with other stakeholders to identify potential overlaps or projects that could potentially be combined.
2. Review other on-going and planned projects to assess impacts and/or integration of needed stormwater improvements.
3. Implement project components in the phasing sequence moving from the conceptual analysis performed into the detailed analysis and design phase, then into construction and ultimately operations.
4. Incorporate stormwater improvements into the GIS Database as they are implemented.
5. Maintain the DFWIA base conditions hydrologic-hydraulic models and update the models as major projects are planned and constructed (or once every two years).
6. Document water quality features and treatment provided (as equivalent load reduction and/or as equivalent inches over the project area or Ac-Ft of retention-detention) as facilities are implemented for TMDL and NPDES documentation.

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Dallas/Ft. Worth International Airport (2017B). Land Use Plan [Brochure]. Available at: https://www.dfwairport.com/landhere/

DFWIA BMP Guidance Document
Dallas/Ft. Worth International Airport (2018). Best Management Practice Guidance Document. DFWIA Airport Stormwater Sampling and Monitoring Plan

EPA SWMM and SWMM-CAT
The computer programs can be downloaded from the EPA website here: https://www.epa.gov/water-research/storm-water-management-model-swmm

FEMA Map Service Center
Regulatory floodplain maps: https://msc.fema.gov/portal/home

Federal Highway Administration Riprap Sizing Guidance
Hydraulic Design Series No. 11: Design of Riprap Revetment, Federal Highway Administration, US Dept. of Tran., 1989.

NCTCOG iSWM Program for Construction and Development
Detailed guidance for stormwater management: http://iswm.nctcog.org/

TXDOT Hydraulic Design Manual (refer to latest edition)
Detailed guidance for hydraulic design:
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/manual_notice.htm

UWRI Water Quality Capture Volume
UWRI, Calculation of the Water Quality Capture Volume for DFW International Airport using the WQCOSM model, Urban Watersheds Research Institute, Denver, CO, April 2020

Appendix B

Green Stormwater Infrastructure Guidance Document

DFW Stormwater Drainage Master Plan

Green Stormwater Infrastructure
Guidance Document

Planning Green Stormwater Quality Infrastructure at DFW Airport

July 2021

CDM Smith

CCA Landscape Architects

CIMM

UWRI

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DFW Stormwater Drainage Master Plan

GREEN STORMWATER INFRASTRUCTURE GUIDANCE DOCUMENT

Planning Green Stormwater Quality Practices at DFW Airport

July 2021

Version	Date	Notes
1.0	July 2021	Initial version of guidance document

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The Stormwater Drainage Master Plan was developed by the

Energy, Transportation, and Asset Management Department

Systems Performance Group/Watershed Management

In collaboration with the:

Environmental Affairs Department

Commercial Development Department

Planning Department

Design, Code, & Construction Department

Disclaimer

This Dallas Fort Worth International Airport (DFWIA) Green Stormwater Infrastructure Guidance Document was prepared for DFWIA in accordance with the professional services agreement, Stormwater Drainage Master Plan Professional Services, Contract No. 8500349. The material in it reflects CDM Smith's best judgement in light of the information available at the time of preparation. Any use of or reliance on this information by a third party is at the sole discretion and responsibility of said third party. CDM Smith explicitly disclaims all liability for damages, if any, suffered by any third part as a result of any third party's reliance on the information contained therein, or for decisions made or actions taken by any third party based on this report. Modification of the content of this document in a way that changes any of the fundamental recommendations in the document, without CDM Smith's prior written agreement, removes the endorsement of the authors on the validity of the document for its original purpose.

Table of Contents

Table of Figures

Section 1

Section 2

Section 3

Appendix C

Table of Tables

Section 2

Appendix A

Appendix B

Section 1 – Introduction

The DFW International Airport (DFWIA) is comprised of almost 27-square miles of land, including the airport operational area (airside) which totals 8.0-square miles. The land surrounding the airside portion of DFWIA, commonly referred to as the landside portion of DFWIA, comprises 18.9-square miles of land. The boundary extents and differentiation between airside and landside areas of the airport are shown below in **Figure 1-1**. The opportunity to implement Green Stormwater Infrastructure (GSI) practices, also commonly termed Best Management Practices (BMPs), apply primarily to the landside area, although opportunities within the airside area also exist. The landside portion of DFWIA is comprised of a variety of land uses (as shown in **Figure 1-2**) and a significant amount of this area is available for development or re-development.

The goal of this document is to promote the cost-effective planning and implementation of Green Stormwater Infrastructure (GSI) which is infrastructure intended for improving the water quality aspects of stormwater runoff from developed areas. GSI, together with stormwater quantity management requirements, are necessary to help DFWIA comply with flooding, erosion protection, environmental, and public safety regulations. Additionally, these measures will help support DFWIA's established goals for sustainability, as outlined in the airport's Sustainability Management Plan, which specifically identifies "Improve and protect stormwater quality and control quantity" as a focus area (07[1]).

The primary objectives of this document are to:

- Provide the means to calculate the water quality benefits of GSI for both new and re-development projects and that complement the other airport guidance documents and requirements related to land development and re-development. Note that water quantity management requirements are defined elsewhere (05, 06, 10) but are discussed briefly below.
- Provide planning and implementation guidance for GSI projects as appropriate for DFWIA to mitigate the water quality impacts from stormwater runoff from developed areas as they discharge downstream of DFWIA.
- Provide recommended resources for developers and their engineers, architects, landscape architects, and constructors of GSI and providing information for working efficiently and effectively with DFWIA staff in the implementation of GSI.

For an entity contemplating developing or re-developing land in DFWIA's jurisdiction, the most significant guidance is that the entity should engage designers, engineers, architects, and landscape architects who have a successful track record of implementing GSI. As with any infrastructure project, success is achieved by cost effectively proceeding from concept, to design, to details and specifications, to construction, and then inspections and maintenance. GSI often

[1] Full references can be found associated with the numerical citation in **Section 4 - References**

takes more attention than the design and implementation of standard infrastructure such as roads, water, wastewater, and other utilities. Improperly designed and constructed GSI projects can render the GSI ineffective, resulting in additional costs to remediate.

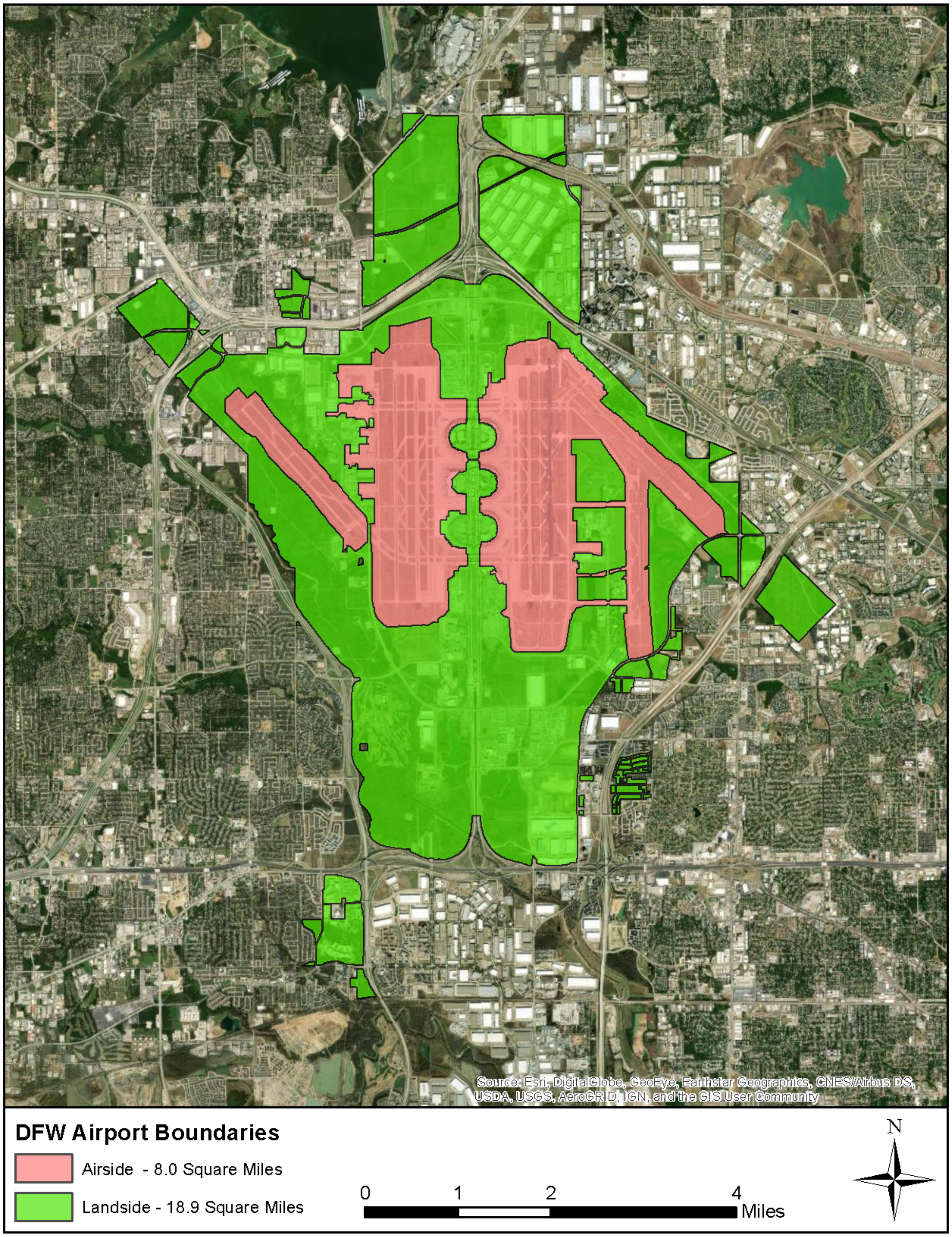

Figure 1-1
DFW International Airport Extents and Differentiation between Airside and Landside Areas (09)

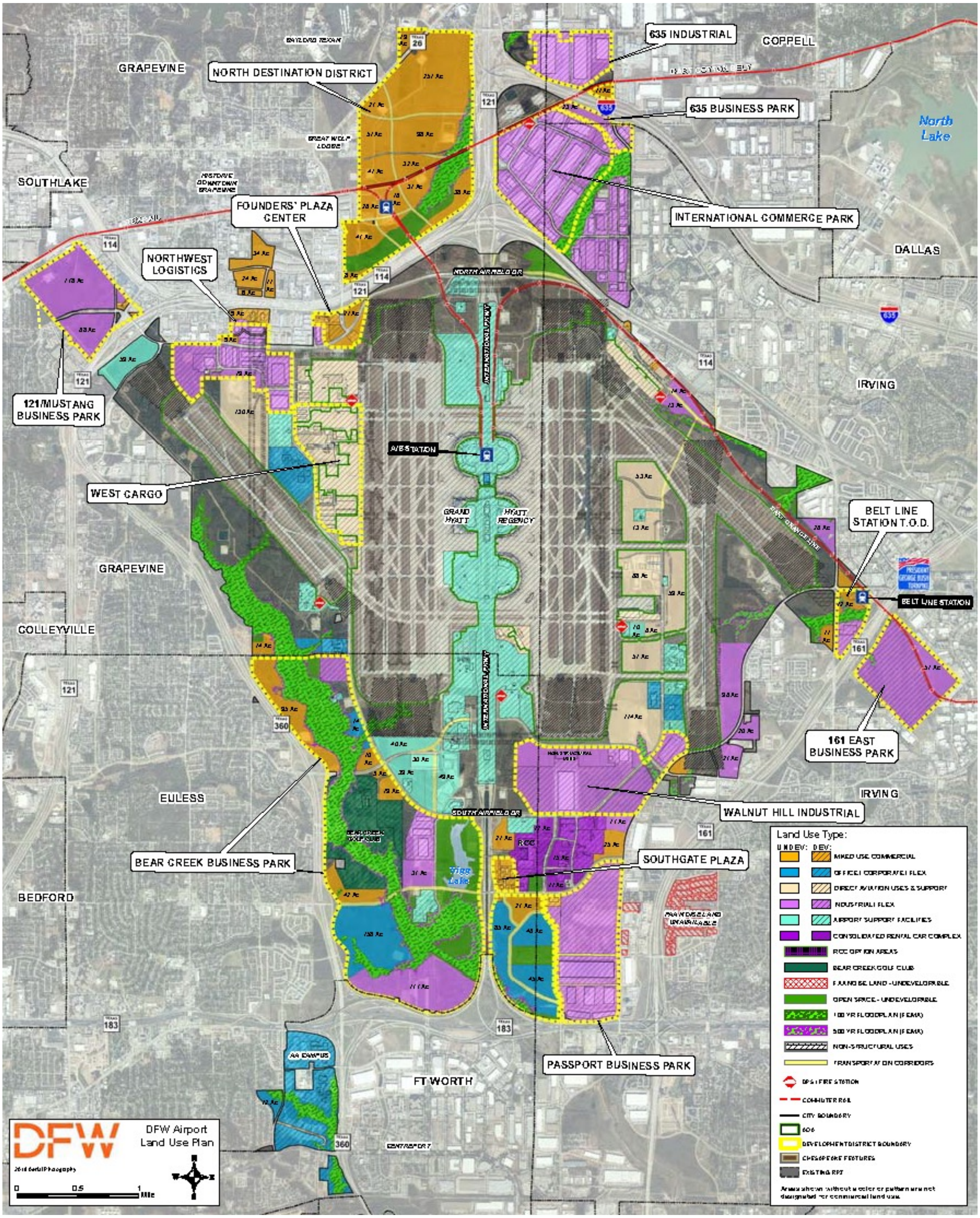

Figure 1-2
DFW International Airport Extents and Land Use Types (DFWIA 2019)

The GSI practices that are identified in this document are intended to foster the use of proven GSI features which mitigate the water quality impacts from development and redevelopment activities. These practices may also provide value-added landscape elements to the developments. Integrating GSI practices with water quantity management practices, such as flood control, is highly encouraged where practical to reduce the overall footprint of stormwater quality and quantity management facilities, while simultaneously achieving cost savings.

Brief explanations of GSI practices that have been determined as appropriate for DFWIA for the landside and airside areas, in around DFWIA, are as follows:

Landside: The GSI practices that are discussed in this document meet DFWIA's goals for the required level of water quality treatment and are acceptable for use on airport property. In addition, these practices are anticipated to provide long service lives (greater than 30 years) with proper/routine inspection and maintenance.

For the landside portion of the airport these include the following:

- Rain garden (bioretention basin);
- Sand or media filter;
- Enhanced detention basins (adding GSI practices to extended dry detention);
- Vegetative filter strip with underdrains;
- Grass swale with underdrains; and
- Pervious pavers (Note that there may be limitations to the drainage areas and traffic loads that can be treated using pavers with prior approval).

To increase the efficiency of managing both stormwater quality and quantity, developers are encouraged to look at combining GSI practices with stormwater quantity practices (such as detention) which are designed to constrain peak post-development discharges to the pre-development peak stormwater discharge.

Airside: There are two GSI practices described in this document that can be used on the airside portion of DFWIA to benefit water quality, where appropriate. These practices are as follows:

- Vegetative filter strips with underdrains; and
- Grass swales with underdrains.

Finally, there is one stormwater quality practice that is not a GSI - First Flush Systems (FFSs) – that are predominantly an airside practice but can be used in landside applications as well. These systems are described as well.

1.1 How to Use This Document

The intended audience for DFWIA's GSI Guidance Document includes developers, architects, engineers, and landscape architects. This document is intended as a planning document for the implementation of GSI practices. It should be seen as a living document that is also complementary to other DFWIA guidance documents related to the development and redevelopment of land within the airport boundary. Additionally, this document should be used in conjunction with DFWIA's stormwater quantity management requirements in the airport's Stormwater Drainage Master Plan (06). With this in mind, this GSI guidance document contains the following sections:

Section 1 – Introduction – Section 1 provides an introduction to the guidance document, including the objectives, the intended users, and background information. This section also provides an overview of DFWIA's review process for GSI practices and highlights major steps in the process.

Section 2 – GSI Planning and Requirements – Section 2 describes the initial steps of evaluating the need, as well as the options, for GSI practices at a site. It provides information about calculating the water quality protection volume to be treated.

Section 3 – GSI Practices – Section 3 provides an introduction to the GSI practices covered in the document. It includes a description of each GSI practice, representative illustrations, the benefits of each GSI practice, and a brief summary of inspection and maintenance requirements for each practice. Detailed inspection and maintenance guidance for GSI practices are included in the *DFW Stormwater Master Plan Program Implementation Document* (10).

APPENDICES

Appendix A – GSI Sizing Workbook – Appendix A provides an Excel-based workbook that can be used to help size GSI practices for a land development or re-development project. This workbook can also give DFWIA's reviewers a common framework to evaluate proposed GSI plans.

Appendix B – Landscape Recommendations and Requirements – Appendix B provides an overview of the specific plant varieties that can be used for GSI practices at DFWIA. Note that plants other than those listed in the appendix require prior approval from DFWIA.

Appendix C – Design Resources – Appendix C provides resources to assist in the design and implementation of GSI practices. These resources provide additional design resources beyond the scope of this document such as representative design details, specification, and construction notes for GSI practice components such as inlets, outlets, and the like. Many of the resources are from other jurisdictions and are seen as adaptable to a DFWIA land development projects. They will, however, require such adaptation by the designers of the GSI implementation for use within DFWIA boundaries.

1.2 Authorities and Jurisdictions

DFWIA boundaries either overlap, or are adjacent to, those of several other jurisdictions including the Cities of Fort Worth, Irving, Euless, Grapevine, and Coppell, as shown **Figure 1-3**. The DFW Airport Board is charged with governing DFWIA and is composed of 12 members, 11 of whom are appointed by the city councils of the Airport's owner cities – Dallas and Fort Worth. Additionally, one Board member is appointed from either Irving, Euless, Grapevine, and Coppell on a rotating basis. The DFW Airport Board is therefore the regulatory authority for activities stormwater management activities affecting airport operations (05, 06, 07, 08).

DFWIA's authority to govern the stormwater management includes both areas within its boundaries and outside of its boundaries as well. Outside of DFWIA boundaries, meeting DFWIA stormwater quantity and quality requirements are required where a development or infrastructure project creates or modifies stormwater infrastructure that is within areas adjacent to the airport that could impact aircraft safety. Coordination with other jurisdictions will also be required when DFWIA stormwater flows pass DFWIA boundaries onto other jurisdictions or vice versa. Projects are advised to seek early clarification on any coordination requirements from DFWIA.

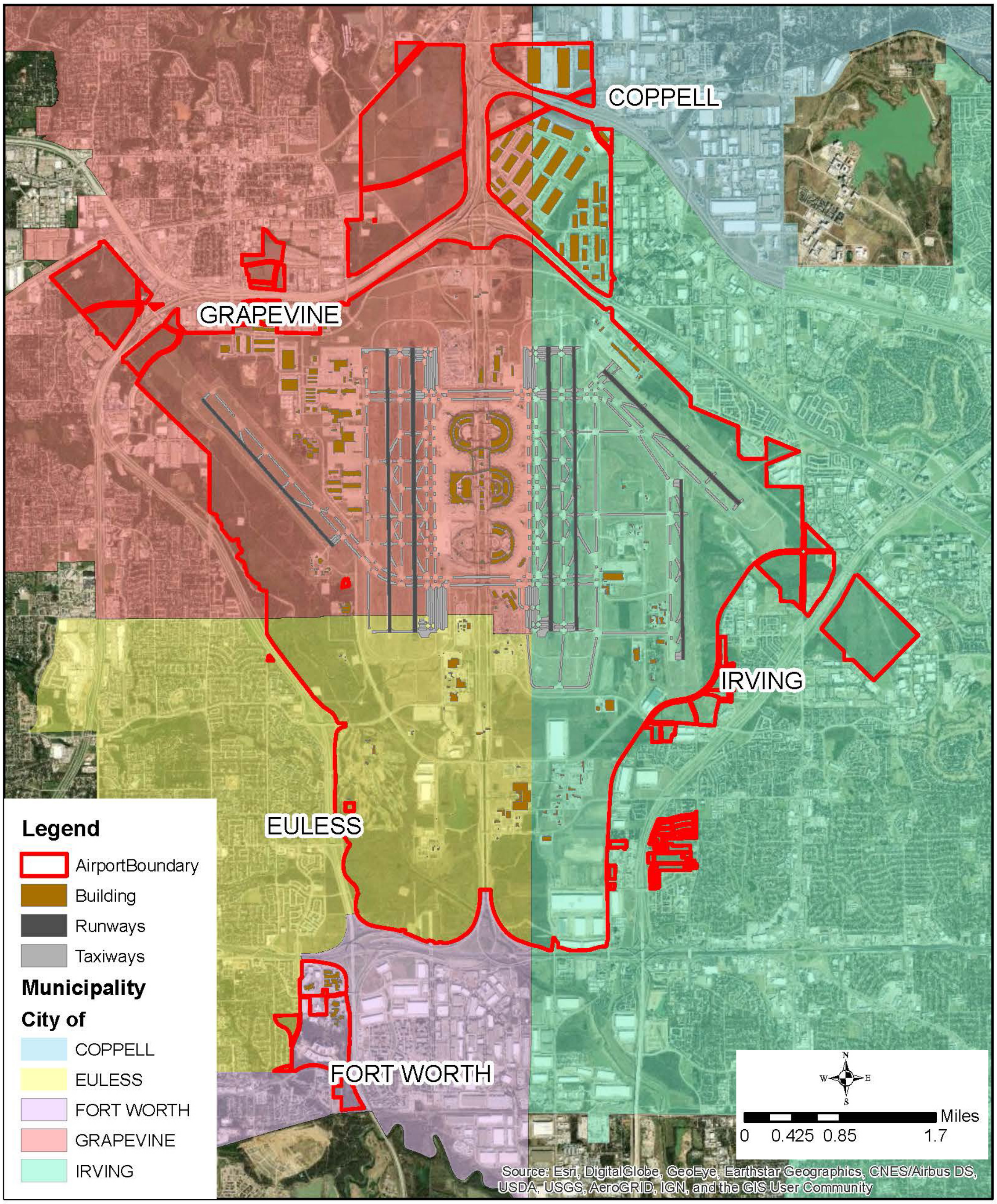

Figure 1-3
DFW International Airport and overlapping and adjacent jurisdictions (09)

Authorities that have bearing on how DFWIA manages stormwater quality and quantity include the following:

- **FAA** - The Federal Aviation Administration (FAA), under the US Department of Transportation, governs and regulates airports in the US, including DFWIA. The FAA has several guidance documents including Advisory Circulars that are relevant to, and can impact, stormwater management at airports. These are covered in the FAA publications, shown in **Section 1.3.3** which are incorporated into DFWIA's Code of Rules and Regulations for stormwater (08) and promulgated through DFWIA's Design Criteria manual (02) and DFWIA's Development Design Guidelines (03).
- **USEPA/TCEQ** - The US Environmental Protection Agency (USEPA) has regulations promulgated under the federal Clean Water Act (CWA) that also govern stormwater discharges from airports. The USEPA has delegated administration of the National Pollutant Discharge Eliminations System (NPDES) permitting to the State of Texas, which is administered by the Texas Council on Environmental Quality (TCEQ). Additionally, the USEPA provides guidance on stormwater management for federal projects (29). These requirements are also incorporated into DFWIA's Code of Rules and Regulations for stormwater (08)
- **NEPA** - The National Environmental Protection Act (NEPA), whose requirements are administered by the Council for Environment Quality (CEQ), require environmental impact documents that demonstrate no negative environmental impacts for projects receiving federal funding. DFWIA is affected by these requirements, and the various environmental assessment studies associated with DFWIA have required that DFWIA's stormwater runoff have no negative environmental impacts.

The specific requirements of these authorities are discussed in the following section.

1.3 Water Quality Requirements for DFW International Airport

There are several regulatory requirements that have a direct bearing on stormwater quality management for lands within the boundaries of DFWIA. Many of these stormwater regulatory requirements affect adjacent jurisdictions as well. These regulations can be grouped into two categories: 1) those requirements that are associated with regulations stemming from the CWA and its amendments, as well as the federal NEPA and its amendments; and 2) those requirements and guidance that affect stormwater management that are specific to airport and aviation activities promulgated by the FAA.

These regulatory requirements are discussed further below. This guidance document for the planning and implementation of GSI practices on DFWIA property adheres to the regulatory requirements outlined below at the time of initial publication or subsequent update.

1.3.1 TCEQ Stormwater Discharge Regulatory Requirements

The TCEQ has the responsibility for operating and enforcing the USEPA's regulations associated with the CWA. In turn, DFWIA's Environmental Affairs Department oversees the processes for Municipal Separate Storm Sewer System (MS4) permitting, permitting under the Multi-Sector General Permit, as well as any discharges that may be classified as Categorical Wastewater Discharges as required by law (08). Though DFWIA overlays several other municipal jurisdictions the boundaries of DFWIA have been identified as a stand-alone MS4 and DFWIA is permitted as such. As a part of DFWIA's MS4 permit (11), DFWIA is required to address the quality of the stormwater discharged from new developments or significant redevelopments to the Maximum Extent Practicable (MEP) standard establish by federal regulation and adopted by the State of Texas. This guidance document assists DFWIA in complying with that requirement.

1.3.2 CEQ NEPA Regulatory Requirements

Because DFWIA continues to receive federal funding for the airport, they are subject to the NEPA requirements. NEPA, through the CEQ, required an initial Environmental Impact Statement (EIS) with a subsequent finding of no negative environmental impacts before the construction of DFWIA could begin in the early 1970's. There have been ancillary environmental assessments associated with NEPA through the years as DFWIA has grown. NEPA requires that, where a potential environmental impact is likely, the impact must be mitigated. NEPA requires that water quality impacts from developed areas within DFWIA be mitigated in order to protect waters of the US. These requirements are reflected in DFWIA's Code of Rules and Regulations (08).

1.3.3 Requirements and Considerations Specific to Airports

The FAA has relied upon the National Academy of Sciences (NAS) and the associated Transportation Research Board (TRB) to evaluate and recommend designs, inspection, and maintenance practices for airports that address a wide variety of airport activities through the Airport Cooperative Research Program (ACRP). Several publications from the NAS/TRB/ACRP have addressed stormwater management on airports, as it relates to aviation safety and environmental protection. Additionally, the FAA releases Advisory Circulars that include additional guidance based on ACRP studies. Each of these will be discussed in more detail below. These publications are available free for download (in PDF format) from The National Academies Press (https://www.nap.edu).

In 2009, Executive Order 13514 was signed encouraging all federal agencies to lead by example on a variety of environmental issues and requiring federal projects impacting greater than 5,000 square feet to incorporate stormwater quality discharge requirements. As such, the USEPA provides technical guidance on stormwater runoff requirements for federal projects, including DFWIA (29).

1.3.3.1 ACRP Publications 39 and 125 and FAA Advisory Circular 150/5200-33C – Wildlife Management

ACRP Publications 39 and 125 (20, 22) address the techniques to non-lethally manage wildlife populations, particularly birds, in and around airports. Where wildlife is present, the opportunity for wildlife being struck, or striking, a moving aircraft increases the risks to aviation safety, as regulated by FAA Advisory Circular 150 (13). As it relates to stormwater management on airport property, it has been shown that reducing wildlife populations can be achieved by not allowing for the ponding of water for greater than 48-hours, and with no standing water occurring between storms. DFWIA has implemented this practice, and in fact modified it such that stormwater management infrastructure must eliminate ponding water within 24-hours, rather than 48-hours. Guidance from these publications has also been used by DFWIA in order to control the types of landscape plants used on airport grounds that are less attractive to wildlife for habitat and food.

1.3.3.2 ACRP 169 – Compliance with Clean Water Act Requirements

ACRP Publication 169 (21) provides airports guidance on the various ways that an airport, like DFWIA, may need to comply with the CWA. This includes the MS4 permitting regulations discussed in **Section 1.3.1.**, but also includes other less frequent elements of the CWA that may arise. For stormwater runoff, ACRP 169 should be compared to the USEPA's stormwater technical guidance document, discussed further in **Section 1.3.3.4**.

1.3.3.3 ACRP 174 – Green Stormwater Infrastructure for Airports

ACRP Publication 174, Volumes 1 and 2, (23) provide both an overview as well as guidance on the use of GSI in airports that will be compliant with previous ACRP guidance on meeting both regulatory requirements and mitigating wildlife attractiveness. ACRP 174 is an excellent overview of how to use GSI for airports in general, but the recommendations typically require specific locality modifications due to variations in climatology, hydrology, nature of the terrain, and nature of receiving water for stormwater discharges.

1.3.3.4 USEPA – Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects

As a requirement of Section 438 of the Federal Energy and Independence Security Act of 2007, the USEPA was required to disseminate technical guidance on the implementation of the stormwater runoff requirements for Federal projects (29). The guidance contains direction on the preservation of pre- and post-development hydrology that includes the integration of GSI for water quality benefits. Like ACRP 174, this guidance document contains generalized recommendations that are typically modified for a specific locality.

1.4 Alternative Approaches

The GSI practices for the landside and airside of DFWIA that are outlined in this document have been selected due to their proven history in other locations of providing cost-effective stormwater quality treatment. These practices have been backed by years of data collection and analyses as to their effectiveness.

Should a developer/designer wish for DFWIA to consider GSI or stormwater quality management practices other than those in this document, the burden will be on the developer and the developer's designers to clearly make the case (based on proven performance in other locations) that any alternative approaches are equivalent to, or better than, the GSI practices in this document. These alternatives must meet the following to be considered for a variance:

1) Stormwater quality treatment in the ability to treat the Water Quality Capture Volume (WQCv), discussed in detail in **Section 2**;

2) Ease and cost of inspection and maintenance;
3) Compliance with other DFWIA requirements for drainage including flood control (preservation of pre-development peak stormwater discharge flows), erosion control (limitation on stormwater flow velocities), allowable landscaping; and
4) Compliance with outside regulatory requirements, discussed in **Section 1.3**, relating to environmental criteria and public health and safety (such as FAA requirements).

For a particular development, if a developer feels that that their ability to meet the guidance in this document is hampered due to constraints beyond their control, then DFWIA is amenable to reviewing the situation with the developer. However, the developer must clearly demonstrate to DFWIA that a variance should be considered.

1.5 Project Submittal and Review Process

It is highly recommended that the developer and their designers meet with DFWIA staff as early in the process as possible regarding the planning, design and implementation of GSI practices, as well as stormwater quantity management approaches. This is a key step in making the project submittal and review process with DFWIA go as efficiently as possible. Specific requirements for project submittal and the subsequent review process are detailed in the DFW Storm Drainage Master Plan Program Implementation Document (10).

1.6 References

References cited in this section can be found in **Section 4 – References** using the numerical citation for each reference,

Section 2 – Green Stormwater Infrastructure (GSI) Practices Implementation and Requirements

Proper planning in the implementation of GSI practices on development or redevelopment projects is important to mitigate the impacts to water quality from developed land on receiving water bodies. It is also critical to do proper planning for stormwater quantity management for erosion and flood control associated with development. Therefore, it can be beneficial to plan both the aspects of stormwater quantity and quality management together. As mentioned in **Section 1**, DFWIA's stormwater quantity requirements are contained in the airport's Design Criteria Manual and Stormwater Drainage Master Plan (02, 06[1]). In combination with stormwater quantity practices, this GSI infrastructure further protects pervious areas and helps minimize both the cost and the footprint of structural drainage practices.

This section provides a brief overview of the GSI planning process for new development and re-development projects. This includes a discussion to support integration of water quality GSI practices into site development and recommendations to help determine the type of GSI practices. Additional detail is provided in **Section 3** and **Appendices A, B, and C**.

It is important to note that GSI practices will vary for airside versus landside systems. Airside and Landside systems *must* meet FAA Advisory Circular 150 (13). This FAA requirement is meant to minimize the occurrence of ground fog and minimize conditions that attract wildlife (e.g., water and wetlands) that can present public safety concerns from wildlife impacts to aircraft (notably bird strikes). The advisory circular further requires only brief allowable ponding on surface areas and stormwater infrastructure. DFWIA has determined that landside systems must meet these FAA criteria by not allowing standing water, or ponding, for more than 24-hours after the end of a precipitation event (06). DFWIA has also set restrictions on allowable landscape plants that can be used in order to prevent introduction of plants that are a wildlife attractant (03)

2.1 GSI Practices and Site Planning

Similar to stormwater quantity management for erosion and flood control, proper GSI practice planning considers site layout, hydrology, topography, soils and infiltration rates, groundwater table, and GSI practice sizing and placement early in the process. Considering both stormwater quantity and water quality infrastructure together allows for the consideration of combining these infrastructures in a smaller footprint. This provides the opportunity to lower the overall capital and inspection and maintenance costs of stormwater management with these multi-purpose systems.

[1] Full references can be found associated with the numerical citation in **Section 4 - References**

The recommended steps for the planning of the site and use GSI practices are as follows:

- In consultation DFWIA staff, identify protected and sensitive features and identify opportunities to preserve and protect these features. This includes such things as setbacks for impervious areas from floodplains/floodways, wetlands, stream riparian areas, and dense or desirable vegetation (currently 25 feet). Other planning practices include procedures such as locating the development in less sensitive areas of the site and fitting the design to the terrain.
- Define the areas that are most suitable for development, as well as the areas to be landscaped and those to be conserved. Conform the site layout along natural landforms and avoid excessive grading, or soil disturbance, unless to modify the soil matrix to increase the effectiveness of GSI practices. Also, where stormwater infiltration will be relied upon, it is imperative to avoid soil compaction. Construction on steep slopes or on erodible soils will require construction practices designed to minimize erosion. Construction in FEMA floodplains, areas of consistent inundation (less than 100-year FEMA designation) or designated flood storage areas is prohibited.
- Assess opportunities to minimize overall impervious coverage on the site.
- Estimate GSI practice size to accommodate the Water Quality Control Volume (WQCv) which is discussed later in this section, the range of depths within the practice, and the areal footprint taking into consideration inspection and maintenance access.
- Locate GSI practices with consideration for capturing stormwater runoff from areas with a high potential for pollutant loading, such as roadways and parking lots.
- Assess the opportunity to integrate stormwater quantity and quality GSI.
- Consider "offline" first flush systems in areas that contribute large amounts of oil-grease, sediment, or trash-debris. This can be accomplished with a diversion weir, or orifice. This improves long term capture efficiency, consolidates O&M, and maintains flood control attenuation performance.

2.1.1 Sensitive Site Condition Considerations

Existing site conditions that serve important hydrologic functions (such as reducing runoff or pollutant loads downstream) should be identified in consultation with DFWIA staff for protection early in the site assessment process. Natural and sensitive features that should be protected include the following:

- Bodies of water such as streams, wetlands, ponds, and lakes
- Natural drainage paths
- Riparian areas
- Floodplains
- Steep slopes
- Erodible soils; and

- Any sensitive area identified by DFWIA staff

The developer should take steps during the planning and construction phases to protect these features. It is important to consider that the disturbance of soil during construction can enable large quantities of sediment to be mobilized during stormwater runoff events. These sediment loads can harm natural features and clog, or otherwise, damage both GSI practices and traditional stormwater infrastructure. Temporary construction controls should be implemented, per DFWIA and TCEQ requirements, to prevent erosion and sediment transport.

Many soils in North Texas, including some on within DFWIA boundaries, are considered highly erodible to concentrated flows of runoff/drainage. Stormwater discharges to natural drainage paths should be done in such a manner that velocities in these pathways are not sufficient to erode these paths. The preference established by DFWIA in the recent Storm Drainage Master Plan (06) are maximum velocities less than 3.0 feet/second. Refer to the current DFWIA Design Criteria Manual (02) for maximum velocities in unlined channels. Applicability of either of these criteria this will depend on pathway slope, vegetative cover, whether the runoff is sheet or concentrated in nature, and the characteristics of the underlying soils. As such, DFWIA staff should be consulted on appropriate discharge velocities for the given development situation.

Stormwater discharges into riparian areas should done in a manner that does not change the nature of the existing riparian habitat. This includes, but is not limited to, the removal of vegetative cover from banks, the erosion of banks, the scouring of the channel bottom, or the discharge of sediment or trash. Existing site flow patterns should be preserved to maintain wetland and riparian hydrology. Similar recommendations are advised for ponds and lakes. DFWIA staff can assist with guidance as to the susceptibility of riparian areas and maximum velocities.

Slopes will also require consideration with respect to the steepness of the slope, the vegetative cover to be maintained, and the erodibility of the soil underneath. Highly erodible soils, both on the ground surface and in stream channels, require special attention so as not to create a long-term maintenance problem. DFWIA staff should be consulted on known erodible soil difficulties of DFWIA property.

Finally, any development or re-development that cannot displace any existing flood storage areas and must maintain a 25-foot buffer from existing 100-year floodplains.

2.1.2 Impervious Surfaces

In the site design, the developer should minimize the amount of new impervious cover where possible to help reduce the size and cost of structural stormwater and GSI practices. WQCv and GSI practice size are calculated based on the impervious cover for new and re-development sites. WQCv is discussed in detail in **Section 2.4**. This is also largely true for managing the amount or quantity of runoff draining from a site for flood control purposes.

Reducing the amount of impervious cover can reduce the volume, cost, and land required for GSI practices, as well as stormwater quantity management practices. Approaches might include using more vertical construction (such as reducing building footprints) or utilizing pervious pavers (see **Section 3**). It may also include designing the site for efficient vehicle circulation, reducing pavement area, and minimizing pavement by using paved areas for multiple functions.

Disconnecting impervious surfaces can also be an effective way to reduce the required WQCv to be treated by structural GSI practices. This can be performed at the individual lot level and at the larger development site level. At an individual lot or property, impervious surfaces can be disconnected by directing gutter downspouts to pervious areas, installing rain gardens, and implementing other small scale GSI practices or pre-treatment devices, thereby maximizing the infiltration and storage capacity of the soil onsite. Similar strategies can be implemented at the larger development scale by draining runoff to pervious areas. Other examples include using stable grass swales instead of curb and gutters, and natural channel paths instead of storm sewers. Both alternatives could function as pre-treatment based on compliance with the design guidelines outlined in this document. This also provides the added benefit of retarding the discharge of stormwater from a site and assisting in meeting DFWIA's requirement that the post-development stormwater discharge be no greater than the pre-development discharge rate (02, 06, 10).

Finally, it should be noted that soil compaction (usually resulting from heavy equipment during grading or prolonged vehicle traffic) can produce a soil that can become almost as impervious as concrete. If not mitigated for, this soil would need to be counted in the percent impervious area which in turn would increase the size of a GSI practice. To prevent the need to account for compacted soils as impervious area, care should be taken to mitigate for any compacted soils before the final stabilization of the site.

2.1.3 Siting GSI Practices

The developer should consider any potential sources of high pollutant loading and then identify GSI practices to capture stormwater runoff from these target areas. For landside applications, GSI integration with site landscaping goals should be considered, where appropriate. As mentioned earlier, there may be opportunities to integrate GSI with stormwater quantity management requirements for performance, cost and inspection and maintenance efficiency.

For airside GSI practices, grass swales or vegetative filter strips for runway-taxiway areas are available. For areas other than runway-taxiway areas, First Flush Systems (FFSs) are generally used to provide runoff quality treatment consistent with FAA requirements.

2.2 GSI Practice Selection

Planning for the types and locations of GSI practices to be implemented on a site should be performed with consideration of the pollutants of concern in the runoff, the available right-of-way, the existing soil types and infiltration rates, and the development goals that impact aesthetics of the development. **Table 2-1** summarizes the level of treatment that each type of GSI practice provides for pollutants of concern. For most of the landside development on DFWIA property, total suspended solids (TSS), oils and greases/total petroleum hydrocarbons (TPH), and bacteria will be the pollutants of concern, but other constituents may be an issue, depending on the use of the property.

Table 2-1: Efficiency of Pollutant Reductions by GSI practice

	Sand and Media Filters* (Airside and Landside)	Bioretention Basins* (Landside)	Enhanced Detention Basin (Airside and Landside)	Vegetated Filter Strips* (Airside and Landside)	Grass Swales* (Airside and Landside)	Pervious Pavers (Landside)
Sediment (TSS)	High	High	Moderate	Moderate to High	Moderate to High	Moderate to High
Nutrients	Low to Moderate	Moderate to High	Low to Moderate	Moderate	Moderate	Low to Moderate
Trash	High	High	High	Moderate	Moderate	Low
Metals	Moderate to High	Moderate to High	Moderate	Low to Moderate	Moderate	Moderate
Bacteria	Moderate to High	High	Moderate to High	Low to Moderate	Low to Moderate	Moderate to High
Oil and Grease	High	High	Low to Moderate	Moderate	Moderate to High	Moderate
Organics	Moderate to High	Moderate	Low to Moderate	Low to Moderate	Moderate to High	Low

Sources: 26, 27, 31
* Removal effectiveness varies dependent on infiltration capacity and design

Section 3 of this document provides additional guidance on these GSI practices for water quality requirements covered in this document. **Appendix A** provides an Excel-based workbook with GSI planning tools, using the efficiencies in **Table 2.1**, to help select and site various GSI practices.

2.4 Calculation of Water Quality Capture Volume (WQCv)

The single firm requirement of the DFWIA GSI Guidance Document is the calculation of the volume of stormwater runoff that must be captured by GSI practices. This is known as the WQCv and is key to cost-effectively treating 80 percent of the average annual runoff from a drainage site while letting larger runoff volumes bypass to flood control structures. This runoff mostly comes in the form of smaller precipitation events that happen frequently every year. Specifically, the required volume of stormwater to captured by a GSI practice to benefit water quality is calculated based on the runoff volume from the 80th percentile runoff event based on two distinct criteria:

1) The percent of impervious area contained within the drainage area.

2) The time required for the GSI practice to drain and be ready for the next event. This is either: 1) a minimum of 12-hours for some GSI practices; pr 2) no more than 24-hours for other practices. **Section 3** and **Appendix A** will provide guidance on these specifics.

A continuous hydrologic simulation model assessment was performed using over 50 years of rain data from the National Weather Service rain gauge at DFWIA to define the WQCv. This was performed using the Water Quality Capture Optimization Statistical Model (WQ-COSM) model (30).

For a drainage area that is part of development or re-development within DFWIA boundaries, the WQCv can be determined using the steps, as shown in **Figure 2-1**.

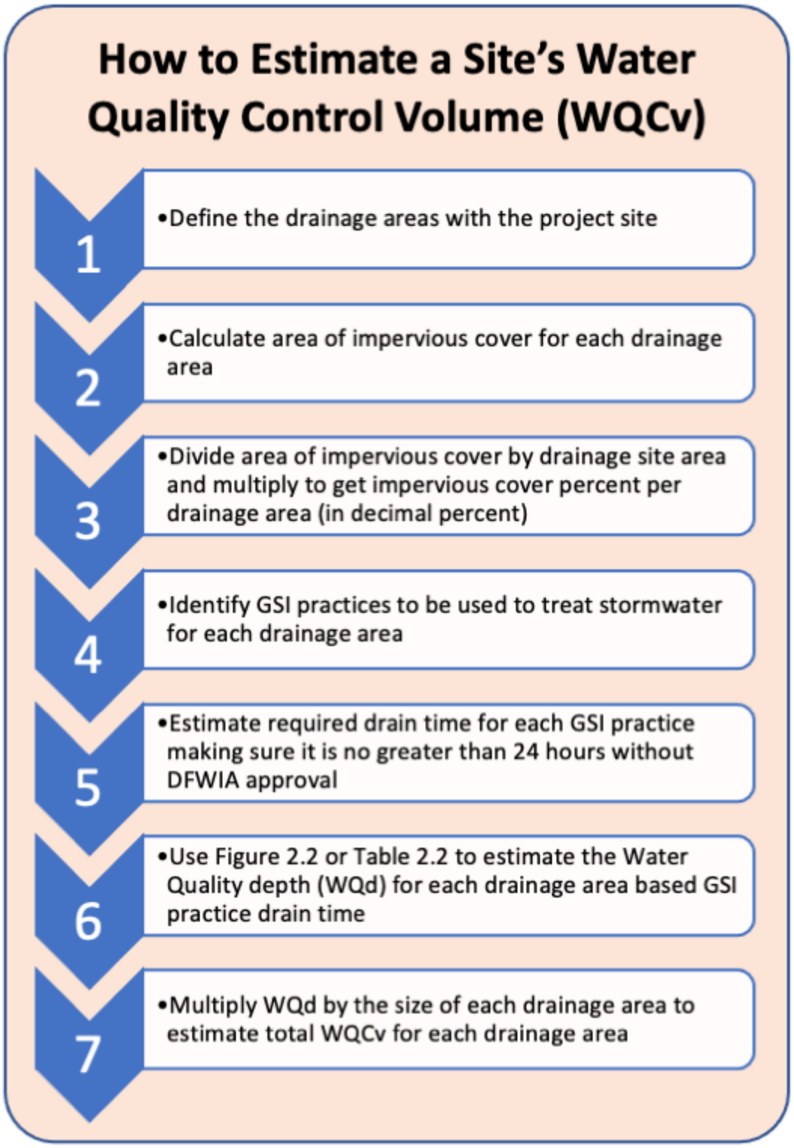

Figure 2-1:
Process for Determining the Water Quality Control Volume (WQCv) from a drainage area.

These steps are described further as follows:

- **Step 1:** The developer/designer should initially define the drainage areas within the project site and calculate the size of each of the drainage areas. Note that the project area may have more than one drainage area, and one or more GSI practices should be used for each drainage area where there will be new impervious or redevelopment. Only the portion of each drainage area within the site boundaries will need to be treated.

- **Step 2:** The developer/designer should estimate the amount of impervious cover, the percentage of impervious cover and soil types, storage, and infiltration rates within each drainage area. This should be done for each drainage area within the site.
- **Step 3:** The developer/designer should then identify the GSI practice types that may be used to treat and attenuate stormwater runoff on the site.
- **Steps 4-7:** The developer/designer should utilize the Excel-based workbook include as a part of **Appendix A** to evaluate the drain time (storage recovery), the corresponding WQCv for the given drain time, the water quality benefits from GSI practices selected for each drainage area, and the water quality benefits from the GSI practices applying to the aggregate drainage areas for the entire site area.

Figure 2-2 provides a graphical representation of the Water Quality Depth (WQd), expressed in inches as a function of the percent impervious area of a development and the intended drain time for the selected GSI practices.

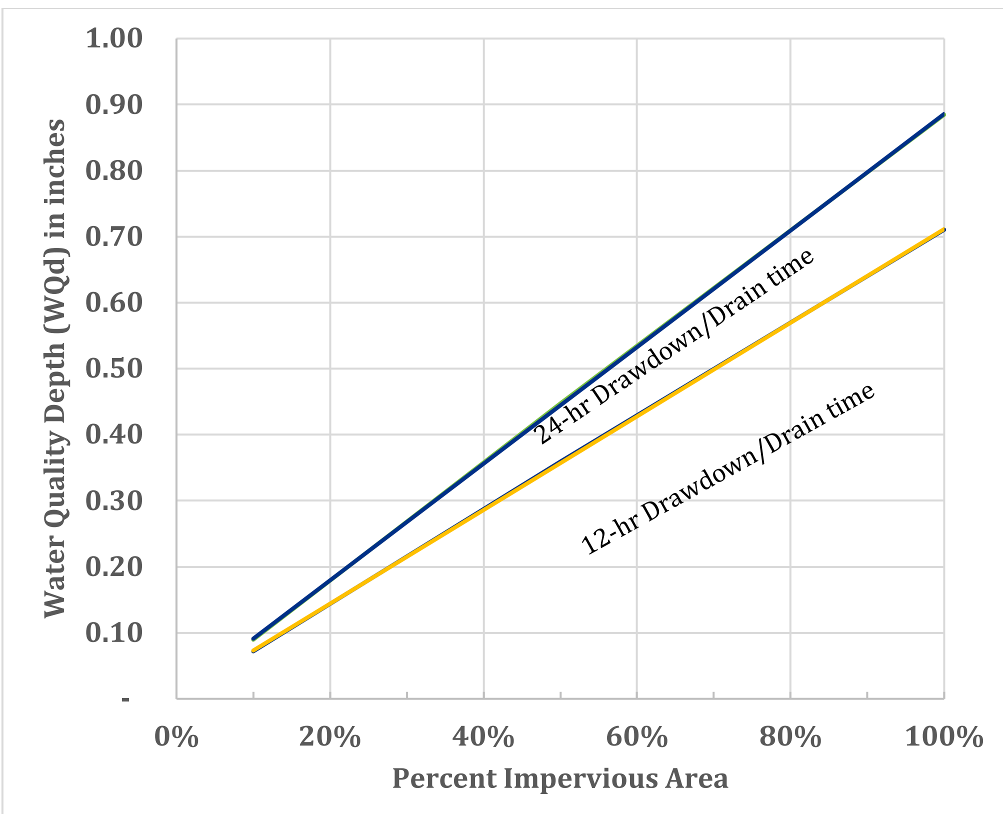

Figure 2-2: Water Quality Depth (in watershed inches) for 80 Percent Capture of Average Runoff Volume (UWRI 2020)

Equations to estimate the WQd are also provided in **Table 2-2. Figure 2-2** and **Table 2-2** are based on the WQ-COSM hydrologic analysis discussed above. The workbook in **Appendix A** utilizes these equations/relationships to calculate the total water quality volume for each drainage area within the project site based on the percent impervious for that drainage area to calculate the WQd. By multiplying the WQd by the drainage area, total WQCv for that drainage area is calculated. The WQd and WQCv should be estimated for each drainage area separately.

Table 2-2: Equations for Required Water Quality Depth (UWRI 2020)

Drain Time	Water Quality Depth
24 hours	$y = 0.8832x + 0.0028$
12 hours	$y = 0.7093x + 0.0022$

Where:
x = percent impervious (%) for drainage area to GSI practice
y = water quality volume in inches

Since the WQCv is based on the percent of the drainage area with impervious cover. By reducing the amount of impervious cover, a new development or re-development project can reduce the required footprint of GSI practices.

The methodology above has proven to result in cost-effective sizing of stormwater quality infrastructure in a wide variety of land development situations. Should a development encounter unusual situations or characteristics, the sizing methodology can be discussed DFWIA staff as outline in **Section 1.4**.

2.5 Designing GSI Practices

The design guidance in this document is based on components. The components for each GSI practice are the critical elements required for that GSI practice to meet the water quality goals. Based on the type of GSI practice, components may include inlets, pretreatment, energy dissipation, area protection, storage media, media barriers, planting media, landscaping, and outlets/piping. The essentials of GSI practice design and components for each GSI practice are outlined in **Section 3**. Design sheets and conceptual layouts for the components can be found from a variety of resources, many of which are listed in **Appendix C– Design Resources**.

2.6 References

References cited in this section can be found in **Section 4 – References** using the numerical citation for each reference,

Section 3 – GSI Stormwater Practices

3.1 Overview

This section provides information about the GSI practices that can be implemented in order to comply with DFW International Airport's (DFWIA) water quality objectives discussed in **Section 1** for either landside or airside portions of DFWIA. This assumes the GSI practices are sized for the required WQCv, as defined in **Section 2**, and are designed, constructed, and inspected and maintained properly.

For airside implementation of GSI practices, it is recommended that as airside construction or existing airside facility rehabilitation occurs, there be a process to identify opportunities early-on where GSI practices could be effectively applied while still being compatible with airside aviation operations. Often the use of GSI practices on the airside can not only improve stormwater runoff water quality, but they can also result in a reduction of infrastructure cost.

The following subsections in **Section 3** provide the following:

1) A short description of each GSI practice;
2) Indications of the applicability of the GSI practice (landside, airside, or both);
3) Information about the application of the GSI practice;
4) Basic design criteria; and
5) An overview of inspection and maintenance considerations with each GSI practice

More detailed considerations for each practice regarding the inspection and maintenance details are included in the *DFW Stormwater Master Plan Program Implementation Document* (10[1]). Since this is a GSI planning document and not a full design manual, developers/designers implementing GSI practices will need to access additional design resources if not experienced in the design and construction of these GSI practices. Some, but not all, of these additional design resources can be found in **Appendix C.** The resources **Appendix C** are considered the most applicable to DFWIA, given the airport's characteristics (such as climate, topography, etc.) and the regulatory constraints. These regulatory constraints are discussed in more detail in **Section 1**.

As indicated in **Section 1,** and reiterated in **Section 2**, there are a few approaches that can greatly increase the ease of planning, sizing, designing, and implementing GSI practices, when taken at the start of a new development or re-development project. These recommended approaches include the following:

1) Engage with DFWIA staff who will be reviewing the proposed GSI practice implementation on a project. Currently this is staff within DFWIA's Energy, Transportation and Asset Management Department (ETAM). ETAM staff can provide early guidance on common difficulties in the review process and have examples of successful implementation of GSI practices at DFWIA for additional guidance.

[1] Full references can be found associated with the numerical citation in **Section 4 - References**

2) If a new development or re-development project expects to seek variance from the DFW's Design Criteria Manual (36) and by extension the guidance in this document, as discussed in **Section 1**, it is imperative that the engagement with ETAM occur as soon as possible. The burden of proof for a variance lies with the developer or re-developer and will require additional documentation and review. This applies to the two situations in which a variance could be requested, namely: a) inability to meet guidance document requirements due to property or other restrictions beyond developer's control; and b) interest in proposing one or more alternative technologies to be used in lieu of GSI practices detailed in this document.
3) For an entity contemplating developing or re-developing land in DFWIA's jurisdiction, they should engage designers, engineers, architects, and landscape architects who have a successful track record implementing GSI. As with any infrastructure project, success is achieved by cost effectively proceeding from concept to design, to plans and specifications, to construction, to inspection, to vegetative establishment, and to inspections and maintenance. GSI often takes more attention to detail compared to standard infrastructure. It is relatively easy to inadvertently diminish the effectiveness of GSI practices without having knowledgeable GSI practitioners involved throughout the project life cycle.
4) Recognize that this guidance document does not contain all the information needed to design and implement GSI, therefore other resources will be required. Recognize also that this document are living documents, as are all DFWIA documents related to land development and stormwater management. It is important that the user is diligent in ensuring the latest guidance information is being relied upon. ETAM staff can help with this.

With the above in mind, the general approach to identifying and designing appropriate GSI practices includes the following steps:

1) Review the descriptions and applicability information provided in this section to determine what GSI are most appropriate for the development.
2) Review the basic design elements in this section to determine the components and characteristics for successful implementation. These basic design elements will translate to specific design plans and specifications that also address construction sequencing, installation, and other requirements for the contractor. Resources outside this guidance document will be needed to produce the detailed design plans, specifications, and other construction documents. Some of the more useful resources are listed in **Appendix C**.
3) Review the inspection and maintenance considerations for a given GSI practice included in this section and consider any preliminary design adjustments that would simplify inspection and maintenance for the site application considered.
4) Submit the preliminary (and eventually detailed) design and associated construction documents (plans and specifications) to ETAM for review and comment and eventual approval. ETAM staff are available throughout these steps to provide feedback to help the review and approval be as efficient as possible.

Additional DFWIA guidance, as outlined in **Sections 1 and 2**, have bearing on implementing GSI, as well as stormwater management overall. It is the responsibility of the developer to seek out the latest guidance from DFWIA on utilizing GSI and integrating water quality GSI practices along with stormwater quantity management requirements.

3.2 Sand Filters - Landside

3.2.1 Description of Practice

Sand filters and other types of media filters filter stormwater to remove pollutants. These type of GSI practices can be implemented to treat a relatively large drainage area, generally up to 10-acres. This document focuses on sand as the filtration media, yet other types of media may be considered on a case-by-case basis. Other types of media are not specifically detailed in this section but may be found in the other design resources such as those listed in **Appendix C.**

Two of the primary components for this practice are the sediment forebay, also referred to as sedimentation chamber, and the filtration chamber. The sediment forebay should be included for sand filters with drainage areas over 2-acres. The forebay can be included in smaller sand filters to remove floatables, large materials, and sediment before it is filtered through the sand or other media. The volume of water conveyed to the treatment system must however be controlled by a diversion structure to prevent inflow rates that exceed the WQCv for the filter.

Figure 3-1 provides a conceptual rendering of a Concrete Sand Filter with the major components identified for reference. These components are dependent on the size and type of sand filter and are described further in **Section 3.2.3**.

3.2.2 Applicability

Unless otherwise determined by DFWIA, sand filters are only approved for use on the landside portion of DFWIA.

The layout of sand filters is highly flexible. They can be incorporated within new developments, in re-developments, or as retrofits on existing sites. They work well in locations with limited space, or where other GSI practices would be difficult to fit. They also work well where aesthetics of the GSI practice is not of a particular concern, such as at the back of warehouse facility or a parking structure. Sand filters can also be modified to fit into situations were aesthetics do matter, yet regardless, their primary functionality remains the same. Although versatile in their potential applications, sand filters are best suited for areas with highly impervious drainage areas. Sites that consistently produce heavy sediment loads will quickly clog the filtration media in this practice. Without frequent maintenance, it will render this practice ineffective.

3.2.3 Basic Design Criteria

This section provides the basic design elements for sand filters and includes the typically necessary components. Guidance on more specific details and specifications for the components of a sand filter, can be found in **Appendix C – Design Resources**. The worksheets in **Appendix A** assist in calculating the WQCv that should be directed to a sand filter for a given drainage area. The basic design criteria for sand filters are described as follows:

1) General Criteria

    a. Runoff from all impervious surfaces should be directed to a GSI practice such as a sand filter if possible.

b. Sand filter design must account for the inspection and maintenance plan for sand filters that includes critical items such as trash removal, accumulated sediment removal, inspection for standing water, and inspection to confirm infiltration capacity provides for a maximum 24-hour drawdown.

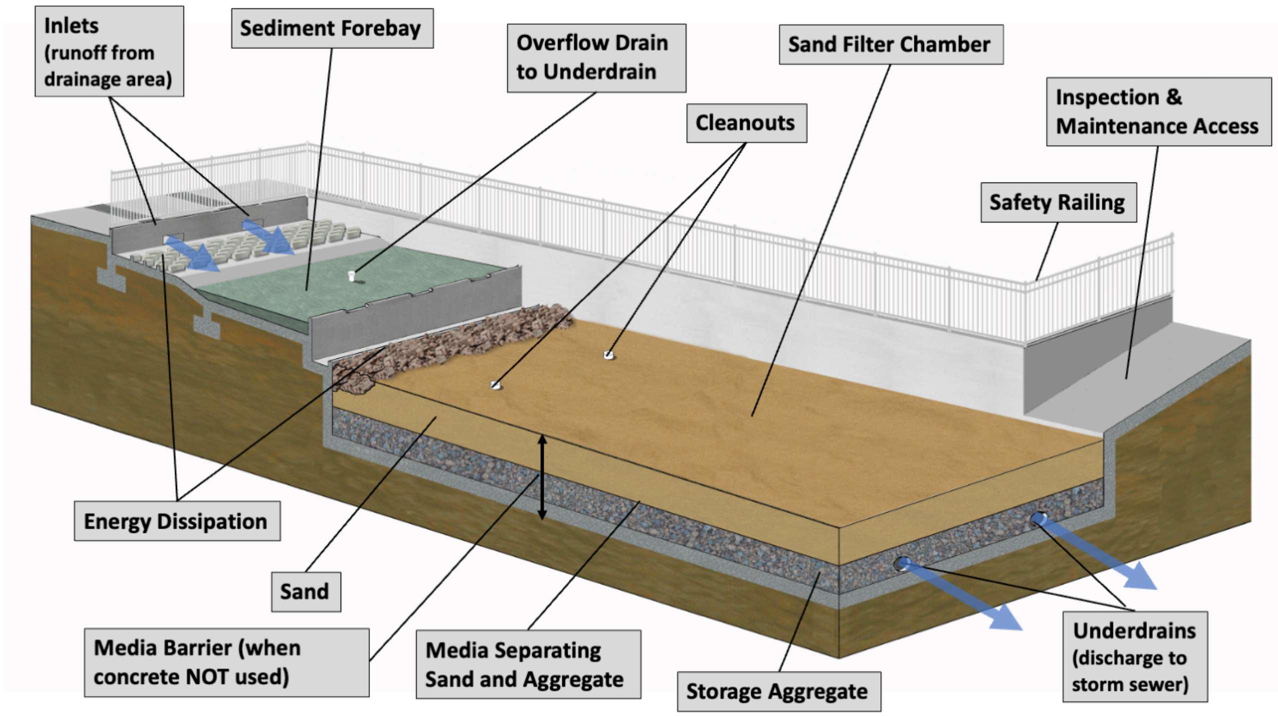

Figure 3-1
Conceptual Rendering of a Sand Filter using Concrete (adapted from 35)

2) Site Conditions

a. Drainage area – Sand filters are recommended for drainage areas less than 10-acres in size. Larger areas should be treated by other GSI practices or subdivided and treated by multiple devices.

b. Depth to water table – A minimum of 2-feet is required between the bottom of the sand filter and the elevation of the seasonal high groundwater table. Isolation of the sand filter from a high groundwater table is possible but requires significant waterproofing efforts to be effective over the long term. It therefore is not typically advised due to the increased capital cost, as well as the additional inspections that are required to confirm functionality.

c. Soils – An underdrain is required for soils that do not allow sufficient infiltration. It is likely that an underdrain system will be required unless site-specific soil infiltration information, confirmed through testing, can be used to demonstrate infiltration capacity sufficient such that no standing water remains in the sand filter 24-hours after receiving runoff. Should infiltration prove inadequate after sand filter installation, retrofitting of the sand filter with an underdrain system would be required.

d. Floodplain – Where feasible, the GSI practice should be located outside of the 100-year floodplain. Where not feasible, the top of walls or embankments for the GSI practice should be above the 100-year floodplain and the GSI practice should be designed to protect against surcharge from downstream waters.

e. Space required – Space required is a function of available head at the site, the holding time, WQCv, and the surface area of the sand layer. For more information, see design resources in **Appendix C.**

3) Structural Criteria

a. Emptying / drain time – Design to drain within a maximum of 24-hours after the end of precipitation events. Sufficiently frequent inspection and maintenance to maintain 24-hour drain down times is mandatory.

b. Minimum head – The elevation difference needed at a site between the inflow and the outflow via an underdrain system is generally 5-feet using outflow via an underdrain system

c. Pre-treatment - A sediment forebay must be used for all sand filters treating over 2-acres and is recommended for all sand filters.

i. The sediment forebay should be designed to hold at least 25 percent of the WQCv.

ii. The sediment forebay should have a length-to-width ratio of at least 2:1.

iii. Inlet and outlet structures should be located at opposite ends of the chamber to prevent short-circuiting of stormwater flows.

iv. A vegetated filter strip or grass swale can be implemented in lieu of a sediment forebay where the drainage area is less than 2-acres.

d. Energy dissipation – Required to dissipate energy and prevent erosion at the inlet to the GSI practice.

e. Sand filter chamber – The structure of a surface sand filter may be constructed of impermeable material such as concrete or using earthen embankments and slopes.

i. Size – The filtration chamber must be designed to hold 100 percent of the WQCv.

ii. Depth – Maximum design depth of WQCv within filtration basin shall not exceed 5-feet. Note that surface area and depth of captured stormwater impacts maintenance requirements. For example, a larger surface area and resulting reduced stormwater depth increases the ability of the sand filter to store sediment without clogging. Therefore, a depth greater than

3-feet may increase the frequency of required maintenance to keep the sand filter effective.

iii. GSI practice media – The primary sand filter media used is sand consisting of an 18-inch (minimum) to 24-inch layer of clean washed medium sand. A storage aggregate layer shall be placed at the bottom of the sand filter chamber for additional water storage capacity. For additional information see **Appendix C** – **Design Resources**. Filter fabric is sometimes used between the sand and gravel to prevent migration of fines; however, experience shows this material can clog and require additional maintenance. Alternatively, an aggregate layer is not required if a slotted underdrain is used to prevent sand from flowing into the underdrain pipe.

It should be noted that lessons learned from previous sand filter applications have found that allowing vegetation to grow on the surface of the sand filter has increased pollutant removal and reduced the frequency of maintenance. These are sometimes referred to as biofilters. Any vegetation allowed to grow on the surface of sand filter must be an acceptable grass variety for DFWIA, as shown in **Appendix B**. Under no circumstances should a shrub, tree, or other woody plant be allowed to exist in a sand filter, and under no circumstances can the ponding of water exceed 24-hours.

iv. Media barrier – A geomembrane liner should be used to line the bottom and side slopes of the structure before installation for sand filters with earthen embankments. This prevents short-circuiting of flows. An impermeable liner must be used for installations adjacent to streets or structures in order to prevent water from getting under the pavement into the base material. This causes infrastructure displacement from the effects of soil swelling and contracting during wet and dry periods.

v. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

vi. Note - TCEQ Dam Safety requirements shall be accounted for as required with higher depth structures.

f. Diversion structure – The diversion structure must be capable of diverting the flow rate associated with the WQCv into the stormwater quality GSI practice and bypassing excess runoff (including up to the 100-year storm) through the diversion structure without overtopping the sidewalls of the sand filter.

3.2.4 Basic Inspection and Maintenance Considerations for Design and Construction

Inspection and maintenance plans contribute to the continued useful performance of a GSI practice. Detailed inspection, operations, and maintenance considerations for each practice are included in the *DFW Stormwater Master Plan Program Implementation Document* (10). The following should be considered during the design and construction process of the GSI practice:

- Access – Adequate access must be provided for all sand filter systems to perform inspection and maintenance, including the appropriate equipment and vehicles. An access ramp with a minimum width of 10-feet and a maximum slope of 10 percent shall be provided. Slopes of higher than 10 percent for access ramps may be approved with appropriate demonstration of slope stability and approval by DFWIA.
- Fencing – To prevent risk to the public, it is recommended that sand filter facilities be fenced in accordance with DFWIA requirements.
- Include cleanouts. These can be used for inspection to make sure that the underdrain is intact, and for ongoing maintenance during and after construction.
- The sand filter should be kept offline until the construction activities are completed. However, excavation for the sand filter can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade. A Sediment and Erosion Control Plan to protect receiving waters during construction activities is required. It should be noted however, that the Sediment and Erosion Control Plan requirements are not discussed in this document. Sediment discharged during construction will clog the sand filter and would require media remediation and additional maintenance.

3.3 Rain Gardens (Bioretention Basins) - Landside

3.3.1 Description of Practice

Rain gardens (also referred to as bioretention basins, biofiltration basins, or biofilters) use the chemical, biological, and physical properties of plants, microbes, and soils to remove pollutants from stormwater runoff via a system of distributed micro-scale stormwater treatment devices. (29). The filter medium is an engineered mix of highly permeable natural media, which are usually mixtures of soil, sand, and organic matter that facilitate pollutant removal via sedimentation, filtration, sorption, and precipitation (29). The defining characteristic of a bioretention system is the integration of plants and microorganisms that are rooted in the filter medium and can provide more treatment of runoff, directly and by uptake by the plant material (Hsieh and Davis 2005). Plants help sustain the permeability of the medium for longer periods and enhance removal of pollutants (26,29). The composition of this GSI practice media is key to the system's overall effectiveness (29).

More information on the components for bioretention basins can be found in the design criteria discussion in **Section 3.3.3**. Additionally, resources for the component details can be found in **Appendix C– Design Resources**.

There are two types of rain gardens that are addressed as part of this handbook: centralized and distributed rain gardens. Each of these basins have applicability, depending on the size and the nature of the drainage areas being addressed.

Centralized rain gardens must be implemented for larger drainage areas and have additional elements as detailed below. Centralized rain gardens include a two-cell system. Distributive rain gardens or green street infrastructure can be implemented for drainage areas of one-acre or less. These are smaller and shallower than the centralized systems and are often placed adjacent to the impervious cover runoff source.

The primary components for each of these basins are different. **Figure 3.2** provides a conceptual rendering of a distributive rain garden with the components identified. For larger centralized rain garden facilities, pre-treatment should be included due to increased flows and a greater chance for higher amounts of sediment and trash to be included in runoff. Additional area protection may also be considered.

3.3.2 Applicability

Unless otherwise determined by DFWIA, rain garden are only for use on the landside portion of DFWIA.

Given the variability of drainage area and the allowable ponding depth within the system, the selection of a rain garden design depends largely on the size of the contributing drainage area. Large, centralized rain gardens are well suited to service large mixed-use developments or less dense commercial developments. Centralized rain gardens are not recommended to treat drainage areas greater than 5-acres.

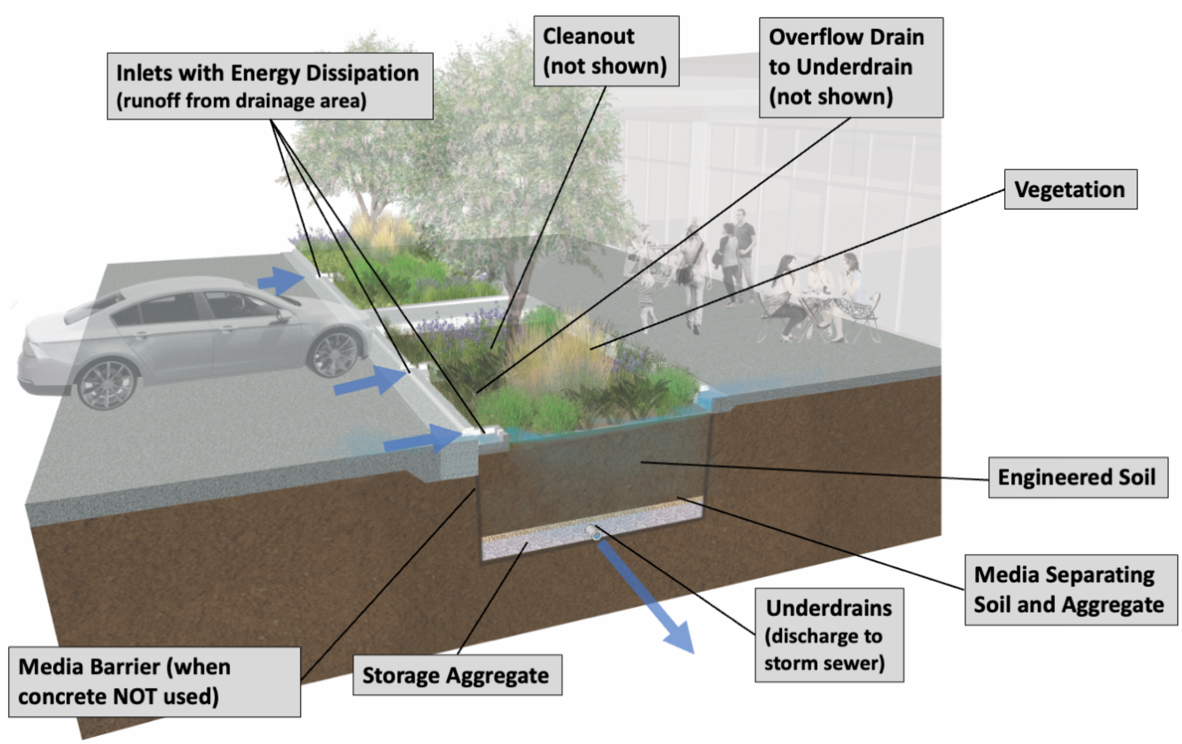

Figure 3-2
Conceptual Rendering of a Distributive Rain Garden/Bioretention Filter (adapted from 35)

Smaller distributed rain gardens may serve a variety of land use types including roadway, mixed-use developments, and less dense commercial developments. However, these small, distributed rain gardens are limited to sites that are generally less than one acre. As such, on larger sites the developer/designer should consider distributing smaller systems throughout the site.

Distributed rain gardens are easy to incorporate into the landscape making it extremely flexible as a GSI practice. This makes it ideal for roadway median strips and curb bump outs, depressed parking lot islands, and roof downspout catchment areas.

3.3.3 Basic Design Criteria

This section provides the basic design criteria for both centralized and distributed rain gardens, including the typically necessary components. More specific details and specifications for the components of a bioretention filter can be found in **Appendix C – Design Resources**. Additionally, the worksheets in **Appendix A** assist in calculating the WQCv that should be directed to a rain garden for a given drainage area.

3.3.3.1 Distributive Rain Gardens

This section provides the basic design criteria for distributive rain gardens.

1) General criteria
    a. Runoff from all impervious surfaces should be directed to a GSI practice such a rain garden if possible.
2) Site conditions
    a. Drainage Area – Maximum drainage area of 1-acre.
    b. Depth to Water Table – Consider depth of 4-feet to seasonal high groundwater table when identifying appropriate locations for rain gardens. A high groundwater level could damage the rain garden basin or limit the treatment by infiltration.
    c. Soils – the characteristics of the native soils will determine if infiltration can effectively be relied upon to occur from the rain garden, otherwise underdrains will be required. The rain garden filtration media must be an engineered media to perform effectively and provide for plant growth. A geomembrane liner must be used for installations adjacent to streets or other structures to prevent water from getting under the pavement or foundation into the subbase material.
    d. Floodplain – Where feasible, this GSI practice should be located outside of the 100-year floodplain. Where not feasible, the top of walls or embankments for the GSI practice should be above the 100-year floodplain and the GSI practice should be designed to protect against surcharge from downstream waters.
    e. Space Required – The GSI practice footprint is a function of the available head at the site, the size of the drainage area, and the designed surface area for the GSI practice.

3) Structural criteria

   a. Emptying / drain time – The optimal drain time for the GSI practice is 12-hours, but the drain time should not be greater than 24-hours.

   b. Minimum Head – The elevation difference needed at a site from the inflow to the outflow is generally 3 to 5-feet.

   c. Energy dissipation – Energy dissipation is recommended, especially for areas with concentrated flow. Gravel or vegetated filter strips can be used to dissipate energy and provide for the capture of trash and sediment.

   d. Rain garden cell – The structure of the bioretention cell is constructed through excavation and the construction of earthen embankments or using concrete.

      i. Size – The entire treatment system must be designed for 100 percent of the WQCv.

      ii. Maximum depth – The maximum ponded depth of water within the rain garden cell is 12-inches. This ponded depth is typically established by installing an overflow inlet.

      iii. Area Protection – Curbing is advised in locations with pedestrian traffic and vehicular traffic. Bollards are advised in locations with vehicular traffic.

      iv. Rain Garden/Bioretention Media – Media consists of a 30-inch (minimum) to 48-inch layer of bioretention or engineered media. A storage aggregate layer shall be placed at the bottom of the distributive bioretention for additional water storage capacity.

      v. Media barrier – Depending on site conditions, a permeable geotextile or geomembrane liner should be used to line the bottom and sides of the GSI practice before installation of the underdrain system and bioretention media. A sand filter bridging layer is also recommended between the bioretention or engineered media and the storage aggregate layer to reduce sediment migration into the storage aggregate layer. Permeable geotextile is not recommended because of the tendency for the material to clog and thus prevent water migration into the storage layer. An impermeable liner must be used for installations adjacent to building foundation or streets to prevent water from getting under the structures or pavements.

      vi. Landscaping – Vegetation must be provided, and mulch used for areas where there is bare soil. Large decorative river rock may be applied for accent or dissipation, but in limited areas. Organic fertilizers and/or root stimulating enhancers may be initially added to promote vegetation growth. **Appendix B** provides landscape guidance for GSI practice facilities. Apply/use only approved organic fertilizers, pesticides, or herbicides.

vii. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

3.3.3.2 Centralized Rain Gardens

This section provides the basic design criteria for large, centralized rain gardens/bioretention basins, defined as those serving drainage areas up to 5-acres. Note that some of the primary differences between sand filters and the centralized rain gardens described in this section are the bioretention media and landscaping.

1) General Criteria

   a. Runoff from all impervious surfaces should be directed to a GSI practice such a bioretention if possible.

2) Site Conditions

   a. Drainage Area – Not recommended for drainage areas greater than 5-acres; there is no minimum drainage area limitation. If proposed for drainage areas greater than 5-acres, additional information must be provided to ensure that the basin will perform effectively, and additional maintenance and inspections may be required to verify.

   b. Depth to Water Table – Consider depth of 4-feet to seasonal high groundwater table when identifying appropriate locations for bioretention. A high groundwater level could damage the rain garden/bioretention basin or limit the treatment by infiltration.

   c. Soils – the characteristics of the native soils will determine if infiltration to groundwater would occur naturally through the centralized rain garden/bioretention basin. If not, an underdrain must be used, An impermeable geomembrane liner must be used for installations adjacent to streets or other structures to prevent water from getting under the pavement or foundation into the subbase material.

   d. Floodplain – Where feasible, the GSI practice should be located outside of the 100-year floodplain. Where not feasible, the top of walls or embankments for the GSI practice should be above the 100-year floodplain and the GSI practice should be designed to protect against surcharge from downstream waters.

   e. Space Required – The centralized rain garden footprint is a function of the available head at the site, the size of the drainage area, and the designed surface area for centralized bioretention.

3) Structural criteria

   a. Emptying / drain time – The optimal drain time for the GSI practice is 12-hours, but the drain time should not be greater than 24-hours.

b. Minimum Head – The elevation difference required at a site from the inflow to the outflow is generally 3 to 5-feet.

c. Pre-treatment – For inlets where there is concentrated flow, the centralized rain garden cells should have a sediment forebay. The sediment forebay should be designed to hold 10 percent of the rain garden/bioretention volume. For areas with sheet flow, the rain garden system should have vegetated filter strips or gravel to dissipate energy, minimize erosion, and capture sediment.

d. Rain Garden/Bioretention cell - The structure of the rain garden cell is constructed using excavations and earthen embankments. Concrete can be utilized instead of earthen embankments but may prove costly.

    i. Size – The rain garden cell must hold 100 percent of the WQCv.

    ii. Length to width – The rain garden cell should maximize the length-to-width ratio.

    iii. Maximum depth – The maximum ponded depth for captured WQCv within the centralized rain garden basin is 12-inches. This ponded depth is typically established by installing an overflow inlet and connected to the underdrain system or storm drain.

    iv. Area Protection – Curbing is advised in locations with pedestrian traffic and vehicular traffic. Bollards are advised in locations with vehicular traffic.

    v. GSI practice Media – Centralized rain garden/bioretention basins require a 30-inch (minimum) to 48-inch (maximum) layer of engineered media. A storage aggregate layer shall be placed below the centralized bioretention for additional water storage capacity.

    vi. Media barrier – Depending on site conditions, a permeable geotextile or geomembrane liner should be used to line the bottom and sides of the centralized bioretention before installation of the underdrain system and bioretention media. A sand filter bridging layer is also recommended between the bioretention or engineered media and the storage aggregate layer to reduce sediment migration into the storage aggregate layer. Permeable geotextile is not recommended because of the tendency for the material to clog and thus prevent water migration into the storage layer. An impermeable liner must be used for installations adjacent to building foundation or streets to prevent water from getting under the structures or pavements.

    vii. Landscaping – Vegetation must be provided, and mulch used for areas where there is bare soil. Large decorative river rock may be applied for accent or dissipation, but in limited areas. Organic fertilizers or root stimulating enhancers may be initially added to promote vegetation growth. **Appendix B** provides landscape guidance for GSI practice facilities. Apply/use only approved organic fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed or pulled and removed as appropriate to prevent the establishment of woody and invasive vegetation.

viii. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

e. The diversion structure must be capable of diverting the WCQv into the stormwater quality GSI practice and bypassing excess runoff, including up to the 100-year storm, away from the GSI practice.

3.3.4 Basic Inspection and Maintenance Considerations for Design and Construction

Inspection and maintenance plans contribute to the continued useful performance of a GSI practice. Detailed inspection, operations, and maintenance considerations for each practice are included in the *DFW Stormwater Master Plan Program Implementation Document* (10). The following should be considered during the design and construction process of the rain garden/bioretention infrastructure:

- Access – For centralized rain gardens, adequate access must be provided for inspection and maintenance, including the appropriate equipment and vehicles. For larger facilities where access may be an issue, an access ramp with a minimum width of 10-feet and a maximum slope of 10 percent shall be provided. Slopes greater than 10 percent may be approved by DFWIA is slope stability concerns are addressed. Distributive rain gardens should be accessible for inspection and maintenance including the appropriate equipment, however due to the smaller facilities, no access ramp is necessary.
- Fencing (optional) – To prevent access and damage to vegetation, it is recommended that centralized rain garden/bioretention facilities be fenced to prevent public access and in accordance with DFWIA requirements.
- The successful establishment of vegetation is required to stabilize the media, retain the soil, and assist with infiltration and water quality. Mulch, where used initially to help retain moisture at plants, should be coarse ground and interlocking to resist floating and clogging outlets.
- Maintenance should be considered during the design and layout. For example, pruning and mowing of vegetation and accessibility to features that will need to be maintained.
- Include cleanouts. These can be used for inspection to make sure that the underdrain is intact, and for ongoing maintenance during and after construction.
- Keep the GSI practice offline until the construction activities are completed. Temporary GSI practices should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities. It should be noted however, that the Sediment and Erosion Control Plan requirements are not discussed in this document.

Sediment discharged during construction can clog the system and would require additional maintenance.

- Consider making the rain garden basin shallower, to make maintenance easier.

3.4 Enhanced Dry Detention Basin - Landside

3.4.1 Description of Practice

Enhanced dry detention basins are a combination of extended dry detention basins (which are used for quantity control (and some quality benefits) with a grass swale at the bottom of the basin. The water quality benefit of enhanced dry detention is achieved through modification of using grass swales instead of concrete low flow channels allowing time for particulate pollutants to settle or be filtered out for the smaller flows associated with the WQCv. DFWIA also requires dry detention basins for streambank protection and flood control mitigation with a maximum of 24-hours for all standing water to be drained from the basin. The basic design and components of an enhanced dry detention basins defined in this document expand on these quantity control requirements and provide additional water quality features.

In addition to using grass swales, extended detention can be converted to enhanced detention with vegetated filter systems, sand filters, or rain gardens. As such, both quantity and quality benefits are realized from a combined system which can take up less space than separate practices and potentially reduce cost. Enhanced dry detention basins must be designed using the criteria specified below, and in conjunction with pre- or post-treatment or other water quality treatment facilities. **Figure 3-3** provides a conceptual rendering of an enhanced detention basin with the major components identified. Area protection should also be considered. Trees and other vegetation with substantial subsurface root systems should not be used within the basin but may be used above the basin on berms or levees or area surrounding. DFWIA approved landscape trees all have predominately horizontal growing root systems. Care should be taken that such root systems will not risk failure of detention systems from roots allowing piping of water through basin containment (e.g., embankments, berms). In no circumstance should trees be planted where they may interfere with the water quality improvement components of the basin. In consultation with DFWIA staff and landscape architects, tree usage must be assessed on a case-by-case basis considering risk of failure, public safety, and cost of repair.

3.4.2 Applicability

This GSI practice is applicable only on the landside portion of DFWIA.

3.4.3 Basic Design Criteria

This section provides the basic design elements for enhanced flood detention facilities and includes the typically necessary components. More specific details and specifications for the components of an enhanced flood detention basin can be found in **Appendix C – Design Resources**. Additionally, the worksheets in **Appendix A** assist in calculating the WQCv that should be directed to an enhanced flood detention facility. A general overview of the basic design criteria for consideration at the GSI practice selection stage of the site design process is provided below:

1) General Criteria

   a. Runoff from all impervious surfaces should be directed to a GSI practice such as enhanced detention if possible.

2) Site Conditions

   a. Drainage area – Enhanced dry detention basins should be implemented at locations serving a drainage area greater than 5-acres but less than 100-acres. For larger basins, additional information must be provided to ensure that the basin will perform effectively, and additional maintenance and inspections may be required to verify.

   b. Depth to water table – a minimum of 2-feet are required between the bottom of the enhanced dry detention basin and the elevation of the seasonal high groundwater table.

   c. Soils – Determine if native soils on site are sufficient for infiltration. An impermeable geomembrane liner must be used for installations adjacent to streets or other structures to prevent water from getting under the pavement or foundation into the subbase material.

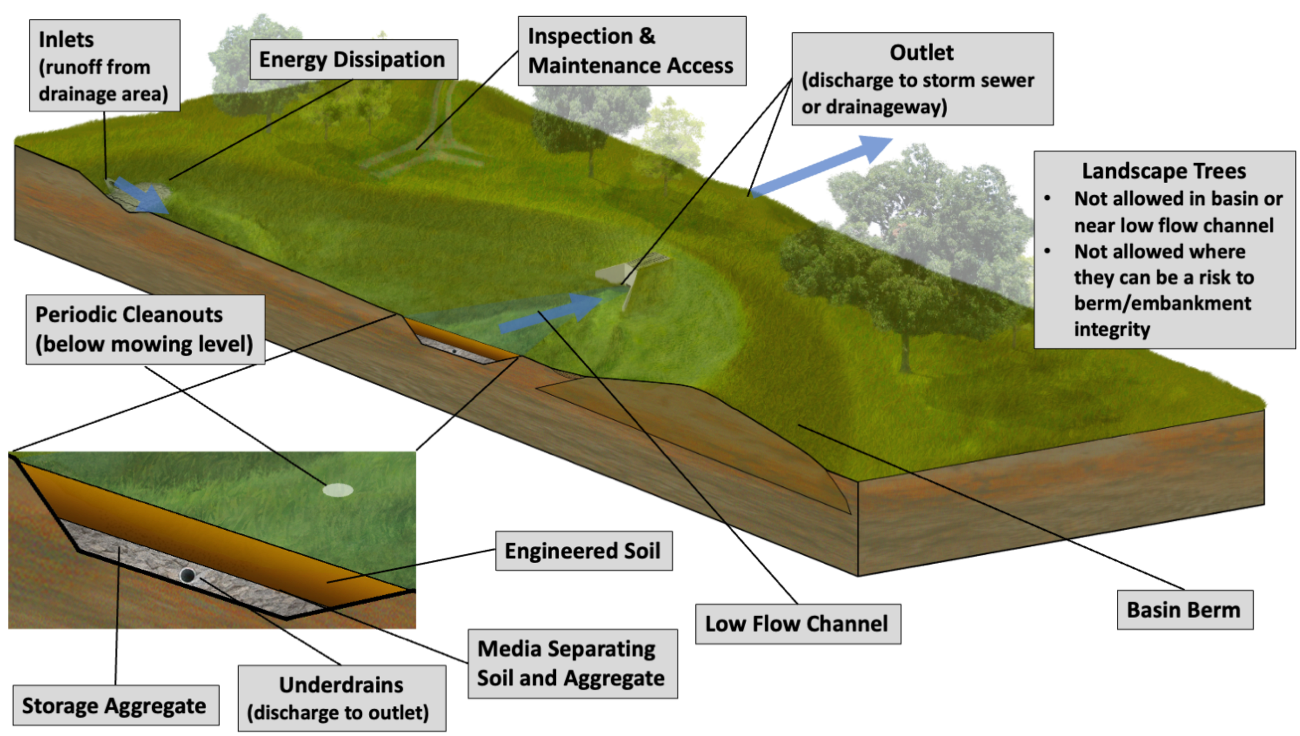

Figure 3-3
Conceptual Rendering of an Enhanced Dry Detention Basin

   d. Floodplain – Where feasible, the GSI practice should be located outside of the 100-year floodplain. Where not feasible, the top of walls or embankments for the GSI practice should be above the 100-year floodplain and the GSI practice should be designed to protect against surcharge from downstream waters.

e. Space – The space required for the GSI practice is a function of available head at the site, required treatment WQCv, and availability of make-up water.

3) Structural Criteria

a. Inlet structure(s) – The inlet structures for the enhanced dry detention basin must be designed with energy dissipation structures at the inlet(s) if the entrance velocities exceed the erosive velocity requirement of the GSI practice surface material and should be able to convey flows from the 100-year annual probability storm without overtopping.

b. Forebay – The enhanced dry detention basin must have a sediment forebay on inlets for WQCv flow to prevent sediment accumulation in the basin.

i. Size – The forebay volume should be sized to contain 10 percent of the WQv. The length to width ratio should be no less than 2:1 (length:width), and the side slopes no steeper than 4:1 (horizontal:vertical).

ii. Drawdown – The forebay outlet should be sized such that the forebay drains within 24-hours.

iii. Flows above the WQCv flow rate should be diverted from sediment forebay.

c. Basin

i. Size – The enhanced dry detention basin should be designed to hold 100 percent of the WQv for a maximum of 24-hours primarily using a low flow channel than can intercept or infiltrate pollutants. The remainder of the basin is used for water quantity control. Side slopes of the basin should be per design criteria manual.

ii. Enhanced detention relies on the use of a low flow channel that is similar to a grass swale, as opposed to concrete, that can both intercept and infiltrate pollutants. The low flow channel also ensures that water entering the basin will be drained within 24-hours.

iii. Landscaping – The enhanced dry detention basin should be appropriately seeded (sodded where most erosion occurs or for stabilization). Ornamental grasses or any woody plant should not be planted or allowed to grow in the swale/low flow channel to preserve its integrity as a filtration practice. *No trees on above grade embankments that are critical for basin performance.* **Appendix B** provides landscape guidance for GSI practice facilities.

iv. Outlet – Design the outlet properly to allow both the passage of smaller flows and an overflow structure for flood control purposes. For smaller flows, a skimmer or trash rack in front of the outlet should be included. In addition, outflows from the underdrain system of the swale/low flow channel must be configured to effectively pass the outlet structure.

v. Drawdown – The enhanced dry detention basin should drain completely within 24-hours after the end of precipitation events.

vi. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

3.4.4 Basic Inspection and Maintenance Considerations for Design and Construction

Inspection and maintenance plans contribute to the continued useful performance of a GSI practice. Detailed inspection, operations, and maintenance considerations for each practice are included in the *DFW Stormwater Master Plan Program Implementation Document* (10). The following should be considered during the design and construction process of the GSI practice:

- Maintenance should be considering during the design and layout. For example, pruning and mowing of vegetation, as well as the accessibility to other features that will need to be maintained. If native grasses and perennials are seeded, verify the appropriate mowing season. Mowing of the low flow channel/swale should be done by hand equipment to prevent damage or compaction of the filtration media.

  Adequate access must be provided for inspection and maintenance, including the appropriate equipment and vehicles. An access ramp with a minimum width of 10-feet and a maximum slope of 10 percent shall be provided.

- Include soil amendments as appropriate to improve plant establishment and reduce need for irrigation.

- The GSI practice should be kept offline until the construction activities are completed, however the GSI practice excavation can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade. Additionally, care should be taken not to traverse the facility with equipment during construction which can result in the compaction of the bottom or sides. This will reduce infiltration capacity and potentially require mitigative measures in order to restore the designed infiltration levels.

Temporary GSI practices should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities. It should be noted however, that Sediment and Erosion Control Plan requirements are not discussed in this document. Sediment discharged during construction can clog the system and would require additional maintenance.

3.5 Pervious Interlocking Pavers - Landside

3.5.1 Description of Practice

Permeable hard surfaces (compared to impervious surfaces) include permeable pavers, porous concrete, porous asphalt, and grassed modular grid systems. Permeable surfaces require careful design, construction, and maintenance to provide good service life and proper drainage. This document focuses on the use of permeable interlocking pavers as these, compared to other permeable hard surfaces have demonstrated resiliency and lower life-cycle costs. Other surfaces can be submitted for review, however porous asphalt is not allowed for compliance with water quality requirements.

There are many types of permeable interlocking pavers systems available today. Manufacturer's recommendations should be strictly followed, unless they are modified by an engineer's signed and sealed design.

Permeable interlocking pavers are not recommended in areas with high sediment loads due to the potential for clogging and need for frequent maintenance to remain effective. To prevent clogging, permeable interlocking pavers are recommended at a ratio of treatment drainage area to permeable paver surface area of 1.5 to 1. Pavers also require bi-annual maintenance that is tailored to the paver system. **Figure 3.4** provides a conceptual rendering of a permeable paver system with an adjacent small bioretention basin.

3.5.2 Applicability

This GSI practice is applicable on only the landside portion of DFWIA and recommended only for passenger car parking areas. Areas subjected to heavy traffic loadings will require prior approval and evidence of the use of design criteria appropriate for the purpose. **Appendix C** provides references to design standards based on weight loadings.

3.5.3 Basic Design Criteria

This section provides the basic design elements for pervious pavers, including the typically necessary components. More specific details and specifications for the components of pervious pavers can be found in **Appendix C – Design Resources**. Additionally, the worksheets in **Appendix A** assist in calculating the WQCv that should be directed to pervious pavers for a given drainage area. The pervious paver design criteria is as follows:

1) General Criteria
    a. Specifications for permeable interlocking pavers must contain technical information detailing the proper procedures for installation, some of which may come from the selected manufacturer of the pavers. Proper paver installation is critical to ensure effective long-term use and is usually very detailed. See **Appendix C** for some additional design resources.
2) Site Conditions
    a. A minimum of 4-feet of clearance is recommended between the bottom of the gravel base course and underlying impermeable layers and the seasonal high groundwater table.

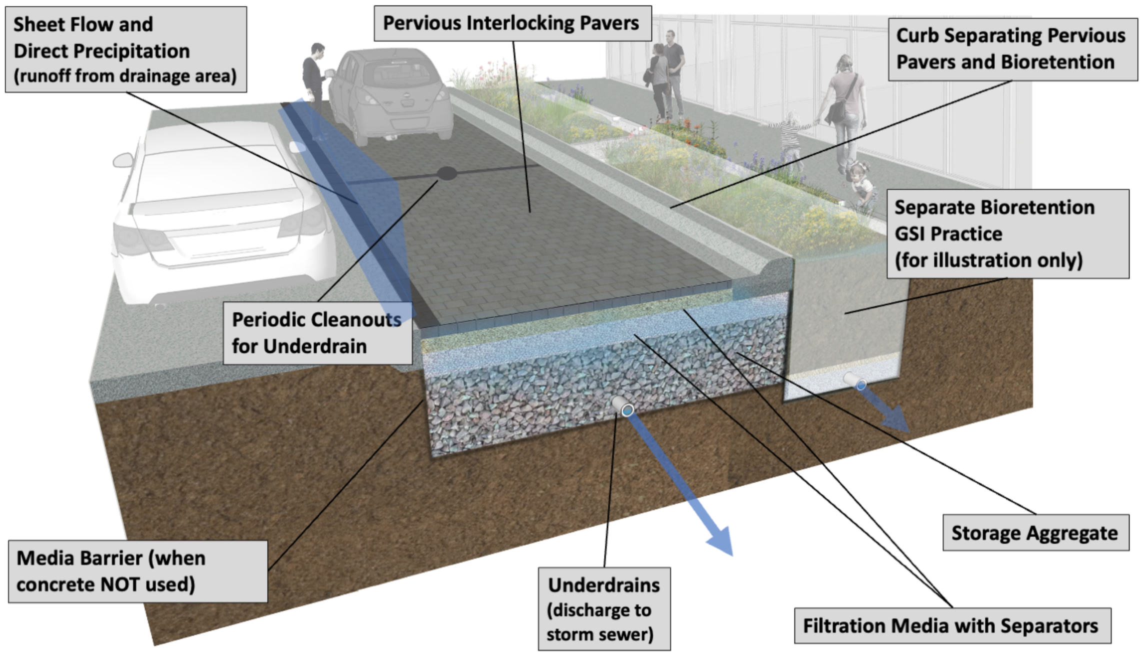

Figure 3-4
Conceptual Rendering of a Pervious Pavers Application (adapted from 35)

b. Permeable interlocking pavers are recommended at a ratio of treatment drainage area to permeable paver surface area of 1.5 to 1.

c. Soils – Determine if native soils on site are sufficient for infiltration. An impermeable geomembrane liner must be used for installations adjacent to streets or other structures to prevent water from getting under the pavement or foundation into the subbase material.

3) Structural Criteria

a. Pretreatment – Vegetated filter strips are recommended to be installed for pervious paver surfaces that receive runoff from vegetated surfaces such as open fields or playgrounds to mitigate sediment loading.

b. Slopes – Permeable interlocking paver systems should not be used on slopes greater than 5 percent, with slopes of no greater than 2 percent recommended. For slopes greater than 1 percent, barriers perpendicular to the direction of flow within the feature storage aggregate should be installed in sub-grade material. This is intended to keep runoff in the media from flowing downstream and surfacing at the toe, which would not provide the needed WQCv under the pavement.

c. Signage – A warning sign should be placed at the facility that states: "Pervious pavers used on this site to reduce pollution. Do not resurface or stripe with non-porous material. Do not sand during icy weather."

d. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

3.5.4 Basic Inspection and Maintenance Considerations for Design and Construction

Inspection and maintenance plans contribute to the continued useful performance of permeable interlocking pavers. Detailed inspection, operations, and maintenance considerations for each practice are included in the *DFW Stormwater Master Plan Program Implementation Document* (10). The following should be considered during the design and construction process of the GSI practice:

- Maintenance should be considering during the design and layout. Pervious pavers require cleaning bi-annually with specialized machinery.
- Consider the installation of an observation well or other means to monitor the drain time of the paver's storage layer over time.

The GSI practice must be protected until the construction activities are completed. Temporary GSI practices should be in place, as detailed in the Sediment and Erosion Plan, to protect permeable interlocking pavers and receiving waters during construction activities. These temporary GSI practices, however, will not be covered in this document. Sediment discharged during construction can clog the system and would require additional maintenance. A pre-construction meeting should be held to ensure the contractor is aware that the permeable interlocking pavers should be protected from sediment load. A construction fence can also be used during construction to prevent the compaction of the underlying material which can reduce infiltration capacity.

3.6 Vegetative Filter Strips with Underdrains - Landside or Airside

3.6.1 Description of Practice

Vegetated filter strips with underdrains are gently sloped to nearly flat vegetated areas designed to receive and maintain sheet flows over the entire width of the strip (30). They are typically linear facilities that run parallel to the impervious surface such as shown in **Figure 3-5**.

3.6.2 Applicability

Vegetive filter strips have applicability to both the landside portion of DFWIA and also to the airside portion of DFWIA.

These systems are not intended to be used as a stand-alone or primary GSI system for landside development or redevelopment. However, if a vegetated filter strip GSI practice is used within close proximity to small, low-density impervious areas, the WQCv for this area can be treated. Otherwise on the landside they are primarily a pretreatment device. On the airside, filter strips can assist in improving water quality where they can be appropriately deployed with respect to all other airside design requirements.

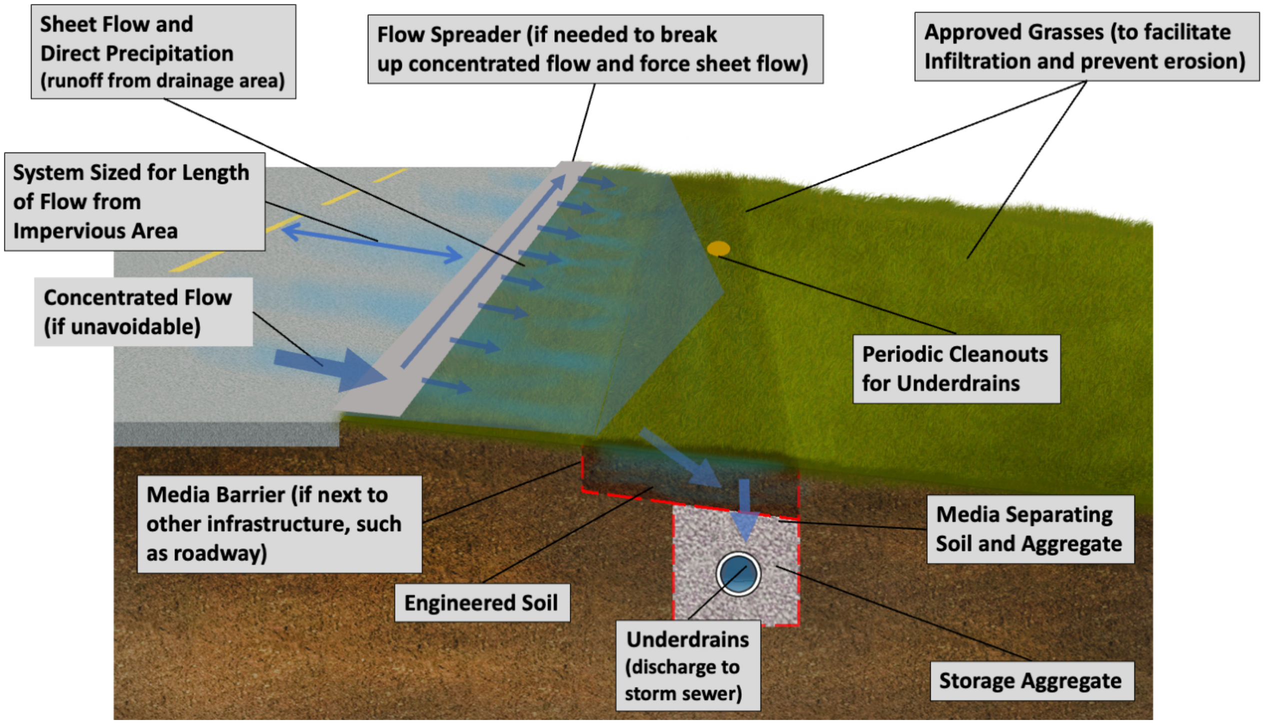

Figure 3-5
Conceptual Rendering of a Vegetated Filter Strip (adapted from 14)

Vegetated filter strips treat stormwater runoff and can reduce flow velocities. Vegetated filter strips remove pollutants by sedimentation, filtration, and infiltration. To function correctly, vegetated filter strips require shallow slopes and well drained soils that increase contact time and remove pollutants. Pollutant removal efficiencies are highly variable and primarily depend on the longitudinal slope, the length of the filter strip, and the amount of vegetation. These variables correspond to the contact time for filtration. The extent of infiltration also depends on the type of soil, the drainage capacity of the soil as it relates to infiltration, the density of the grass, and the slope of the strip (18). Soils at DFWIA are almost exclusively clay, so it should be assumed that an engineered soil will be needed to provide effective infiltration.

These GSI practices can be used most effectively in areas with low density impervious cover, with linear impervious cover, or as pre- or post-treatment for other water quality GSI practices. Vegetated filter strips are intended to treat sheet flow only. They are commonly used to receive runoff from roads and highways, roof downspouts, very small parking areas, walkways and driveways, as well as pervious surfaces (16). Filter strips can be easily integrated into the site design.

3.6.3 Basic Design Criteria

This section provides the basic design criteria for vegetative filter strips, including the typically necessary components. More specific details, as well as specifications for the components of a vegetative filter strips, can be found in **Appendix C – Design Resources**. Additionally, the worksheets in **Appendix A** assist in calculating the WQCv that should be directed to a vegetative filter strip for a given drainage area.

1) General Criteria
    a. Maximum depth of sheet flow over the filter strip should not exceed 2-inches for the water quality event; 1-inch is preferred.
    b. Designers should assume that underdrains will be required unless sufficient infiltrative capacity can be demonstrated in the soils underlying the filter strip. Airside application will require underdrains regardless of soil characteristics. Periodic cleanout facilities will need to be provided for underdrains.
2) Site Conditions
    a. Drainage Area – The system must be designed for the length of the contributing drainage area in the direction of flow a shown in **Figure 3-5**.
    b. Flow Spreaders – Where concentrated flow is unavoidable; flow spreaders should be used to promote sheet flow. For roadway applications where curbs are required, curbs will need to have cut-outs to allow flow to the filter strip and a flow spreader will be required. On applications without curbs, the flow spreader can have a simple inlet to allow concentrated flow into the spreader.

       In general, for drainage area lengths longer than 75-feet, the designer should consider a flow spreader as preventing concentrated flow becomes more difficult. Also, for longer flow lengths, a grass swale should be considered instead of a filter strip for cost-effectiveness,

       Flow spreaders should be installed so as not interfere with regular maintenance (such as mowing).
    c. Soils – Soils should have a minimum depth of 12-inches and must allow for dense vegetative coverage.
    d. Space Required – To achieve the desired level of treatment, the length of the filter strip in the direction of flow should be no less than 15-feet, and 25-feet is preferred. However, vegetated areas will provide some level of treatment at less than 15 feet. Therefore, if the available space does not allow for the length of the filter strip to be at least 15-feet, then including vegetated areas is still encouraged to help reduce sediment loads.
    e. Pedestrian traffic across filter strips shall be limited through channeling pedestrians onto sidewalks.

3) Structural Criteria

   a. Slope – The longitudinal (direction of flow) slope of a filter strip should be no less than 2 percent and no greater than 6 percent.

   b. Landscaping – An appropriate planting pallet should be selected to ensure vegetation is sustained over the course of wet and dry periods, capable of withstanding large rain events, and able to withstand relatively high velocity flows at the entrances to prevent erosion rills. **Appendix B** provides planting pallets for GSI practice facilities. Apply/use only approved organic fertilizers, pesticides, or herbicides. Vegetation within the filter strips should be regularly mowed, bagged and clippings removed to prevent thatch and re-seeding and establishment of weeds or invasive species. If native grasses and perennials are seeded, then verify the appropriate mowing season.

   c. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

Permeable berms – Installed enhanced filter strips should have a maximum height of 12-inches with a 3:1 side slope. They should be level and constructed with a non-settling core to prevent erosion or channelized flow downstream of the berm resulting from high flow storm events.

3.6.4 Basic Inspection and Maintenance Considerations for Design and Construction

Inspection and maintenance plans contribute to the continued useful performance of a GSI practice. Detailed inspection, operations, and maintenance considerations for each practice are included in the *DFW Stormwater Master Plan Program Implementation Document* (10). The following should be considered during the design and construction process of the GSI practice:

- Access - Limit pedestrian access across filter strips by directing pedestrians to sidewalks or other marked walkways.
- Maintenance should be considering during the design and layout. For example, pruning and mowing of vegetation and accessibility to features that will need to be inspected or maintained.
- Consider installing vegetated filter strips 1- to 3-inches below adjacent impervious surfaces.

Include soil amendments as appropriate to improve plant establishment and reduce the need for irrigation.

3.7 Grass Swales – Landside or Airside

3.7.1 Description of Practice

Grass (vegetated) swales are gently sloped channels that are designed to receive and treat stormwater as it is conveyed to a standalone or primary GSI practice or after discharge from a GSI practice (16). These systems are not intended to be used as a stand-alone or primary GSI practice system for a development. However, if a grass swale GSI practice system is used within close proximity to small, low-density impervious areas, or the swale is augmented with engineered soils, check dams, and underdrains, the WQCv can be treated effectively. From small, low-density areas grass swales without augmentation can be used ahead of other GSI practices and reduce WQCv drain to the main GSI practice. Therefore, the WQCv from that area is reduced from the total WQCv for the site.

These remove pollutants primarily by maintaining shallow flow through vegetation that encourages sedimentation or particle settling and infiltration. **Figure 3-6** shows a representation of a grass swale. These processes can be enhanced by resistance of vegetation to flow (King County 2016). To a much lesser degree, pollutants may adhere or sorb to grass and thatch. Swales generally do not remove dissolved pollutants effectively, although some infiltration to underlying soils may occur depending on the nature of those soils (15).

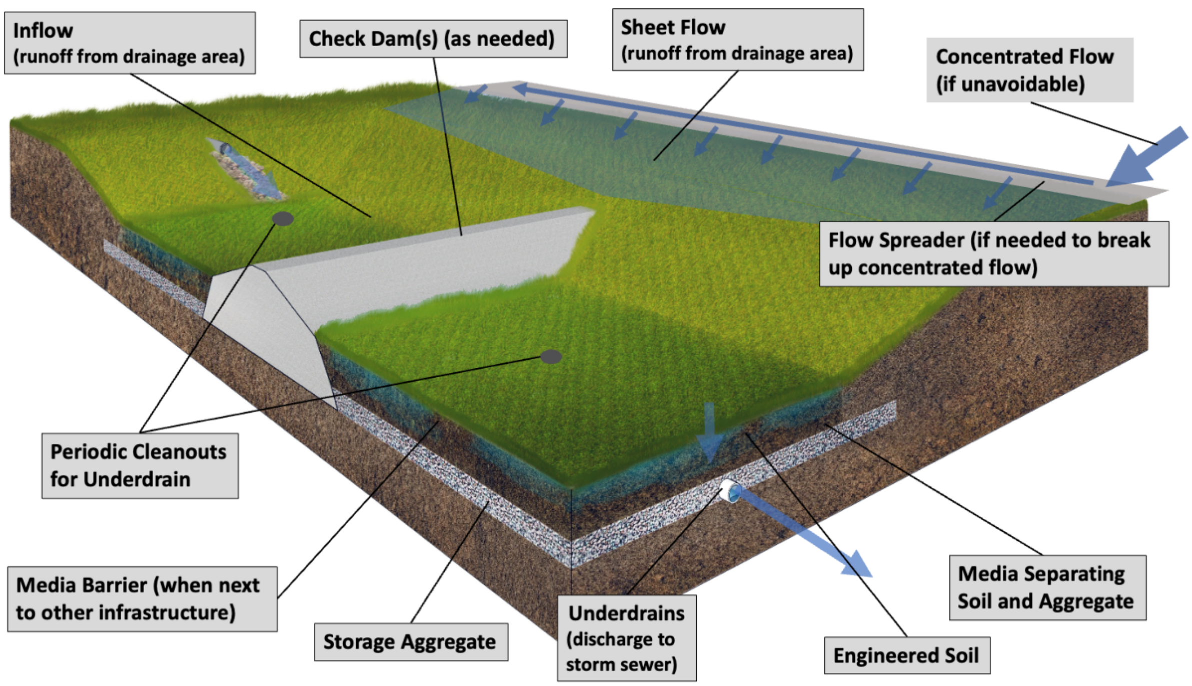

Figure 3-6
Conceptual Rendering of a Grass Swale (adapted from 19)

3.7.2 Applicability

Vegetated swales can be used on both the landside and airside of DFWIA. On the landside, they are used most effectively in areas with low density impervious cover or linear impervious cover, such as roadways or sidewalks, or as pre- or post-treatment for other water quality GSI practices. Grass swales are intended to treat shallow concentrated flow. They are commonly used to receive and convey runoff from roads and highways, roof downspouts, parking areas, walkways and driveways, as well as pervious surfaces (18,25). To function correctly, grass swales require shallow slopes and well drained soils that increase contact time and remove pollutants. They can be easily integrated into the site design.

On the airside, where space for surface GSI practices is often limited, grass swales can provide a useful means to achieve stormwater quality treatment based principally on infiltration and interception of pollutants in the vegetative matrix where most pollutants decompose or are bound up to soil particles. Grass swales can also provide limited storage for runoff to help with water quantity management. For airside applications, underdrain systems are required to ensure systems completely drain in 12- to 24-hours.

3.7.3 Basic Design Criteria

This section provides the basic design criteria grass swales and includes the typically necessary components. More specific details and specifications for the components of a grass swale can be found in **Appendix C – Design Resources**. Additionally, the worksheets in **Appendix A** assist in calculating the WQCv that should be directed to a grass swale for a given drainage area.

1) Site Conditions

    a. Drainage Area – Less than 5-acres. If the practices are used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.

    b. Soils – Generally unrestricted. Swales should not be used on soils with infiltration rates less than 0.27-inches per hour if infiltration of small runoff flows is intended. If increased infiltration rates are needed, native soils can be replaced with material more conducive to faster infiltration and treatment. These will have to be supplemented with an underdrain system that delivers the stormwater that has been filtered by the swale to the nearest stormwater drainage system.

    c. Space Required – Dependent on the contributing drainage area and anticipated flow.

2) Structural Criteria

    a. Cross section design - The swale should have a trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter).

    b. Channel bottom – The bottom of the channel should be between 2 and 6-feet wide. The minimum width ensures an adequate filtering surface for water quality treatment, and the maximum width prevents braiding, which is the formation of small channels within the swale bottom. The bottom width is a dependent variable in the calculation of velocity based on Manning's Equation. If a larger channel is needed, the use of a compound cross section is recommended.

    c. Slope – Relatively flat slopes of less than 4 percent; channel slopes between 1 percent and 2 percent are recommended.

    d. Maximum velocity - Target maximum velocity less than 1.0-foot per second.

    e. Flow Spreaders – If sheet flow is intended to enter the swale perpendicular to the swale's channel, and if concentrated flow is unavoidable from this perpendicular direction; flow spreaders should be used to promote sheet flow. For roadway applications where curbs are required, curbs will need to have cut-outs to allow flow to the filter strip and a flow spreader will be required. On applications without curbs, the flow spreader can have a simple inlet to allow concentrated flow into the spreader.

Flow spreaders should be installed so as not interfere with regular maintenance (such as mowing).

f. Landscaping – An appropriate planting pallet should be selected to ensure vegetation is sustained over the course of wet and dry periods, as well as capable of withstanding large rain events, in order to prevent erosion rills. **Appendix B** provides planting pallets for GSI practice facilities. Apply/use only approved organic fertilizers, pesticides, or herbicides. Invasive and non-planted vegetation within the grass swale should be hand-pulled or mowed, bagged, and removed as appropriate to prevent re-seeding and establishment. If native grasses and perennials are seeded, then verify the appropriate mowing season.

g. Permeable berms – Should have maximum height of 12-inches with a 3:1 side slope. They should be level and constructed with a non-settling core to prevent erosion or channelized flow downstream of the berm because of high flow storm events.

h. Riprap - Riprap-protected side slopes shall be no steeper than 2:1.

i. Check dams – If check dams are installed, then the ponding depth behind check dams shall be designed to infiltrate or drain stormwater runoff within less than 24-hours. Check dams shall not be employed in airside applications.

j. Sediment forebay – Depending on the expected sediment loading to the swale form the inlet(s), a sediment forebay can be included immediately downstream of the inlet to provide energy dissipation, large particulate sediment to be captures, as well as trash/floatables capture.

k. Underdrains - The filter media shall be located above the underdrain system and underdrains shall be located within the storage aggregate layer. Typically, DFWIA requires three underdrains, typically with 4-inch pipe. However, the number and size of underdrains is the responsibility of the designer to determine.

3.7.4 Basic Inspection and Maintenance Considerations for Design and Construction

Inspection, operations and maintenance plans contribute to the continued useful performance of a GSI practice. Detailed inspection, operations, and maintenance considerations for each practice are included in the *DFW Stormwater Master Plan Program Implementation Document* (10). The following should be considered during the design and construction process of the GSI practice:

- Access - Limit pedestrian access across filter strips by directing pedestrians to sidewalks or other marked walkways.
- Maintenance should be considered during the design and layout. For example, mowing of vegetation and accessibility to features that will need to be maintained.

- Inspection and maintenance should be frequent enough to ensure no ponding of water in the swale beyond 24-hours.

Include soil amendments to improve plant establishment and reduce the need for supplemental irrigation.

3.8 First Flush Systems – Airside or Landside

3.8.1 Description of Practice

While not strictly a GSI practice, rather a structural stormwater quality management practice, first flush systems (FFSs) are included in this document. They are included since they are utilized heavily on the airside portion of DFWIA and are currently utilized to capture the first flush from highly impervious surfaces where the potential for stormwater contamination is higher due to spills and material handling. Most FFSs are subsurface so as not to interfere with other infrastructure or airport operations. However, FFSs might be applicable on the landside of the DFWIA and are therefore included as a stormwater practice option,

3.8.2 Applicability

3.8.2.1 Airside Application

FFSs are intended principally as an airside practice, but may find applications on the landside, such as situations where less common pollutants of concern (e.g., oils and greases) can be most cost-effectively handled with this practice. FFS are particularly useful for the airside operations area where space constraints make it difficult, if not impossible, to place GSI practices where aircraft are operating. DFWIA has numerous FFS in operation in the airport operations area with the principal intent to capture sediment and chemical compounds (such as fuels, lubricants, etc.) that may make it into stormwater runoff. These FFSs all drain to a dedicated wastewater system which further separates pollutants from drainage flows.

For a designer working on an airside application, DFWIA has design resources from previous FFS applications to consider. There may also be proprietary technologies worthy of consideration. Regardless, the designer must closely consult with DFWIA staff to get approval of a FFS design regarding its design performance, its connection to the dedicated airside FFS wastewater system, and the the FFS inspection and maintenance characteristics and requirements. **Figure 3-7** shows a cross-section of an existing FFS on use on the airside of DFWIA.

3.8.2.2 Landside Application

Although FFSs are intended principally as an airside practice, there may applications on the landside of DFWIA. The design of an FFS would need to take into consideration the pollutants of concern, why the FFS is better suited to the application than other GSI practices, and independent verification that the FFS will meet pollutant removal goals. **Figure 3-8** shows a typical cross section of a subsurface first flush treatment system that could be applicable to DFWIA landside applications. There are many proprietary systems based on this basic concept, some with the ability to achieve higher levels of pollutant removal using additional design elements.

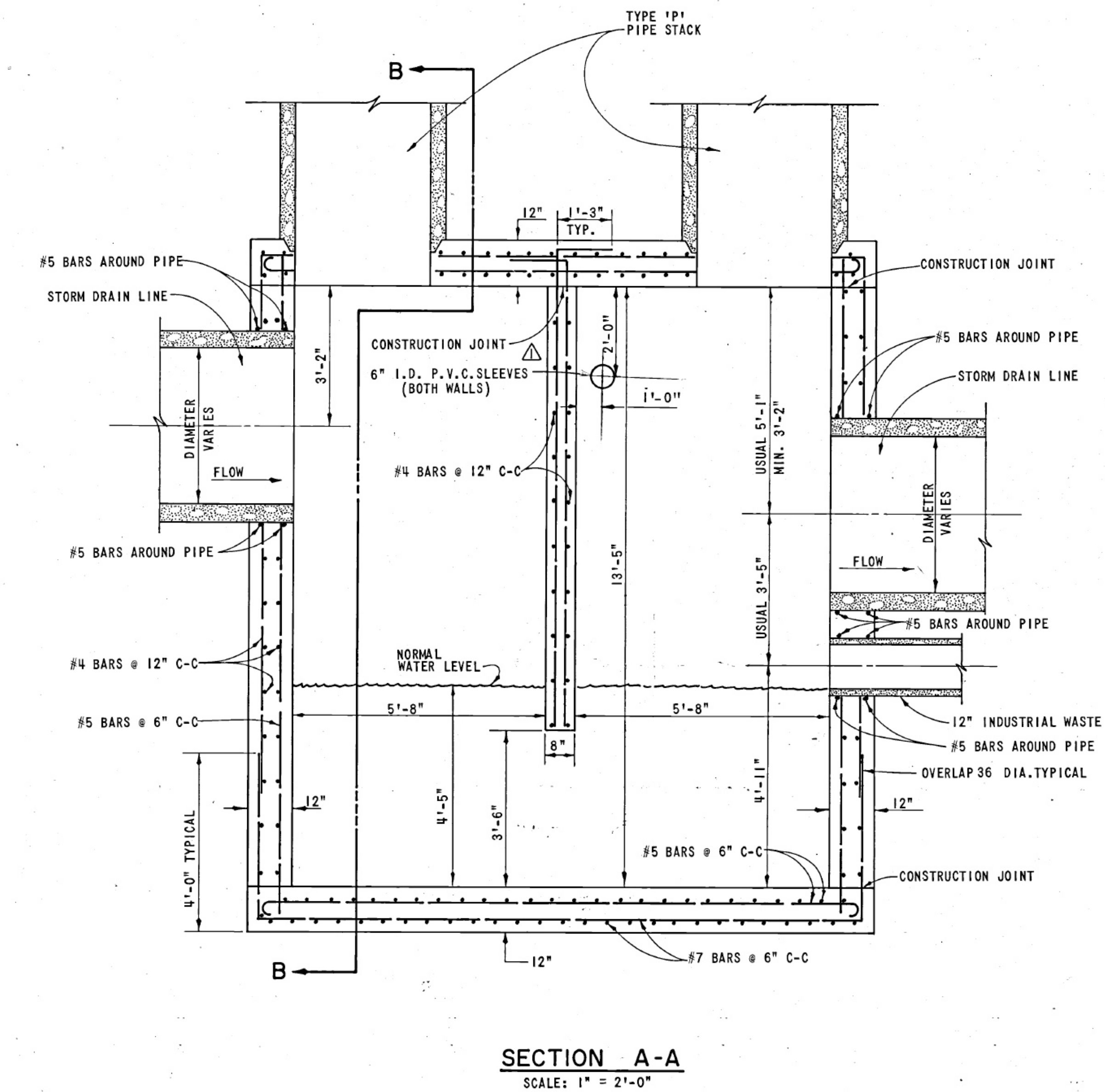

Figure 3-7
Cross Section of a Typical First Flush System (FFS) for Existing Airside Fuel Separators.

Finally, landside FFSs will not be connected to DFWIA's FFS wastewater system dedicated to airside FFSs. Depending on the pollutants of concern being captured where discharge of the effluent from a landside FFS is appropriate must be determined in consultation with DFWIA staff. As such, the use of an FFS on the landside of DFWIA as well as its discharge requirements absolutely require coordination and approval of DFWIA staff, so consultation with staff should begin at the earliest possible opportunity.

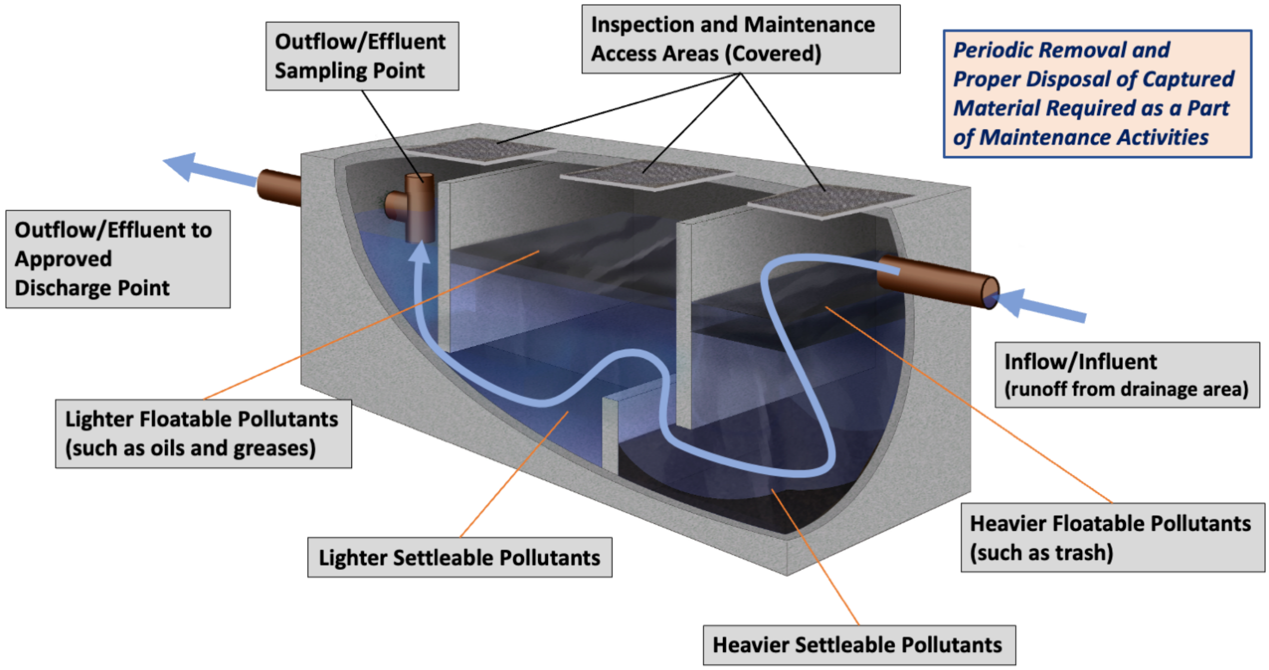

Figure 3-88
Cross Section of a TypicalFirst Flush System (FFS) for Landside Applications.

3.8.3 Basic Design Criteria

Landside FFSs should be sized to intercept WQCv, as outlined in **Section 2.** Airside applications must intercept, at a minimum, the runoff from 0.25-inches of precipitation.

DFWIA's Department of Energy, Transportation, and Asset Management (ETAM) leads the design and operation of the airside first flush system. Therefore, ETAM should be consulted for additional design criteria based on DFWIA preferences, as well as based on lessons learned with the existing system.

ETAM also takes the lead regarding inspections and maintenance of the airport's first flush system. ETAM hires contractors who assist DFWIA in inspecting and maintaining these systems. As such, ETAM will have specific requirements regarding operations and maintenance access to a FFS that must be taken into consideration in design. ETAM must be contacted in advance of sizing, siting, and design of an FFS to ensure airport specific considerations are accounted for.

Any proposal for use of proprietary FFSs (such as premanufactured systems or systems with additional design elements) should be discussed at length with ETAM to assess whether they meet the essential needs of DFWIA. Based on that assessment and the cost, ETAM may approve proprietary systems.

Any new airside FFSs must be coordinated with ETAM so that ETAM can assess whether the additional flows from any new FFSs may overwhelm the dedicated airside FFS collection and treatment systems.

3.8.4 Basic Inspection and Maintenance Considerations for Design and Construction

As mentioned above, DFWIA hires, through ETAM, contractors who assist DFWIA in inspecting and maintaining the airport's existing FFS assets. DFWIA would therefore do the same for any new FFSs utilized on the airside.

As mentioned previously, any landside FFS must be closely coordinated with and approved by DFWIA staff. Part of the approval process for a landside FFS will be a thorough and complete documentation of the necessary inspection and maintenance requirements for the FFS. It will also require a commitment from the owner/operator of the FFS that the system's inspection and maintenance will adhere to the documented requirements and that inspection and maintenance activities are thoroughly documented.

3.9 References

References cited in this section can be found in **Section 4 – References** using the numerical citation for each reference.

Section 4 – References

4.1 Overview

Documents cited in the sections and appendices of the GSI Guidance Document are listed in this section for easy reference. References are numbered numerically (01, 02, 03, etc.) and cited as such in the document. Generally, the most recent version of a reference has preference if it is newer than the reference cited in the document at the time of publication. It is the responsibility of the user to ensure they are using the most recent version of a reference, especially when it comes to hard requirements such as rules, regulations, and criteria. *Users should also endeavor to check with DFWIA to ensure they are working with the latest version of documents that govern stormwater management at DFWIA.*

Where appropriate internet links to references have been provided for easy access to the reference material. *Please note that internet links to referenced documents were valid at the time of this guidance document's publication, but links may be changed or eliminated over time and reference documents may be updated as previously discussed.*

4.2 References

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Appendix A – GSI Application Workbook

A.1 Introduction

An Excel workbook has been developed for the DFWIA GSI Guidance Document as a part of this appendix to assist developers/designers with determining the water quality improvement/pollutant reduction efficiency of their proposed development plans.

As was indicated in **Section 2**, the GSI practices included in this guidance document have different degrees of pollutant removal efficiency. For use in the Excel workbook, **Table A-1** shows the numerical equivalents used in the workbook for calculating a Water Quality Score per drainage area and for the overall development.

Table A.1 Efficiency of Pollutant Reductions by GSI practice (based on Table 2-2, Section 2)

	Sand and Media Filters*	Bioretention Basins*	Enhanced Detention Basin	Vegetated Filter Strips*	Grass Swales*	Pervious Pavers	No GSI Practices Applied
Sediment (TSS)	5	5	3	4	4	4	0
Nutrients	2	4	2	3	3	2	0
Trash	5	5	5	3	3	1	0
Metals	4	4	3	2	3	3	0
Bacteria	4	5	4	2	2	4	0
Oil and Grease	5	5	2	3	4	3	0
Organics	4	3	2	2	4	1	0
Pollutant Reduction Efficiency: 5 = high level; 4 = moderate to high; 3 = moderate; 2 = moderate to low; 1 = low; and 0 = none							

A.2 Using the DFWIA GSI Excel Workbook

For the user of the DFWIA GSI Excel Workbook, the following input is required of the user:

1) Number of separate drainage areas for the entire development. The Excel workbook will handle up to ten (10) distinct drainage areas.
2) Name/designation of the development.
3) Name/designation of the individual drainage areas that are a part of the development.

4) The total area (in square feet) of each individual drainage area (rounded up to a whole number).

5) The percent of each individual drainage area that contains what are considered to be impervious surfaces. This includes rooftops, pavement, and highly compacted soils. Pavement includes, roadways, parking areas (including elevated structures), pedestrian walkways, any paved area used as a part of the development not otherwise listed.

   a. The percentage is entered as a decimal percent (i.e., 60 percent = 0.60) and the percentage should be rounded up to represent a whole number (i.e., 64.5 percent = 65 percent = 0.65).

   b. This convention does not affect accuracy of the results and avoids potential error conditions in the workbook.

6) An initial selection of GSI practices that would be applied to each individual drainage area.

Once the user has this information, they may begin to utilize the workbook to assess one or more scenarios for implementing GSI practices as a part of the development/re-development project.

A.3 Basic Instructions for Utilizing the Workbook

User input sections of the workbook are highlighted in orange. All calculated portions of the workbook (non-user modifiable portions) are highlighted in green.

1) User should begin with the WQCv sheet of the workbook:

2) On the WQCv sheet users should input the user required information highlighted in Appendix Section A.2 into the orange cells:

3) Once the WQCv sheet input is complete, the user should move the GSI Practice Worksheet. Data for the water quality efficiency and the minimum drain times for each practice can are referenced on this sheet and used in calculation. They are not user modifiable.

GSI Practice Pollutant Control Efficiency and Minimum Drain Times

	CORRESPONDING POLLUTANT CONTROL EFFICIENCY SCORE						
GSI RPRACTICE	Sediment (TSS)	Nutrients	Trash	Metals	Bacteria	Oil and Grease	Organics
Sand and Media Filters	5	2	5	4	4	5	4
Bioretention Basins	5	3	5	4	5	5	3
Enhanced Detention Basin	3	2	5	3	4	1	1
Vegetated Filter Strips	3	2	2	2	1	2	2
Grass Swales	4	3	3	2	2	3	2
Pervious Pavers	5	1	5	3	5	3	1
No Treatment	0	0	0	0	0	0	0

Note: Pollutant Reduction Efficiency: 5 = high level; 4 = noderate to high; 3 = moderate; 2 = moderate to low; 1 = low; and 0 = none

GSI PRACTICE MINIMUM DRAIN TIME HOURS	
Sand and Media Filters	24
Bioretention Basins	24
Enhanced Detention Basin	12
Vegetated Filter Strips	12
Grass Swales	12
Pervious Pavers	12

4) For each drainage area, users should assign a portion of the total percentage (again in decimal percent) of the drainage area's impervious between desired GSI Practices or if there are areas that can't be cost-effectively treated, the assigned to No Practice.

Drainage Area 1 - ALPHA

					WATER QUALITY SCORES						
GSI Practice	Percent Impervious Area Served by Practice (decimal percent)	Impervious area (sq ft)	Drain Time (hrs)	WQCv to GSI Practice (cublic ft)	Sediment (TSS)	Nutrients	Trash	Metals	Bacteria	Oil and Grease	Organics
GSI Practice: Sand and Media Filters		-	0	0	0	0	0	0	0	0	0
GSI Practice: Bioretention Basins	0.35	4,200	24	186	5	3	5	4	5	5	3
GSI Practice: Enhanced Detention Basin		-	0	0	0	0	0	0	0	0	0
GSI Practice: Vegetated Filter Strips		-	0	0	0	0	0	0	0	0	0
GSI Practice: Grass Swales		-	0	0	0	0	0	0	0	0	0
GSI Practice: Pervious Pavers	0.15	1,800	12	64	5	5	5	5	5	5	5
No Treatment	0.10	1,200	NA	0	0	0	0	0	0	0	0
Percent Impervious Area & Impervious Area Check:	GOOD	GOOD	Total WQCv (cu ft):	251							
User Input Percent Impervious Area:	0.60										
User Input Drainage Area (sq ft):	12,000	7,200	= calculated impervious area (sq ft)								
			Drainage Area 1 - ALPHA Aggregate Water Quality Scores:		4.2	3.0	4.2	3.6	4.2	4.2	3.0

Note: Weighted Average based on drainage area imperviousness (sq ft)

From this a water quality score will be generated for each of the constituents of concern (sediment/TSS, bacteria, nutrients, etc.). The score is weighted on the percentage of impervious area treated by the GSI Practice.

5) Once all drainage area has had GSI practices applied, an aggregate Water Quality Score for the overall development project will be shown at the top of the worksheet.

DFWIA GSI GUIDANCE DOCUMENT

GSI Practice Worksheet

This worksheeet will indicate water improvement score for the sum of all drainage areas

Project Name: DFW Airport Example Development

calculated | user input

					WATER QUALITY SCORES						
USER INPUTS	NAME/DESIGNATION	IMPERVIOUS AREA (square feet)	WQCv 12-Hr Drain Time (cubic feet)	WQCv 24-Hr Drain Time (cubic feet)	Sediment (TSS)	Nutrients	Trash	Metals	Bacteria	Oil and Grease	Organics
Drainage Area 1	ALPHA	7,200	428	533	4.2	3.0	4.2	3.6	4.2	4.2	3.0
Drainage Area 2	BRAVO	13,500	801	998	3.3	1.7	3.5	2.7	3.0	3.3	2.3
Drainage Area 3	CHARLIE	42,500	2521	3140	3.4	1.8	3.3	2.6	2.9	3.3	2.3
Drainage Area 4	DELTA	3,750	223	278	3.0	2.0	5.0	3.0	4.0	1.0	1.0
Drainage Area 5	ECHO	150	9	11	1.0	2.0	2.0	2.0	1.0	2.0	2.0
Drainage Area 6	FOXTROT	9,001	347	433	1.0	3.0	5.0	4.1	4.5	5.0	3.9
Drainage Area 7	GOLF	7,200	427	532	4.0	2.3	4.8	3.3	4.0	3.0	2.2
Drainage Area 8	HOTEL	14,000	830	1034	4.5	2.8	4.5	3.8	4.2	4.5	3.5
Drainage Area 9	INDIA	1,300	78	97	4.0	3.0	3.0	2.0	2.0	3.0	2.0
Drainage Area 10	JULIET	6,300	357	445	3.8	3.8	3.8	3.8	3.8	3.8	3.8
		104,601	6022	7500							
			Development Overall Water Quality Score:		3.8	2.5	3.9	3.1	3.5	3.3	2.6

Pollutant Reduction Efficiency: 5 = high level; 4 = moderate to high; 3 = moderate; 2 = moderate to low; 1 = low; and 0 = none

6) The Water Quality Scores will vary by constituents. Generally, the GSI Practices included in this guidance documents are intended to be the most effective with sediment, bacteria, and trash. Developers and designers should consult with DFWIA staff regarding appropriate Water Quality Score targets for a given development as the characteristics of the development may have bearing on appropriate targets.

As general guidance as users run scenarios with the DFWIA GSI Excel Workbook, scores of between 3.5 and 4.5 for sediments, bacteria, and trash indicate effective water quality management.

Appendix B – Landscape Requirements

B.1 Introduction

The successful performance, application, and aesthetic for each type of Green Stormwater Infrastructure (GSI) stormwater quality practice for new and re-development projects requires proper plant and related materials selection. Basic design elements for each GSI practice is discussed in **Section 3**.

This appendix provides guidance for developers and their designers in their knowledge and application of plants for the successful implementation of GSI practices.

B.2 Plant Use

The listed GSI practices in **Section 3** create different environments where selected plants and plant seed mixes should be of appropriate form and size for each application regarding desired aesthetics, mature height, spread, and maintenance. The plants should be tolerant of the soil types and media; drought tolerant and adaptive to the varying rainfall events and seasons; tolerant of dry, hot conditions; not require supplemental irrigation once turf or seed mixes are well established; permanent irrigation provided for supplemental water to establish shrubs and trees; capable of living in the media and amended soils for each GSI practice; and are commonly available from the regional seed and turf growers or nursery trade.

B.3 Considerations for Design

Plants will be selectively chosen from the current DFWIA acceptable plant list categories for plant types and species (sp) contained in the DFW Development Design Guidelines (37[1]). In comparison, design resources in **Appendix C** may allow for a broader list of recommended plant lists, seed mixes and applications for each type of similar GSI practice. The Tarrant Regional Water District's (TRWD) Water Quality Guidance Manual (38) manual covers the Fort Worth, Texas area and is therefore based on similar climatology, regional characteristics, soil types and plant hardiness zones. The TRWD plant lists provides plant images for review and includes plant list matrix for similar GSI practice locations with soil moisture tolerances for each plant and species to help guide selection for location application. (Example: Wet, Semi-wet, Semi-dry, and Dry).

Recommended plant species or cultivars not specifically listed in the DFWIA plant list documents must be submitted and reviewed by DFWIA staff as a variance for approval. DFWIA "prohibited" plants must be removed from design consideration as well as native grass and/or perennial seed mixes that may be listed in the design resources in **Appendix C** due to wildlife attractant issues such as seed-head or nesting issues.

[1] Full references can be found associated with the numerical citation in **Section 4 - References**

Planting requirements based on the specific requirement and application to each of the GSI practices listed in **Section 3** include:

- Size and location, gradients, slope stabilization, amount of water required and provided, depth, drawdown time, remediation of soil compaction for root penetration, infiltration rate of filter material or planting media, media composition and depth, drainage layer, drought resistance, sun exposure, and changing rainfall events and environment.
- Plant density will vary depending on the GSI basin size and location, plant species size, available root zone volume, and application. Plants should be spaced further apart than normal or planted in groups to prevent root competition and allow access for maintenance. Refer to DWFIA plant lists below for specific plant restrictions on mass plantings of one species.
- Sod for turf applications over top of sand or soil media shall be grown in sand to provide infiltration. Sod for other applications may be grown in clay.
- Seeds and seed mixes will be supplied by local seed suppliers due to regional variations and hardiness and gathered or produced within a 200-mile range. All seeds shall be tested and approved by AOSA (Association of Official Seed Analysis), compliant with TDA (Texas Department of Agriculture) seed laws and contain no noxious weed seeds or non-native seeds. Seed mixes must be installed in their specific germination period date window, monitored, invasive species/weeds removed, and germination warrantied to provide coverage and establishment for soil stabilization.
- The plants mature height shall not block visibility or sight lines at intersections or drives to maintain safety and to eliminate continual maintenance pruning
- Planting plans for GSI shall provide a limited variety of species for ease of maintenance where larger container grown plants and/or plant species are to be used. Where seed mixes are used, consider the location, soil moisture conditions, appropriate visual application, stabilization of the slopes or basins to determine the mix and type or frequency of mowing maintenance.
- Planting areas not seeded or sodded, must be covered with a minimum 3-inch layer of double shredded and/or hammer mill processed interlocking native hardwood much (natural, undyed, no pallets or treated woods) to help reduce planting media disturbance. Selecting mulch that is heat processed eliminates latent weed seeds or harmful diseases that can affect the maintenance and plant health of the GSI practice.
- Design of GSI practices also need to consider compaction remediation, soil preparation, soil amendments, testing, engineered media, and flow rates where appropriate. Design resources for many of these can be found in **Appendix C**.
- Soil stabilization with biodegradable fabrics, bonded matrix, hydro-mulch, or other approved material for seed or seed mixes shall not affect water infiltration rate or water quality.

- Decorative gravel aggregate, river rock, or riprap may be used in inflow locations to minimize erosion. Consider the size of the material to resist disturbance and to allow trash and debris removal. Do not use rock throughout the entire planting bed.
- Separate mulched planting beds from sodded or seeded areas with a concrete mow strip to allow for mower tires and maintenance. Perforated metal or stone edging may be used where appropriate.
- Protect the GSI practice planting area with temporary fencing to prevent traffic or access and allow the plants to establish.
- Irrigation systems, both temporary and/or permanent, should be designed and installed to establish and maintain planted features depending on location, slope, type, and visibility. Temporary to permanent irrigation is needed for long term establishment of larger plant materials such as shrubs or trees and provides supplemental water during extended droughts.
- Protect and incorporate existing trees into GSI practices where opportunity allows.
- Consider short and long-term maintenance requirements and frequency.
- Comply with all updated airport codes and development guidelines.

B.4 Acceptable Plants Extracted from DFWIA Plant Lists for Application to Specific GSI Features

In developing this document, DFWIA's recommended plant lists were compared with the applications of plants for similar GSI features in the North Texas Region, such as those in in the TRWD manual. Guidance documents such as the TRWD manual identify appropriate plant species for use in various GSI practices, but notably do not have to be concerned with plants that might be wildlife attractants which could present hazards in an airport setting. DFWIA, on the other hand, developed a planting list with that particular concern in mind. Therefore, some of plants that may be recommended outside of DFWIA are not included as plants for use in a GSI practice implementation.

Seven plant categories were identified from DFWIA plant lists for application which are combined into five categories in the following tables and analysis.

- Turf Grasses
- Ornamental Grasses and Perennials
- Groundcovers,
- Shrubs, and
- Ornamental Trees and Shade Trees

Descriptive analysis for each plant category and its application to GSI practice is provided below. The plant categories are presented into tables with acceptable plants from the DFWIA list correlated with information from the TRWD manual for the best location within each GSI practice based on available soil moisture.

B.4.1 Turf Grasses

The DFWIA Seeding and Sodding specification provides a variety of turf grasses that can be planted and survive in both wet/dry conditions for many of the recommended GSI practices in the Non-Public development areas. Turf grasses include native Buffalo, Blue Grama and non-native Bermuda grass. Other mow-able grasses specified in DFWIA seed mixes with Buffalo and Blue Grama but not as short as turf grasses include Hooded Windmill and Sand Dropseed. See **Table B-1** below.

The one (1) species available for all DFWIA Land Use areas is Bermuda grass. Although non-native, it has adapted to wet and dry extremes. For GSI applications, Bermuda grass should be restricted to only areas where there are no alternate species allowed. Native Buffalo grass sod cultivars are wet/dry tolerant for installation in applicable GSI practice. Seeded grasses can be installed where allowed in the Public and Non-Public land use areas to grow and root into the media provided. Sods for the installation over tops of infiltration/drainage media need to be grown at nurseries or turf farms in and with retained sandy soil to allow water infiltration. Turf grass sod with clay soil bases does not provide infiltration and will cap the tops of the GSI infiltration/drainage media. However, clay-based sod may be used for slope stabilization or where infiltration is not a requirement.

Table B-1. Turf Grass Varieties and Grasses: Sod, Seed Mix, and possible Container Plants (03, 28)

Scientific Name	Common Name	Location (Wet or Dry Range)	Sun or Shade
Bouteloua dactyloides (cultivars)	Buffalo Grass	Semi-Wet/Semi-Dry/Dry	Sun
Bouteloua dactyloides w/ Bouteloua gracilis	Buffalo Grass with/ Blue Grama Grass	Semi-Wet/Semi-Dry/Dry	Sun
Bouteloua dactyloides w/ Chloris cucullata	Buffalo Grass with/ Hooded Windmill	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Bouteloua dactyloides w/ Sporobolus cryptandrus	Buffalo Grass with/ Sand Dropseed	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Bouteloua gracilis	Blue Grama Grass	Semi-Wet/Semi-Dry/Dry	Sun
Cynadon dactylon	Bermuda spp.	Semi-Wet/Semi-Dry/Dry	Sun
TxDOT Permanent Urban Seed Mix – see also Table 2. Ornamental Grass			
Leptochloa dubia	Green Sprangletop	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Boutelous curtipendula 'El Reno'	Sideoats Grama	Wet/Semi-Wet/Semi-Dry/Dry	Sun

B.4.2 Ornamental Grasses and Perennials/Wildflowers

Ornamental grass and perennial plant groups provide plant buffering at some GSI practices to slow down runoff impact, promote deeper root infiltration, and detain storm water runoff depths. They provide the best survival and resilience to extreme dry/wet conditions and clay soils that shrink/swell. In addition to turf grass sod, overlapping seed mixes of grasses for warm weather root growth and perennials for cool weather root growth, stabilize and hold the soils on detention slopes and basin bottoms from erosion. Ornamental grasses and perennials additionally provide seasonal aesthetics and dense root structure for distributive bioretention basins (rain gardens).

DFWIA's Seeding and Sodding specification provides the Texas Department of Transportation (TXDOT) Permanent Urban See Mix (District 18 Clay Soils) which includes several additional ornamental grass species that are applicable to stormwater features. These are listed in the **Table B-2**.

DFWIA lists native ornamental grasses and perennials that are very suitable to GSIs. Varied mixes allow higher survival rate of plants to establish based on success of certain species. Many of the seed mixes are based on plants that inhabit natural undisturbed sites with multiple types and species growing together and adapted to seasonal changes.

Table B-2. Ornamental Grasses and Perennials – Seed Mix, Plugs and Container Plants (03, 28)

Scientific Name	Common Name	Location (Wet or Dry Range)	Sun or Shade
Ornamental Grasses			
Andropogon gerardii	Big Bluestem	Semi-Wet/Semi-Dry/Dry	Sun
Chasmanthum latifolium	Inland Sea Oats	Wet/Semi-Wet/Semi-Dry	Part Shade/Shade
Muhlenbergia capillaris	Gulf Muhly	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Schizachyrium scoparium	Little Bluestem	Semi-Wet/Semi-Dry/Dry	Sun
Sorghastrum nutans	Indiangrass	Wet/Semi-Wet/Semi-Dry/Dry	Sun
TxDOT Permanent Urban Seed Mix – Ornamental Grasses			
Boutelous curtipendula 'El Reno'	Sideoats Grama	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Leptochloa dubia	Green Sprangletop	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Perennials			
Asclepias sp.	Milkweed	Wet/Semi-Wet/ Semi-Dry	Sun/Part Shade
Conoclinium gregii	Gregg's Mistflower	Semi-Wet/Semi-Dry	Sun/Part Shade
Coreopsis sp.	Tickseed	Semi-Wet	Sun/Part Shade
Iris sp.	Iris	Wet/Semi-Wet	Part Shade/Shade
Liatris sp.	Gayfeather	Semi-Wet	Sun
Malvaviscus drummondii	Turk's Cap	Wet/Semi-Wet/Semi-Dry/Dry	Part Shade/Shade
Rudbeckia sp.	Coneflower	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Salvia sp.	Salvia, sage	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Solidago sp.	Goldenrod (some)	Wet/Semi-Wet/Semi-Dry/Dry	Sun
Wedelia hispida	Zexmenia, orange Wedelia	Semi-Wet/Semi-Dry/Dry	Sun/Part Shade

B.4.3 Groundcover

One (1) generic groundcover (shown **Table B-3**), the sedges, can be applied from the DFWIA plant list to the GSI practice with success due to its moisture tolerance. Sedges vary in the amount of moisture and dry tolerance.

Table B-3. Groundcover – Plugs and Container Plants (03, 28)

Scientific Name	Common Name	Location (Wet or Dry Range)	Sun /Shade
Carex sp.	Sedges	Wet/Semi-Wet/ Semi-Dry	Varies dep. sp.

B.4.4 Shrubs

One (1) shrub species - Yucca sp. (listed as a perennial) from the DFW plant list is recommended for use within GSI Bioretention Basin (rain garden) application (**Table B-4**).

Table B-4. Shrubs – Container Plants (03, 28)

Scientific Name	Common Name	Location (Wet or Dry Range)	Sun/Shade
Yucca sp.	Yuccas	Semi-Wet/ Semi-Dry	Varies dep. sp.

B.4.5 Ornamental and Shade Trees

Table B-5 shows one (1) native ornamental tree for GSI application that can tolerate high moisture to dry conditions. Its size will not overgrow the smaller features. Shade trees that tolerate wet/dry extremes can be applied to the edges of the larger GSI features to help stabilize slopes, uptake water, and provide seasonal and aesthetic interest. Three (3) native shade trees from the DFWIA plant list meet these requirements.

Table B-5. Ornamental Trees and Shade Trees – Container or B&B Plants (03, 28)

Scientific Name	Common Name	Location (Wet or Dry Range)	Sun/Shade
Ornamental Trees			
Sophora affinis	Eve's Necklace	Semi-Wet/Semi-Dry/Dry	Sun/Part Shade/Shade
Shade Trees			
Fraxinus texensis	Texas Ash	Semi-Wet/Semi-Dry/Dry	Sun/Part Shade/Shade
Taxodium distichum	Bald Cypress	Wet/Semi-Wet/Semi-Dry	Sun
Ulmus crassifolia	Cedar Elm	Wet/Semi-Wet/Semi-Dry/Dry	Sun

B.5 References

References cited in this section can be found in **Section 4 – References** using the numerical citation for each reference,

Appendix C– Design Resources

C.1 Introduction

As indicated in **Section 1**, DFWIA's GSI Practice Guidance Document is an aid to planning the proper GSI practices for a development or re-development on land within the boundaries of DFWIA. Once a development plan for one or more GSI practices is developed, that plan must be translated into design and the design then translated into construction documents. This appendix provides some recommendations for resources to aid in the design and construction steps. The resources selected are not exhaustive nor are they intended to exclude resources not listed. However, these are resources that have been found to have design and/or construction resources that result in successful GSI practice implementation.

Effective design and construction of GSI practices requires attention to several critical elements shown in **Figure C-1**. Proper attention to these steps helps ensure that GSI practices perform as needed.

Figure C-1
Critical Steps in the Design and Construction of GSI Practices

C.2 Recommended Design Resources

C.2.1 DFW Airport Resources

First and foremost, developers and designers should check with DFWIA departmental resources for any design resources available specifically for DFWIA. This includes resources principally from DFWIA's Engineering Transportation and Asset Management Department (ETAM) as well from the Commercial Development Department (CD), Planning Department (PLNG), Environmental Affairs Department, and Design Code and Construction Department (DCC). ETAM should be viewed as the clearinghouse for DFWIA design resources related to stormwater quality and quantity and ETAM should be contacted early on in the development planning process on stormwater issues.

C.2.2 Tarrant Regional Water District (TRWD) Water Quality Manual

The TRWD Water Quality Manual includes additional resources such as typical design details (such as inlets and outlets) for Bioretention, Sand Filters, and Pervious Pavers. As of the time of publication of this guidance document, TRWD had not yet published its more extensive standard design details, specifications, and construction notes for these three practices which they completed in late 2020.

One of the advantages to the design resources in the TRWD Water Quality Manual is that the manual was developed for use principally in the Fort Worth area so the climate, soils, and topography are similar to DFWIA. The Manual also refers users to common public works details and specifications used in the North Texas region and published the North Central Texas Council of Governments (NCTCOG 2017)

The TRWD Water Quality Manual can be found here: https://www.trwd.com/wp-content/uploads/2019/04/TRWD-WQ-Guidance-Manual_June-2018-Updated-Sept.-2018-Compressed.pdf

C.2.3 Mile High Flood District (MHFD) Criteria Manual Volume 3: Stormwater Best Management Practices (BMPS)

The Volume 3 of MHFD's Criteria Manual address stormwater quality BMPs and includes extensive additional resources such as typical design details in AutoCAD for Filter Strips (Grass Buffers), Grass Swales, Bioretention (Rain Garden), Extended Detention, Sand Filters, and Pervious Pavers.

The MHFD Criteria Manual Volume 3: Stormwater Best Management Practices can be found here: https://mhfd.org/resources/criteria-manual-volume-3/

C.2.4 American Society of Civil Engineers (ASCE) Standards for Permeable Interlocking Concrete Pavement (68-18)

ASCE, along with the Transportation and Development Institute and the Interlocking Concrete Pavement Institute, permeable interlocking concrete pavement (Pervious Pavers) in 2018. This standard covers the following topics: Definition of common permeable pavement terms; structural design methods to accommodate incidental or frequent vehicular use; hydrologic design methods to accommodate water infiltration and flow within the pavement system; construction and inspection procedures; a guide to construction specifications; and permeable pavement maintenance procedures.

The standard is available for purchase from ASCE, Amazon, and other sources. To locate search for "ASCE 68-18"

C.2.5 North Central Texas Council of Governments (NCTCOG) iSWM Manuals

Beginning with the original USEPA MS4 NPDES permitting in the early 1990's, NCTCOG has served as a clearinghouse for municipalities and other governmental agencies in North Central Texas for stormwater quality management information. Currently NCTCOG's information on stormwater management (quality and quantity) resides within their Integrated Storm Water Management (iSWM) online resources (http://iswm.nctcog.org),

iSWM contains a comprehensive compilation of planning information for stormwater quality management from development and redevelopment. iSWM also contains some good design and construction criteria/guidance for a wide variety of stormwater quality practices. iSWM does not include any stormwater quality practice design details or specifications similar to the public works construction standards they publish (NCTCOG 2017). However, as a resource that has been continuously updated since the early 1990's, NCTCOG may add these key resources in the future to iSWM.

C.3 References

NCTCOG, Public Works Construction Standards Specifications and Drawings – 5th Edition, North Central Texas Council of Governments, https://www.nctcog.org/envir/public-works/construction-standards, Arlington, Texas, 2017


Mud Springs Creek
Watershed
PROTECT OUR RIVERS

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Appendix C

Stormwater Geospatial Data Management Review Technical Memorandum

(Geodatabase Provided Digitally)

Memorandum

To: *Ada Inda, PM ETAM/WSM*

From: *CDM Smith Inc.*

Date: *January 25, 2019*

Subject: *Stormwater Geospatial Data Management Review Technical Memorandum*

Section 1

1. Scope

This technical memorandum (TM) satisfies the deliverable requirement in Section 2.1 of the Stormwater Drainage Master Plan (SDMP) scope of services. Its purpose is to document the GIS data received, the review process and results indicating whether the data support the project in its current state or require additional information not present to develop the model, and recommendations to address some of the data deficiencies with respect to this project going forward. In addition, we have included documentation and procedures on terrain model development and pervious/impervious area extraction from land use data.

2. Data Received

The following geodatabases were received on March 23, 2018 from DFW. Data was provided to CDM Smith by Stefan Hildebrand (DFWIA/ETAM) via FTP transfer and were noted as the best available data. These data represent the complete GIS database of DFWIA and include data that will not be used in the final stormwater geodatabase. The stormwater geodatabase will be compiled largely from data gathered from the utilities and environmental geodatabases. Other geodatabases contain useful reference information but are not expected to contribute data to the final stormwater geodatabase.

- Airfield.gdb
- Airspace.gdb
- Cadastral.gdb
- Environmental.gdb

- Geodetic.gdb
- Jurisdictions.gdb
- NavigationalAids.gdb
- Security.gdb
- Structure.gdb
- SurfaceTransportation.gdb
- Utilities.gdb

3. Data Reviewed

This memorandum focuses only on data critical to the completion of the SDMP. For consistency and clarity, datasets are referenced using the naming conventions applied by DFWIA –i.e. First Flush Stormwater Infrastructure was provided as Pretreat Line and Fitting. Remaining datasets received a cursory review and will be used as reference layers as needed and as appropriate.

The datasets critical to the analysis portion of the SDMP were reviewed for data quality as well as completeness with respect to attributes required to support the project.

All data was received in the State Plane Texas North Central (feet) projection.

Utilities Geodatabase

Stormwater feature dataset

- Storm Fitting (manholes, inlets, catch basins, etc)
- Storm Line (pipes)

First Flush Stormwater feature dataset

- Pretreat Fitting (manholes, inlets, catch basins, etc)
- Pretreat Line (pipes)

Environmental Geodatabase

- Permitted Outfalls feature class
- Stream feature class

4. Data Evaluation

The Stormwater Storm Fittings feature class and the First Flush Stormwater Pretreat Fitting feature class fields containing invert attributes were sparsely populated. Storm and pretreat fittings contained elevation fields for rim elevation, flow in elevation and flow out elevation, however, those fields contained many null values.

The table below lists the attributes with null values and the percent total for Storm Fittings.

Table 1 - Storm Fitting Features and Attributes

	Feature Count	RIMELEV is null	Flowelev In is null	Flowelev Out is null
Storm Fitting	7029	6977	7029	6957
Percent Total		99.26%	100.00%	98.98%

Figure 1 shows storm fittings, highlighted in blue that are not connected or snapped to storm lines. The lack of connectivity is apparent when zoomed in (see inset in image where points appear to be hovering above the lines) but when zoomed out it appears that these features are snapped to lines. Approximately 10% of fittings were found to be disconnected. Disconnected features can produce errors when using the geometric network trace functions in GIS used to determine flow origination

Figure 1. Storm Fittings not connected to Storm Lines

Table 2 lists results of the attribute analysis for storm lines, including diameter, material, and pipe class. Approximately (45%) of storm lines are either equal to or greater than 24 inches in diameter. Thirteen percent (13%) of pipes have a diameter coded as 0 which seems to indicate that the diameter is unknown. The data have a relatively small amount of missing material information, only 1.92% of pipes equal to or greater than 24 inches in diameter are missing material information.

Table 2 - Storm Lines Features and Attributes

	Feature Count	Size (diameter) = 0	Material is null	Pipeclass is null
Storm Line	15,354	2,078	2,247	11,084
Percent Total		13.53%	14.63%	72.19%
>= 24 inches	6,865		132	4,901
Percent Total or Percent of >= 24 Inches	44.71%		1.92%	72.19%

Table 3 shows the attributes associated with pretreat fittings. Less than 1% are missing fitting type. However, more than 85% of fittings are missing elevation information.

Table 3 Pretreat Fitting Features and Attributes

	Feature Count	Type is null	Class is null	Rimelev is null	Flowelev In is null	Flowelev Out is null
Pretreat Fitting	862	2	616	760	776	763
Percent Total		0.23%	71.46%	88.17%	90.02%	88.52%

Table 4 lists attributes for pretreat lines. Only 2% of the pipes have a diameter of 0 indicating that the diameter is unknown. Of the remaining pipes, 11% are greater than or equal to 24 inches in diameter.

Table 4 - Pretreat Lines Features and Attributes

	Feature Count	Size (diameter) = 0	Material is null	Pipeclass is null
Pretreat Line	839	24	146	473
Percent Total		2.86%	17.40%	56.38%
>= 24 inches	94		7	54
Percent Total or percent of >= 24 inches	11.20%		7.45%	57.45%

Permitted Outfalls features are nearly fully attributed and show no significant deficiencies. Two features are lacking IDs though this should be easily resolved. See **Table 5.**

Table 5 - Permitted Outfalls Features and Attributes

	Feature Count	ID is null	Outfall is null
Permitted Outfalls	106	2	0
Percent Total		1.89%	0%

Streams are broken down by class and there are no features with a null class attribute. There are 312 streams coded as channelized, 150 coded as culvert and 163 coded as natural. Stream names are incomplete and noted in **Table 6.**

Table 6 - Streams Lines Features and Attributes

	Feature Count	Stream Name is null	Stream System is null
Streams	625	279	109
Percent Total		44.64%	17.44%

5. Quality Recommendations

The following concerns about the data should be addressed as indicated below:

- Connectivity / Snapping
- Direction of Digitization vs Direction of flow
- Unsplit
- Duplicate features/ Features in different geodatabases or feature datasets

Connectivity/Snapping

Snapping issues – For QAQC purposes, a geometric network was developed with snapping using the lowest tolerance. After the network was built there were 50,593 junctions, locations where points were not connected to lines. Of those, 839 (2%) could not be associated with a pipe at all - meaning there was no pipe in the immediate vicinity of the point. The remaining are issues where points visually appear to be connected to a line, but they are not topologically connected.

A geometric network was created for analysis using Storm Line, Storm Fitting (from Stormwater GDB) and Permanent Outfalls (from Environmental GDB) and Stream (from Environmental GDB), 15,593 junctions were created because of the network build. Of those, 839 are not snapped to anything meaning that points were floating in space not near any lines. 217 junctions are within half a foot of a storm fitting which may be an indication that some storm fittings are not actually snapped to pipes. This geometric network was created using snapping and using the lowest tolerance (default).

734 of 7029 (10%) storm fittings not touching a pipe from storm line and that may also be indicative of a snapping issue between storm fittings and storm lines.

Direction of Digitization vs Direction of flow

More analysis is needed, possibly using a data reviewer check to determine if there are issues with direction of digitization. There are currently issues with pipes not being digitized in the correct direction of flow. This presents problems when setting flow direction in a geometric network, using the network tracing tools and completing the hydraulic modeling effort.

Unsplit

A check was run for pipes with of pipe length of less than 5 ft. There are 908 of 15,354 (approximately 6%) pipes that are less than 5 feet in length. These should be examined to determine if those are actual pipes or are the result of an undershoot or a pipe needing an unsplit.

Duplicate Features/ Features in different geodatabases or feature datasets

51 of the 106 points in the Permitted Outfalls feature class appear to be directly on top of points in the Stormwater Fitting feature class. These should be examined to determine if they are duplicate features.

There are several storm lines that fall on top of the streams – they are coded as Channels and Culverts under the Pipe Class field.

Permitted outfalls are a separate feature class. It is unclear if these point features are also part of the storm fittings. This should be examined to determine if there are duplicate features.

Section 2

Image Analysis and Impervious Surface Polygon Creation

Image analysis was used to process a raster image of the project area to obtain an impervious surface polygon data layer. Tools in ArcGIS were used to compute a normalized difference vegetation index (NDVI) from a multispectral image which was clipped to the area where no land use data classification was available. This then led to the development and refinement of an impervious surface polygon data layer.

Analysis began with the land use data layer in the cadastral geodatabase received from DFW. This data layer was examined for unclassified polygons. In addition, a raster image of the area was used.

Figure 2 shows the land use data layer as received with unclassified areas outlined in red. This included all runways, taxiway and most service roads. All other land use areas are colored in purple.

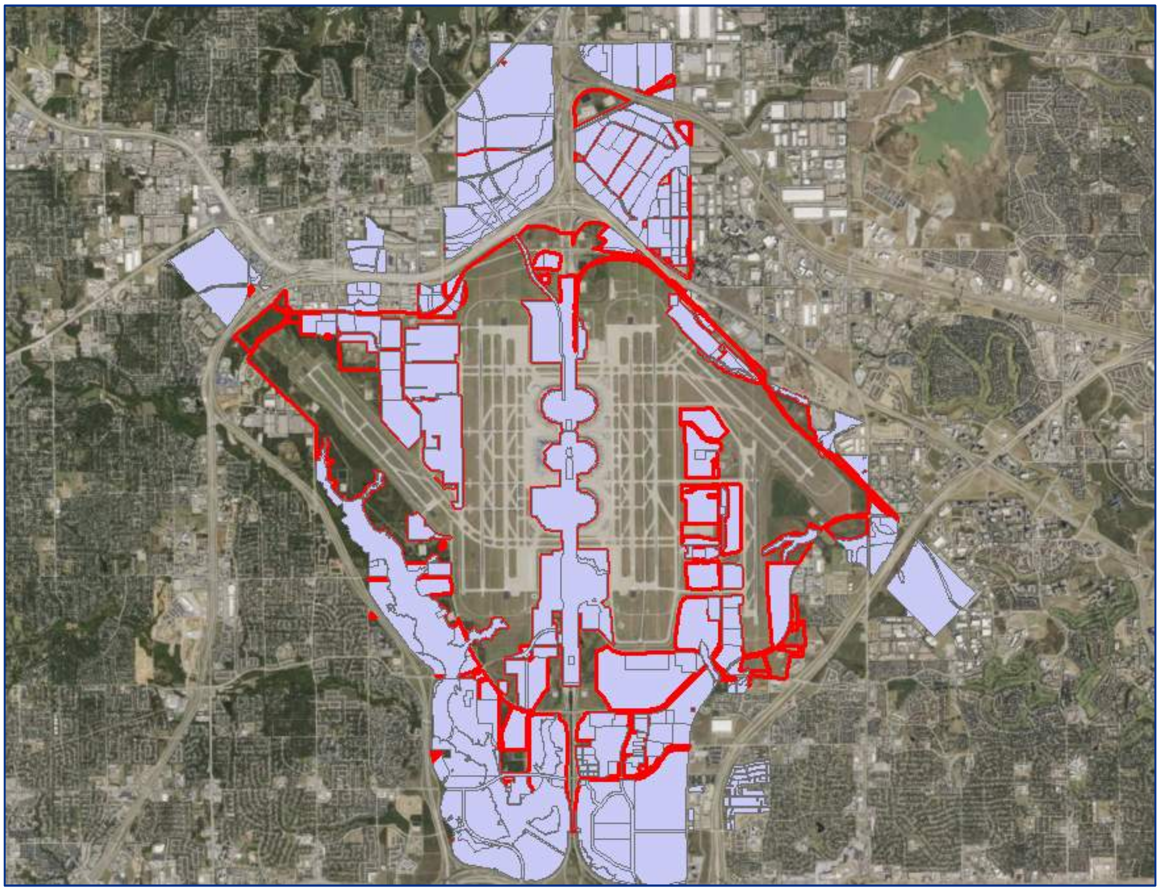

Figure 2. Land use data layer with unclassified area outlined in red

The raster image was clipped to only contain the unclassified land use polygons using the Image Analysis toolbar in ArcGIS. The raster was then converted to a polygon using the raster to poly tools.

The resulting dataset contained polygons coded either as impervious or not impervious.

Note that in some cases, because this analysis used contrast, the pavement markings and other markings were lighter in color than the pavement were mistaken for vegetation.

Figure 3 shows pavement markings (in green) mistaken for vegetation.

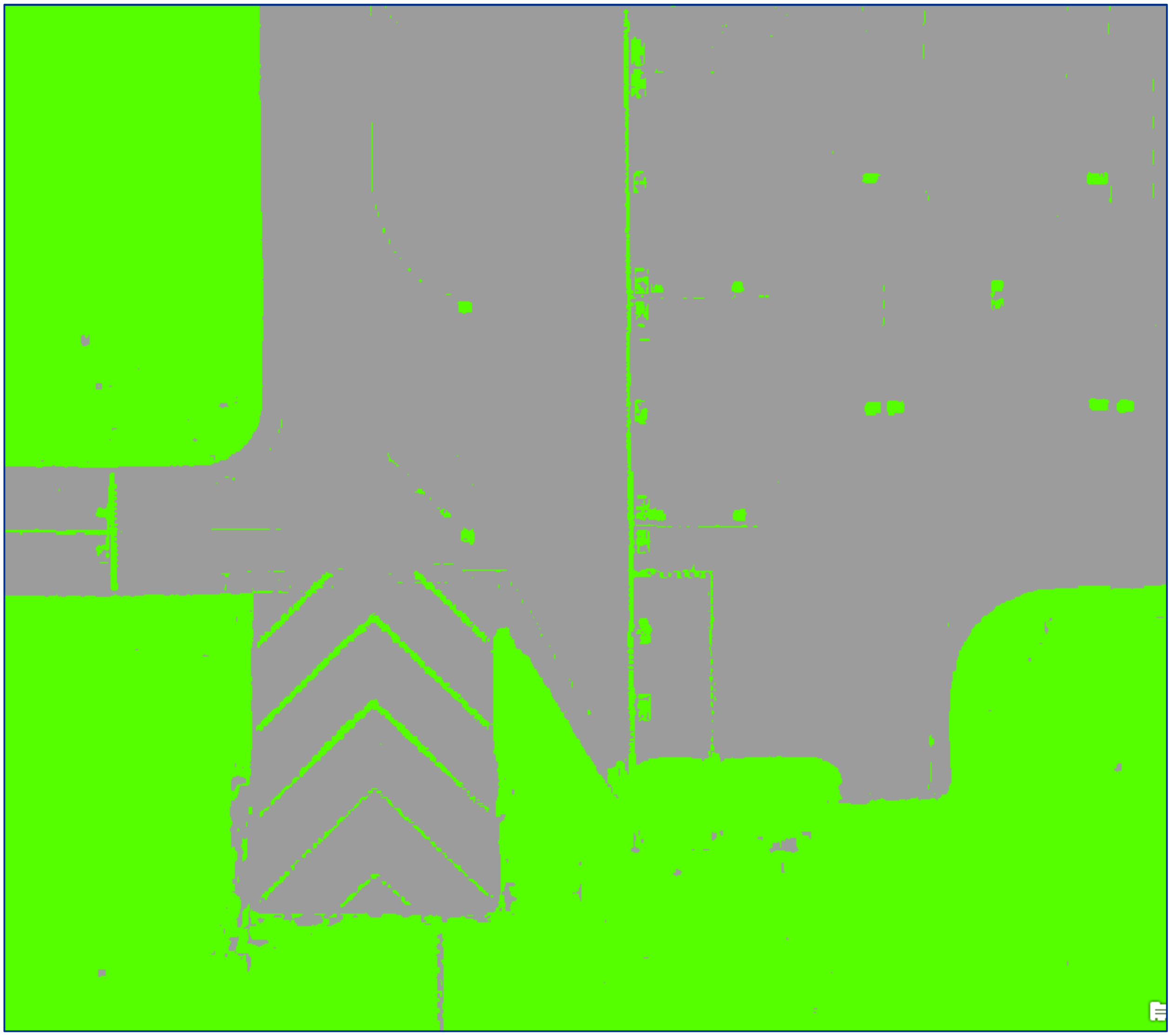

Figure 3. Initial Analysis showing pavement markings incorrectly classified

Further editing used dissolving techniques with a minimum area to clean up the initial analysis and create a polygon impervious surface layer.

The resulting dataset, shown in **Figure 4**, consists of polygons coded impervious or not. Impervious areas are grey, pervious areas are green and areas colored purple have land use classifications. The red outline defines the “airside” portion of the study area.

This product will be provided to DFWIA as part of the final deliverable.

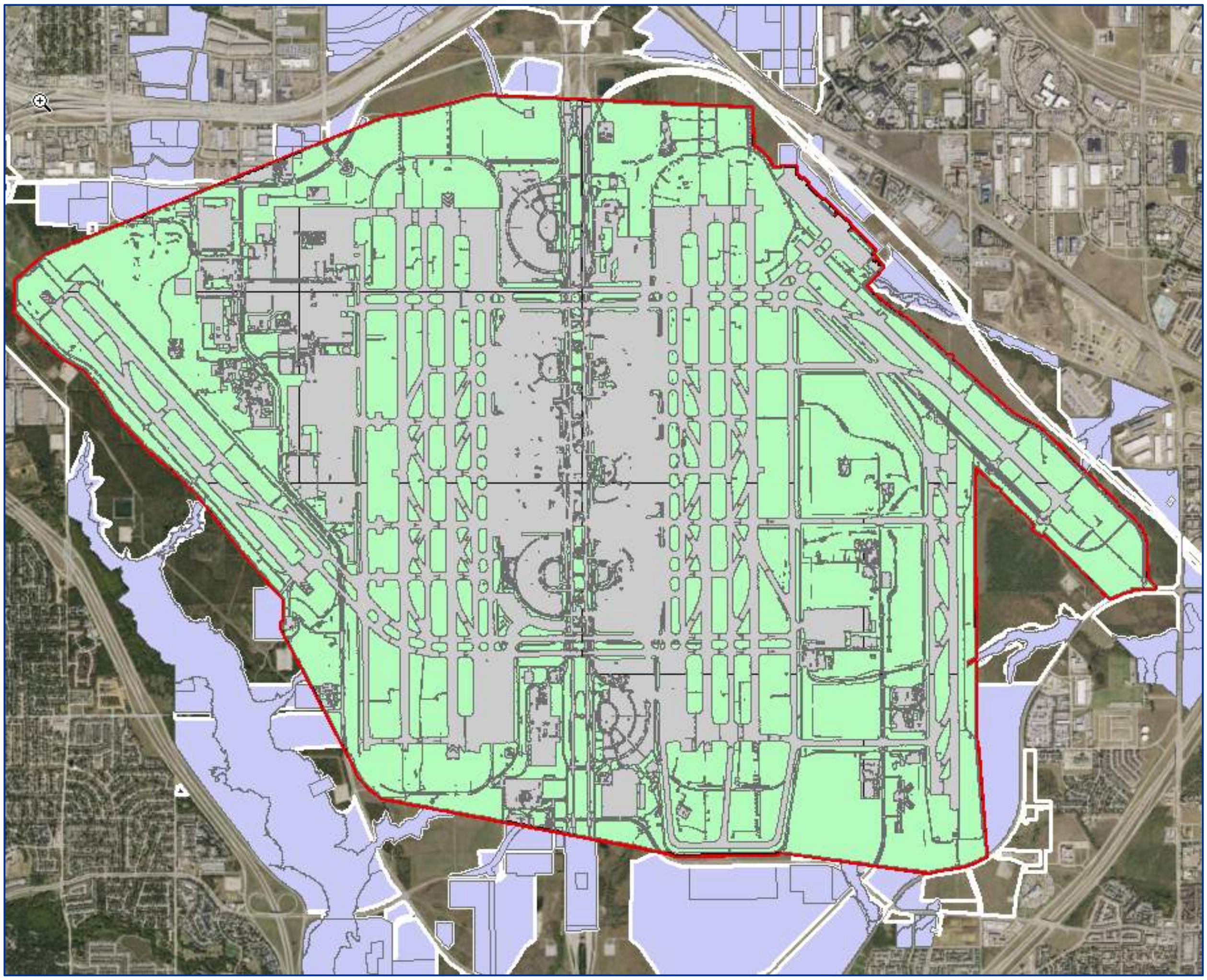

Figure 4. Impervious data layer

Section 3

Digital Terrain Model Generation

The digital terrain model for this project was generated from Light Detection and Ranging (LiDAR) data acquired during three separate flights: 2007, 2015 and 2017. These data were purchased from the North Central Texas Council of Governments (NCTCOG) by DFWIA and provided to CDM Smith for processing.

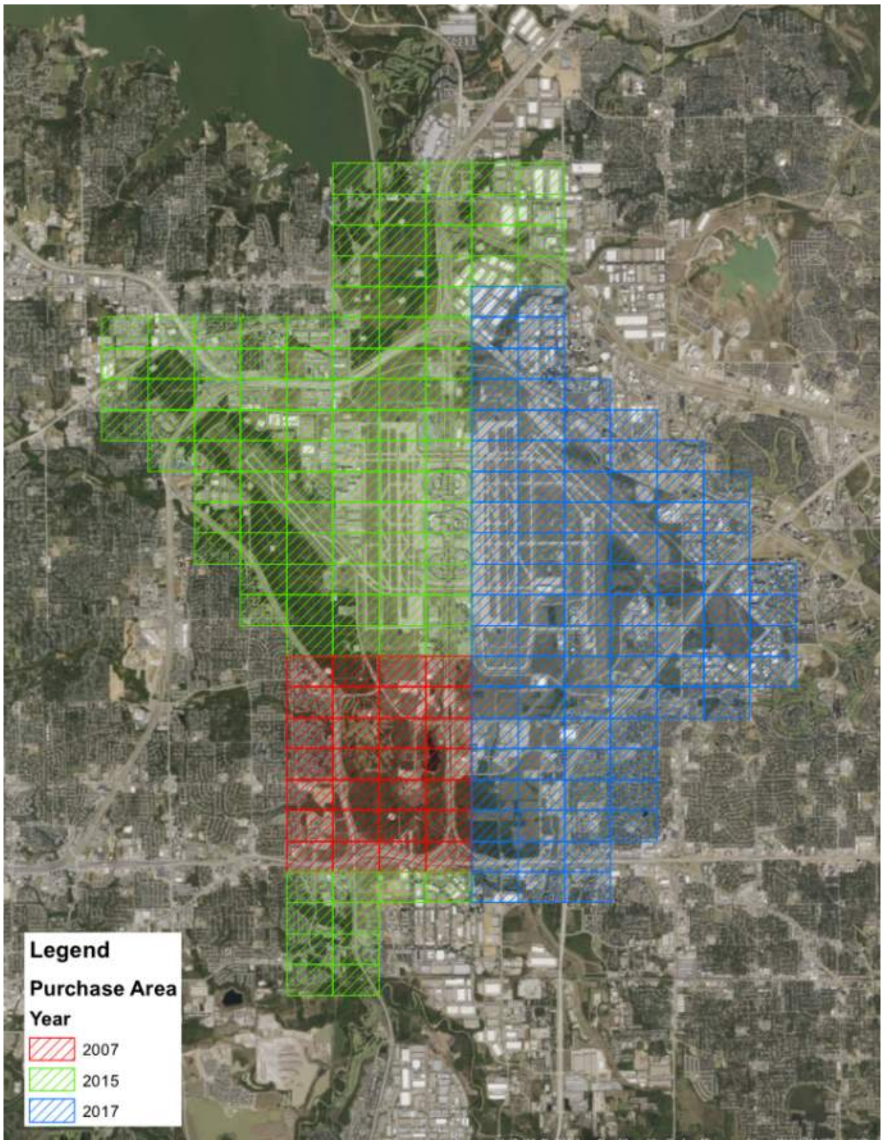

Figure 5. LiDAR Purchase Areas by Year

Metadata and flight reports supplied with the data establish the vertical accuracy as:

2007 – 1.06 feet

2015 – 0.431 feet

2017 – 0.374 feet

These data were processed using ArcGIS Desktop LAS Dataset Tools to reflect bare earth returns only. This removes rooftops, tree canopies, etc. along with incidental returns that do not reflect ground elevation.

These filtered LiDAR data where processed into a 4x4 foot Digital Elevation Model (DEM) providing complete and seamless elevation coverage of DFWIA property. The digital terrain model along with intermediate data will be provided to DFWIA as part of the final deliverable.

Section 4
Next Steps and Long-Term Recommendations

1. To support both the modeling efforts as well as future needs that will rely on an accurate and complete GIS, CDM Smith recommends adding invert elevations to stormwater infrastructure of 24” and greater. CDM Smith understands these data only exist as scanned As-Builts which will require a review, geo-referencing and manually determining invert elevations. However, this is critical information and will be necessary to complete the hydraulic modeling in this stormwater masterplan.

2. CDM Smith recommends DFWIA stormwater infrastructure be converted to and maintained within the ESRI Stormwater Utility Data Model. This data model represents the industry standard, provides standardized naming conventions and will allow DFWIA to seamlessly include tools/functionality provided by ESRI. ESRI tools support inventory maintenance, inspections and supports the use of mobile devices for field crews. In addition, the stormwater data model can be used to identify core NPDES information and can be extended to support local regulations. DFWIA can continue to store and maintain data specific to their system (such as contract IDs) within the stormwater model without affecting core functionality.

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Appendix D
Stormwater Modeling Methodology

STORMWATER MODELING METHODOLOGY REPORT

DALLAS FORT WORTH INTERNATIONAL AIRPORT

January 2019

CDM Smith

Table of Contents

List of Figures

List of Tables

Appendices

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Section 1

Introduction and Background

1.1 Introduction

The Dallas Fort Worth Internal Airport (DFWIA) is located in north-central Texas, between Dallas and Fort Worth, as shown in **Figure 1-1**. The stormwater system at DFWIA, including its contributing watersheds are being evaluated under the Stormwater Drainage Master Plan (SDMP by developing hydrologic and hydraulic models to facilitate the analysis of conveyance and water quality issues. The modeling of the Primary Stormwater Management System (PSMS) will be performed using the EPA Stormwater Management Model (SWMM), version 5+. This modeling effort allows for the assessment of underlying causes of flooding and erosion issues in the system and predict areas of concerns, preventing further issues from occurring. Models are being built to simulate both existing and future land use conditions of all eight major watersheds contributing to DFWIA. The watersheds are shown on **Figure 1-2**.

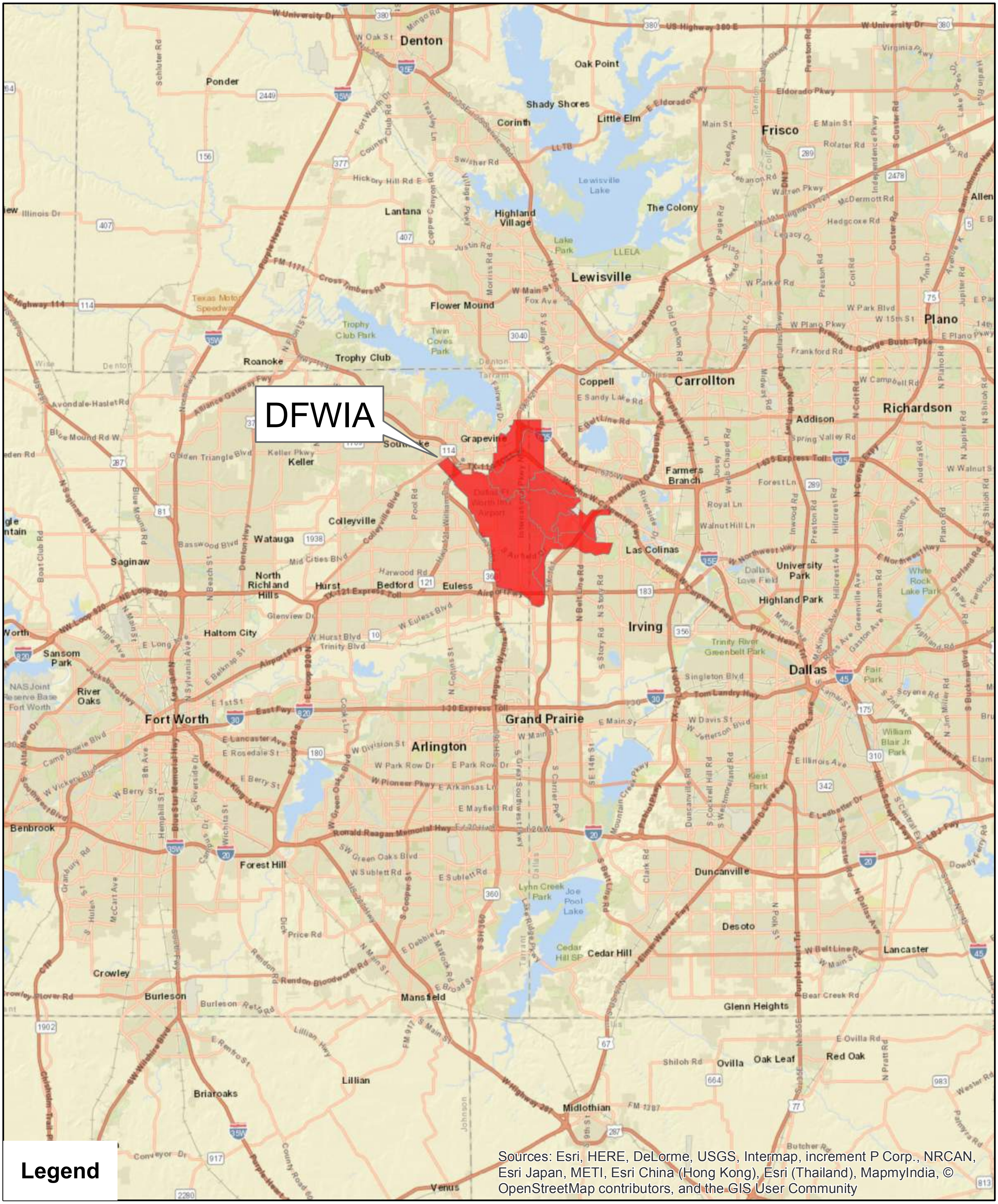
The developed models represent the PSMS and will be used to:

- Determine baseline hydrology and hydraulic conditions for the basins.
- Assess the system's drainage characteristics for established design storm events.
- Provide sufficient level of detail for FEMA floodplain delineation requirements.
- Identify possible causes of existing flooding and erosion problems.
- Determine size recommended system components.
- Analyze stormwater management approaches such as GSI/LID strategies.

The project study area encompasses the DFWIA property as well as interactions with the following municipalities:

- City of Irving;
- City of Coppell;
- City of Grapevine;
- City of Euless, and
- City of Fort Worth.

This methodology volume provides background and supplemental information on the various methodologies applied for modeling the respective basins.

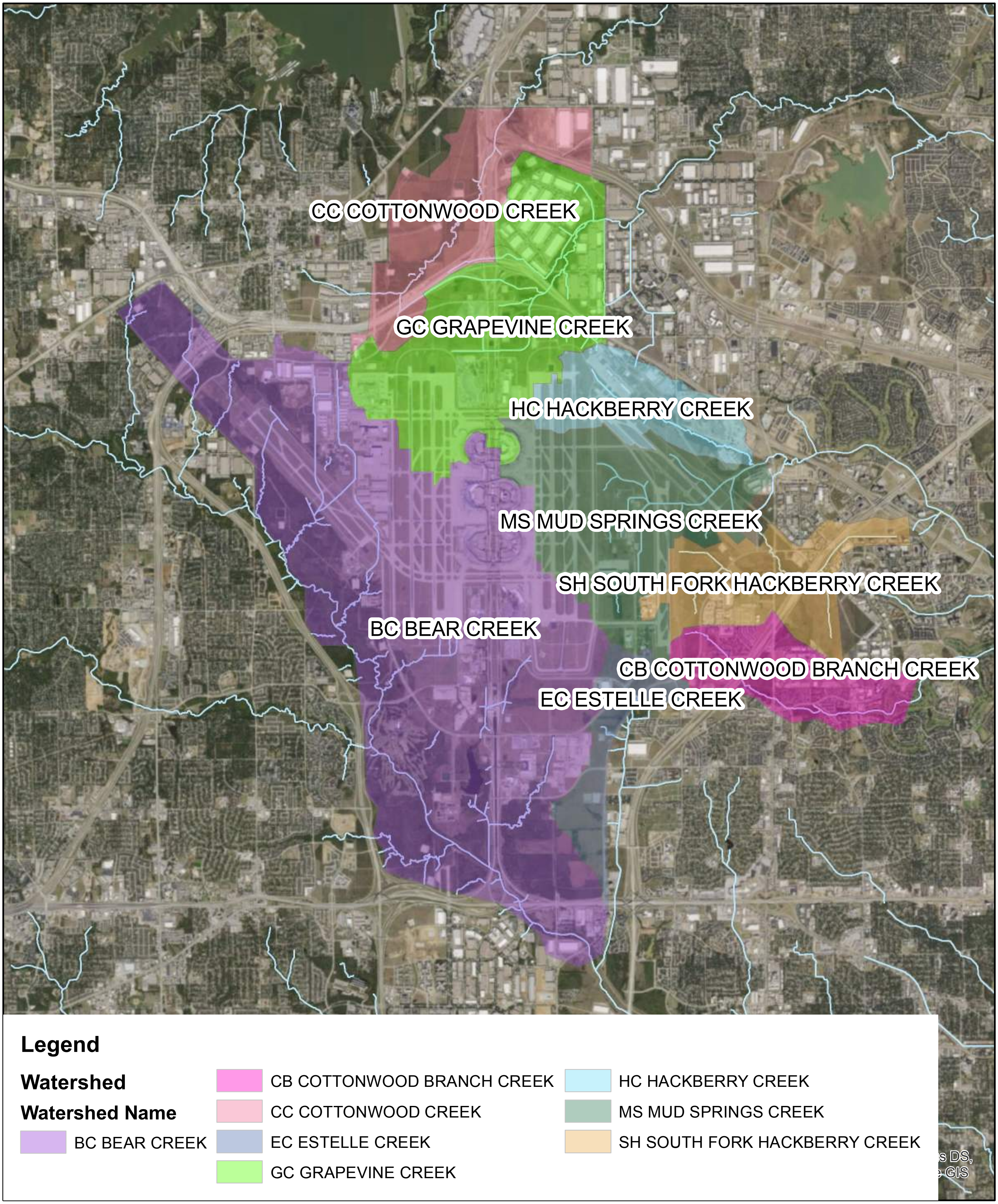


CDM Smith

N W E S

Miles
0 1 2 4 6 8

DFWIA SDMP
Figure 1-1
Project Location



N W E S

Miles
0 0.5 1 2

DFWIA SDMP
Figure 1-2
Major Watersheds

1.2 Project Background

This section outlines the information to be provided in each of the watershed reports and provides references to other pertinent information that should be considered in conjunction with the information contained in the individual report sections.

1.2.1 Watershed Information

Each watershed report includes a description of the hydrologic and hydraulic parameters used to model the area. The methodology for establishing specific model input parameters such as Manning's roughness coefficients, soil types and characteristics, and impervious area percentage by land use are explained in detail in Section 3.0 of this report.

1.2.2 Existing Conditions

This section of the watershed report includes a description of current conditions within the watershed. This section is intended to provide a brief summary of existing land use and major CIP projects included in the basin.

1.2.3 Supplementary Information

In addition to the information explicitly detailed in the watershed reports, there are supplementary materials which, when used in conjunction with the SDMP report, provide additional information on flooding and water quality issues within each watershed. The following supplementary information will be referenced as applicable within each watershed report:

- Previously compiled reports
- FEMA Flood Insurance Study (FIS)
- FEMA Digital Flood Insurance Rate Maps (DFIRM)

Coincident with the development of the SDMP, CDM Smith will conduct a review of the available FIS and FIRM.

1.2.3.1 FIS

The FEMA FIS includes a description of the modeling effort used to update the special flood hazard areas within DFWIA. More importantly, the FIS includes floodway data tables, discharge tables, and flood profiles for each flooding source defined for DFWIA.

1.2.3.2 Discharge Tables

The FIS contains a Summary of Discharges table which outlines the peak discharges for each modeled flooding source within DFWIA at major cross roads. The discharge tables include peak discharges for the 10-. 50-, 100-, and 500-year storm events. Locations of discharges are noted in the tables and can be cross referenced with the DFIRM panels.

1.2.3.3 Floodway Data Tables

The FIS contains a Floodway Data Table (FDT) for each flood source identified. The FDT includes the floodway width, Base peak flow, and base peak velocity at each model node where floodway is established. Additionally, the FDT includes information on the water surface elevation both with and without floodway. Locations of nodes are can be cross referenced with the DFIRM panels.

1.2.3.4 Stream Profiles

The FIS contains a stream profile for each flood source identified. Each profile documents the water surface elevation along the length of the stream for the 10-. 50-, 100-, and 500-year storm events. Major road crossings and relevant model nodes are noted on each profile. Locations of nodes are can be cross referenced with the DFIRM panels.

1.2.4 Level of Service

Each watershed report details the exceedances of Level of Service (LOS) for water quantity, water quality, and operations and maintenance. The ability of a project to improve the LOS in a basin is the basis for project selection. The desired LOS defined for each category as well as the methodology for determining exceedances of LOS is detailed in Section 6.0 of this report. The LOS will be evaluated using the United States Environmental Protection Agency (USEPA) StormWater Management Model (SWMM), which is a public domain hydrologic, hydraulic and water quality model.

1.2.5 Alternative Evaluation

This section of the watershed report describes each alternative developed to address LOS exceedances within the watershed. Alternatives may address multiple LOS exceedances (e.g. water quantity and water quality) or may focus on a single LOS violation (e.g. water quality only) depending on the needs of the watershed and the specific alternative characteristics. Each alternative description will include a figure depicting project location, a brief description of the alternative, and a summary of the alternative's expected benefits.

In some cases, there may be multiple options available at a single project site. For example, an empty parcel may be used for dry detention or biofiltration accompanied by conveyance improvements. To evaluate which of these options best addresses LOS exceedances in the watershed, the CDM Smith team will evaluate each of the options as a separate alternative for comparison.

1.4.6 Recommended Plan

Each watershed report concludes with a description of the recommended plan for the watershed. This description includes a list of all the individual components of the recommended plan as well as a summary of its expected benefits. This information should be used during project design to ensure that detailed design results in the expected project benefits (e.g., flood stage and velocity reductions, treatment by BMPs).

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Section 2

Project Nomenclature

2.1 Watersheds

For purposes of consistency and understanding, the SDMP established a specific project nomenclature to create meaning to the model IDs and project files. The SDMP project includes 8 basins, each identified by a 2-digit code as shown on **Figure 1-2**.

2.2 Hydrologic Units

Hydrologic Units (HUs) are used by SWMM to evaluate areas that directly load to the stormwater management system. To provide for consistency in naming each HU will be assigned a unique ID number and to help understand the location of the HUs, the 2-letter watershed code was added in front of each HU ID as well as the letters HU to identify the entity as a HU. Refer to hydrologic units nomenclature guidelines on **Figure 2-1**.

2.3 Nodes and Conduits

Similar to HUs, the 2-letter subbasin code was added to the front of a five-digit ID for the nodes (also sometimes called junctions) and conduits. Additionally, suffixes were added when necessary to identify structures, overflows, or approximated conduits as shown in the nodes and conduits nomenclature guidelines in **Figure 2-1**. Nodes are named starting with the smallest number at the outfall and increasing in value as the nodes move upstream. Each branch within the subbasin is given its own 1000 series and conduits are named with the ID of the upstream node. More than one conduit may be needed through a structure. **Figure 2-1** displays a figure of structure overflow where one conduit goes under the roadway and a second conduit overtops the roadway. These two conduits are given suffix of S and O for the structure and overflow, respectively. Approximated conduits are given a suffix of A. These conventions as well as model input filename conventions are shown on **Figure 2-2**.

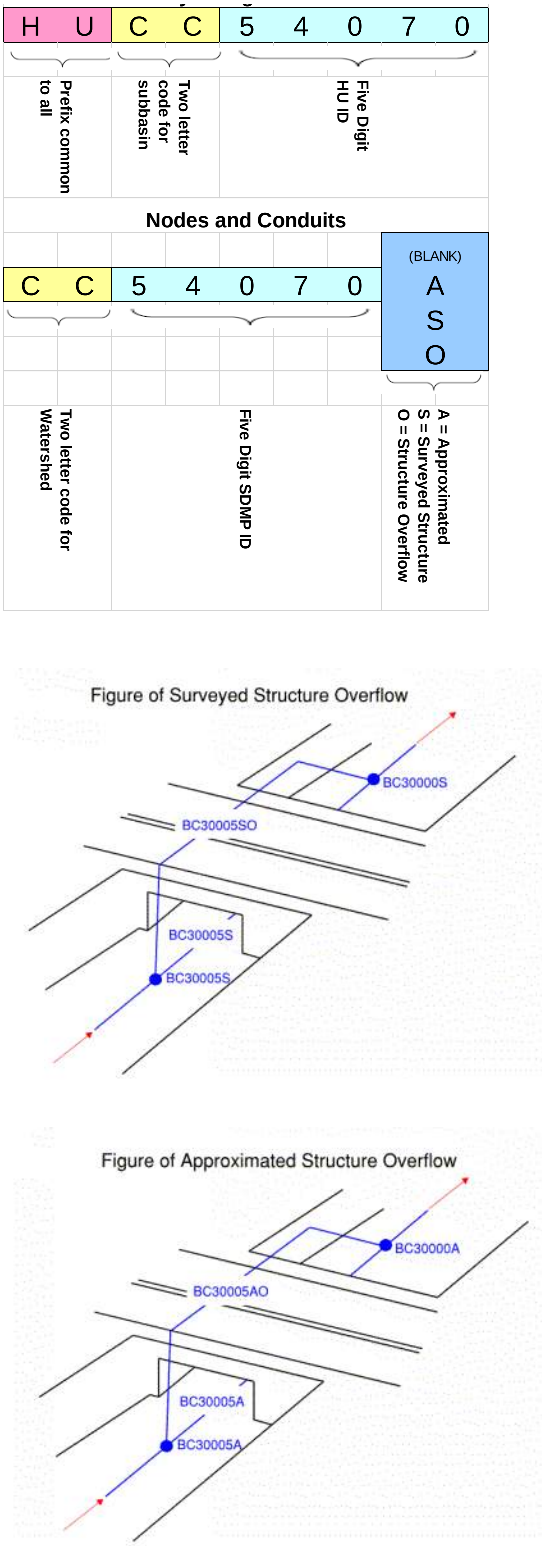

Figure 2-1. DFWIA Stormwater Drainage Master Plan Nomenclature for Model Elements

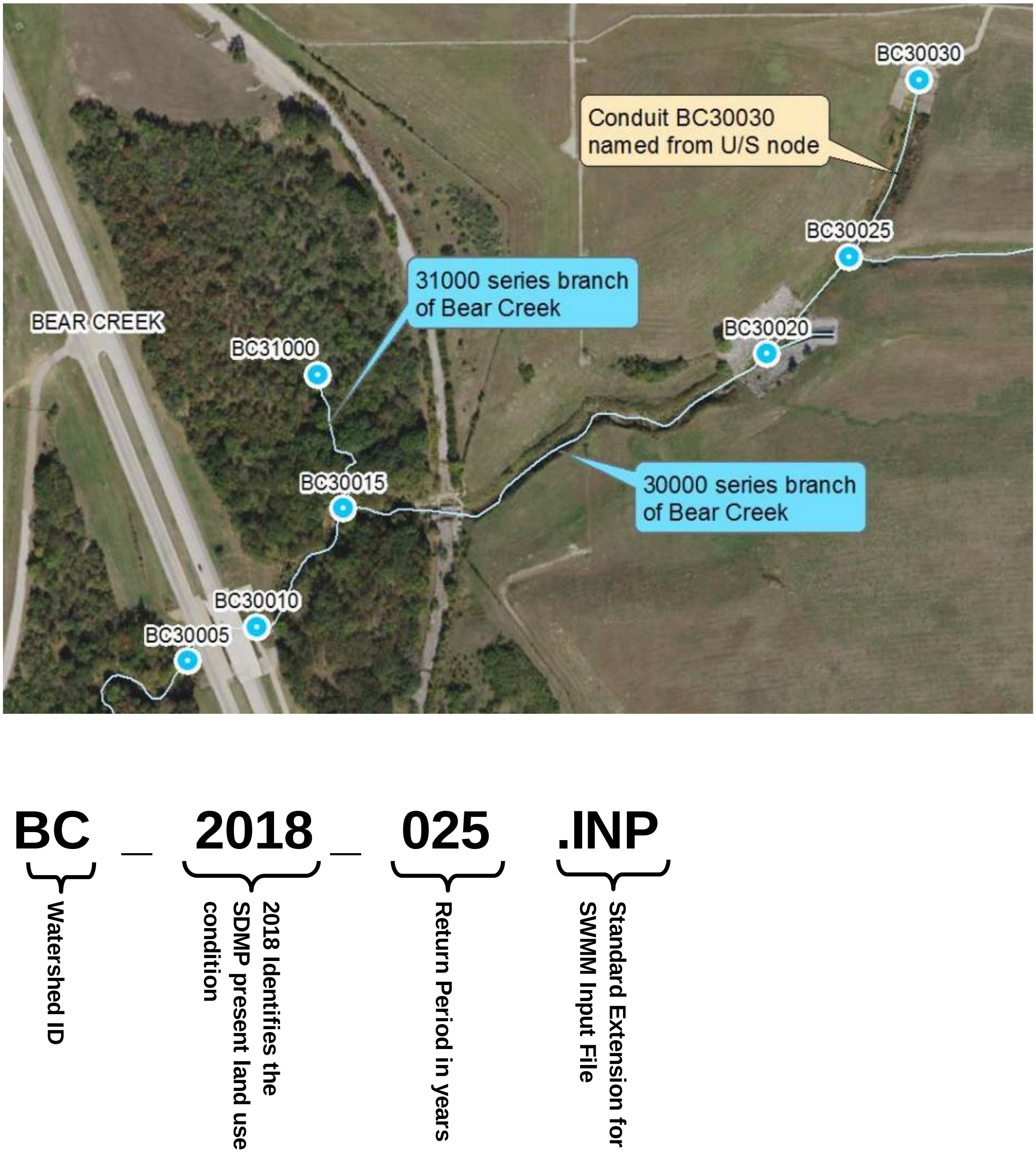

Figure 2-2. DFWIA SDMP Nomenclature for Nodes, Conduits, and Model Input File Names

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Section 3

Model Hydrologic and Hydraulic Parameters

To provide for consistency between stormwater models of the 8 watersheds the following guidance is provided with respect to hydrologic and hydraulic parameters. An overall model checklist is included in Appendix A.

3.1 Stormwater Modeling

Proper evaluation of existing stormwater facilities (conveyance and storage) is critical in order for DFWIA to effectively manage flood and erosion risk, capital improvements, water quality issues, and future development. For this evaluation, the CDM Smith Team will use USEPA SWMM version 5+ to simulate the surface water hydrology and hydraulics. This model was chosen because it has been verified through use in Stormwater Drainage Master Plans at airports throughout the United States. SWMM is also approved by FEMA for floodplain mapping and accepted as an industry standard modeling platform for urban systems with systems of combined open channels and piped networks.

SWMM is a dynamic hydrologic and hydraulic model capable of performing continuous or event simulations of surface runoff, and subsequent hydraulic conveyance in open channel and pipe systems.

The hydrologic system operates by applying precipitation across HUs and through hydrologic calculations, determining surface runoff to loading points on the user-defined Primary Stormwater Management System (PSMS). Runoff hydrographs for these loading points provide input for hydraulic routing the PSMS to the outlet.

The hydraulic flow routing routine of SWMM 5 uses a link-node representation of the stormwater management system to dynamically route flows by continuously solving the complete one-dimensional Saint-Venant flow equations. The dynamic flow routing allows for representation of channel storage, branched or looped networks, backwater effects, free surface flow, pressure flow, entrance and exit losses, weirs, orifices, pumping facilities, rating curves, and other special structures/links. Control rules may be used to operate the structures based on timing and/or stage and flow conditions within the model.

Earlier versions of SWMM (versions 3 and 4) used separate models for hydrology (RUNOFF Model) and Hydraulics (EXTRAN Model), which were linked by an interface file. SWMM 5 uses similar architecture; however, the hydrologic and hydraulic engines are modules within the same model and run simultaneously.

3.2 Hydrologic Parameters

Hydrologic model parameters used for the model simulations are described in this section.

3.2.1 Topographic Data

Topographic data will be used to define hydrologic boundaries, overland flow slopes, channel floodplains, critical flood elevations, and stage-storage area relationships. Topographic data are available from four major sources:

1. Existing survey data (creek cross section and roadway crossings) requested by CDM Smith and provided by DFWIA;
2. Light Detection and Ranging (LiDAR) survey obtained in 2015 and 2017 by the North Central Texas Council of Governments (NCTCOG);
3. As-built plans for upgraded roadway crossings and improvements to the PSWMS; and
4. Site specific topographic survey to be obtained as part of this SDMP.

The CDM Smith team will use the data to delineate hydrologic divides, define stage-area-storage relationships, define channel geometries with survey, and define bridge/culvert/control structure characteristics.

All models will be referenced to the North American Vertical Datum of 1988 (NAVD88).

3.2.2 Hydrologic Units (HUs)

Natural physical features or constructed stormwater management systems that control and direct stormwater runoff to a common outfall generally define HUs. The following general criteria were used to determine HU boundaries:

- Topographic highs;
- Large-scale physical features such as railroad grades, airport runways, and roads;
- Where structures of topographic features could appreciably impound water for the 100-year event; and
- Existing reports and studies and field verification, to define ambiguous boundaries.

For the SDMP, the previously developed watershed boundaries will be analyzed and modified as appropriate based upon the refined topography provided by the LiDAR survey. GIS software will be used to digitize the HUs, calculate properties, and to extract land use and soil properties for use in calculation of HU hydrologic parameters.

3.2.3 Rainfall Intensities and Quantities

NOAA Atlas 14, Volume 11, Version 2 was used to determine rainfall depths for six recurrence intervals of 24-hour duration design storms as shown in **Table 3-1** and **Appendix B**. The rainfall depths will be applied in the models using the SCS Type II rainfall distributions, according to methodologies developed by the North Central Texas Council of Governments (NCTCOG) and published in the integrated Stormwater Management (iSWM) Hydrology guidance documents. A sensitivity analysis revealed minimal variation in rainfall depths across DFWIA, therefore consistent values shall be applied to all watersheds.

Table 3-1. NOAA Atlas 14 Rainfall Depths

24-hour Storm (in)	1-yr	5-yr	10-yr	25-yr	100-yr	500-yr
	3.3	5.0	5.9	7.1	9.2	12.0

3.2.4 Hydrologic Parameters

The hydrologic module of SWMM uses overland flow data in the form of width, slope, and Manning's roughness coefficient to create a physically based overland flow runoff plane to route runoff to the PSMS for hydraulic routing. The overland flow hydraulic length is the weighted-average travel length to the PSMS.

Overland flow slope is the average slope across the overland flow hydraulic length. Length and slope information will be estimated from topographic map data and field inspection data. Manning's equation is used for the overland flow routing. **Table 3-2** lists typical Manning's roughness coefficient (n) values for overland flow. Note that pervious land use coverages appear rough because the depth of overland flow (a few inches) is equal to or less than the height of the roughness feature.

Table 3-2. Published Values of Manning's Roughness Coefficients for Overland Flow

Source	Ground Cover	Manning's n	Range
Crawford and Linsley (1966)[a]	Smooth asphalt Asphalt of concrete paving Packed clay Light turf Dense turf Dense shrubbery and forest litter	0.012 0.014 0.03 0.20 0.35 0.4	
Engman (1986)[b]	Concrete or asphalt Bare sand Graveled Surface Bare clay-loam (eroded) Range (natural) Bluegrass sod Short grass prairie Bermuda grass	.011 .01 .02 0.02 0.13 0.45 0.15 0.41	0.01-0.013 0.01-0.16 0.012-0.03 0.012-0.033 0.01-0.32 0.39-0.63 0.10-0.20 0.30-0.48

Notes:
[a]Obtained by calibration of Stanford Watershed Model.
[b]Computed by Engman (1986) by kinematic wave and storage analysis of measured rainfall-runoff data.

Examination of the Land Use GIS shapefile provided by DFWIA reveals 16 different land uses. These land uses have been aggregated into 10 land use classes for hydrologic modeling as described in Section 3.2.6. Land use-based Manning's roughness coefficient values used in the SWMMs are shown in **Table 3-3**.

Table 3-3. Land Use Based Manning's Roughness Coefficients used in SWMM.

	Forest, Open & Park	Pasture	Agricultural & Golf Courses	Low Density Residential	Medium Density Residential	High Density Residential	Light Industrial, Commercial & Institutional	Heavy Industrial	Wetlands	Watercourses & Waterbodies
Impervious Manning's n	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.100	0.024
Pervious Manning's n	0.400	0.300	0.300	0.250	0.250	0.250	0.250	0.250	0.400	0.060

3.2.5 Soils Types and Characteristics

Soils within the site were obtained from NCTCOG, and the data originate from the U.S. Department of Agriculture, Natural Resources Conservation Service, published January, 2007 as the Soil Survey Geographic (SSURGO) database. The data table available with the NCTCOG file must be linked to data available from https://sdmdataaccess.nrcs.usda.gov/ to obtain descriptions of soil types appropriate to your application.

The hydrologic model within SWMM uses both soil storage and infiltration rates to determine the volume of surface water runoff and infiltration in pervious land areas. Soil capacity (or soil storage) is a measure of the amount of storage (in inches) available in the soil type for a given antecedent moisture condition. The average antecedent moisture condition (AMC II) was used for all design storm analyses. Soil capacities were estimated based on the NCTCOG iSWM Hydrology manual.

The Horton soil infiltration equation was used within SWMM to simulate infiltration into the soil. For design storm modeling, the Horton method presumes that the infiltration rate varies exponentially from an initial maximum infiltration rate to a minimum infiltration rate during the event. Model input includes maximum and minimum infiltration rates, and a decay constant that determines how fast the infiltration rate is moving toward the minimum rate during the event. Additionally, a total maximum infiltration depth can be specified based on the moisture capacity of the soil. SWMM will not allow the infiltration volume during the event to exceed this volume.

Each of the soil types described above has been assigned to one of the four Hydrologic Soil Groups (A, B, C, or D) established by the SCS. Hydrologic Soil Group A is comprised of soils with a very high infiltration potential and a low runoff potential. Hydrologic Soil Group D is comprised of soils with very low infiltration potential and a high runoff potential. The other two categories fall between A and D soil groups. Dual class soils (e.g., A/D) mean that a hard pan or impermeable layer limits vertical infiltration, but the surficial soils are highly permeable and could infiltrate as a Class A soil if the confining layer was cut with a ditch or swale.

Global parameters were established for each Hydrologic Soil Group and were used to determine area-weighted parameter values based on the percent of each Hydrologic Soil Group within each HU. Detailed information on the use of the Horton infiltration equation is described in the *SWMM 5 User's Manual.* **Table 3-4** lists the global infiltration parameters used to calculate the hydrologic input data used in this study.

Table 3-4. Global Horton Infiltration Parameters

Hydrologic Soil Group	Maximum Infiltration Rate (in/hr)	Minimum Infiltration Rate (in/hr)	Decay Rate (1/hr)	Drying Time (days)	Maximum Soil Storage (in)
A	9.0	0.50	2.0016	2.1	5.00
B	6.0	0.25	2.0016	2.1	3.80
C	4.0	0.10	2.0016	2.1	1.40
D	2.0	0.05	2.0016	2.1	1.0

3.2.6 Land Use and Impervious Areas

For this study, existing land use is defined as year 2017, and derived from DFWIA land use data collected on 5-31-2017 and provided as part of the airport geodatabase for that year. Examination of the Land Use GIS shapefile provided by DFWIA reveals 16 different land uses. The land use codes within DFWIA were aggregated into 10 land use classes used in the hydrologic modeling as shown below with the 10 classes in *italics*:

1. AIRPORT SUPPORT FACILITIES: *Heavy Industrial*
2. BEAR CREEK GOLF CLUB: Agricultural & Golf Courses
3. COMMERCIAL RETAIL – NEW: Light Industrial, Commercial, & Institutional
4. CONSOLIDATED RENTAL CAR COMPLEX: Light Industrial, Commercial, & Institutional
5. DIRECT AVIATION USES AND SUPPORT: Light Industrial, Commercial, & Institutional
6. FLOOD PLAIN: Forest, Open & Park
7. FLOOD PLAIN - OPEN SPACE: Forest, Open & Park
8. INDUSTRIAL/FLEX: Heavy Industrial
9. MIXED USE COMMERCIAL: Light Industrial, Commercial, & Institutional
10. NOISE LAND: Forest, Open & Park
11. OFFICE/CORPORATE/FLEX: Light Industrial, Commercial, & Institutional
12. PLANNED RAIL: Forest, Open & Park
13. RIGHT OF WAYS – NEW: Forest, Open & Park
14. SURFACE WATER: Watercourses & Waterbodies
15. UNCLASSIFIED: to be examined on a case by case basis and assigned
16. WETLANDS: Wetlands

And the NCTCOG Land Use GIS shapefile contains 22 land uses for areas within the airport as follows:

1. AIRPORT
2. CEMETERIES
3. COMMERCIAL
4. COMMUNICATION
5. EDUCATION
6. HOTEL/MOTEL
7. INDUSTRIAL
8. INSTITUTIONAL/SEMI-PUBLIC
9. MOBILE HOME
10. MULTI-FAMILY
11. OFFICE
12. PARKING
13. PARKS/RECREATION
14. RAILROAD
15. RANCH LAND
16. RETAIL
17. RUNWAY
18. SINGLE FAMILY
19. SMALL WATER BODIES
20. UTILITIES
21. VACANT
22. WATER

These NCTCOG land uses will be used as needed to classify areas outside the limits of the airport land use coverage, and will be aggregated into the 10 land use classes as shown.

Each land use class has unique parameters for percent impervious, percent of directly and non—directly connected impervious areas (DCIA and NDCIA, respectively), and pervious and impervious cover roughness factors. The land use distribution for the airport is presented in **Table 3-5**. For airside areas the actual percent imperviousness will be measured, with the remaining portion classified as "Forest, Open & Park".

Table 3-5. DFWIA Land Use Distribution

Land Use Class	Area (Acres)	Percent
Forest, Open & Park	2,231.7	13.0
Pasture	0.0	0.0
Agricultural & Golf Courses	201.6	1.2
Low Density Residential	0.0	0.0
Medium Density Residential	0.0	0.0
High Density Residential	0.0	0.0
Light Industrial, Commercial & Institutional	10,145.4	59.0
Heavy Industrial	4,563.3	26.6
Wetlands	0.0	0.0
Watercourses & Waterbodies	41.2	0.2
Total	**17,183.2**	**100.0**

The DCIA represents all the impervious surfaces that are directly connected to the stormwater system. The NDCIA represents the impervious surfaces that have a pervious buffer prior to discharge into the stormwater system. Using the spatial distribution of the ten land use classes, an area-weighted average percent imperviousness for each hydrologic unit can be obtained.

After rainfall and area, the percent imperviousness of each hydrologic unit is the most sensitive parameter defined in the SWMM hydrologic model which determines the volume and rate of surface water runoff. As discussed above, the imperviousness is based on land use percentages. A summary of model input parameters per land use is presented in **Table 3-6**.

Table 3-6. Impervious by Land Use Category

Land Use Category	Percent Impervious[1]	Percent DCIA	Percent NDCIA	Percent Pervious
Forest, Open & Park	5	1	4	95
Pasture	5	1	4	95
Agricultural & Golf Courses	5	1	4	95
Low Density Residential	15	8	8	85
Medium Density Residential	35	23	12	65
High Density Residential	83	65	18	18
Light Industrial, Commercial & Institutional	90	81	9	10
Airport/Heavy Industrial	90	81	9	10
Wetlands	100	100	0	0
Watercourses & Waterbodies	100	100	0	0

Note:
1. Total Impervious Area

3.2.7 Depression Storage

Land use specific depression storage values are used in the model to account for initial abstractions of rainfall totals for the design storm events. The parameter accounts for small depressions in the landscape that form puddles, as well as rainfall that is caught in tree canopies and the foliage of vegetation. These initial abstractions are withheld from the hydrologic routing and effectively removed from the system. At the beginning of a rainfall event and for each land use, rainfall is intercepted up to the depth reported in **Table 3-7**, after which the rainfall bypasses the initial abstraction and is used for hydrologic routing.

Table 3-7. Land Use Based Initial Abstractions Used in SWMM

	Forest, Open & Park	Pasture	Agricultural & Golf Courses	Low Density Residential	Medium Density Residential	High Density Residential	Light Industrial, Commercial & Institutional	Heavy Industrial	Wetlands	Watercourses & Waterbodies
Impervious Ia (inches)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.50	0.10
Pervious Ia (inches)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.10

3.3 Hydraulic Parameters

This section presents the development of the hydraulic parameters for SWMM.

3.3.1 Field Investigations, As-Built Data, and Additional Survey

The DFWIA PSMS consists of streams, culverts, bridges, control structures, underground pipe networks, vaults, a first flush system, and detention ponds. The CDM Smith team conducted field investigations to assist in updating the definition of the hydraulic network.

As part of the development of the SDMP, additional field surveys will be required for cross sections and structures to augment the previous work. Survey will be taken in the NAVD88 datum and in accordance with FEMA Data Capture Standards.

3.3.2 Model Schematic

The SWMM hydrologic and hydraulic model uses a node/link representation of the PSMS as shown previously in **Figure 2-2**. Nodes are located at:

- The ends of culverts;
- At points along a pipe system where there is a change in material, size, or a significant inflow;
- Upstream and downstream of bridge structures;
- Points along the streams where the geometry, direction, and/or slope of the channel varies significantly;
- Stream intersections;
- Structures along the streams (weirs, but in general may include pump stations, orifices, etc.);
- Problem areas;
- Gage locations;
- Potential future development connections; and
- Points representing the HU low elevations.

3.3.3 Stage-Area Relationships

Stage area relationships will be computed for low lying areas in some HUs using the LiDAR data. The plan area for storage at 0.5 and 1.0 ft intervals will be calculated from the topographic surface as appropriate. The models will be used to evaluate large storm events, up to the 500-yr storm, therefore the channel reaches will need to extend sufficiently to increase the floodplain. In SWMM, the stage-area data can be assigned to a “storage node.” SWMM uses the data to calculate the relationship between stage and storage volume.

To avoid “double counting“ of storage in the model, storage associated with the floodplain of a stream reach must be kept separate from the stage-area storage nodes outside of the stream reach floodplain. Therefore, stage-area relationships will only be provided to storage junctions at the furthest upstream node on a tributary, upstream of a structure, in roadway swales, to represent inline ponds, and to represent inline or offline storage where reaches do not include floodplains. Stage -area relationships are necessary in relatively flat models where flood waters may overflow the channel banks and fill low-lying areas. An accounting of the volume of these areas is needed for both accurate flood elevation predictions as well as peak flow estimates.

3.3.4 Conduits

The following data was incorporated in SWMM to characterize conduits (channel, pipes, and bridges): local losses, Manning’s n value, length, height, and width.

3.3.4.1 Culverts

For circular and elliptical pipes, as well as rectangular box culverts, model input data includes surveyed depth, width (if non-circular), length and upstream and downstream inverts. Local loss coefficients are listed in **Tables 3-8** and **3-9**. Additionally, losses can be evaluated via commonly accepted methods, such as those published by Vennard and Street.

3.3.4.2 Natural Channels

Most of the natural channel (or irregular conduit) cross-sections to be modeled do not have topographic survey data, and these will be represented using LiDAR data where possible and augmented and confirmed as necessary with survey. In some locations survey will be required, as LiDAR does not penetrate the water surface. Due to the requirement of modeling the 500-yr storm, it is necessary to augment the surveyed cross-sections (where available) with floodplain elevations from the LiDAR topography. As the top of bank is reached during extreme events, SWMM treats irregular cross-sections as a closed conduit and the cross-sectional area becomes limited at this elevation. For the more intense storms, flood water is simulated to the top of the bank for many of the cross-sections and flows over floodplains. These floodplains will be added to the stream reaches in the model by augmenting the measured survey, while the significant storage that then was represented in each reach must be removed from the stage-area relationship in the adjacent storage junctions, where applicable.

3.3.4.3 Bridges and Roadway Overflows

Bridges are irregular cross-sections that are unique in that if flood stages rise high enough, the cross-section is cut off by the bottom of the roadway (at the lower chord elevation) and the flow regime changes from an open channel with free water surface to a pressurized flow regime. In order to model bridges, the custom shape type conduit will be used in SWMM 5. A custom shape may be any closed conduit shape that can be characterized by depth versus width at multiple depths in the section. From this data a shape curve is used to represent the bridge in SWMM. To validate the use of shape curves for use in simulation of bridge hydraulics, testing and comparison of the SWMM shape curve methodology to the United States Army Corps of Engineers model HEC-RAS was performed.

Due to the high intensity of the design storms, many of the roads within DFWIA are expected to be flooded, especially for the 25, 100 and 500-yr storms. For the SDMP, the surveyed road crown elevations, where applicable, will be merged with the LiDAR data to provide a wider, deeper cross-section for flow, in the same manner as channel cross-sections.

Table 3-8. Entrance Loss Coefficients

Type of Structure and Design of Entrance	Coefficient K_{ent}
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. Cut end	0.5
Headwall or headwall and wingwalls	
▪ Socket end of pipe (groove-end)	0.2
▪ Square-edge	0.5
▪ Rounded (radius - 1/12 D)	0.2
Mitered to conform to fill slope	0.7
End-Section conforming to fill slope	0.5
Beveled edges, 33.7 or 45 bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
End-Section conforming to fill slope	0.5
Beveled edges, 33.7 or 45 bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
▪ Square-edged on 3 edges	0.5
▪ Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides	0.2
Wingwalls at 30 to 75 to barrel	
▪ Square-edged at crown	0.4
▪ Crown edge rounded to radius of 1/12 barrel dimension, or beveled top edge	0.2
Wingwall at 10E to 25 to barrel square edge at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side-or slope-tapered inlet	0.2

Table 3-9. Exit and In-Pipe Loss Coefficients

Description	K
Inlet to manhole	0.25
Manhole in straight section of closed conduit	0.10
Manhole at a 45 degree bend	0.25
Manhole at a 90 degree bend	0.50
Exit closed conduit to lake	1.00
Exit closed conduit to open channel	0.3-0.7

3.3.5 Boundary Conditions

Hydraulic boundary conditions are needed in order to accurately simulate peak stages and flows throughout the system. Existing FEMA models will be used to determine boundary conditions where available. In locations where FEMA information does not exist local stream gages will be used, and in cases where neither exist engineering judgement will be used to establish model boundary conditions.

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Section 4

Water Quality Evaluations

4.1 Introduction

The DFWIA SWMM hydrologic and hydraulic models can be used to evaluate water quality. This includes consideration of the following:

- Evaluation of existing surface runoff loadings from various land cover categories, focusing on total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS), although other parameters may be added as needed;
- Evaluation of existing watershed groundwater inflows and associated loads of TN, TP and TSS; and
- Evaluation of existing and proposed Best Management Practices (BMPs)/Stormwater Control Measures (SCMs).

4.2 Green Stormwater Infrastructure Runoff Volume Control Load Reduction

SWMM can explicitly model the effects of Green Stormwater Infrastructure (GSI) features including bioretention, porous pavement, infiltration trench, rain barrel and vegetative swale. The hydrologic processes associated with a GSI feature in SWMM are presented in **Figure 4-1**.

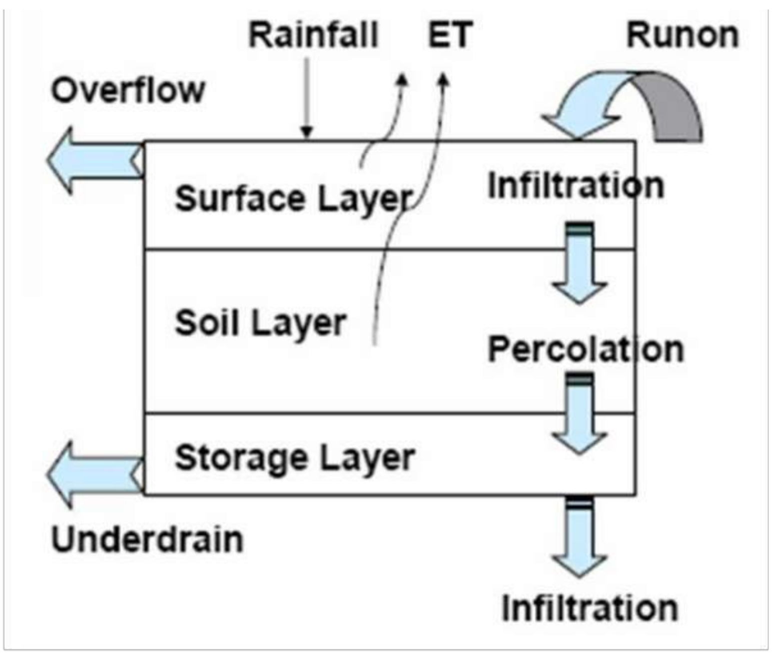


Figure 4-1. SWMM Representation of Green Stormwater Infrastructure Features

The SWMM program refers to these controls as Low Impact Development (LID) controls, for consistency in nomenclature this document will use the term GSI. Not all of the GSI features require all of the generic layers shown in the figure (e.g., pervious pavement would not have a soil layer; GSI feature may or may not have an underdrain). Using this explicit GSI modeling, runoff and associated pollutant load from adjacent impervious areas accumulate on the surface layer of the GSI feature, and the model will explicitly determine the fraction of water that is lost via infiltration and ET and what fraction will overflow to the subcatchment outlet. Use of these GSI features is recommended for the BMPs that are reducing pollution loads primarily through runoff capture and infiltration.

As an example, a conceptual bioretention facility can be defined in SWMM that includes a surface ponding layer of 6 inches, soil layer of 12 inches, and a stone storage layer of 6 inches. If the soil and storage layers are assumed to have 30% of the layers on average available to accept stormwater, then the overall storage in the conceptual bioretention facility is 6 + 30% * 18 inches = 11.4 inches. If the bioretention facility is designed to capture 0.5 inches of runoff from the impervious tributary area, then the area of the conceptual bioretention facility would be 0.5 / 11.4 * 100% = 4.4% of the impervious tributary area.

To apply the conceptual bioretention facility to a particular model subcatchment, the percent of the subcatchment impervious area that is treated by bioretention BMPs needs to be entered as a model input, and the subcatchment input needs to include the conceptual bioretention BMP with a surface area in this example that is 4.4% of the treated impervious area. SWMM will route the appropriate impervious area runoff to the conceptual bioretention facility, and the remaining impervious runoff will be routed as before (to the subcatchment outlet and/or to adjacent pervious area).

In other subcatchments with bioretention facilities, the same conceptual bioretention facility can be assigned. What would vary between subcatchments is the percentage of impervious area that is treated by bioretention, and the associated footprint of the conceptual bioretention facility (again 4.4% of the treated impervious area).

Pollutant reduction associated with the GSI feature is generally associated with the reduction in runoff volume from the subcatchment. Overflow from the GSI feature would have essentially the same concentration as the incoming runoff or water that has ponded in the feature. Previous experience with SWMM also indicates that, when an underdrain is simulated, the concentration of water passing through the underdrain may be zero or may be equal to the concentration of water in the GSI feature, depending upon whether or not there is inflow to the feature at the time. Water that infiltrates from the GSI feature will be added to the subsurface groundwater budget.

The performance of the modeled BMPs can be compared to literature values presented in sources such as the Texas Commission on Environmental Quality (TCEQ) surface water quality standards and the Virginia Runoff Reduction Method (VRRM) spreadsheet which evaluates compliance with State water quality criteria. Values included for some BMP types are presented in **Table 4-1**. The values for each BMP type include runoff reduction, treatment removal efficiency, and overall removal (accounting for both runoff reduction and treatment).

Table 4-1. Typical BMP Pollutant Removal Efficiencies for TP and TN

BMP Type	Runoff Reduction (%)	Treatment Efficiency (%)		Overall Reduction (%)	
		TP	TN	TP	TN
Vegetated Roof	45 - 60	0	0	45 - 60	45 – 60
Rooftop Disconnection	25 – 90	0 - 50	0 – 60	25 - 95	25 - 96
Permeable Pavement	45 - 75	25	25	59 - 81	59 – 81
Grass Channel	10 - 20	15	20	24 – 32	28 – 36
Dry Swale	40 - 60	20 - 40	25 – 35	52 - 76	55 – 74
Bioretention	40 - 80	25 - 50	40 – 60	55 - 90	64 – 92
Infiltration	50 - 90	25	15	63 - 93	58 – 92
Extended Detention Pond	0 - 15	15	10	15 - 28	10 - 24
Sheetflow to Filter/Open Space	50 - 75	0	0	50 - 75	50 – 75
Wet Swale	0	20 - 40	25 – 35	20 - 40	25 - 35
Filtering Practices	0	60 - 65	30 – 45	60 - 65	30 - 45
Constructed Wetlands	0	50 - 75	25 – 55	50 - 75	25 - 55
Wet Ponds	0	50 - 75	20 – 40	50 - 75	20 – 40
Manufactured Treatment Device	0	20	0	20	0

Notes:

1. Overall Reduction = Runoff Reduction + Treatment Efficiency * (100 – Runoff Reduction)/100
2. Source: Virginia Runoff Reduction Method spreadsheet.

For washoff treatment BMPs that are not explicitly modeled as part of the watershed hydraulic system, the removal efficiency values in **Table 4-2** are more applicable. As noted in the table, the load reduction for GSI will be proportional to the runoff reduction calculated by SWMM.

These features within SWMM will be applied as applicable to create developer guidance and evaluate the efficiency of BMPs throughout the airport.

Table 4-2. BMPs and Associated Removal Efficiencies for SWMM

BMP Type	Classification	Washoff Treatment Efficiency (%)			
		DP	PP	TSS	TN
Vegetated Roof	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Rooftop Disconnection	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Permeable Pavement	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Bioretention	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Infiltration	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Dry Swale	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Sheetflow to Filter/Open Space	LID - Runoff Reduction	Load reduction proportional to simulated runoff reduction			
Grass Channel	Washoff Treatment	20	35	25 [3]	30
Extended Detention Pond	Washoff Treatment	10	35	60 [2]	15
Wet Swale	Washoff Treatment	15	45	25 [3]	30
Filtering Practices	Washoff Treatment	55	70	85 [2]	40
Constructed Wetlands	Washoff Treatment	40	80	80 [2]	40
Wet Ponds	Washoff Treatment	40	80	80 [2]	30
Manufactured Treatment Device	Washoff Treatment	10	35	50 [4]	0

Notes:

1. Selected values for DP, PP and TN selected for consistency with Table 4.
2. Source: Chesapeake Bay Program, Best Management Practices for Sediment Control and Water Clarity Enhancement, October 2006.
3. Source: Geosyntec Consultants Inc. and Wright Water Engineers Inc., International Stormwater Best Management Practices (BMP) Database Pollutant Category Statistical Summary Report: Solids, Nutrients, and Metals, December 2014.
4. Source: Virginia DEQ, Stormwater Management Plan Review Course.

Section 5
FEMA Floodplain Models

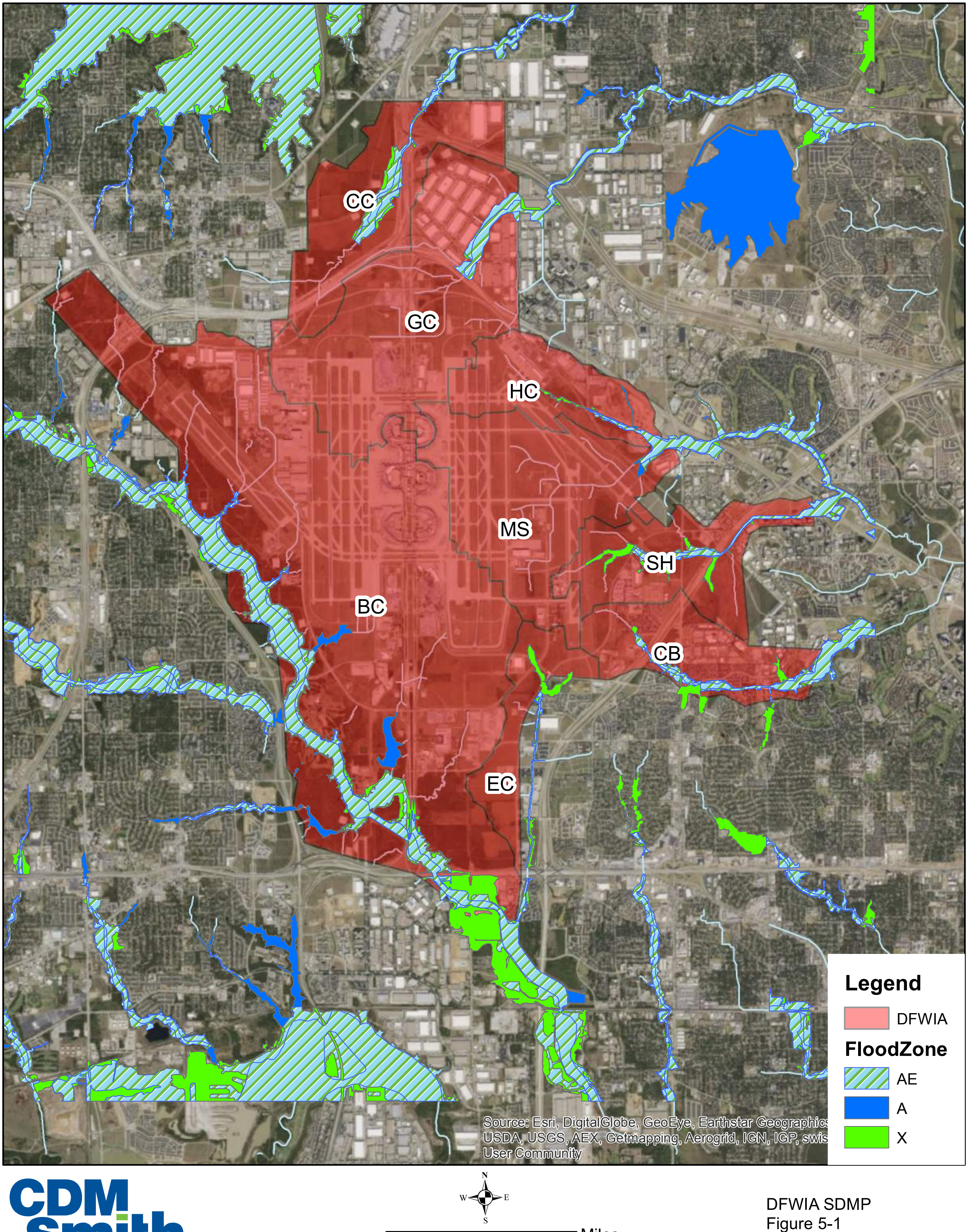
A number of the waterways within DFWIA have been modeled, and FEMA regulated floodplains have been developed as shown in **Figure 5-1**.

5.1 Use of Existing FEMA Models

Prior to initiating modeling of any watersheds the area should be checked to confirm the presence or absence of existing FEMA models. When FEMA models are present the modeler should review the model(s) and use relevant information to inform the development of the SWMM models of the area. After development of the SWMM model, results should be compared with the FEMA model(s). Discrepancies should be noted with respect to location and deviation, the validity of the discrepancies should be confirmed, and the differences documented.

5.2 Use of SWMM Models to Support FEMA Mapping

The EPA SWMM model is a FEMA approved platform for flood modeling and mapping. While the current SDMP effort does not include FEMA map development or modifications, the models will be developed to a level of detail where they can be used in the future to support FEMA related activities such as mapping, and the development of LOMRs/LOMAs/CLOMRs.



CDM Smith

DFWIA SDMP
Figure 5-1
FEMA Regulated Floodplain

Section 6

Stormwater Criteria and Level of Service

This report section summarizes the various stormwater quantity Level of Service (LOS) design criteria which may be applicable to DFWIA and presents recommended LOS criteria for the development of the DFWIA Stormwater Drainage Master Plan.

6.1 Stormwater Flood Control and Quantity Criteria

Multiple agencies and jurisdictions have developed criteria for flood control which may apply to DFWIA. These various criteria are summarized in the following sections. Section 2.1.4 presents the CDM Smith recommended criteria for the DFWIA SDMP, which is based on a comprehensive review of the various applicable criteria.

6.1.1 Federal Requirements and Regulations

This section presents a summary of the Federal water quantity criteria that apply to stormwater management at DFWIA.

6.1.1.1 Federal Aviation Administration (FAA)

The United States Department of Transportation Federal Aviation Administration (FAA) has developed an Advisory Circular, *AC 150/5320-5D, Airport Drainage Design, August 2013*, for the design and maintenance of airport surface drainage systems. This Advisory Circular combines existing surface drainage topics covered in different agency manuals into one Unified Facilities Criteria Surface Drainage Design document. The Advisory Circular establishes general concepts and procedures for the hydrologic design of surface structures. In the Circular FAA sets minimum standards; however, each facility may be designed to a higher standard as required by local and/or state regulations.

Surface Drainage Design

AC-150/5320-5D recommends different design storm frequencies for different airport facilities. For public-use airports like Love Field, the FAA recommends:

- A 5-year design storm with no encroachment of runoff on taxiway and runway pavement (including paved shoulders).
- For the 5-year storm a ponding limit of 4 inches around apron inlets.
- Areas other than airfields (landside) will normally be based on a 10-year design storm.
- The center 50% of runways, taxiways and helipad surfaces along the centerline should be free from ponding for the 10-year design storm.
- The design frequency for depressed pavement sections and underpasses is a 50-year storm.

- Storm durations for all cases are recommended to be 24-hour events unless local requirements are greater.
- Surface runoff from the selected design storm will be disposed of without damage to facilities, undue saturation of the subsoil, or significant interruption of normal traffic.

The use of a lesser frequency event, commonly the 100-year storm, to assess hazards at critical locations where water can pond to appreciable depths is referred to as a check storm.

Table 6-1 summarizes the design storm requirements of FAA.

Table 6-1. FAA Minimum Surface Drainage Standards

Facility Type	Design Storm Return Period	Design Storm Duration (hr)	Notes
Taxiway & Runway Pavement	5	24	No ponding encroaching on edge of pavement A ponding limit of 4-inches around apron inlets
Runway, Taxiway, & Helipad Centerlines	10	24	Center 50% free from ponding
Landside Areas	10	24	
Depressed pavement sections and underpasses	50	24	

For areas other than airfields and heliports, check the appropriate local regulatory agency for guidance on design storm requirements.

Other Design Criteria

- AC 150/5320-5D, also requires that conduits or channels greater than 96 square inches passing through or beneath security fences have security barriers.
- Traverse grade within the runway or taxiway safety area outside of the shoulders will be between 1.5 and 3 percent as required by *AC 150/5300-13 Airport Design.* Drainage ditched may not be located within the safety area. The first 200 feet of the runway safety area beyond the end of the runway the longitudinal grade will be between 0 and 3 percent, with a maximum of -5 percent thereafter.

Fog and Wildlife Attractant Land Uses

Aviation facilities have restrictions on surface storage of water due to the potential development of fog and attraction of wildlife, especially waterfowl. The FAA recommends a separation distance of 10,000 feet from wildlife attractants. The FAA circular, *AC 150/52000-33B, Hazardous Wildlife Attractants On or Near Airports, August 2007*, contains the land-use practices that potentially attract wildlife. The FAA also recommends a distance of 5 statute miles between the furthest edge of the airport operating area (AOA) and the wildlife attractant, if the attractant could cause hazardous wildlife movement into or across the approach, departure, or circling airspace.

6.1.1.2 Federal Emergency Management Agency (FEMA)

FEMA determines floodplain boundaries on the basis of hydrologic and hydraulic modeling. The US Army Corps of Engineers (USACE) and local communities support FEMA in the production of the Flood Insurance Rate Maps (FIRMs). The floodplain boundaries are presented on the FIRMs, and the area within the DFWIA boundaries is identified on the current FEMA issued Flood Insurance Rate Maps (FIRMs). The DFWIA is covered by multiple FIRMs, which can be accessed at the following website https://msc.fema.gov/portal/search#searchresultsanchor. As shown in **Figure 5-1** there are numerous areas within the DFWIA that are within the FEMA regulated floodplain, and are hence subject to FEMA regulations.

6.1.2 State Requirements and Regulations

6.1.2.1 Stormwater Discharges

Permitting of storm water discharges under the National Pollutant Discharge Elimination System (NPDES) has been delegated to the State of Texas since September 1998. A final version of the Texas Pollutant Discharge Elimination System (TPDES) Storm Water Multi-Sector General Permit TX R05000 was published on August 14, 2016. Air Transportation Facilities are included as part of Sector S under Activity Code 4581. Accordingly, the airport must comply with the Texas Commission on Environmental Quality (TCEQ) issued Texas Pollution Discharge Elimination System (TPDES) Municipal Storm Separate Sewer System (MS4) regulations and requirements of the TX R050000 Multi-Sector General Permit. This requires DFWIA to develop a stormwater management program that includes stormwater pollution prevention plans (SWPPPs), treatment or pollutant removal techniques, stormwater monitoring, and other stormwater quality controls.

6.1.3 Municipal Requirements and Regulations

DFWIA is surrounded by a number of cities that will be directly involved in stormwater management via either contributing to, or receiving flows from, the DFWIA stormwater management system. Cities directly affected include:

- City of Irving;
- City of Coppell;
- City of Grapevine;
- City of Euless, and
- City of Fort Worth.

Each of these municipalities has their own stormwater rules and regulations which should be consulted when establishing LOS in areas that are coincident to the municipality and DFWIA.

6.1.4 NCTCOG Regional Stormwater Regional Strategy

The North Central Texas Council of Governments (NCTCOG) has developed a regional program which provides guidance and a framework to develop and implement regional strategy to address water quality issues affecting the region. The goals of this regional program are to:

- Protect the health and welfare of citizens and the environment,
- Effectively address state and federal regulations,
- Share professional knowledge and experience, and
- Provide training to governmental staff and the development community.

The overall program, titled "Integrated Stormwater Management (iSWM)" provides four types of documentation, criteria, technical, tools and program guidance.

NCTCOG has developed iSWM to help cities implement more environmentally friendly approaches to storm water management. The program is intended to provide guidance for all development and redevelopment related to storm water activities. iSWM provides comprehensive guidelines for each project phase from planning through design, construction and maintenance. The City of Dallas has adopted the iSWM Criteria Manual for Site Development and Construction, as amended with local provisions on June 2010, for voluntary use in conjunction with the City of Dallas Drainage Design Manual (1993). iSWM stormwater quantity criteria highlights are summarized in this section.

The City of Dallas amended iSWM Criteria Manual recommends that a stormwater management system be designed for four storm events (listed in **Table 6-2**).

Table 6-2. Dallas iSWM Storm Events

Storm Event Name	Storm Even Focus	Storm Event Description
Water Quality	Remove pollutants in stormwater runoff to protect water quality	Criteria based on a volume of 1.5-inches of rainfall, not storm frequency
Streambank Protection	Regulate discharge from site to minimize downstream bank and channel erosion	1-year, 24-hour storm event
Conveyance	Control runoff within and from the site to minimize flood risk to people and properties for the conveyance as well as the 100-year storm	5-year, 24-hour storm event
Flood Mitigation		100-year, 24-hour storm event

A downstream assessment for 1-year, 5-year, and 100-year events is required to protect downstream properties, determine the extent of necessary improvements for streambank protection and flood mitigation. The downstream impacts have two focus areas, Streambank Protection and Flood Mitigation.

Once the analysis is complete, the following questions at each determined junction downstream must be answered to determine the necessity, type, and size of non-structural and structural controls to be placed on- site or downstream of the proposed development:

- Are the post-development discharges greater than the pre-development discharges?
- Are the post-development velocities greater than the pre-development velocities?
- Are the post-development velocities greater than the velocities allowed by the receiving systems?
- Are the post-development flood heights greater than the pre-development flood heights?

Should undesirable downstream impacts be found, iSWM states the general options available for the two Focus Areas. These are shown in **Table 6-3**.

Table 6-3. Dallas iSWM Storm Events

Design Focus Area	Design Options
Streambank Protection	Option 1: Reinforce/stabilize downstream conditions
	Option 2: Install stormwater controls to maintain or improve existing downstream protection
	Option 3: Provide on-site controlled release of the 1-year, 24-hour storm event over a period of 24 hours
Flood Mitigation and Conveyance	Flood Mitigation
	Option 1: Provide adequate downstream conveyance systems
	Option 2: Install stormwater controls on-site to maintain or improve existing downstream conditions
	Option 3: In lieu of a downstream assessment, maintain existing on-site runoff conditions
	Conveyance
	Minimize localized site flooding of streets, sidewalks, and properties by a combination of on-site stormwater controls and conveyance systems

Additional guidance, options and design criteria are also contained in iSWM which are intended to be used in tandem with local Drainage Design Manuals.

6.1.5 Recommended Stormwater Quantity Criteria

As noted in this section, DFWIA is subject to both federal and local requirements, as well as, existing and future conditions which must be considered in development criteria. The recommended Stormwater Quantity Criteria takes into consideration these variations. This section summarizes the recommended Stormwater Quantity Criteria which will be used in the foundation of alternatives for the DFWIA SDMP.

The water quantity (flooding and erosion) criteria standards presented in the preceding sections may be summarized by separating the property into airside and landside areas. Note that for all design storms, the NRCS (formerly SCS) Type II 24-hour hyetographs shall be used with storm frequency volumes as shown in Section 3.

General

The stormwater drainage system should safely collect, store, and convey the flow from the 100-year frequency flow. Various methods should be considered to accommodate these flows.

- Only dry detention or underground systems may be applied for the airport and the surrounding neighborhoods up to 10,000 feet from the airport boundary. No BMPs that may be considered wildlife or fog attractants are allowed within this range. The dry detention areas must be designed according to the iSWM parameters discussed in the previous sections.
- Future building construction or major renovations should be checked against and protected against the 100-year storm event.

For Airside Areas

- Taxiways, runways, and shoulders should not be encroached at all for the 5-year storm, while maintaining 50% from centerline clear from ponding for the 10-year storm.
- The 100 year 24 hour design storm will be checked versus runway and taxiway elevations to determine stages at runway-taxiway crown elevations.
- The maximum ponding at apron inlets should be 4 inches for the 5 year storm.
- Temporary storage of stormwater between runways, taxiways, and aprons should be considered.
- Traverse grade outside of runway-taxiway shoulders, not to exceed three (3) percent.

Landside Areas

- Hydraulic design should follow criteria and guidelines as presented in the iSWM Manual as edited.
- Future development/re-development should be required to evaluate and implement onsite measures that will be established as part of this SDMP and published in the developer guidance manual to reduce peak discharges to the DAL system.
- For the major roads (principal arterials), one lane of traffic in each direction should remain open for the 100-year storm, and the peak flood stage should be below the top of curb.
- For all other roads within the airport boundary, or immediately adjacent to it, peak flooding for the 100-year storm may not exceed 6-inches or the top of the curb, whichever is greater.

Offsite Areas

For all offsite areas, the criteria are established so as to “do no harm” downstream. Runoff at the airport must be collected, and attenuated so that peak stages do not increase for the neighboring areas, velocities do not create erosion problems, and water quality is maintained.

Summary

This section is not inclusive of all criteria that must be met, but is meant to be a summary guide for allowable flood levels versus design storms. The criteria that cover airside areas apply for existing as well as future conditions. Alternative designs will be presented as part of this SDMP to mitigate problem areas for which the criteria are not being met. The designs may apply to landside building flooding and road flooding as well, where applicable. The offsite area criteria cover future airport development, including the alternative designs for onsite mitigation.

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Appendix A

Hydrologic and Hydraulic Model QM Checklist

This spreadsheet includes a check list for the hydrologic and hydraulic (H/H) model applications for the DFWIA Stormwater Master Plan (SWMP). Add initials, dates and comments as completed.

Created: **03/15/88** MFS (CDM Smith)
Edited: **04/15/18** **MFS (CDM Smith) - Draft**

Step By Step Process and QM Checklist
Hydrologic and Hydraulic Models

Watershed: Example

Step	Item	Completed By	Date	Checked By	Date	Notes	Comments
1	Define H/H Model Levels of Detail	MFS	04/15/18	Someone Else	Enter	Define extent of PSMS based on problem areas, causes, floodplains, and growth areas where development/redevelopment criteria are needed.	The SWMM hydraulic model was extended to address a problem area that also affects the primary system.
2	Define Catchments	MFS	04/15/18	Someone Else	Enter	Delineate based on appropriate detail for problem and development/redevelopment areas; average 150 acres in District Service Area (into 300 acre LSSs in Service Area) and average 1,000 acres in upstream tributary areas	Average of X acres is generally met
3	Asset and Catchment Identification	MFS	04/15/18	Someone Else	Enter	DFWIA asset management codes, geodatabase	Alphanumeric codes are consistent with DFWIA standards
4	Rainfall Hyetographs and Evaporation	MFS	04/15/18	Someone Else	Enter	Historic storms and time periods for calibration, validation, and continuous simulation. Historic gage and radar rainfall data as appropriate for historic events. SCS Type II uniform distribution for design storms (1, 2, 5, 10, 25, 50, 100 and 500 yr 24 hr). Monthly evaporation for continuous simulation periods.	Three events were considered in the time period from 2002 through 2012. The _____ rain storm was used because it was a design magnitude events (ranged from a x to a y storm) for comparable land use and hydraulic conditions in the subwatershed. Rainfall data appear to be correctly entered into the model. Radar rainfall data were also used and were corrected =/- 5% based on nearest gage verification and refinement.
5	Define Hydrograph Load Points	MFS	04/15/18	Someone Else	Enter	Load points based on actual delivery of pipes and channels to model (inlets, sumps, channels, streams, wetlands, lakes and reservoirs). Discretize catchments and distribute load points as necessary to avoid artificial mounding and flow reversals.	Hydrograph loading appears appropriate to the X acre scales respectively. No artificial mounding observed.
6	Soils and Groundwater	MFS	04/15/18	Someone Else	Enter	Green-Ampt and Horton parameters (soil suction, soil storage, max and min infiltration rates, decay rate, regeneration rate for continuous simulation) for soil types (A, B, C, D) and a range of antecedent moisture conditions (AMCs). Use AMC II for design storms. As necessary, estimate depths to seasonal water table and baseflow by reach from NRCS (SCS) Soils Reports, District geotechnical data, and stakeholder data. Use at least 1 month start-up (spin-up) period for continuous simulation to bring soils into equilibrium with actual conditions. Use AMC I at the beginning of the start-up period to allow the soil parameters to achieve AMC I during dry periods.	AMC II was used
7	Land Uses & DCIAs	MFS	04/15/18	Someone Else	Enter	Aerial photogrammetry, impervious test areas to refine estimates, future land use development/redevelopment build-out from ALP	Impervious area values and DCIA from _____.
8	Overland Flow Paths and Parameters	MFS	04/15/18	Someone Else	Enter	Use 3 to 5 paths to develop average area-weighted path and parameters for length, slope, Manning n roughness, and fraction of catchment each path represents; spreadsheet of parameters	Three paths averaged based on estimate of representative fraction of catchment. Manning n roughness will not be an area-weighted value by catchment but may be area-weighted by land use distribution
9	Time of Concentration (Tc)	MFS	04/15/18	Someone Else	Enter	For models that use Tc, it should be varied by design storm using the NRCS kinematic wave equation and varying rainfall accordingly.	Not used for this SWMM application
10	Model Schematic	MFS	04/15/18	Someone Else	Enter	To-scale on aerial or other planimetric base map, show watershed, subwatershed, catchments, conduits and junctions/nodes with identification numbers. Problem areas and floodplains should also be layers that can be added or removed as added.	Appropriate levels of detail for problems and development/redevelopment/ordinance guidance. Consistent with Mapping standards.
11	Define Time Steps	MFS	04/15/18	Someone Else	Enter	Generally will be less than 1 to 5 minutes for hydrologic model and 1 second or less for hydraulic model. A wet-dry time step may be used for the water quality continuous simulations	Hydrology at 1 minute, hydraulics at 0.1 seconds due to deep, short conduit at problem area location
12	Hydrologic Model/Layer (SWMM RUNOFF, HEC-HMS) Conduits	MFS	04/15/18	Someone Else	Enter	For SWMM, conduits will be in the hydraulic layer (EXTRAN) at whatever level of data is available for sections, shapes, lengths and inverts). Existing SWMM RUNOFF models from the RIDE program or from FEMA (e.g., HEC HMS) or other entity, hydrologic routing conduits may have used for delivery of water to the hydraulic model (HEC-RAS or EXTRAN network) in uniform flow reaches where the slope of the hydraulic grade line is relatively uniform. This model data may be used to extract information for the hydraulic network.	None in this model
13	Hydrologic Model Stage-Area	MFS	04/15/18	Someone Else	Enter	Stage-area-storage relationships in SWMM will be represented in the hydraulic layer (formerly called EXTRAN). This may be used to calculate initial abstractions in the hydrologic layer for conceptual representations of smaller scale and/or LSS SCMs. Use GIS to define from 2 ft contour DEM.	None in this model
14	Hydrologic Model WSELs	MFS	04/15/18	Someone Else	Enter	These may have been used in RIDE SWMM RUNOFF OR FEMA HEC HMS models for conceptual representations of smaller scale and/or LSS SCMs. This model data may be used to extract information for the hydraulic network.	None in this model
15	Hydrologic Model Boundary Conditions	MFS	04/15/18	Someone Else	Enter	May be used for conceptual representations of smaller scale and/or LSS SCMs	None in this model
16	Hydrologic Model Connectivity	MFS	04/15/18	Someone Else	Enter	Define and confirm connections for load points to the hydraulic model and hydrologic model conduits	Each load point matches a hydraulic model node
17	Hydrologic Model Results	MFS	04/15/18	Someone Else	Enter	Continuous simulation period of 1 to 3 years; 1, 2, 5, 10, 25, 50, 100 and 500 yr 24 hr design storms under existing and future land use conditions as appropriate); and the calibration and validation storms.	Checked and confirmed continuity (less than 0.1% error for all events) and generated hydrographs for continuous simulation and design storm conditions.
18	Hydraulic Model/Layer (SWMM EXTRAN, HEC-RAS) Channels	MFS	04/15/18	Someone Else	Enter	Irregular cross-sections from LiDAR, associated DEM, and survey (every ____ section on average). Check for absolute floodplain storage (check that the minimum section point, called GR values, in SWMM is between the elevations/inverts of the upstream and downstream junction points). Overbank n values should be based on field recon/photos and/or Chow Open Channel Hydraulics (1959). Road overflows should be represented as parallel surface flow channels with a raised invert for the road overflow elevation.	Confirmed splicing of survey for every fourth section into the 2 ft contour and (from LiDAR). Noted variations as appropriate for spot elevation confirmation survey
19	Hydraulic Model Pipes	MFS	04/15/18	Someone Else	Enter	Transportation Crossings (culverts and bridges), Culverted Streams; Model as realistic as possible (actual vs. equivalent shapes, sizes and lengths). The pipe representation should reflect appropriate roughness coefficient, entrance and exit losses, and internal local losses if necessary	Combined survey and stakeholder data (ODOT, County A, City B)
20	Hydraulic Model Junctions/Nodes	MFS	04/15/18	Someone Else	Enter	Connecting conduit and explicit storage for floodplain storage beyond stream channel representations, detention basins, SCMs/BMPs. The modeler should check the maximum and minimum values for connected conduits to confirm that flood stages are maintained within the model network.	Use_____ database
21	Hydraulic Model Inverts	MFS	04/15/18	Someone Else	Enter	Inverts in North American Vertical Datum (NAVD) 1988 or invert offsets (ZPs in EXTRAN)	Confirmed or modified all datum to NAVD 1988
22	Hydraulic Model Stage-Area	MFS	04/15/18	Someone Else	Enter	Separate storage from channel and pipe storage. Explicit representation of major detention basin SCMs/BMPs, dams-reservoirs, and other floodplain storage not included in channel cross-sections from LiDAR, associated DEM, and survey. Check vs. FEMA DFIRMs for changes/differences.	Confirmed absolute floodplain storage (appropriate depth of floodplain to incised channel - not biased by a minimum cross-section survey point at a relative channel "hump" or "hole"). Two small tributaries were added as stage-area at nodes x and Y
23	Hydraulic Model Initial Water Surface Elevations (WSELs)	MFS	04/15/18	Someone Else	Enter	Base flows and lake NWLs from USGS records, reservoir operations records and other surveys. The modeler can use a "hot start" file for start-up periods or to establish initial flows for a given storm.	AMC III conditions
24	Hydraulic Model Boundary Conditions	MFS	04/15/18	Someone Else	Enter	FEMA FIS, sensitivity analyses, USGS gages, consider time-variability; As appropriate use existing FEMA HEC-RAS models in dynamic mode to estimate stage-time and identify relative differences in peak flows and stages.	Used USGS data and FEMA data to define a stage-time range. Tested sensitivity of the BC. Relatively insensitive after station X.
25	Indicator Road/Building Elevations	MFS	04/15/18	Someone Else	Enter	Elevations in Ft-NAVD 1988, low gutter, low road crown and low building evaluations by junction/node; Show in Flood Summary Tables for LOS comparison by design storm	Surveyed X locations to confirm numbers.
26	H/H Model Connectivity	MFS	04/15/18	Someone Else	Enter	Check versus model schematic	Connectivity is confirmed.

27	H/H Model Verification	MFS	04/15/18	Someone Else	Enter	Check input and output, continuity, connectivity, regression equation result comparisons. Note ranges of variation, potential reasons and refine to meet < +/- 1% continuity error in all models. In addition, the modeler should: - Check for and eliminate any node flooding (water loss from system) by refining node maximum depth, increasing size of open channel section, adding roadway or land surface overflow conduits; - Check for high velocities (>10 ft/s) that may reflect model instability; - Check model peak flows/stages increasing from upstream to downstream (otherwise may indicate instability); and - Use a GUI to view of stage/flow/velocity time series and also water surface profiles that may graphically depict oscillations and instability.	Continuity is maintained within tolerances for the combined H/H results.
28	Calibration	MFS	04/15/18	Someone Else	Enter	Use at least three rain gages with radar rainfall as appropriate. USGS gage stage-velocity-flow/time, HWMs, USGS Regression, and FEMA FIS comparisons. Modify parameters to match stage, then velocity if available, and then flow and volume. Watch for potential hysteresis (looped rating curve) in the gage data. Prepare tabular summaries of flood stage and HWM comparisons. Perform statistical evaluations for goodness-of-fit for continuous simulation periods (Nash-Sutcliffe, et al)	Chose event for calibration (dates and year). This ranged form approximately w to Z inches over the subwatershed for the three day period (approximately a 5 to 10 year design storm). Peak stages at two USGS stations and Y HWM locations were within +/- 0.5 ft which is within the tolerance.
29	Validation	MFS	04/15/18	Someone Else	Enter	Independent event; Use at least three rain gages with radar rainfall as appropriate; USGS gage comparisons, Stage/Flow/Velocity-Time, HWMs. Tabular summaries of flood stage and HWM comparisons. Statistical evaluations for goodness-of-fit for continuous simulation periods (Nash-Sutcliffe, et al). Do not modify parameters to match stage, velocity, or flows/volumes. Note reasons for differences and advise on potential model refinement.	Chose the January X, 200X event. Results match within tolerance. Validation acceptable. Proceed to production simulations.
30	Model Application	MFS	04/15/18	Someone Else	Enter	Apply model for the design storms and continuous simulation period. Compare velocity peaks, frequencies and durationsto define asset condition and potential problem areas for erosion (and associated structural concerns), sedimentation, and flooding. Apply model for design storms for existing and potential future lands use conditions as appropriate.	Erosion problem areas are generally consistent with noted erosion from field investigations.
31	Hydraulic Results - Condition Assessment Tables (Flooding and Erosion)	MFS	04/15/18	Someone Else	Enter	Report stages, velocities, flows for a continuous simulation period of 1 to 3 years along with the 1, 2, 5, 10, 25, 50, 100 and 500 yr 24 hr design storms using an NRCS Type II distribution under existing and future land use conditions as appropriate. Peak flood stage summary tables by junction/node for the 1 through 500 year events (flag locations where peak stage is above indicator evaluations). Appendix tables of peak flows and velocities by conduit for each design storm (flag velocities above 3 ft/sec and above 7 ft/sec).	Problem areas are generally consistent with FEMA floodplains, previous studies, and noted erosion from field investigations.
32	Hydraulic Results - Inundation Maps	MFS	04/15/18	Someone Else	Enter	Flood inundation maps for the 100 year storm (screen results with 5 and 25 year also)	Noted large differences in inundation form the 5 to the 25 year events at nodes T and U
33	Hydraulic Results - Flood Profiles	MFS	04/15/18	Someone Else	Enter	Flood profiles for the 2, 5, 10, 25, 50, 100 and 500 yr 24 hr design storms under existing and future land use conditions as appropriate.	Identified two reaches as bottlenecks
34	Alternative 1	MFS	04/15/18	Someone Else	Enter	Define components clearly for watershed, reach and problem or group of problems. Flood summary tables for 1 through 500 year events (flag locations where peak stage is still above indicator evaluations). Appendix tables of peak flows and velocities by conduit for each design storm (flag velocities that are still above 3 ft/sec and above 7 ft/sec).	Includes O&M enhancements (sediment removal, bank and slope regrading as noted). Tested floodplain storage protection (turned off for simulation to compare increases). Evaluated 0.25 inches of onsite retention.
35	Alternative 2	MFS	04/15/18	Someone Else	Enter	Alt 2 builds upon Alt 1. Define components clearly for subwatershed, reach and problem or group of problems. Flood summary tables for 1 through 500 year events (flag locations where peak stage is still above indicator evaluations). Appendix tables of peak flows and velocities by conduit for each design storm (flag velocities that are still above 3 ft/sec and above 7 ft/sec).	Alt 1 with floodplain storage protection recommended plus streambank stabilization and restoration coordinated with floodplain storage restoration as noted.
#REF!	Costing (Construction & O/M)	MFS	04/15/18	Someone Else	Enter	Coordinate model results with life cycle cost estimates (20 year design life - confirm); Discount rate (to be determined).	Estimated costs of flood damages and reductions.
#REF!	Recommended Alternative	MFS	04/15/18	Someone Else	Enter	Finalize recommended model for details and components at a conceptual design level of detail for plan, section, and profile views	Summary tables and figures for Alt Xare consistent the model representations.
#REF!	Model Documentation	MFS	04/15/18	Someone Else	Enter	Draft report sections as tasks are completed. At completion, finalize documentation for recommended models and write copies to CDs. Include details, quantities and locations in tables and figures as appropriate for project components at a conceptual design level of detail for plan, section, and profile views. Identify potential sequencing needs for projects and potential phases of larger projects as appropriate.	Summary report tables and figures for Alt X are consistent the model representations. Digital versions of Alts 1 through 4 are saved with recent updates and refinements include. Filenames are X.X
#REF!	**Additional Comments/Notes:** Add additional discussion as needed here.						

Appendix B

NOAA Atlas 14 Precipitation

NOAA Atlas 14, Volume 11, Version 2
Location name: Dallas, Texas, USA*
Latitude: 32.8892°, Longitude: -97.0411°
Elevation: 569.55 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.419 (0.317-0.553)	0.487 (0.373-0.639)	0.600 (0.457-0.789)	0.692 (0.519-0.921)	0.818 (0.594-1.12)	0.913 (0.646-1.28)	1.01 (0.695-1.45)	1.11 (0.744-1.63)	1.24 (0.806-1.88)	1.34 (0.849-2.09)
10-min	0.671 (0.508-0.886)	0.781 (0.597-1.02)	0.962 (0.733-1.26)	1.11 (0.833-1.48)	1.31 (0.955-1.80)	1.47 (1.04-2.06)	1.62 (1.12-2.33)	1.77 (1.19-2.61)	1.97 (1.28-3.00)	2.12 (1.34-3.30)
15-min	0.835 (0.632-1.10)	0.970 (0.743-1.27)	1.19 (0.910-1.57)	1.38 (1.03-1.83)	1.62 (1.18-2.22)	1.81 (1.28-2.54)	2.00 (1.38-2.87)	2.19 (1.47-3.23)	2.45 (1.59-3.73)	2.65 (1.68-4.12)
30-min	1.16 (0.877-1.53)	1.34 (1.03-1.76)	1.65 (1.26-2.17)	1.90 (1.43-2.53)	2.24 (1.62-3.06)	2.49 (1.76-3.49)	2.74 (1.89-3.95)	3.01 (2.03-4.44)	3.38 (2.20-5.14)	3.67 (2.32-5.71)
60-min	1.50 (1.14-1.99)	1.75 (1.34-2.29)	2.15 (1.64-2.83)	2.48 (1.86-3.31)	2.94 (2.13-4.01)	3.27 (2.31-4.58)	3.62 (2.50-5.20)	3.99 (2.68-5.87)	4.50 (2.92-6.84)	4.90 (3.10-7.62)
2-hr	1.84 (1.41-2.40)	2.16 (1.67-2.79)	2.68 (2.07-3.49)	3.12 (2.37-4.11)	3.73 (2.74-5.04)	4.20 (3.00-5.82)	4.69 (3.26-6.66)	5.22 (3.53-7.58)	5.95 (3.89-8.92)	6.53 (4.16-10.0)
3-hr	2.03 (1.57-2.64)	2.41 (1.87-3.09)	3.01 (2.33-3.89)	3.53 (2.69-4.61)	4.25 (3.13-5.70)	4.81 (3.45-6.61)	5.40 (3.77-7.61)	6.04 (4.11-8.70)	6.93 (4.55-10.3)	7.65 (4.88-11.6)
6-hr	2.40 (1.86-3.07)	2.87 (2.24-3.62)	3.61 (2.82-4.60)	4.25 (3.28-5.49)	5.16 (3.84-6.84)	5.88 (4.26-7.99)	6.65 (4.68-9.24)	7.48 (5.12-10.6)	8.64 (5.70-12.7)	9.57 (6.15-14.3)
12-hr	2.81 (2.21-3.56)	3.37 (2.66-4.20)	4.26 (3.37-5.36)	5.02 (3.91-6.42)	6.11 (4.60-8.00)	6.98 (5.09-9.35)	7.89 (5.60-10.8)	8.88 (6.13-12.5)	10.3 (6.84-14.9)	11.4 (7.38-16.9)
24-hr	3.27 (2.60-4.10)	3.93 (3.14-4.85)	4.97 (3.97-6.19)	5.87 (4.62-7.40)	7.14 (5.42-9.23)	8.15 (6.00-10.8)	9.21 (6.59-12.5)	10.4 (7.21-14.4)	12.0 (8.04-17.1)	13.4 (8.68-19.4)
2-day	3.80 (3.06-4.71)	4.57 (3.68-5.56)	5.76 (4.65-7.08)	6.79 (5.40-8.47)	8.26 (6.33-10.5)	9.42 (7.00-12.3)	10.7 (7.69-14.2)	12.0 (8.41-16.4)	13.9 (9.38-19.6)	15.5 (10.1-22.2)
3-day	4.15 (3.36-5.10)	4.98 (4.04-6.02)	6.28 (5.10-7.66)	7.40 (5.92-9.15)	8.99 (6.93-11.4)	10.3 (7.66-13.3)	11.6 (8.41-15.4)	13.1 (9.20-17.7)	15.2 (10.3-21.1)	16.9 (11.1-23.9)
4-day	4.40 (3.57-5.38)	5.28 (4.30-6.34)	6.65 (5.43-8.08)	7.84 (6.30-9.65)	9.54 (7.38-12.0)	10.9 (8.16-14.0)	12.3 (8.96-16.2)	13.9 (9.81-18.7)	16.1 (10.9-22.3)	17.9 (11.8-25.3)
7-day	4.93 (4.04-5.96)	5.91 (4.85-7.03)	7.44 (6.13-8.94)	8.77 (7.12-10.7)	10.7 (8.35-13.3)	12.2 (9.25-15.6)	13.9 (10.2-18.1)	15.7 (11.1-20.8)	18.2 (12.4-24.9)	20.3 (13.4-28.3)
10-day	5.38 (4.43-6.47)	6.44 (5.33-7.61)	8.10 (6.71-9.67)	9.54 (7.78-11.6)	11.6 (9.11-14.4)	13.3 (10.1-16.8)	15.0 (11.1-19.4)	17.0 (12.1-22.4)	19.7 (13.5-26.7)	21.9 (14.5-30.3)
20-day	6.93 (5.77-8.23)	8.15 (6.85-9.57)	10.1 (8.48-11.9)	11.8 (9.69-14.1)	14.1 (11.1-17.2)	15.9 (12.1-19.8)	17.8 (13.2-22.6)	19.9 (14.3-25.8)	22.9 (15.8-30.5)	25.3 (16.9-34.4)
30-day	8.23 (6.91-9.70)	9.58 (8.13-11.2)	11.8 (9.97-13.8)	13.6 (11.3-16.2)	16.2 (12.8-19.6)	18.1 (13.9-22.3)	20.1 (15.0-25.4)	22.3 (16.1-28.8)	25.5 (17.6-33.7)	28.1 (18.8-37.8)
45-day	10.1 (8.50-11.8)	11.7 (9.97-13.6)	14.3 (12.2-16.7)	16.5 (13.8-19.4)	19.5 (15.6-23.5)	21.8 (16.9-26.8)	24.2 (18.1-30.3)	26.7 (19.4-34.2)	30.2 (21.0-39.6)	33.0 (22.2-44.0)
60-day	11.7 (9.93-13.6)	13.6 (11.6-15.7)	16.6 (14.2-19.2)	19.1 (16.1-22.4)	22.7 (18.3-27.1)	25.4 (19.8-31.0)	28.2 (21.2-35.1)	31.0 (22.5-39.3)	34.8 (24.2-45.2)	37.6 (25.4-49.9)

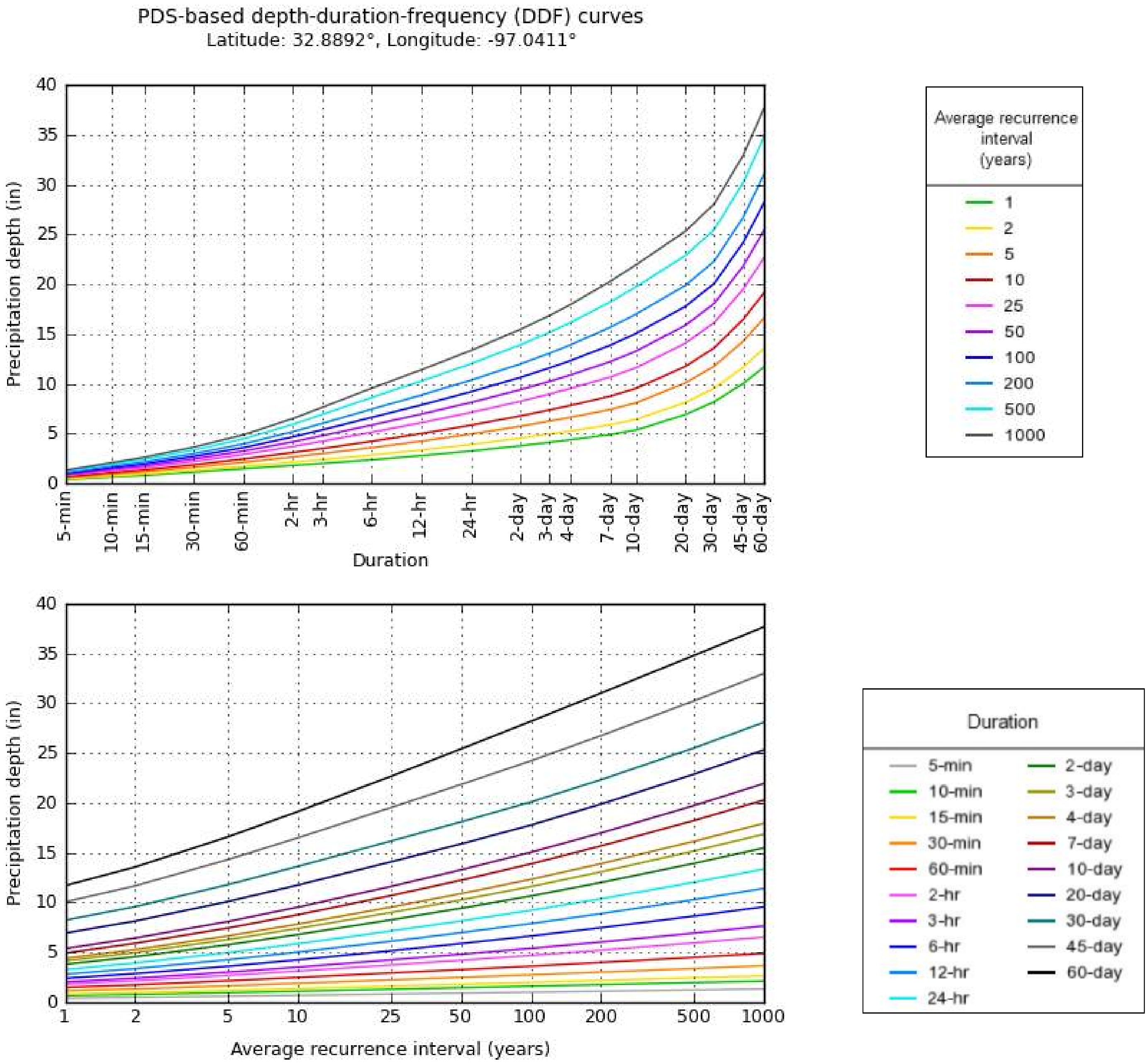
[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Back to Top

PF graphical



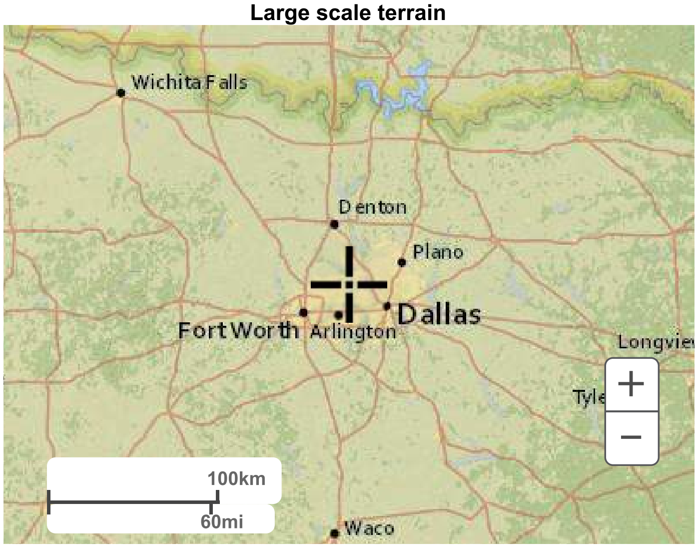
NOAA Atlas 14, Volume 11, Version 2 Created (GMT): Thu Oct 4 19:01:10 2018

Back to Top

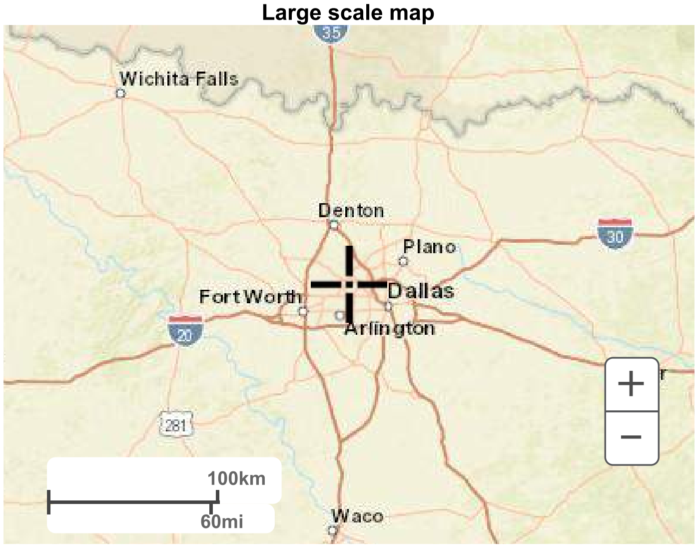
Maps & aerials

Small scale terrain

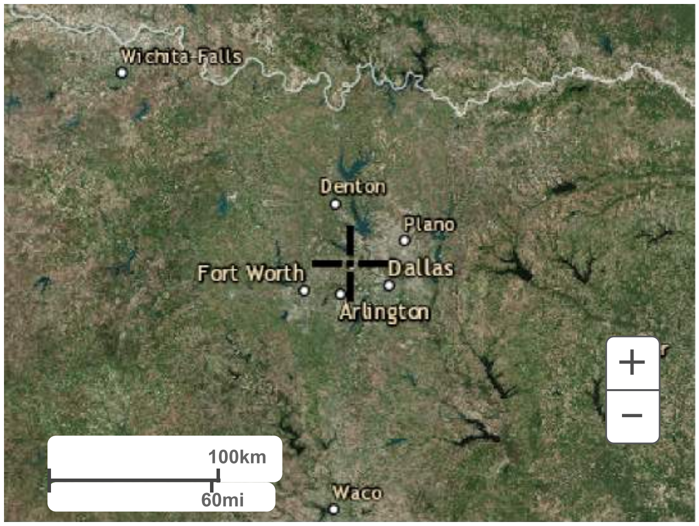
Large scale terrain



Large scale map



Large scale aerial



Back to Top

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National Oceanic and Atmospheric Administration
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

Disclaimer


DFW
DALLAS
FORT WORTH
INTERNATIONAL
AIRPORT

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Appendix F

Climate Change Assessment Report

CLIMATE CHANGE ASSESSMENT

STATE OF TEXAS
ROBERT P. ARMSTRONG
87107
LICENSED
PROFESSIONAL ENGINEER

06-03-2020

Huitt-Zollars, Inc.
Firm Registration No. F-761

DFW DALLAS FORT WORTH INTERNATIONAL AIRPORT

June 3, 2020

HUITT-ZOLLARS

in association with

CDM Smith

Table of Contents

Figures

Tables

Appendices

Executive Summary

Dallas Fort Worth International Airport (DFWIA) is committed to pursuing resiliency in the face of global climate change. The foundation of this pursuit is to develop an understanding of the best available science regarding anticipated impacts to climate in the DFW area. The Transportation Research Board's (TRB) Airport Cooperative Research Program (ACRP) Report 147: Climate Change Adaptation Planning: Risk Assessment for Airports (ACROS 147 Report) provides guidance to understand the impacts climate change may have upon specific airports.

The ACROS 147 Report provides valuable insight on the risks to DFWIA that may result from the anticipated changes in climate. With respect to temperature, the average number of hot days and humid days per year are expected to significantly increase. These increases are expected to adversely survivability of vegetation that is used in Green Stormwater Infrastructure and to help resist erosion. To adapt to the expected temperature increases, the use of drought-tolerant vegetation should maximized in all stormwater BMP designs.

While impacts resulting from increased temperature are clear, potential impacts to precipitation and design rainfall depths are significantly less certain. The ACROS tool precipitation projection shows no significant trend at DFWIA from climate change.

The many Global Climate Models (GCMs) utilized in the U.S. National Climate Assessment show agreement that temperatures are expected to increase as a result of climate change. However, the models reveal significant uncertainty in the impact that the increased temperatures may have upon precipitation in Texas, with more than 50% of the models showing no statistically significant change in the number of days of extreme rainfall (rainfall exceeding 1" in 24-hours) per year in Texas.

Regardless of the uncertainty in GCM predictions as it relates to precipitation, the United States Environmental Protection Agency (US EPA) has developed a tool that allows users to estimate future rainfall probabilities by averaging the results of the various GCMs. This tool is available within the US EPA Storm Water Management Model (SWMM).

An alternative method for providing resiliency against extreme rainfall events is to utilize the new NOAA Atlas 14 upper-bound 90% confidence limit rainfall depth at DFWIA as design criterion for critical airport infrastructure. While this method does not explicitly incorporate climate change predictions, it facilitates resiliency against extreme events via proven statistical methods to reduce uncertainty in our design storm estimates. The upper 90% confidence limit for the 24-hour, 1% annual exceedance probability (AEP) event is 12.5 inches. For comparison, the NOAA Atlas 14 rainfall design depth for the 24-hour 1% AEP event is 9.2 inches. We recommend the use of the 90% upper confidence design rainfall amount of 12.5 inches over 24 hours as design criterion for the airport's critical infrastructure.

1 Introduction

Dallas Fort Worth International Airport (DFWIA) is committed to pursuing resiliency in the face of global climate change. The foundation to this pursuit is to develop an understanding of the best available science regarding anticipated impacts to climate in the DFW area. The Transportation Research Board's (TRB) Airport Cooperative Research Program (ACRP) Report 147: Climate Change Adaptation Planning: Risk Assessment for Airports (ACROS 147 Report) provides guidance to understand the impacts climate change may have on specific airports. The focus of this review is to provide an understanding and assessment of potential risk to the DFWIA stormwater system with regards to anticipated changes to the region's climate.

2 ACROS Tool

2.1 Purpose

The TRB developed a tool for users to obtain information regarding climate change risk at specific airport locations in an effort to "communicate climate projections and provide the knowledge base needed to begin climate adaptation activities". This tool provides information on several potential climate change vectors (defined in Section 2.2) and impacts and also assesses the risk associated with climate change and provides adaptation options to mitigate these impacts. The tool assesses risk associated with a variety of climate stressors from temperature and precipitation that could affect post-disaster recovery as well as present opportunities to become resilient. Results are provided for both the years 2030 and 2060.

2.2 Definitions

Risk for each airport service is categorized as low, medium, or high. The results of the ACROS tool compile possible risks after assessing two critical parameters: criticality and vulnerability.

$$Risk = (Criticality)\ x\ (Vulnerability)\ x\ (Climate\ Vector\ \Delta)$$

Criticality is defined as the importance of an asset or operation to the overall functionality of the airport in terms of service, public health, reputation, restoration cost and regulatory impacts. Criticality is divided into three categories:

1- Loss of asset/operation would have negligible impact on the airport.
2- Loss of the asset/operation would hamper airport function.
3- Loss of asset/operation would significantly impair or shut down the airport until repair, replacements, etc., were secured

The tool also considers airport asset vulnerability, including infrastructure life cycle or known weaknesses. Vulnerability is defined as the sensitivity of an asset or operation to a climate stressor. The tool defines 3 vulnerability levels:

1- Asset/operation is unlikely to be affected by this impact (climate stressors)
2- Asset/operation is likely to be impaired by this impact
3- Asset/operation is likely to be significantly impaired or disabled by impact

The climate vector is the change, in number of days, for each vector in the tool. It estimates the magnitude of shift towards more hazardous conditions.

Definitions for each climate vector are provided below:

Hot Days – a day with a temperature at or above 90° F, measured in days per year

Very Hot Days – a day with a high temperature at or above 100° F, measured in days per year

Freezing Days – a day with a high temperature at or below 32° F, measured in days per year

Frost Days – a day with a low temperature at or below 32° F, measured in days per year

Hot Nights – a night with a low temperature at or above 68° F, measured in nights per year

Humid Days – a day with an average dew point temperature above 65° F, measured in days per year. The dew point temperature is the temperature at which water vapor in the air condenses into dew.

Snow Days – a day with a snowfall accumulation more than 2 inches, measured in days per year

Storm Days – a day with a thunderstorm rainfall accumulation more than 0.15 inches that may include high wind events and hail, measured in days per year

Heavy Rain 1 Day – a day with a rainfall accumulation more than 0.8 inches, measured in days per year

Dry Days – a day with a rainfall accumulation less than 0.03 inches, measured in days per year

Cooling Days – a day with an average temperature at or above 68° F, measured in days per year

Heating Days – a day with an average temperature at or below 62° F, measured in days per year

Cooling Degree Day (CDD) – a unit of measure that reflects the energy demand needed to cool a building. The daily CDD is calculated by subtracting 65 from the day's average temperature. Daily CDDs are summed to obtain the accumulated CDD per year.

Heating Degree Day (HDD) – a unit of measure that reflects the energy demand needed to heat a building. The daily HDD is calculated by subtracting the day's average temperature from 65. Daily HDDs are summed to obtain the accumulated HDD per year, and

Heavy Rain 5 Day – a measure of the maximum amount of rainfall that accumulates, in inches, over a five-day period

2.3 Input

The ACROS tool has a simple airport selection screen. The only item needed is the airport's three-letter FAA identifier and a climate information overview will be compiled with information on how to read the results of the airport chosen with data sources, units, level of confidence, and model ranges.

The tool utilizes daily data from a general circulation model or global climate model (GCM) output, which will be discussed later in this report. The tool adopts the Coupled Model Intercomparison Project Phase (CMIP5) data. The CMIP is a collaborative effort by climate modeling groups around the world to work under a standard framework designed to study and compare climate simulations made with various coupled climate models. A coupled climate model is the joining of individual global climate models (GCM's) that each focus on the ocean, atmosphere, cryosphere, or land. The coupled models transfer data between the individual GCM models. CMIP5 is the latest phase of this collaborative effort by climate modeling groups and is the data utilized by the United Nations in their latest Intergovernmental Panel on Climate Change (IPCC) report.

Each coupled model can be simulated with different scenarios for future emissions. The ARCOS tool uses the representative concentration pathway (RCP) 8.5 scenario. This scenario assumes little to no global mitigation of carbon dioxide emissions, giving a worst-case scenario look at climate change. The ACROS tool utilizes this scenario because it does not diverge from the other scenarios until after the period of interest for the tool (Year 2060).

2.4 Results

The following table summarizes the results from the ACROS tool for DFW Airport.

Table 1: Summary of ACROS Results for DFW

Vector	Unit	2013	Δ 2030	Δ 2060	Confidence Level
Hot Days	days/yr.	73	+13.9	+34.7	High
Very Hot Days	days/yr.	11.8	+13.8	+34.5	High
Freezing Days	days/yr.	1.5	-0.6	-1.1	High
Frost Days	days/yr.	26.6	-4.5	-11.1	High
Hot Nights	days/yr.	121.3	+13.5	+33.9	High
Humid Days	days/yr.	101.8	+13.7	+34.2	High
Snow Days	days/yr.	0.2	-0.1	-0.2	Moderate
Storm Days	days/yr.	51.8	-0.8	-2	Low
Heavy Rain 1 Day	days/yr.	9	+0	+0	Low
Dry Days	days/yr.	24.9	+0.8	+2	Moderate
Cooling Days	days/yr.	220.2	+11.1	+27.6	High
Heating Days	days/yr.	102.6	-10.1	-25.3	High
Cooling Degree Day	yearly accumulation	1548.8	+249	+622.4	High
Heating Degree Day	yearly accumulation	1162.4	-124.8	-311.9	High
Heavy Rain 5 Day	inches	3.5	+0	+0	Low

There is significant change predicted at a high confidence level that temperatures will increase at DFW airport. However, there is little to no predicted change to precipitation at DFW as a result of climate change. As noted in Table 1, there is no expectation for a change in the “Heavy Rain 1 Day” category (more than 0.8 inches per day) at DFW airport. The ACROS tool makes no prediction regarding potential changes to the intensity of precipitation within a rainfall event.

2.4.1 Impacts & Adaptation Options

The most impactful climate vectors to the DFW airport determined by ACROS were hot days, very hot days, hot nights, humid days, and Cooling Degree Days.

Table 2 lists impacts, criticality and vulnerability assessments, and adaptations that are associated with drainage-related risks due to climate change per the ACROS tool. These impacts are rated by the tool as being a low risk for the airport.

Table 2: Impacts & Adaptations

Impact	Criticality	Vulnerability	Adaptation Option
Drier Soils lead to reduced vegetation and increased erosion	2	1	• Improvements to BMP resiliency • Replace vegetation with drought-resistant vegetation or structural BMP’s
Difficulties Re-establishing vegetation	2	1	• Use appropriate wildlife and landscape management techniques

2.4.2 Risk Summary

The results from the ACROS tool demonstrate a trend toward a hotter climate while precipitation projections showed no significant trend. The hotter temperatures are expected to place stress on the vegetation components of Green Stormwater Infrastucture (GSI) and upon vegetation that is relied upon to prevent erosion. DFW Airport should plan on increased difficulty establishing and maintaining vegetation due to the anticipated additional heat. In order to adapt to the increased heat, selection of drought-resistant vegetation and more robust means to establish vegetation will be an important aspect of landscape management. More specific impacts and adaptations to assets can be found in the ACROS report, which can be found in Appendix A.

3 Global Climate Model (GCM) Rainfall Uncertainty

3.1 Introduction

The ACROS tool is beneficial for its focused assessment of potential climate change impacts to airport operations and assets. A review of the science used to provide input to the tool helps to explain the general lack of specificity regarding potential impacts to extreme precipitation that may result from climate change. This section of the report discusses GCM results and the inherent uncertainty associated with those results in more detail.

3.2 GCM Background

A global climate model, also known more specifically as a general circulation model, is a tool used to simulate responses of the global climate system to increases in greenhouse gas emissions. GCMs simulate climate in a 3-dimensional grid, using equations to depict interactions between ocean, atmosphere, cryosphere, and land.

These global climate models were developed to be used as a regional tool to understand trends, if any, in climate in the near and long-term future. The results from the climate models can be seen as a large-scale planning tool to prepare for changing conditions due to climate. These results lose accuracy as you try to pinpoint a single location as they have a resolution of about 100 miles. There are methods to statistically downscale the data to attempt to predict the change in conditions at a specific location, but they are using low-resolution outputs to produce higher-resolution results, which leads to a high degree of uncertainty.

Different emissions scenarios were developed based on narrative storylines of different levels of development and adoption of climate initiatives. For the NOAA reports discussed in this memorandum, the A2 and B1 emissions scenarios were used, which both assume an increase in CO_2 emissions over time. The A2 emissions scenario is the primary basis for the high climate future used by the IPCC in their assessment of climate change. The B1 emissions scenario is used by the IPCC to reflect a low climate change future. These scenarios were selected by NOAA because they incorporate a range of possible climate outcomes.

3.3 NOAA Reports

NOAA Technical Report National Environmental Satellite, Data, and Information Service (NESDIS) 142-4, released in January 2013, is one of a series of documents in the development of the National Climate Assessment. This report addresses climate trends and scenarios specifically for the Great Plains region of the US. The data was based on the Coupled Model Intercomparison Project Phase 3 (CMIP3) suite. For the report, statistically –downscaled data sets based on these models were also used.

NOAA Technical Report NESDIS 144 was released July 2015 comparing the CMIP Phase 5 results, released in 2014, with the CMIP3 climate models simulations that were previously used as the basis for climate scenarios. There were no major differences between the two models.

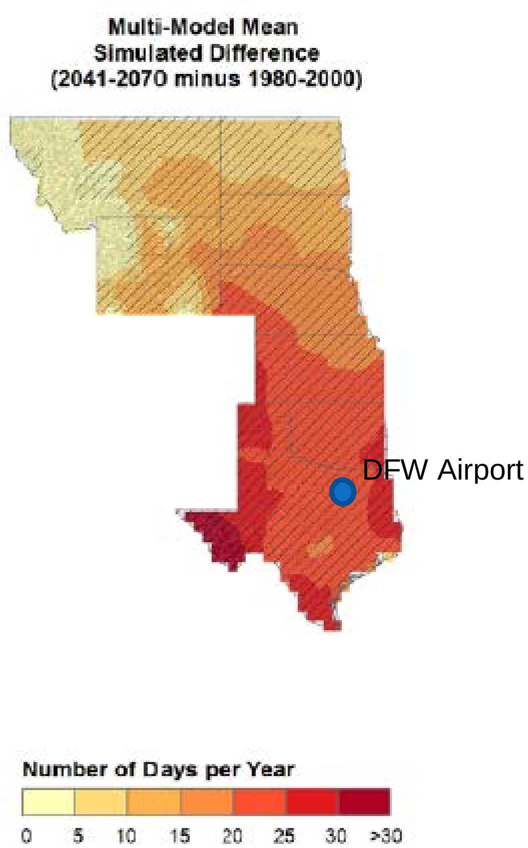
CMIP5 results and impacts are summarized in the Fourth National Climate Assessment Report *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* Results from CMIP6 are still in development.

The climate change results presented in this report are from the NESDIS 142-4 Report.

3.4 Impact to Temperature

For the southern Great Plains region, trends are statistically significant for showing an increase in temperature with a confidence level of 95%. There is an expected increase of about 0.14° F and 0.11° F per decade in winter and spring respectively in the Southern Great Plains region, resulting in an overall temperature increase of 0.09° F per decade. For the Southern Great Plains, results are not significant in summer and fall. The models also show an increase in the number of consecutive days over 95° of 12 days or more in Texas, with an expected increase in the total numbers of high temperature days as shown in Figure 1.

Figure 1: Annual Number of Days Tmax > 95°F

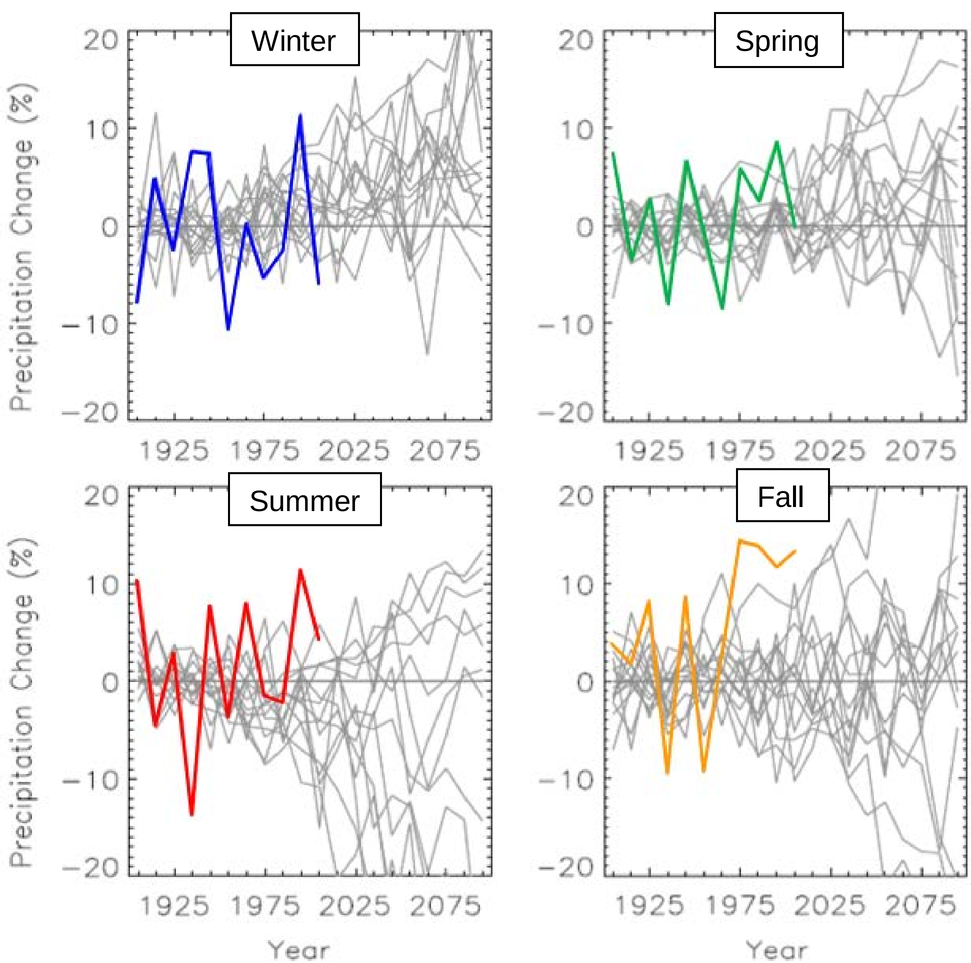


3.5 GCM Rainfall Estimate Uncertainty

3.5.1 Average Annual Precipitation

Precipitation trends for annual precipitation are not statistically significant for any season in the Great Plains. This means that there is no agreement between the various models as to what changes will occur in the future. Figure 2 shows historical data (in color) with the 15 climate models (shown in gray) referenced in NESDIS 142-4. As demonstrated in each of these figures, there is widespread disagreement among these 15 models as to what the impact of global warming will have upon rainfall in the Great Plains region, particularly in the spring and fall periods, which encompass a high percentage of the severe weather in Texas.

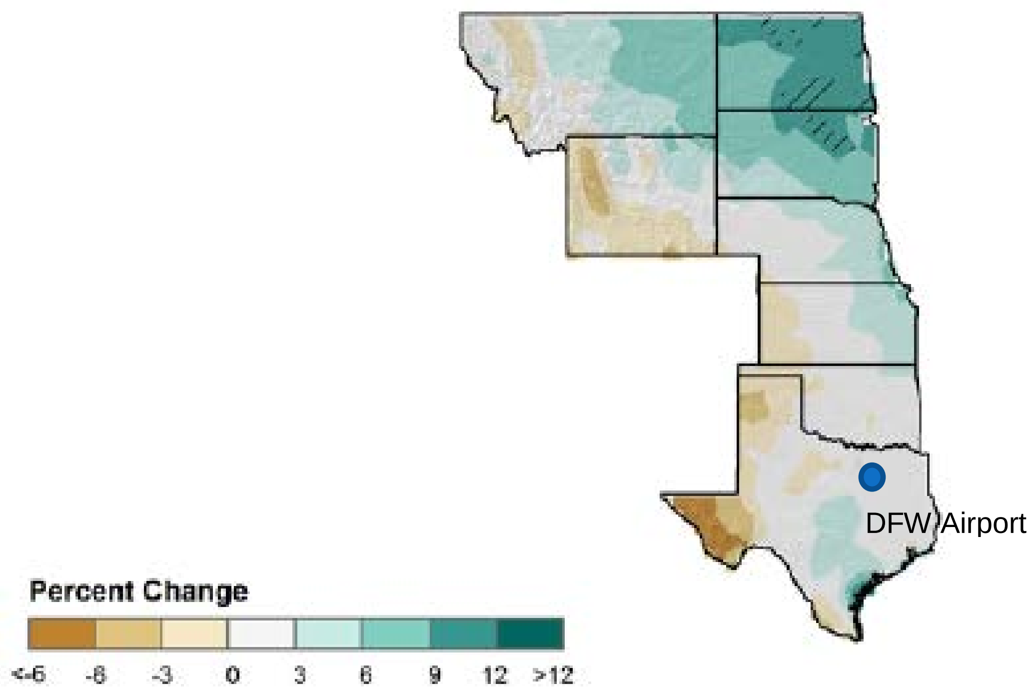
Figure 2: Historical vs. Predicted Change in Precipitation for Winter, Spring, Summer, & Fall*



*Historical local data are in color; GCM results in gray

In Figure 3, areas that are shaded, but not hatched, represent areas where less than 50% of the models show a statistically significant change in future precipitation relative to existing conditions. In other words, the projected change in precipitation in these areas could be random and not a result of climate change. Only areas with both color and hatching are representative of regions where more than 50% of the models indicate a statistically significant change AND where at least 67% of the models agree upon the direction of the change. As demonstrated in Figure 3, there are no locations in Texas where the models agree upon statistically significant annual precipitation changes in Texas.

Figure 3: Predicted Changes in Annual Mean Precipitation (From NESDIS 142-2, Figure 25)



3.5.2 "Extreme" Events

In climate modeling, "extreme" precipitation events are categorized as events "over 1 inch per day". Similar to the figure relaying changes in annual precipitation, the Figure 4 map of changes to "extreme" precipitation indicates that there are very few locations in the Great Plains region where more than 50% of the models predict a statistically significant change, and at least 67% of the models agree on the direction of change.

Figure 4: Annual Number of Days Precipitation > 1 inch (From NESDIS 142-2, Figure 28)

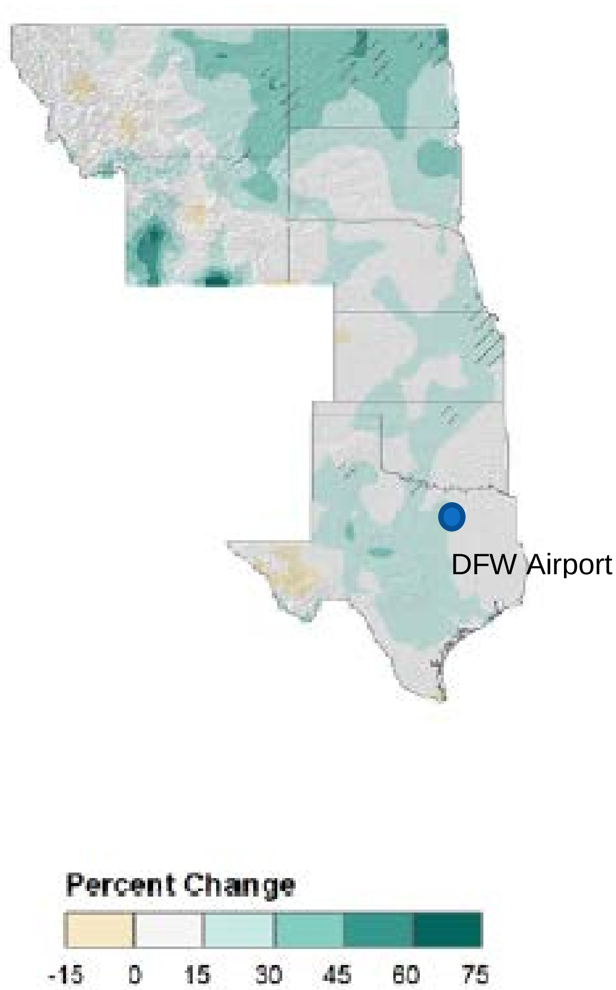


Figure 4 shows simulated difference in mean annual number of days with precipitation of greater than one inch. Color only indicates that less than 50% of the models show a statistically significant change in precipitation. Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days and more than 67% agree on the direction of the change.

3.6 Climate Science Uncertainty in Texas

All of the models used in the U.S. National Climate Assessment point to an increase in temperatures for North Texas. However, the models are in disagreement regarding what impact the changing climate will have on extreme rainfall events. Additionally, the models do not predict statistically significant changes to the frequency of extreme event precipitation.

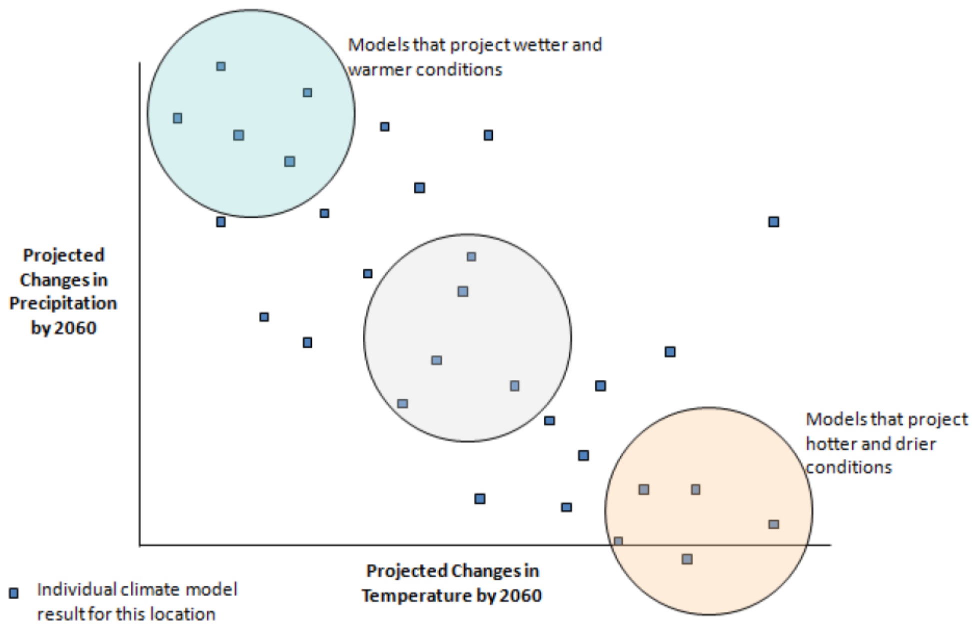
4 SWMM-CAT

The Storm Water Management Model Climate Adjustment Tool (SWMM-CAT) is an application for SWMM that allows for future climate change projections based on a set of location-specific adjustments derived from CMIP3. This tool utilizes the data described previously, regardless of the uncertainty inherent with the data.

Fifteen models were used to create three “middle of the road” averages to provide changes associated with climate change for the near term (2020-2049) and far term (2045-2074). Estimated revisions to annual exceedance probability rainfall depths as a result of climate change are provided per the methodology described below.

SWMM pulls its data from the US EPA Climate Resilience and Awareness Tool (CREAT), to determine changes in precipitation per degree of warming, referred to as a scalar, for different storm recurrence intervals. The CREAT tool takes scalar data that is compiled from each of the GCMs and ranks the scalar models based on the 5-year return interval rainfall depths. Then, averages are determined for 5 “warm and wet” models, 5 “moderate” models, and 5 “hot and dry” models. The selected models are then used to provide average scalars for changes in precipitation per degree of warming for return intervals relative to historical data under each of these scenarios. Figure 5 illustrates how a group of models are used to determine the average scalar to apply for each of the three future climate scenarios. The user can then determine which future climate scenario to use to assess anticipated climate impacts.

Figure 5: Illustration of Model Selection for Three Potential Climate Scenarios (From CREAT, Version 3.0 Methodology, Figure 5)



The potential changes in event magnitudes are calculated using the scalars to create a precipitation curve per future time period. This is calculated as follows:

$$Intense\ Precip(RI, Proj) = Intense\ Precip(RI, Hist) * \left(1 + \Delta Intense\ Precip(RI, Proj)\right),$$
$$\text{where } \Delta Intense\ Precip(RI, Proj) = Scalar(RI, Proj) * \Delta Temp(Proj)$$

And ΔTemp is the global mean temperature change from the same model.

Figures 6 and 7 display the predicted future 24-hour design storm depths for a range of recurrence intervals for the near-term (2020 - 2049) and far term (2045 – 2074) projections, respectively.

**Figure 6: SWMM-CAT Near Term Output for DFWIA (2020-2049)
(From NESDIS 142-2, Figure 28)**

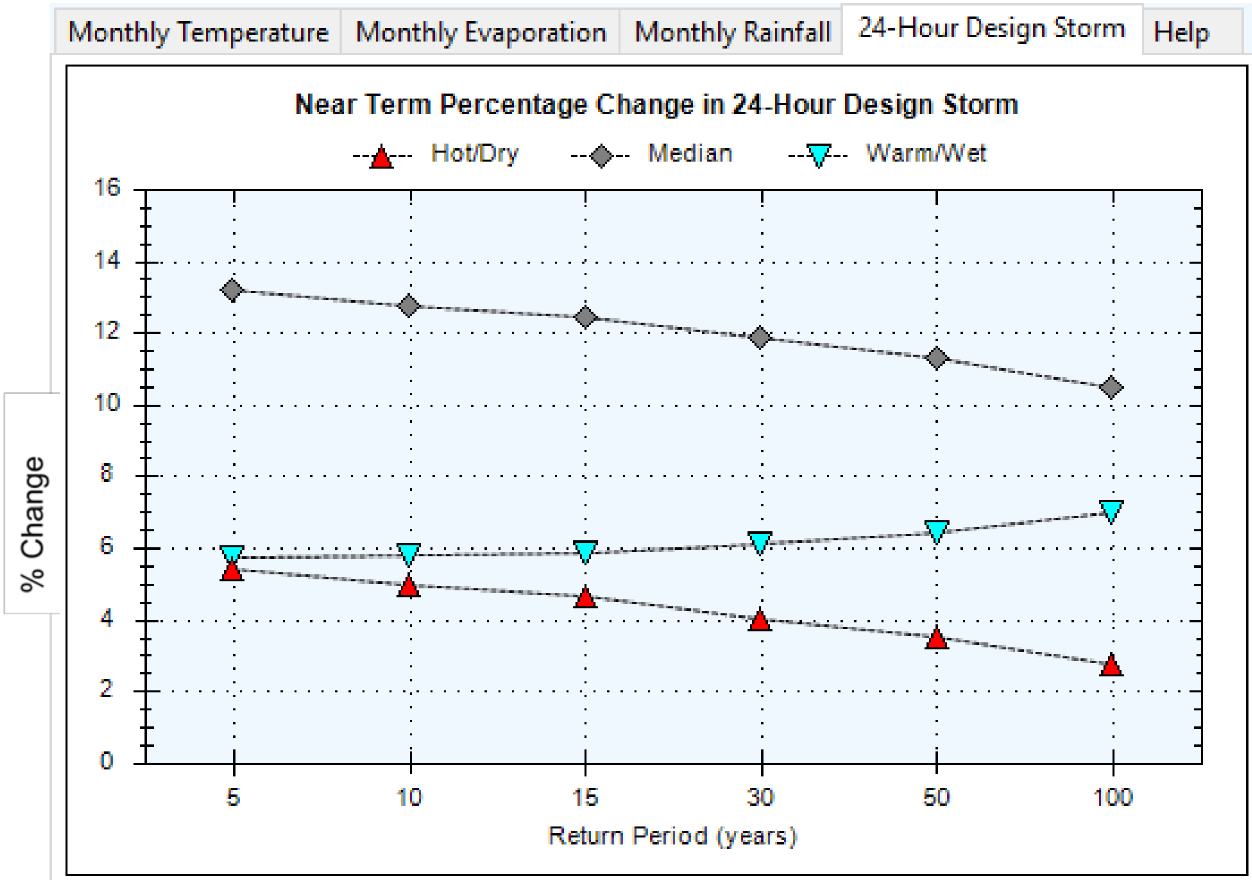
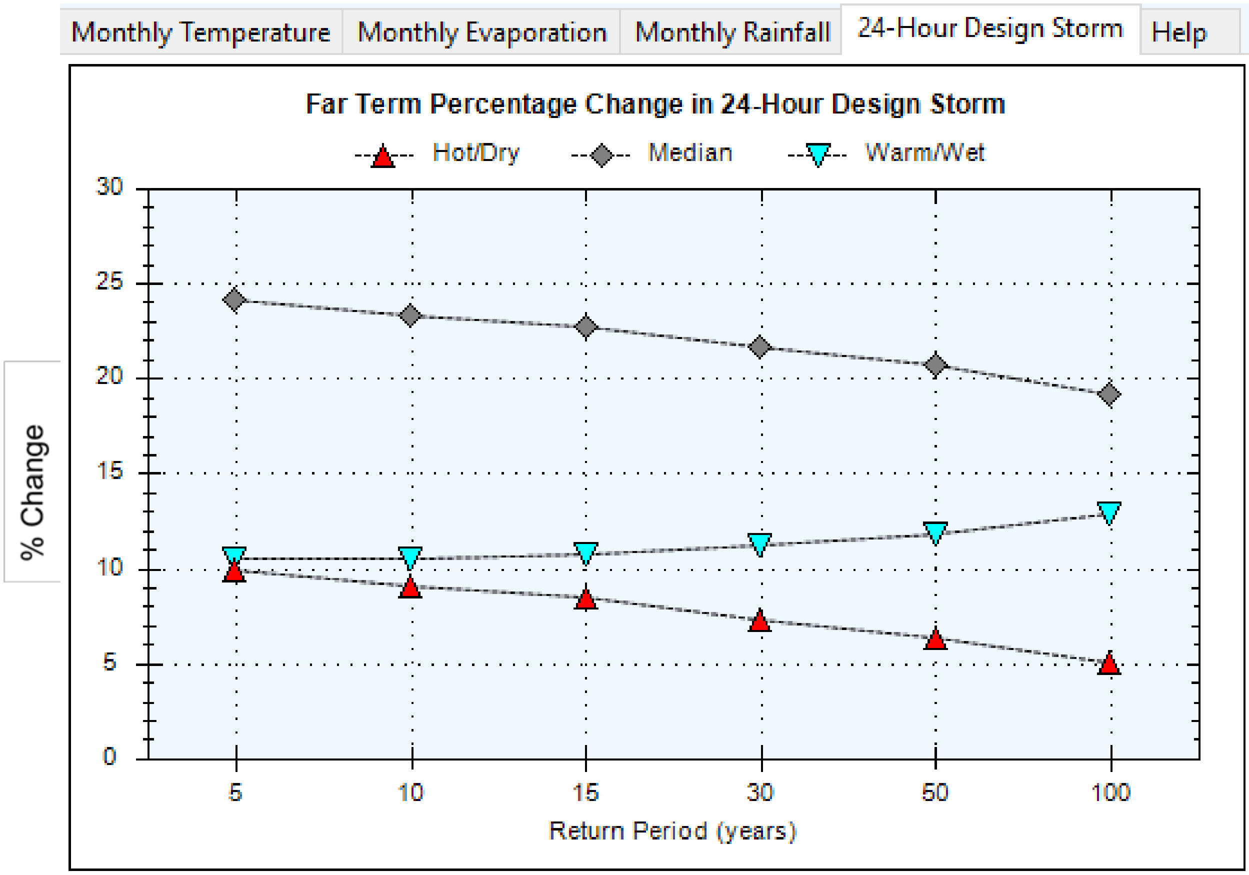


Figure 7: SWMM-CAT Far Term Output for DFWIA (2045-2074)
(From NESDIS 142-2, Figure 28)



If used, these percentages would be applied to the new NOAA Atlas 14 precipitation depths, because the tool does not develop the percentages relative to true historic data or previous estimates of historic probabilities. Rather, the tool estimates the percentage change relative to the models' estimates of historic exceedance probabilities.

The models are not able to accurately re-create or reliably predict numeric values for design rainfall depths; they were not developed for that purpose, but instead are used to provide information on regional climate trends and anticipated percent changes over time. Precipitation depth predictions based upon these datasets are therefore considered unreliable.

5 Precipitation Design Event Uncertainty

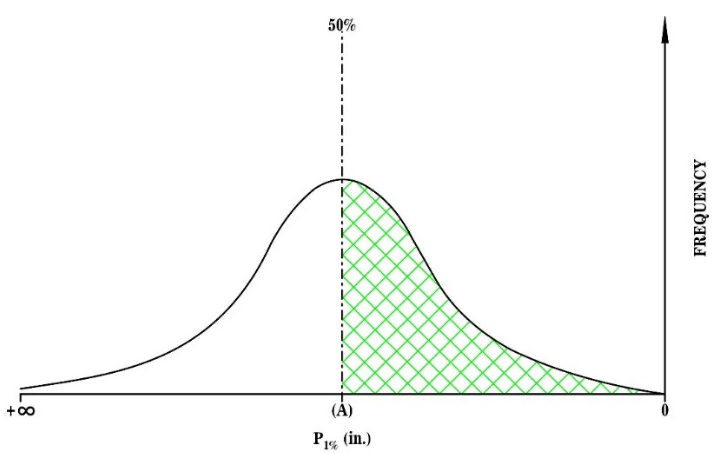
5.1 Sample Size

While there is significant uncertainty in our ability to predict how climate change may impact the probability of rainfall depths in the future, there is also uncertainty in our estimates of historic data. Understanding this uncertainty can aid our application of engineering judgment to the selection of design precipitation depths. Our level of confidence in exceedance probability estimates is impacted by the length of the historic record. Using a small sample size to estimate statistical parameters of a larger population produces a degree of uncertainty in our estimates. Analysis prepared by the USACE shows that it can take 300-400 years of record before we can be confident in our 1% AEP estimates. However, we do not presently have hundreds of years of rainfall records, so we need to understand that there is a degree of uncertainty in our rainfall design storm estimates. Fortunately, there are statistical methods that allow us to quantify that uncertainty. Higher rainfall amounts and intensities can be tested for sensitivity on flood stages, velocities, and flows. It should be noted that the following discussion of uncertainty assumes stationarity of our rainfall patterns, assuming that future rainfall patterns are not impacted by climate change.

5.1.1 Confidence Intervals

Confidence intervals are used to give a range of values with a probability that the observed value will lie within it. Statistical estimates, such as the NOAA design rainfall values, typically provide the projected estimate at the 50% confidence value. This interval means that there is a 50% chance that the observed value could lie below or above the estimated value (See Figure 8). Or, said another way, there is a 50% chance that in 300 years, future engineers will look back and see that we underestimated the 24-hour 1% AEP design storm depth.

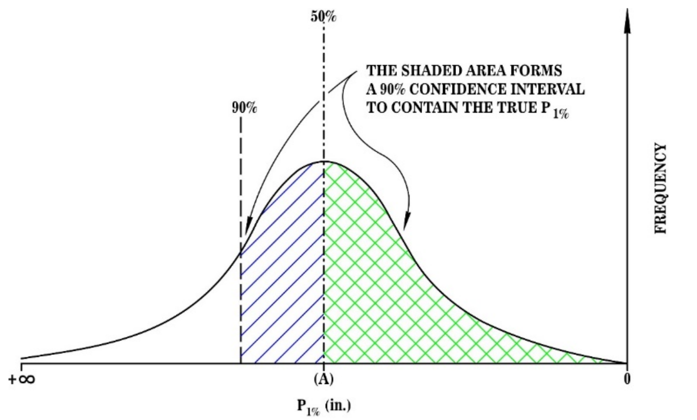
Figure 8: 50% Confidence Probability Distribution



FREQUENCY DISTRIBUTION OF $P_{1\%}$ VALUES
(VARIATION IN $P_{1\%}$ VALUES DUE TO SAMPLING ERROR)

Confidence intervals can be provided to give a range in which it becomes more certain that the observed value would lie within the range. For instance, NOAA now provides the 90% confidence limits for the design rainfall estimates. By selecting the 90% upper confidence limit, there is only a 10% chance that the future observed value would exceed this estimate (See Figure 9).

Figure 9: 90% Upper Confidence Limit

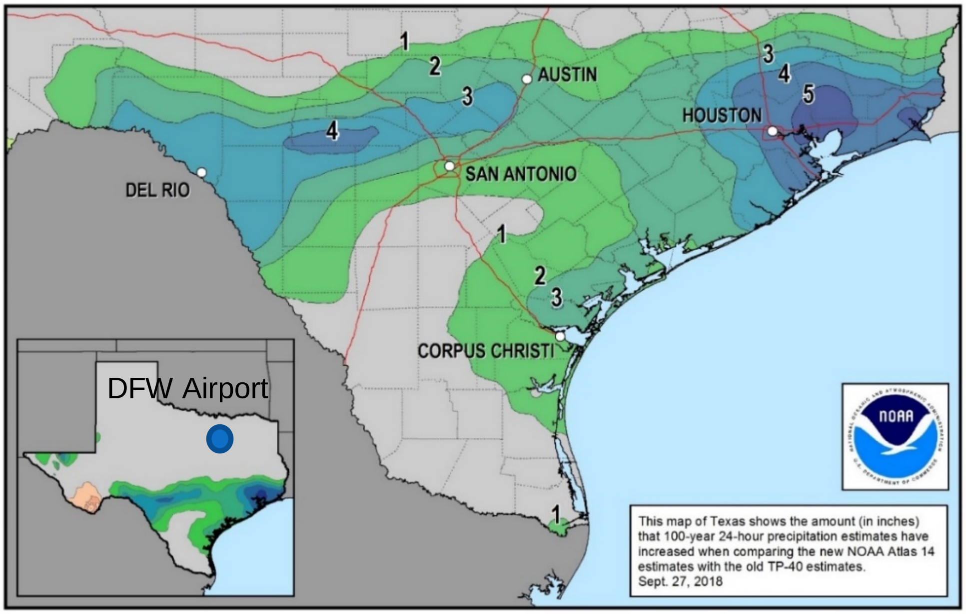


FREQUENCY DISTRIBUTION OF $P_{1\%}$ VALUES
(VARIATION IN $P_{1\%}$ VALUES DUE TO SAMPLING ERROR)

5.2 NOAA Atlas 14 Update

The uncertainty of precipitation estimates due to sample size is exemplified by the latest release of NOAA Atlas 14, which utilizes a longer period of record than previous estimates were able to use to estimate rainfall probabilities. While the DFW area precipitation event probability has seen little change, some areas have seen a 1% AEP (e.g., 100-year return period) design rainfall increase of 5 inches, while other areas have seen a decrease. Figure 10 illustrates the change in 1% AEP design rainfall in Texas. The gray shading signifies areas where the 1% AEP has changed less than 1 inch. These revised estimates include rainfall records from Hurricane Harvey.

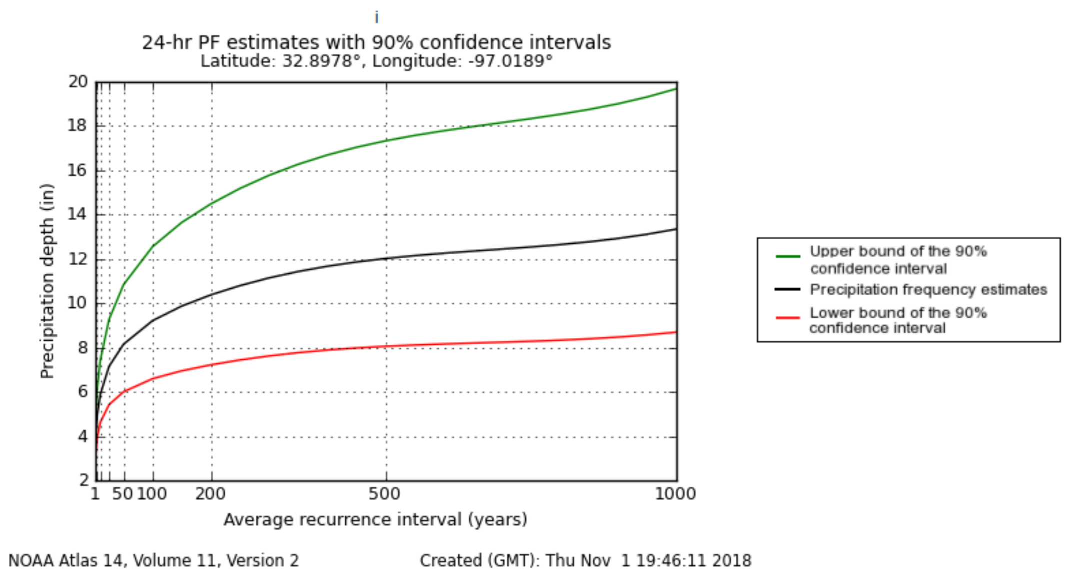
Figure 10: Change in 1% AEP Design Rainfall with NOAA Update



5.3 Confidence Interval Data

NOAA Atlas 14 now provides the 90% confidence intervals with design rainfall estimates. Figure 11 shows these values for the 1% AEP 24-hour storm at DFW airport. While the estimated 1% AEP value is 9.2 inches, the upper 90% confidence limit is 12.5 inches, which is a 3.3 inch increase above the current design storm amount.

Figure 11: 1% AEP Design Rainfall with 90% Confidence Interval

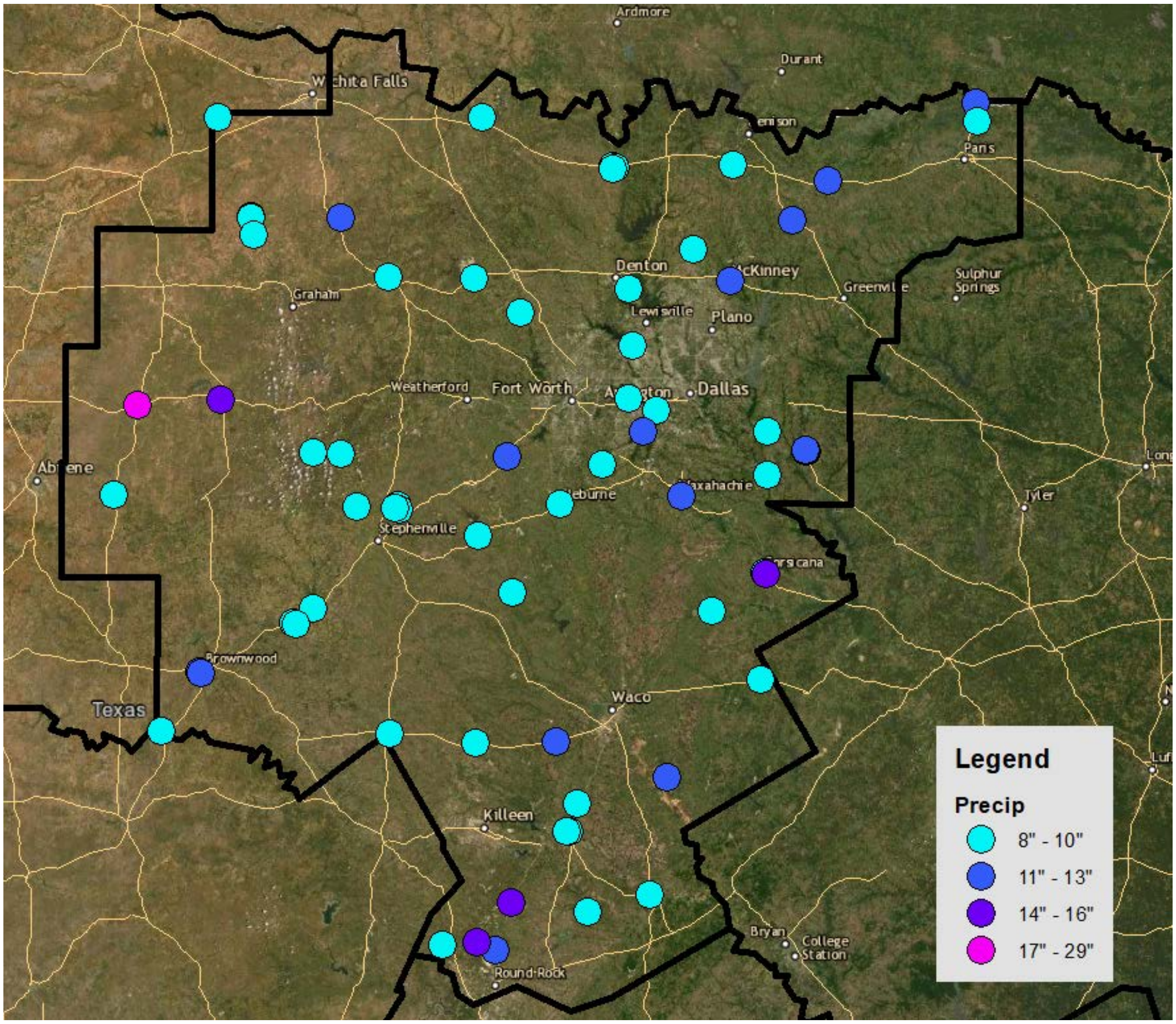


5.4 Regional Events

Statistical analysis of gage data is performed on individual sets of recorded historical gage data to derive site-specific estimates of rainfall probabilities. Regional analysis is used to some extent in the development of probabilities and to fill in missing data at a particular gage. However, the probability estimates are still largely based upon site-specific gage analysis. It is important to note that the preceding discussion on uncertainty relates to the magnitude of uncertainty that results from having a short period of record. There is additional uncertainty related to whether an event that hit gage A and not gage B, has the potential to hit gage B in the future. Or, perhaps an area was subjected to an extreme event that missed all local gages so the event was never recorded. In other words, our historic analysis is location-biased, and may not tell the whole story regarding risk from extreme events. An examination of severe events within a region can help provide an understanding of risk.

Individual hydrologic regions have been defined for the state of Texas by the USGS in its “Water Resources Investigations Report 96-4307”. Figure 12 displays the North Central Texas hydrologic region and extreme events that have occurred within this region between 1890 and 2018. The 1% AEP, 24-hour precipitation depth for this region range between 8 inches and 10.5 inches per NOAA Atlas 14. The only events shown in Figure 12 are the events that have exceeded 8 inches in 24-hours. This data was developed from an assessment of historical rainfall data provided by the Texas State Climatologist. As illustrated by the wide spatial variation of extreme events in North Texas, there is inherent uncertainty with the 9.2 inch NOAA Atlas 14, 1% AEP, 24-hour estimate.

Figure 12: North Central Texas Extreme Storm Events (1890 – 2018)



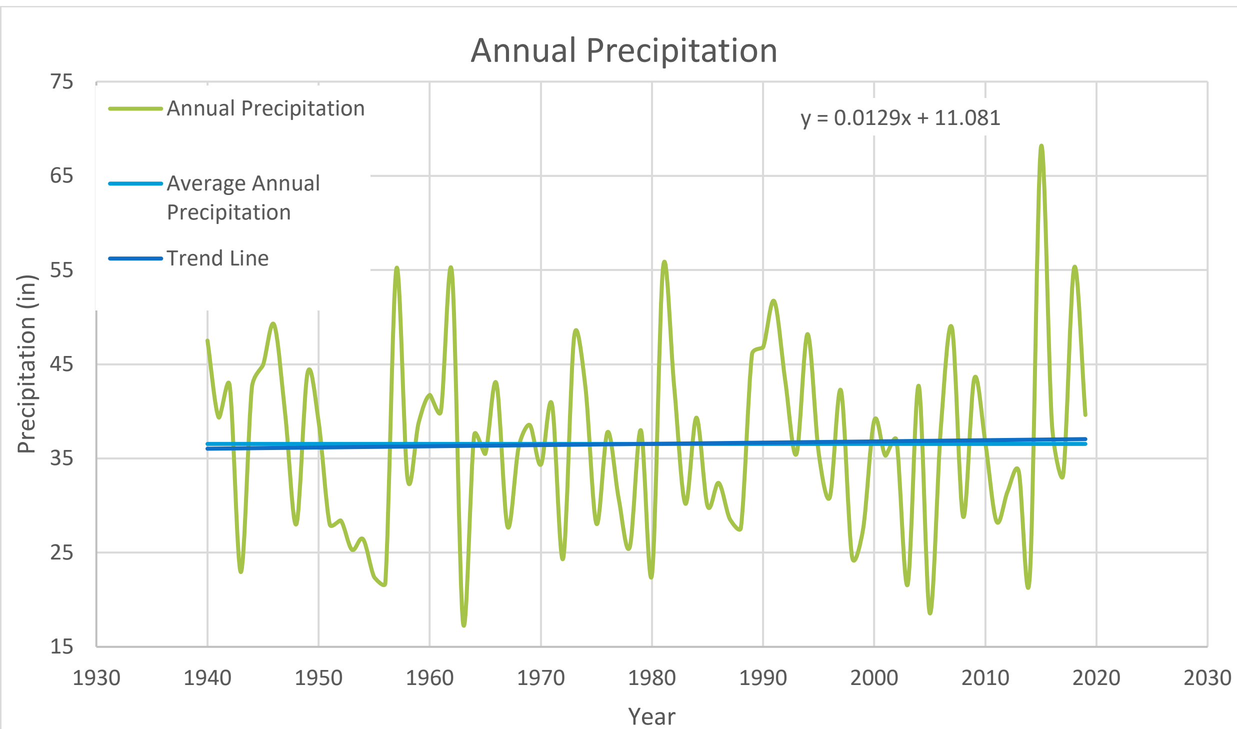
6 Local Area Trend Analysis

Another way to assess risk related to climate change is to perform a trend analysis on historic data in order to see if there is evidence of how climate change may already be affecting precipitation.

6.1 Average Annual Rainfall

Assessing historic average annual rainfall trends can shed some light on whether our climate is generally getting drier or wetter. Rain gages in the DFW area were examined to determine the longest available period of record for the analysis. Station ESW00013960, the rain gage at Love Field, is the longest available continuous record of data. Figure 13 shows annual precipitation, average annual precipitation, and the period of record trend in annual precipitation. As evident from the figure, the trend line shows a minor increase in annual precipitation values. A statistical analysis indicates that the change is not considered statistically significant, meaning that the departure from the average may be the result of chance rather than a representation of an expectation for future increases in annual precipitation values.

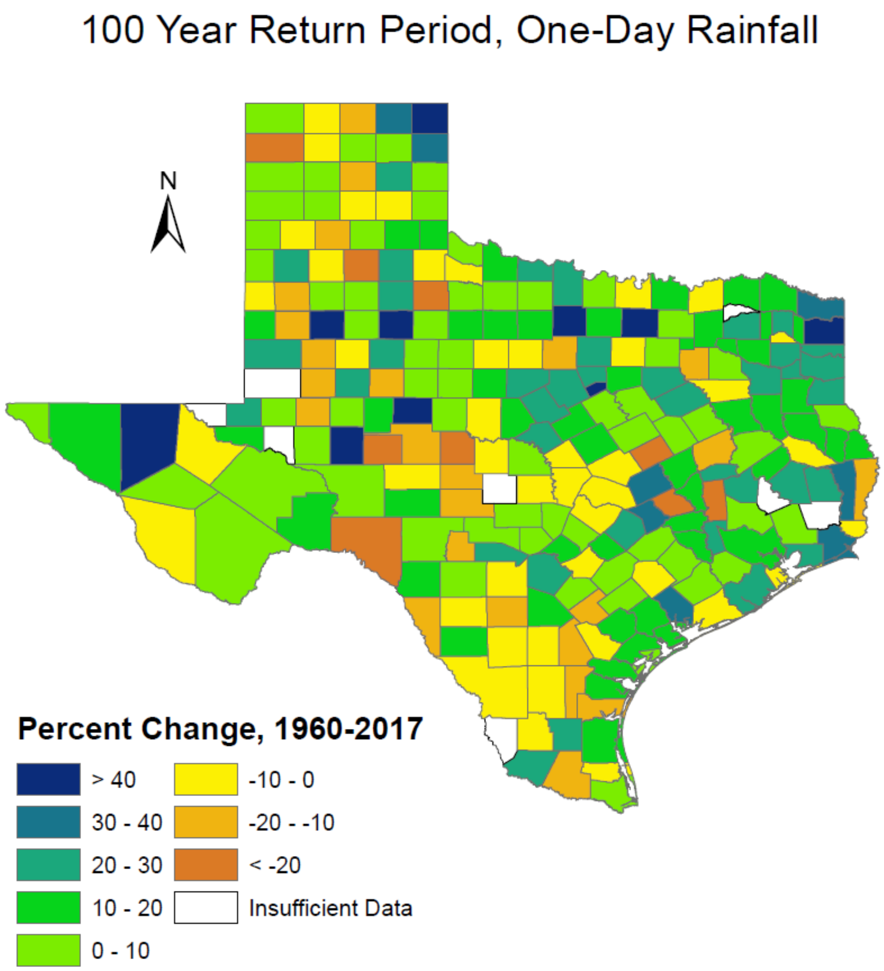
Figure 13: Annual Precipitation Trend



6.2 24-hour 1% AEP Event

Examination of trends in the 1% AEP estimate can be used to understand how climate change may affect extreme rainfall events that can place infrastructure at risk. The Texas State Climatologist, Dr. John Nielson-Gammon, has performed an assessment of trends within the State of Texas, by county, of the 1% AEP event for 1-day rainfall. Figure 14 presents the percent change in the 1% AEP (100-year) estimate from 1960 to 2017. This data is not yet published. The assessments were made by compositing, for each county, historic rainfall from multiple gages to reflect a continuous period of record for a single gage. Note that the trend in Dallas County shows a 0-10 percent increase in the 100-yr event, while Tarrant County indicates a 0-10 percent decrease in the 100-yr event. The DFW airport is located at the boundary between the two counties, so extracting an actionable trend value is problematic.

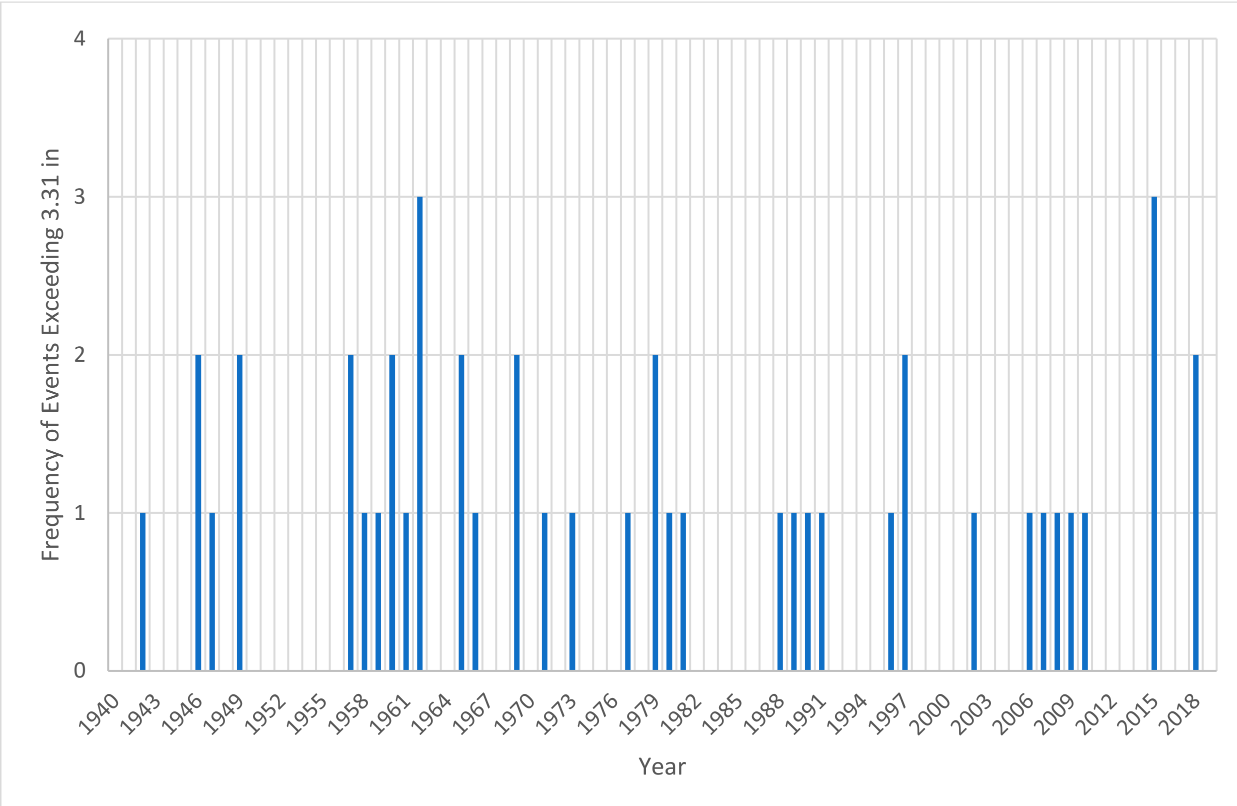
Figure 14: 100-yr, 1-Day Rainfall Trend (1960 – 2017)



6.3 24-hour 100% AEP Event

Examination of long-term trends for more frequent rainfall events was also performed by examining the 24-hour 100% AEP, or 1-year event at the same local long-term gage located at Love Field. NOAA Atlas 14 indicates that the 24-hour 1-year event is 3.31 inches of precipitation depth. Figure 15 displays the number of occurrences per year that have exceeded this 24-hour rainfall depth between 1940 and 2019. A trend in the frequency of this more common rainfall event is not apparent. A statistical analysis also indicates no statistically significant trend in the number of occurrences per year.

Figure 15: 24-Hour 100% AEP Exceedance



6.4 1-Hour Event Exceedance

1-hour duration storms were examined in order to assess whether a trend may be observed for changes in the frequency of intense, short-duration events. The 1-hour 20% AEP (5-year) and 10% AEP (10-year) events for the DFW airport are 2.16 inches and 2.49 inches, respectively. Figures 16 and 17 below display the number of occurrences that the 1-hour 20% and 10% AEP events have been exceeded at DFW airport when examining the 1-hour rainfall dataset for the airport. The results do not indicate a significant trend in the occurrence of these events.

Figure 16: 1-Hour 20% AEP Exceedance

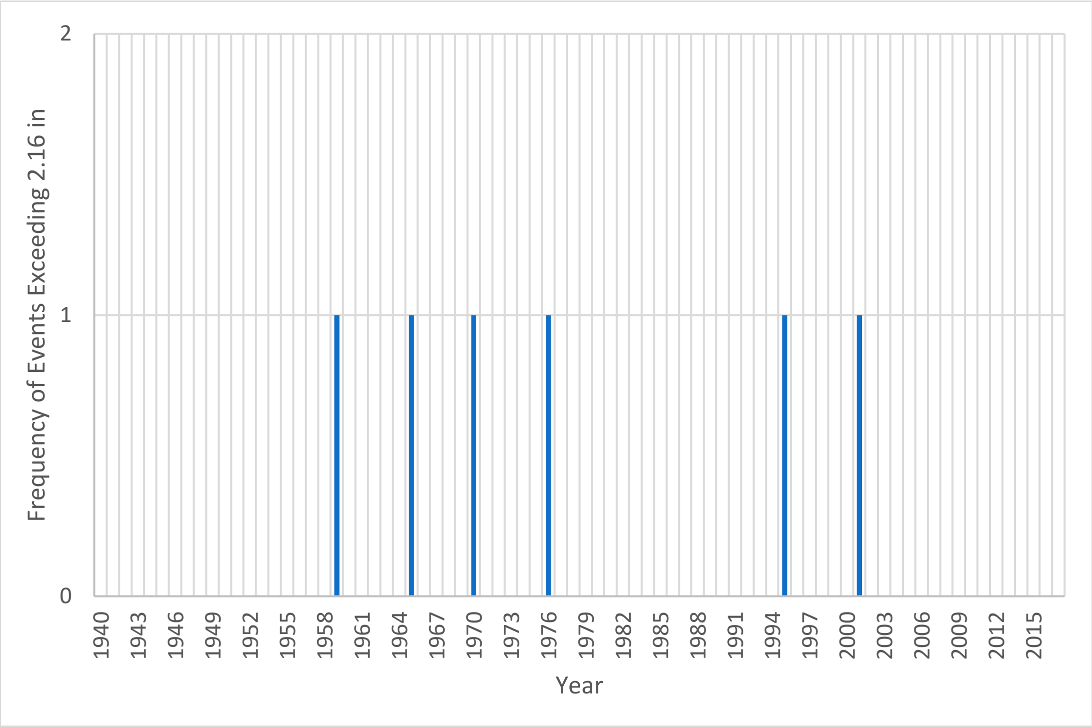
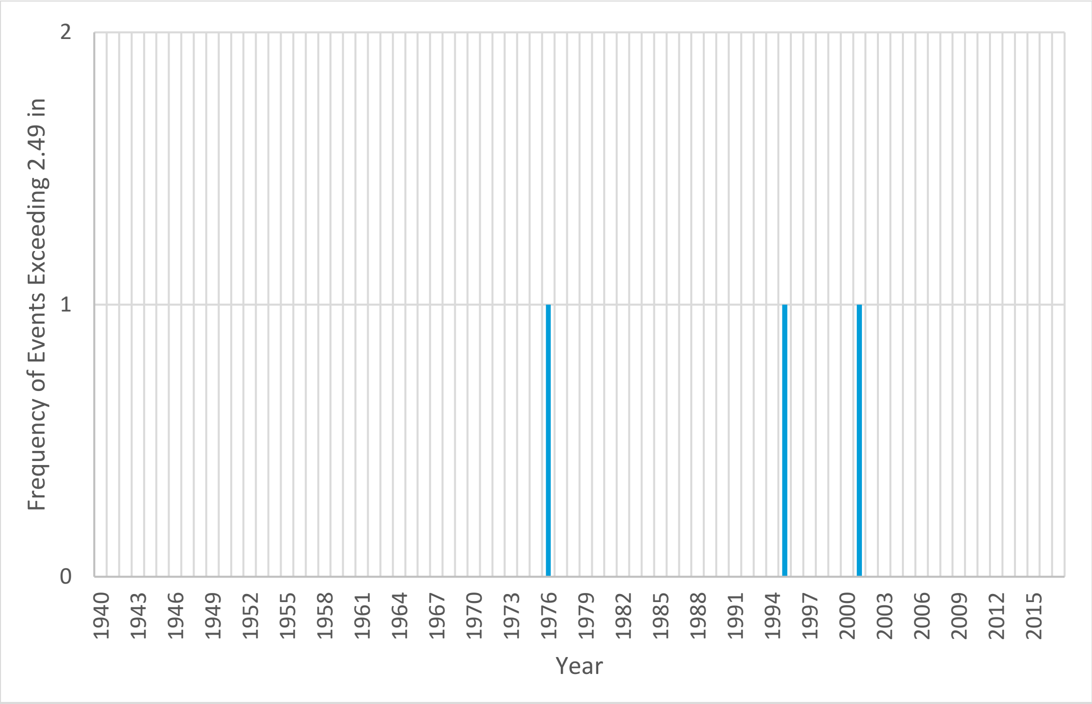


Figure 17: 1-Hour 10% AEP Exceedance



7 Conclusions & Recommendations

There exists widespread GCM agreement on expected future temperature increases in Texas as a result of climate change. Assessment of impacts to DFWIA using the ACROS tool reflect the anticipated increase in temperature. These increases, if observed, have the potential to cause an adverse impact on the survivability of vegetation that is used in Green Stormwater Infrastructure and to help resist erosion. To adapt to the expected temperature increases, the use of drought-tolerant vegetation should maximized in all stormwater BMP designs. The ACROS tool indicates that there is low confidence regarding conclusions on the impact of climate change on precipitation at DFWIA.

While there is widespread agreement on changes to temperature, the models have greater uncertainty and a lack of consensus regarding anticipated changes to precipitation. The US EPA has developed a tool to estimate percent change in rainfall probabilities that may result from climate change. This tool is made available to the SWMM model via the SWMM-CAT tool. However, this tool utilizes averages from the model output utilized in the NESDIS 142-4 report, which indicates that anticipated changes in extreme precipitation are not statistically significant in Texas. The tool exists, but confidence in its results are considered low.

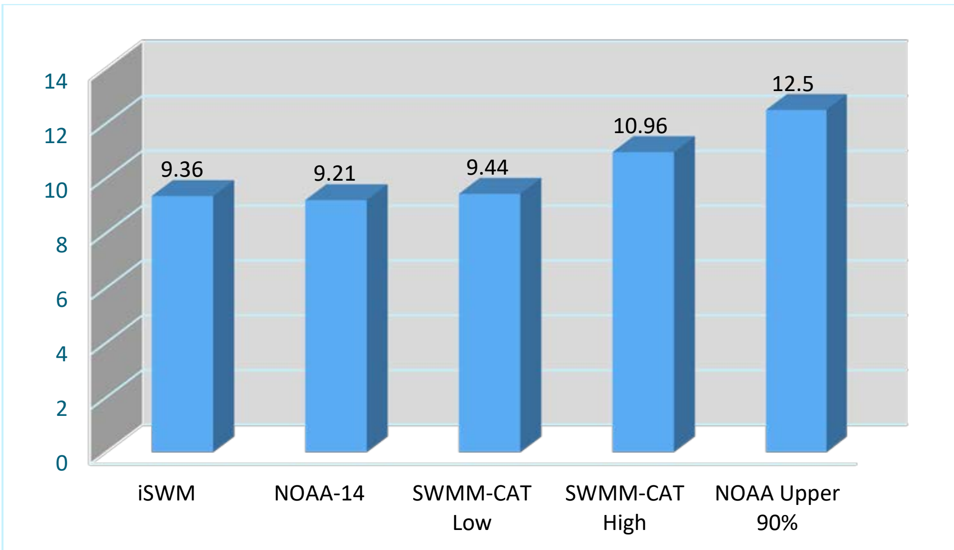
Trend analysis of historic rainfall data do not yield evidence of significant trends in annual precipitation totals, nor probability of the 1% AEP event, nor an identifiable trend in the occurrence of more frequent intense events.

Our estimates of historic rainfall probability are also laden with significant uncertainty because our estimates of probability are based upon a relatively small sample size of records. However, there are statistical means available for quantifying that uncertainty. Utilizing the upper 90% confidence interval rainfall as the design storm for protecting critical infrastructure such as emergency services and critical equipment provides resiliency against severe rainfall events. While the 90% confidence interval rainfall is not associated with climate change estimates, it can serve as a means to provide additional resiliency in protecting critical infrastructure against potential climate change impacts as well as serve to improve certainty of function for these critical assets.

Figure 15 presents a comparison of 24-hour 1% AEP rainfall depths from the North Central Texas Council of Governments (NCTCOG) integrated Stormwater Management (iSWM), NOAA Atlas 14 design value, a range of SWMM-CAT values, and NOAA upper 90% confidence limit values. We recommend the NOAA Atlas 14 upper 90% confidence interval rainfall depth to be used as design criteria for critical infrastructure. Rather than trying to pinpoint the exact change in precipitation that climate change is going to create based on very uncertain data, the NOAA Atlas 14 upper 90% confidence interval provides a conservative estimate that is less likely to be exceeded when changes in climate do occur. For practical purposes, the 0.2% AEP (500-yr) event can be used for this more-resilient design approach because the values round to the same 12.5 inches of depth.

Critical infrastructure will be assessed on an individual basis regarding potential impact on flooding and erosion using the higher design value. A comparison of the cost versus benefit of providing this higher level of protection for critical infrastructure can be assessed on a case-by-case basis. As state-of-the-art science regarding climate predictions improves in the future, greater model certainty regarding precipitation estimates may warrant revisiting the use of that data for selection of design criteria.

Figure 18: 24-hr 1% Rainfall Depth Comparison



Appendix A: ACROS Tool DFW Report

Airport Climate Risk Operational Screening Tool Report

Airport: DALLAS/FORT WORTH INTL

FAA Region: ASW

Section I: Climate

Summary of climate data changes

Summary of Historical Record and Projected Changes (Days/Year)								
Climate Vector	Units	2013	2030			2060		
		Baseline	25th Percentile	Median	75th Percentile	25th Percentile	Median	75th Percentile
HotDays	days per year	73	84.3	86.9	91.2	101.3	107.7	118.6
VeryHotDays	days per year	11.8	22.3	25.6	31.8	38.1	46.3	61.8
FreezingDays	days per year	1.5	0.3	0.9	1.3	0	0.4	1
FrostDays	days per year	26.6	18.9	22.1	24.2	7.4	15.5	20.8
HotNights	days per year	121.3	131.8	134.8	138.4	147.6	155.2	164
HumidDays	days per year	101.8	106.6	115.5	124.7	113.6	136	159
SnowDays	days per year	0.2	0	0.1	0.2	0	0	0
StormDays	days per year	51.8	49.7	51	52.8	46.5	49.8	54.4
HeavyRain1Day	days per year	9	8.7	9	9.2	8.3	9	9.5
DryDays	days per year	24.9	24.6	25.7	27	24.3	26.9	30.1
SeaLevelRise	days per year	0	0	0	0	0	0	0
CoolingDays	days per year	220.2	228.5	231.3	233.3	241	247.8	253
HeatingDays	days per year	102.6	91.9	92.5	94.9	75.7	77.3	83.2

Summary of Historical Record and Projected Changes (Various Unit)								
Climate Vector	Units	2013	2030			2060		
		Baseline	25th Percentile	Median	75th Percentile	25th Percentile	Median	75th Percentile
CoolingDegreeDays	yearly accumulation	1548.8	1750.6	1797.8	1864.8	2053.4	2171.2	2338.8
HeatingDegreeDays	yearly accumulation	1162.4	1011.6	1037.6	1055.2	785.4	850.5	894.4
HeavyRain5Day	inches	3.5	3.4	3.5	3.6	3.2	3.5	3.8
SeaLevelRise_BaseFloodElevation	feet	0	0	0	0	0	0	0

Climate Projections (Days/Yr)

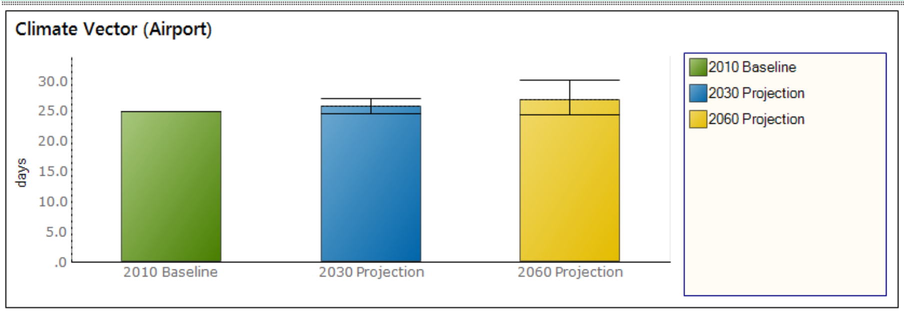
The majority of the climate vectors in the report are shown in units of days per year. By using a common unit, it is possible to provide a risk estimate across multiple climate vectors. Additional explanatory vectors are available below.

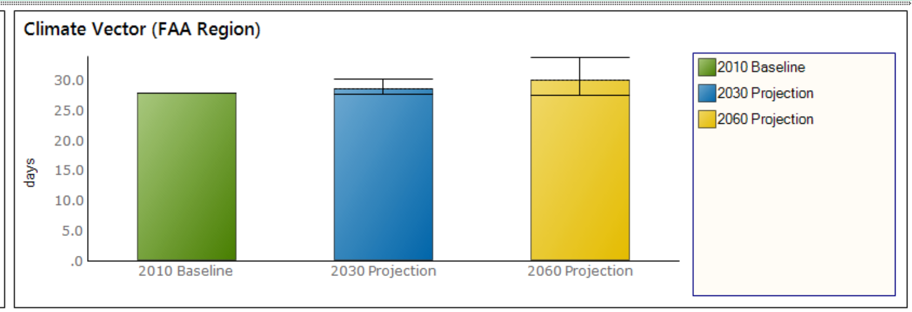
Dry Days
CONFIDENCE: Moderate

DryDays

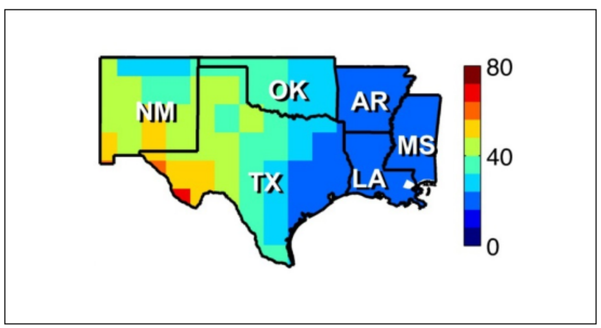
CONFIDENCE: MODERATE

A Dry Day is a day with a rainfall accumulation less than 0.03 inches. Dry Days are measured in days per year.



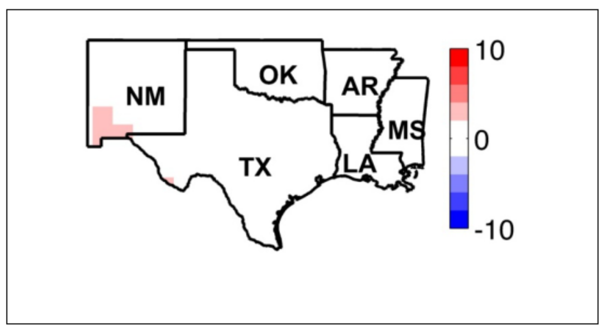


Number of Days



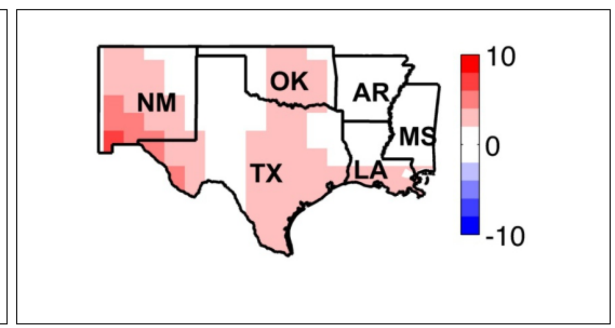
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



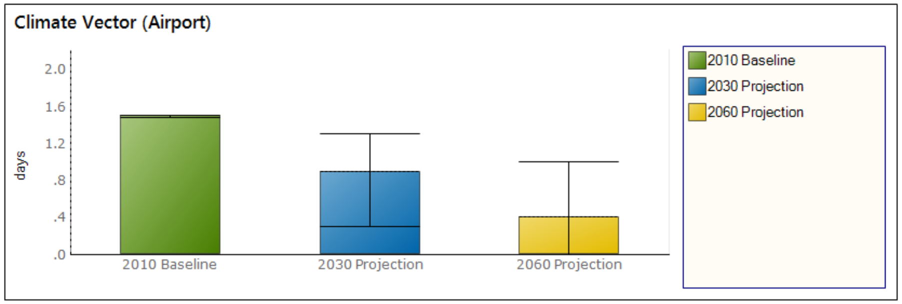
2060 (Median)

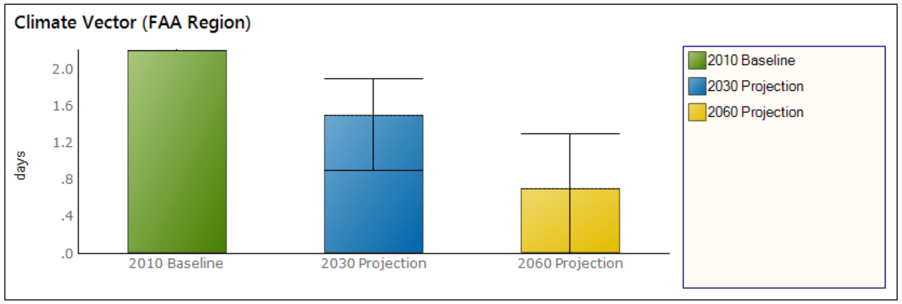
Freezing Days
CONFIDENCE: High

FreezingDays

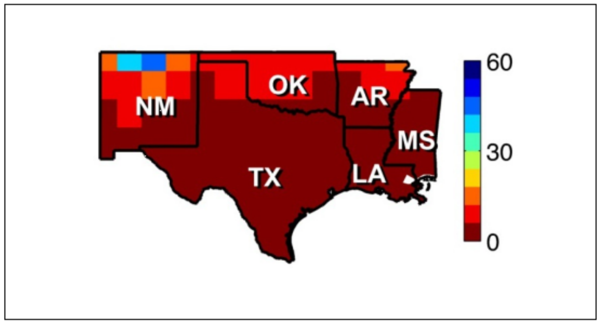
CONFIDENCE: HIGH

A Freezing Day is a day with a high temperature at or below 32°F. Freezing Days are measured in days per year.



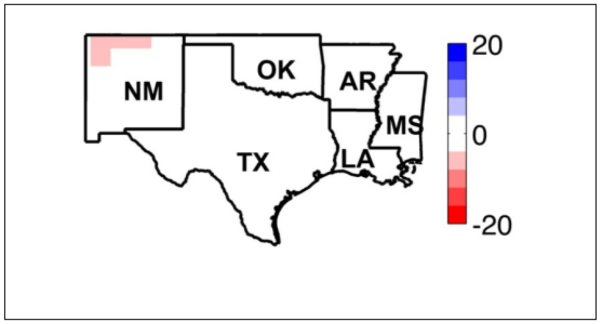


Number of Days



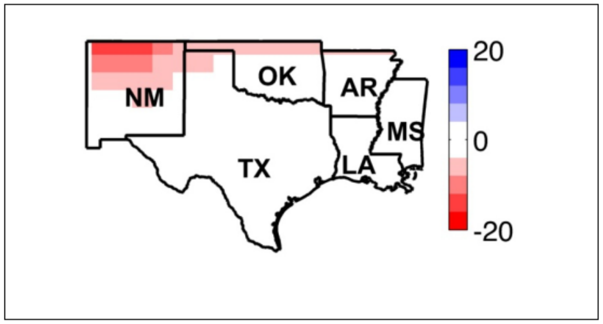
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



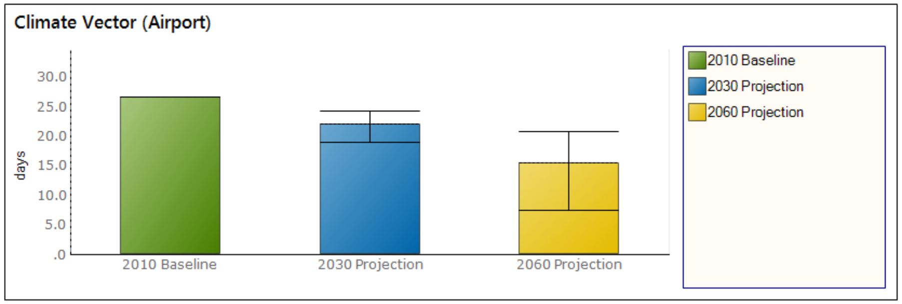
2060 (Median)

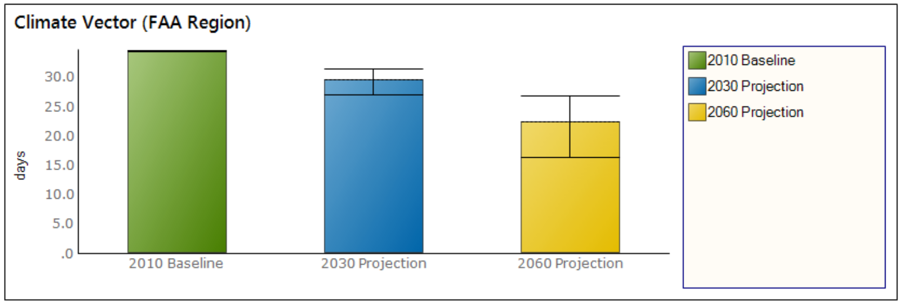
Frost Days
CONFIDENCE: High

FrostDays

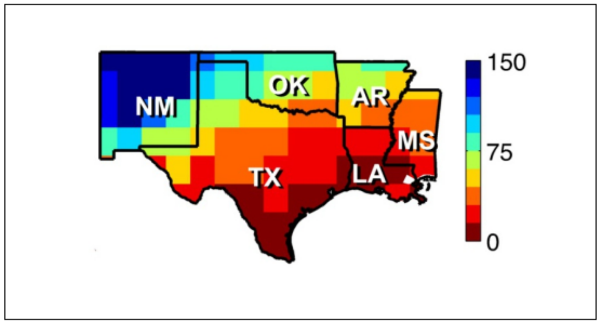
CONFIDENCE: HIGH

A Frost Day is a day with a low temperature at or below 32°F. Frost Days are measured in days per year.



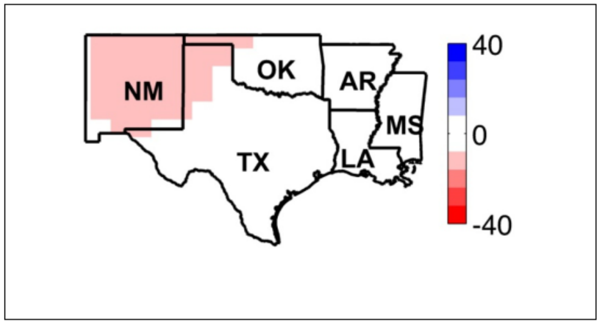


Number of Days



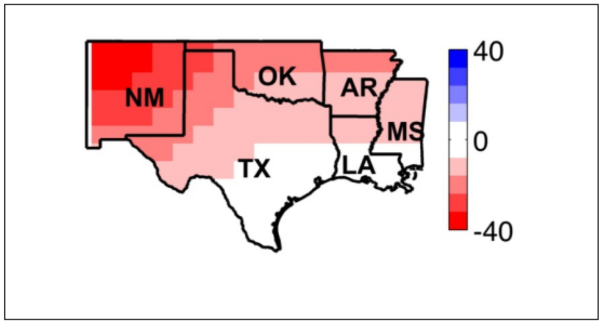
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

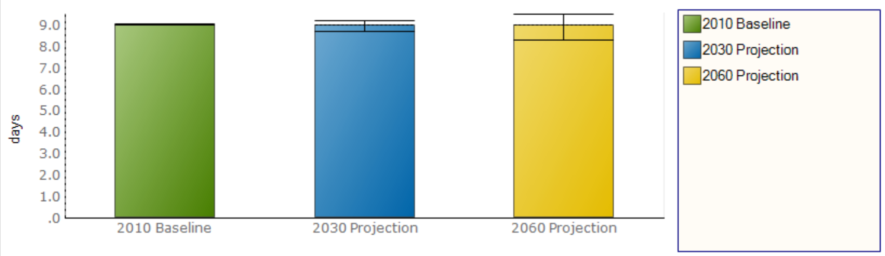
Heavy Rain (1 Day)
CONFIDENCE: Moderate

HeavyRain1Day

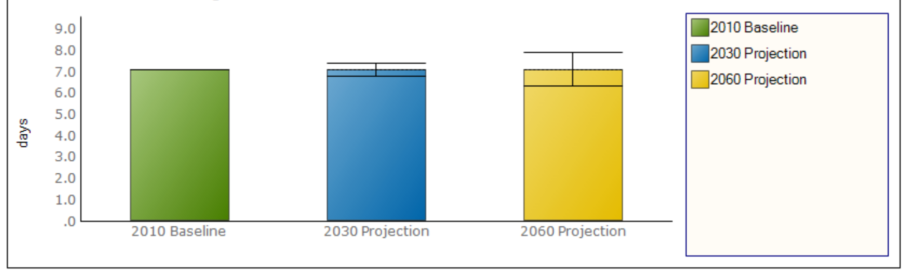
CONFIDENCE: LOW

A One-Day Heavy Rain day is a day with a rainfall accumulation more than 0.80 inches. One-Day Heavy Rain is measured in days per year.

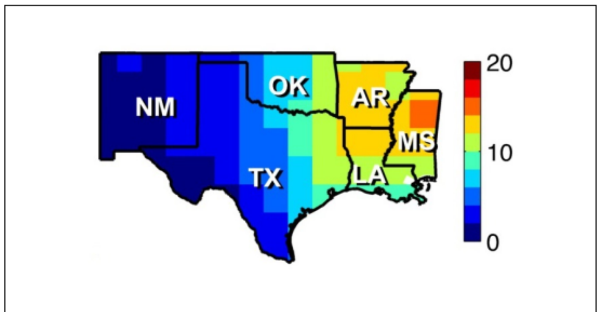
Climate Vector (Airport)



Climate Vector (FAA Region)

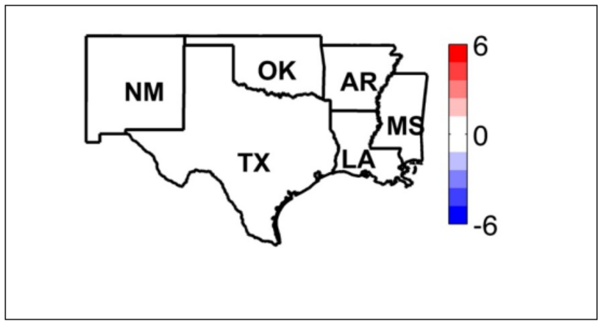


Number of Days



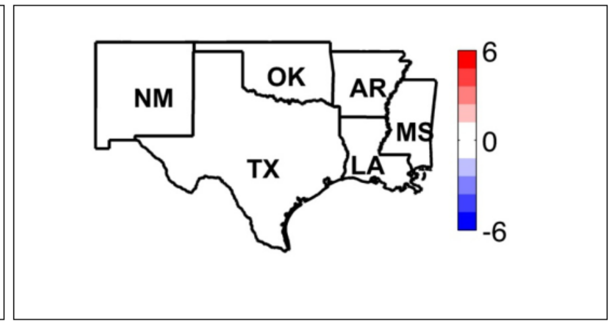
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

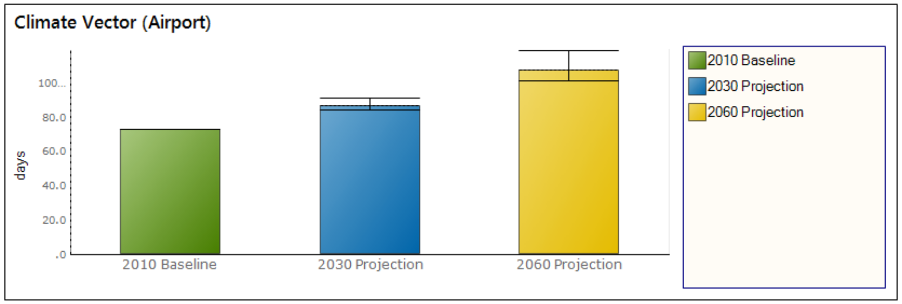
<u>Hot Days</u>

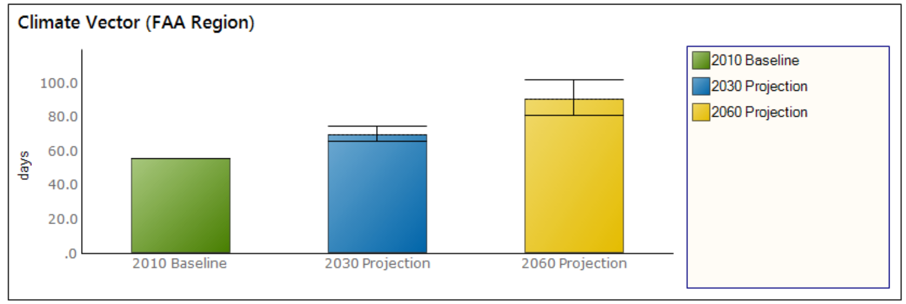
CONFIDENCE: High

HotDays

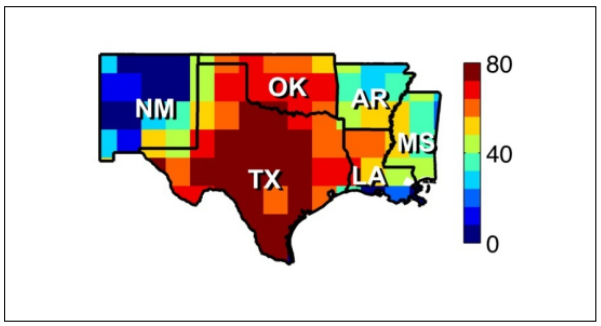
CONFIDENCE: HIGH

A Hot Day is a day with a high temperature at or above 90°F. Hot Days are measured in days per year.



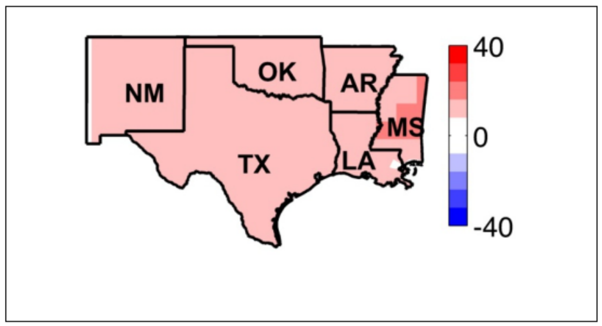


Number of Days



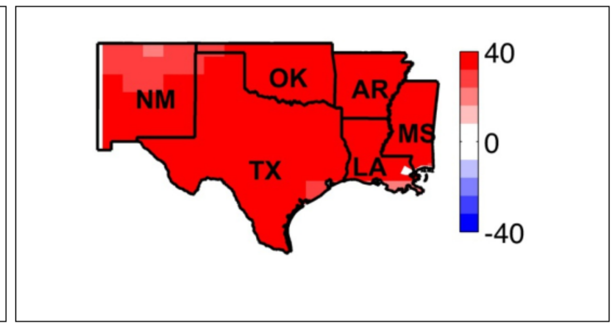
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



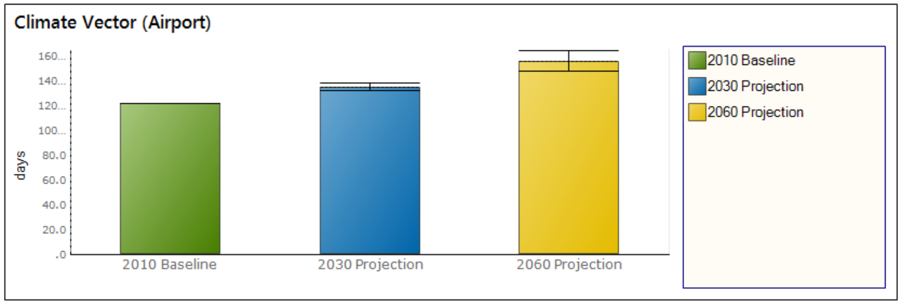
2060 (Median)

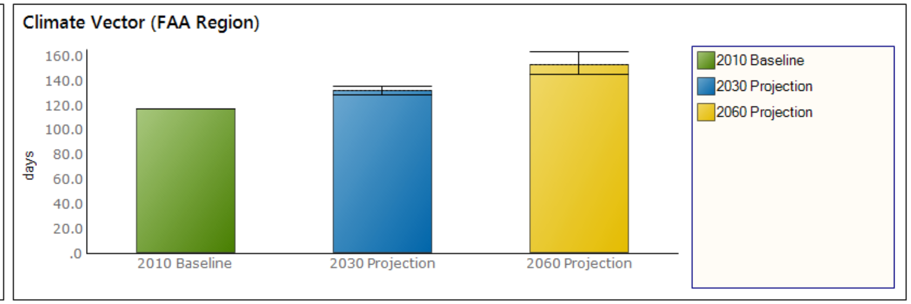
Hot Nights
CONFIDENCE: High

HotNights

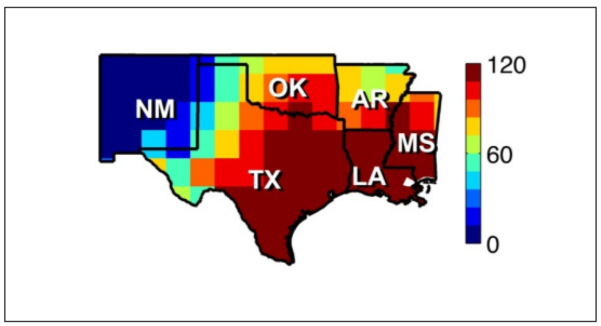
CONFIDENCE: HIGH

A Hot Night is a night with a low temperature at or above 68°F. Hot Nights are measured in nights per year.



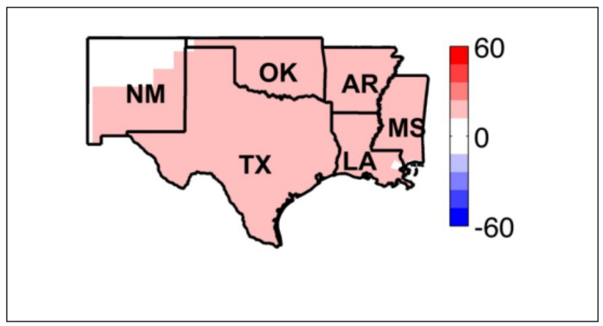


Number of Days



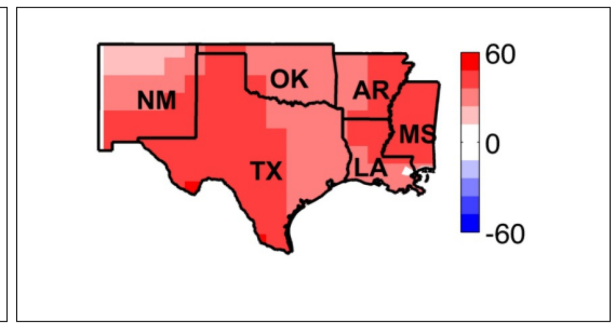
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



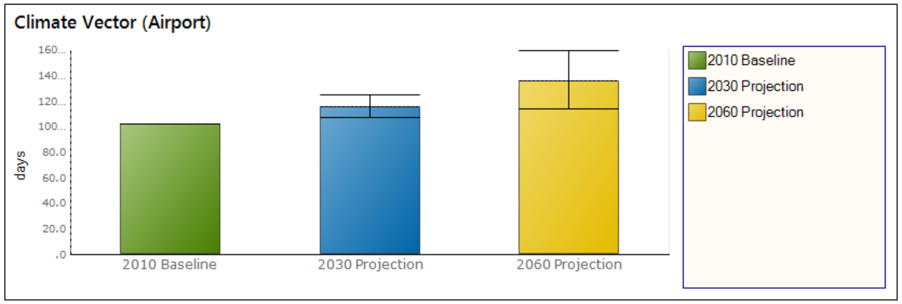
2060 (Median)

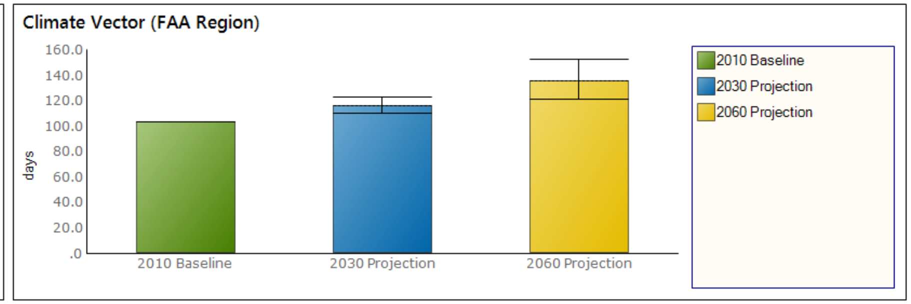
__Humid Days__
CONFIDENCE: High

HumidDays

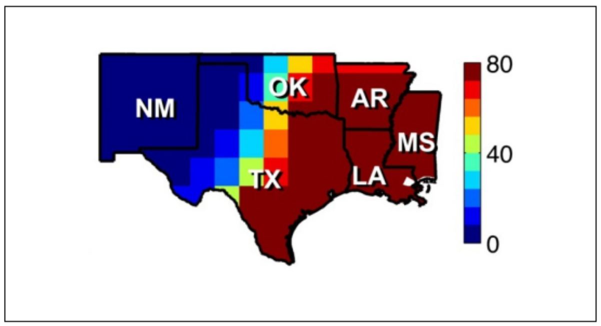
CONFIDENCE: HIGH

A Humid Day is a day with an average dewpoint temperature above 65°F. The dewpoint temperature is the temperature at which water vapor in the air condenses into dew. Humid Days are measured in days per year.



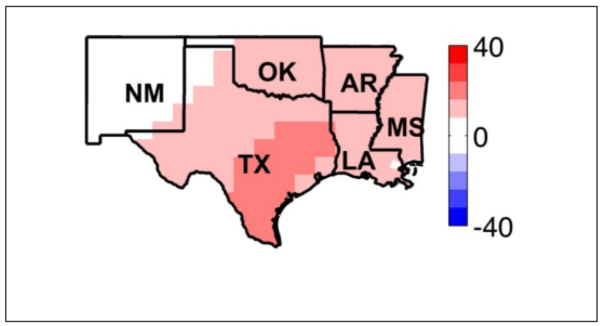


Number of Days



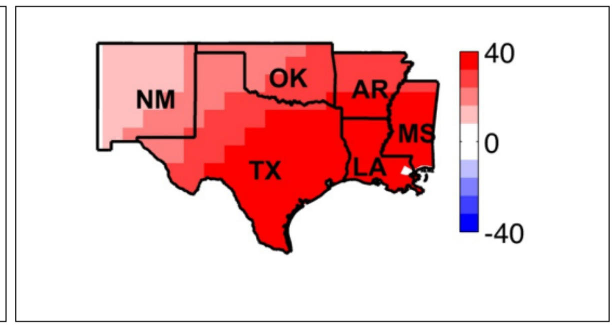
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



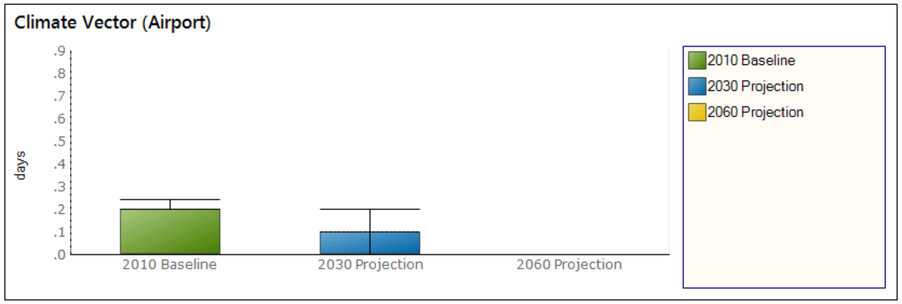
2060 (Median)

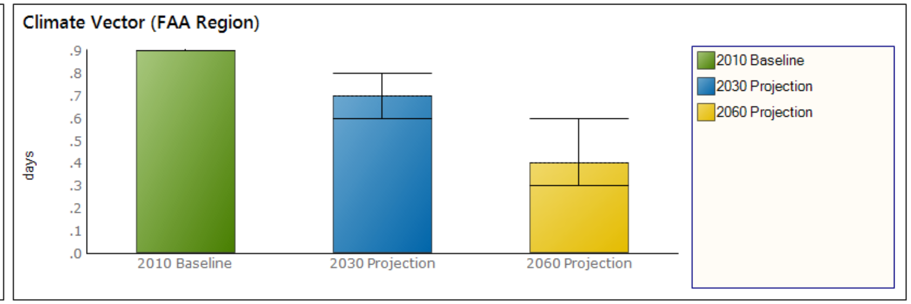
Snow Days
CONFIDENCE: Moderate

SnowDays

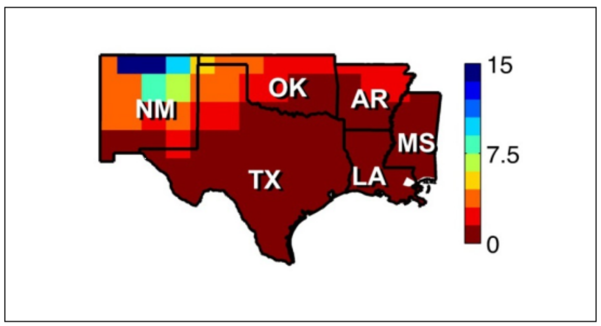
CONFIDENCE: MODERATE

A Snow Day is a day with a snowfall accumulation more than 2 inches. Snow Days are measured in days per year.



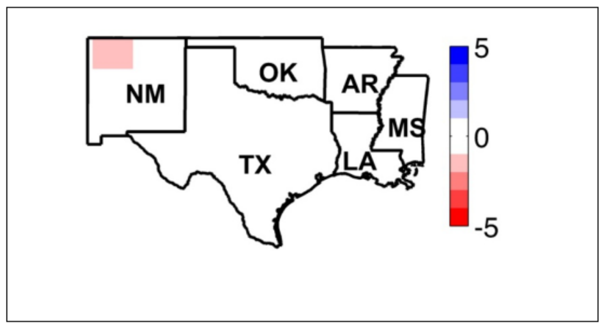


Number of Days



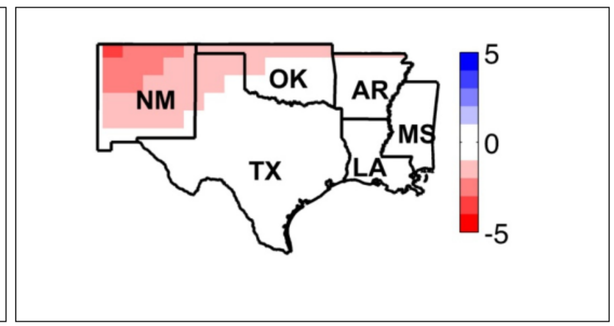
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

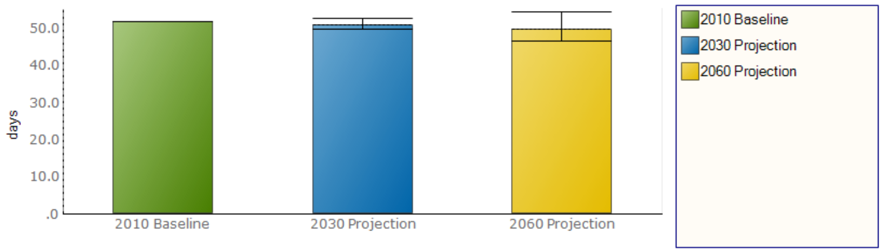
Storm Days
CONFIDENCE: Low

StormDays

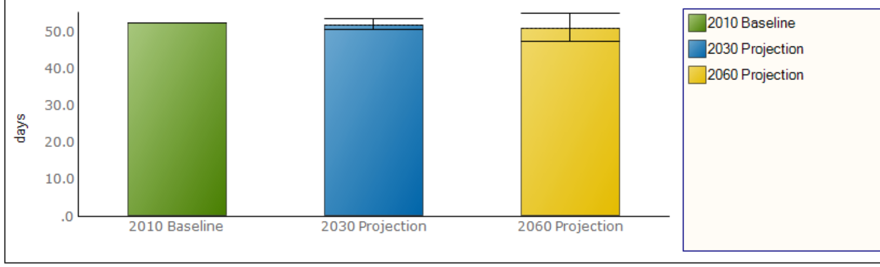
CONFIDENCE: LOW

A Storm Day is a day with a thunderstorm rainfall accumulation more than 0.15 inches. May include high wind events and hail. Storm Days are measured in days per year.

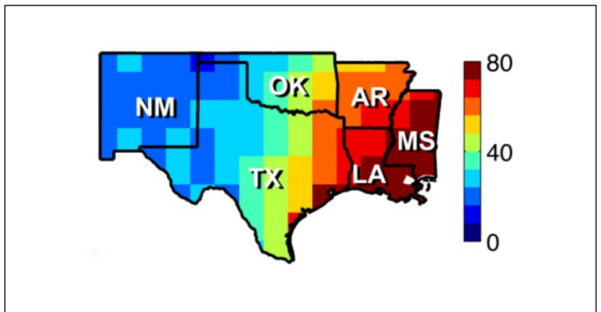
Climate Vector (Airport)



Climate Vector (FAA Region)

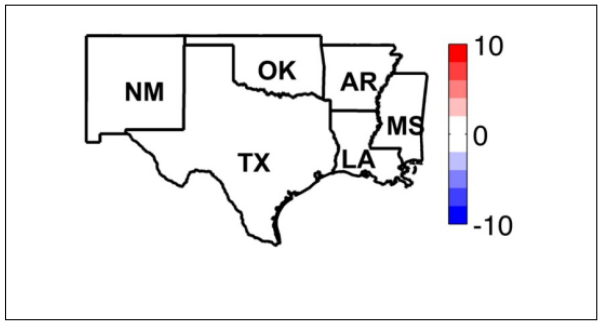


Number of Days



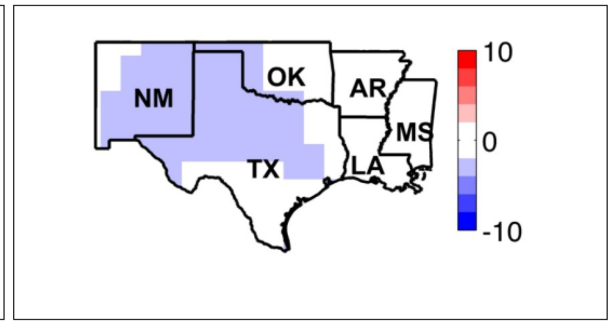
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

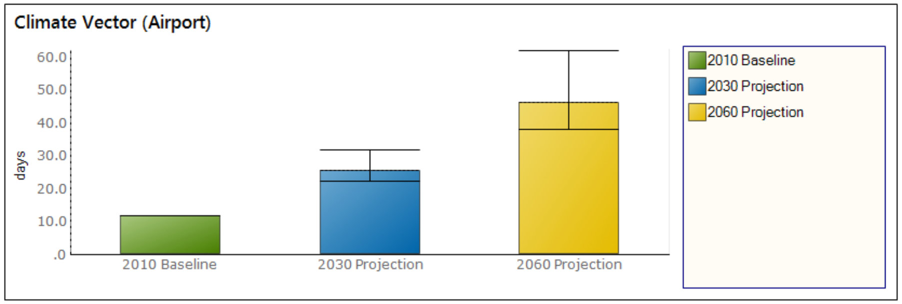
Very Hot Days

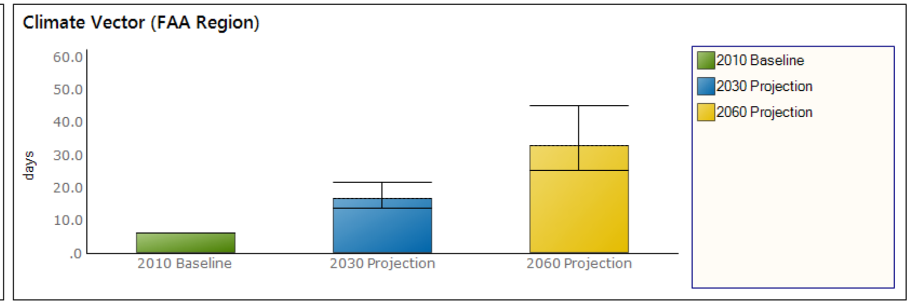
CONFIDENCE: High

VeryHotDays

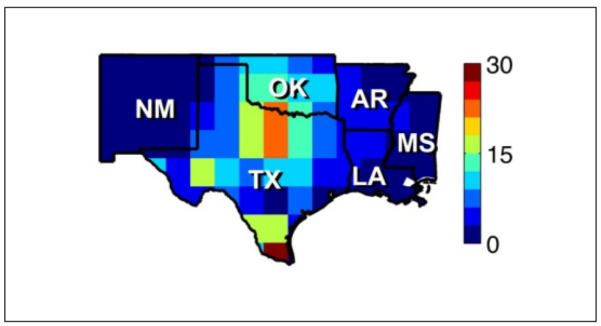
CONFIDENCE: HIGH

A Very Hot Day is a day with a high temperature at or above 100°F. Very Hot Days are measured in days per year.



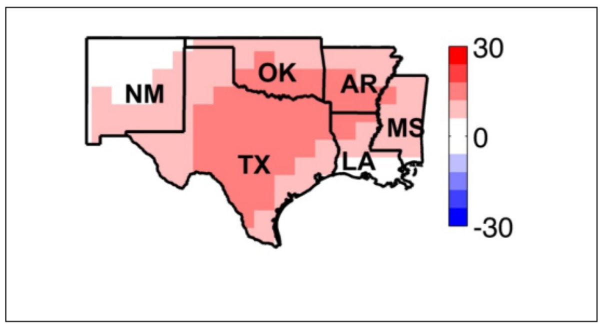


Number of Days



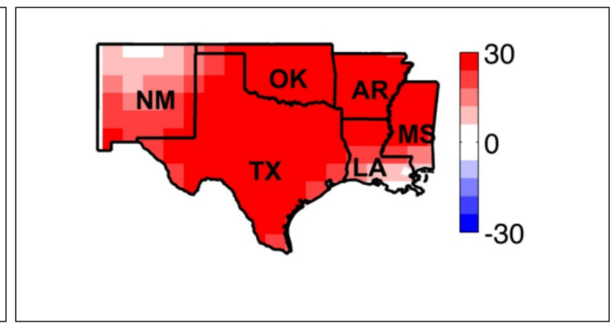
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

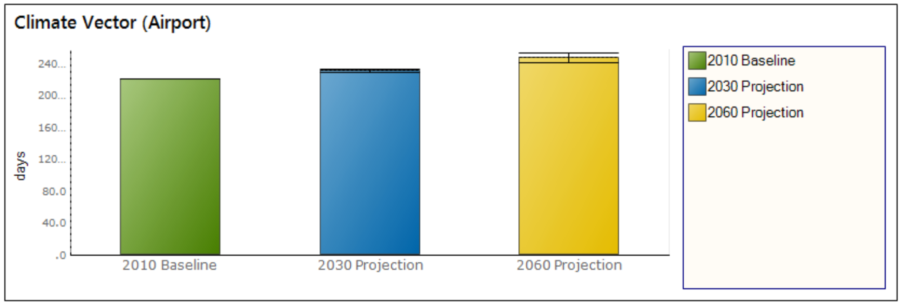
Cooling Days

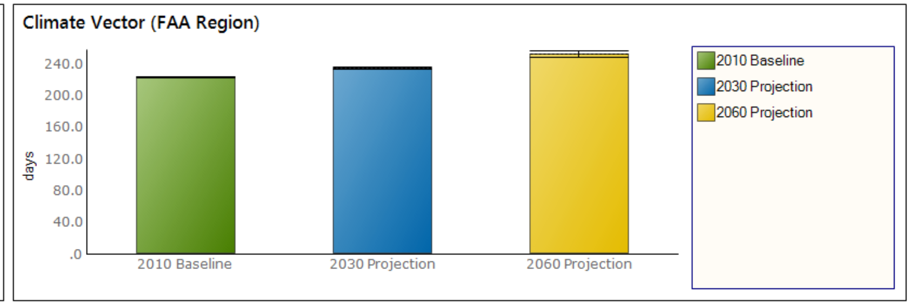
CONFIDENCE: High

CoolingDays

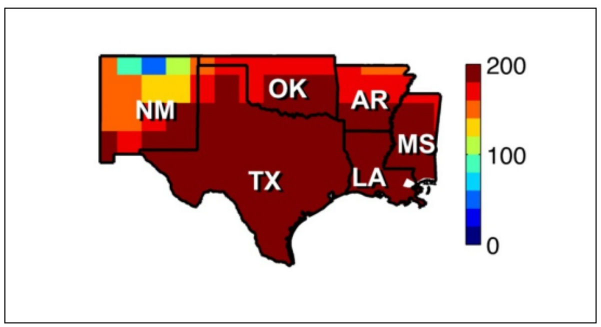
CONFIDENCE: HIGH

A Cooling Day is a day with an average temperature at or above 68°F. Cooling Days are measured in days per year.



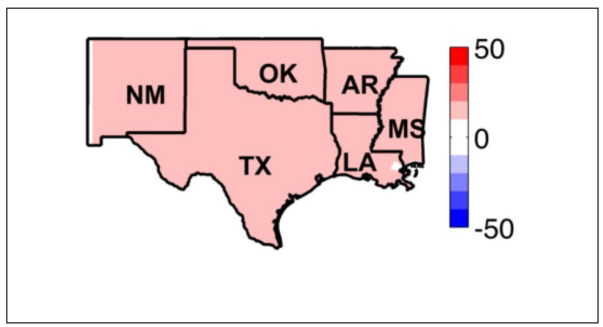


Number of Days



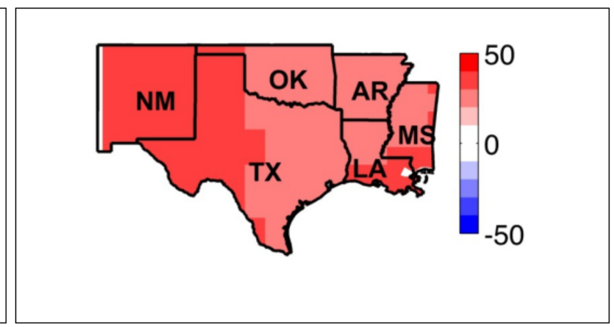
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

Heating Days

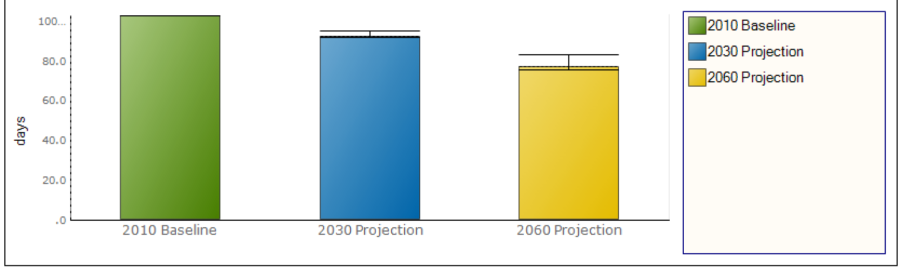
CONFIDENCE: High

HeatingDays

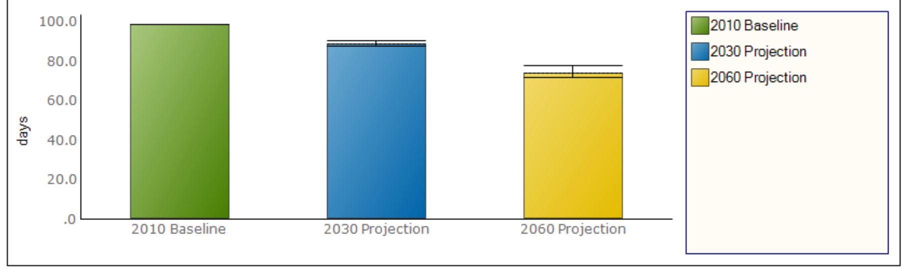
CONFIDENCE: HIGH

A Heating Day is a day with an average temperature at or below 62°F. Heating Days are measured in days per year.

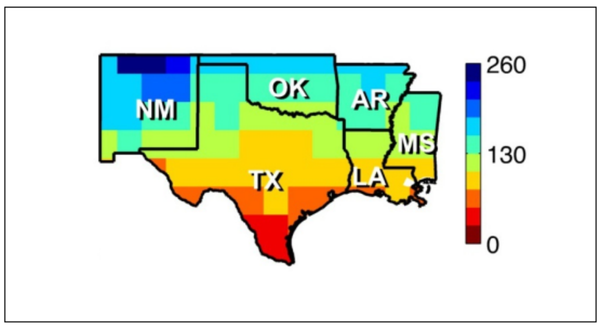
Climate Vector (Airport)



Climate Vector (FAA Region)

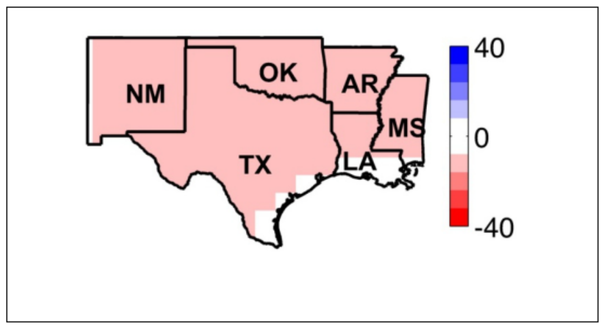


Number of Days



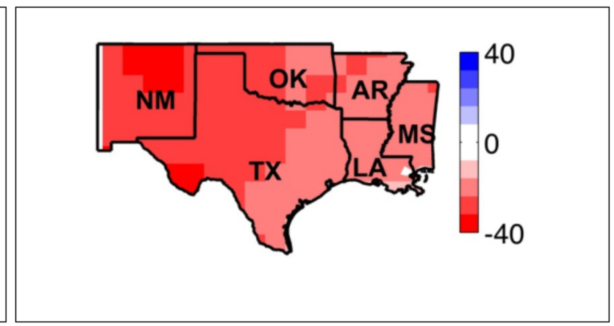
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

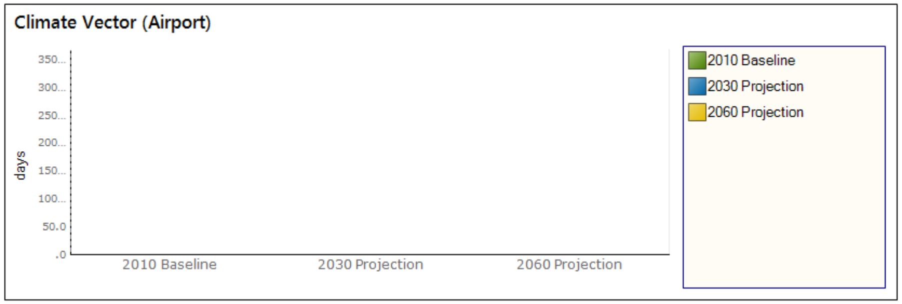
Sea Level Rise

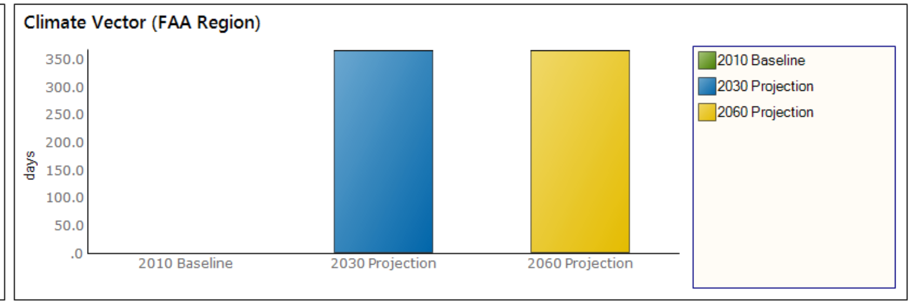
CONFIDENCE: High

SeaLevelRise

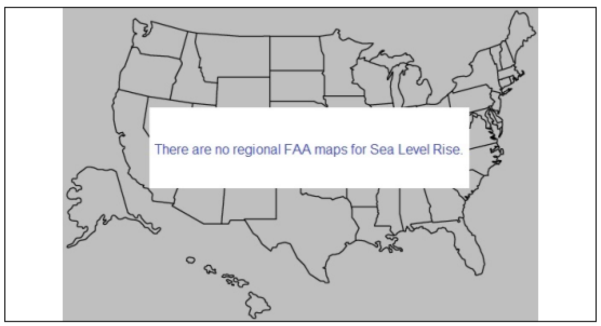
CONFIDENCE: HIGH

Sea Level Rise measures the number of days per year where the runway elevation is inundated by tidal flooding. Runways protected by levees at OAK and MSY airports are flagged as inundated to emphasize the importance of maintaining flood protection.



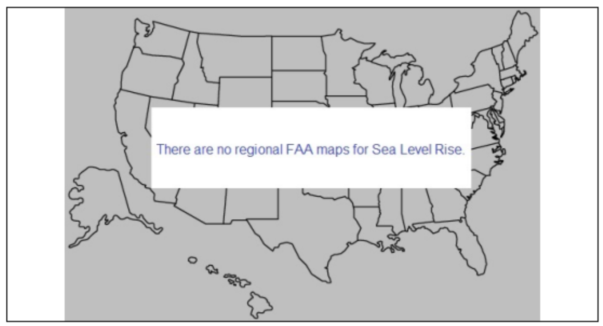


Number of Days



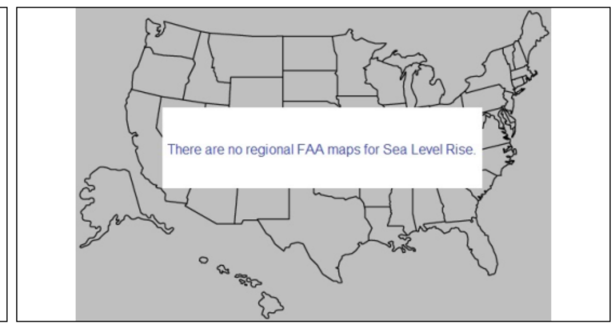
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

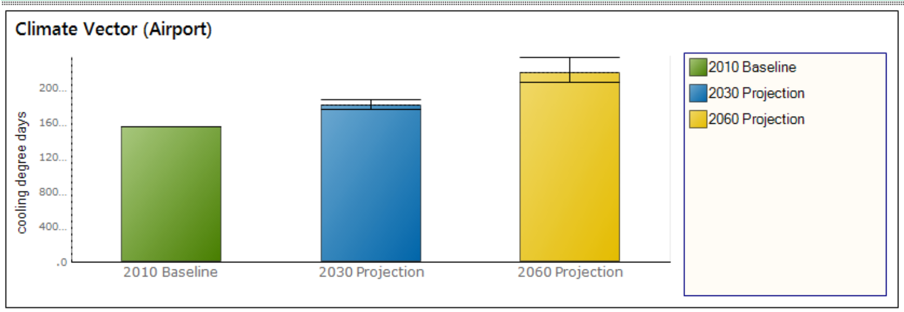
Additional Climate Projections (Various units)
The climate vectors below are reported in various units. While these cannot be accounted for in the risk estimate (which requires comparison across the same unit of change), these vectors are shown to provide additional information.

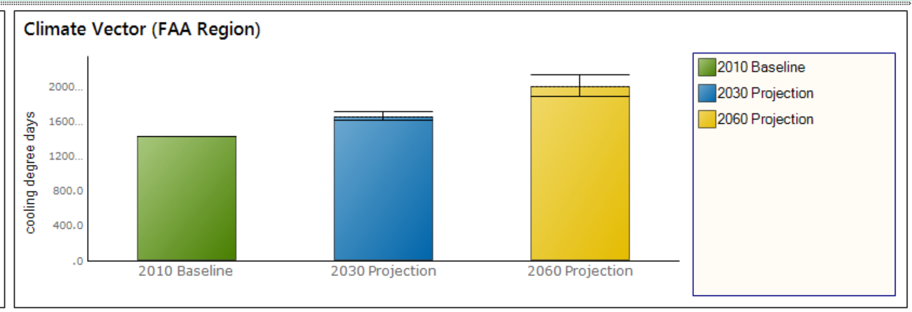
Cooling Degree Days
CONFIDENCE: High

CoolingDegreeDays

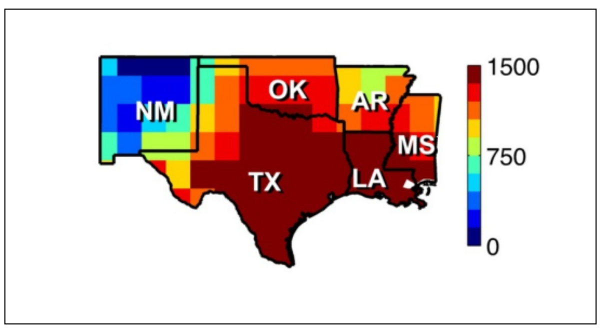
CONFIDENCE: HIGH

A Cooling Degree Day (CDD) is a unit of measure that reflects the energy demand needed to cool a building. The daily CDD is calculated by subtracting 65 from the day's average temperature. Daily CDDs are summed to obtain the accumulated CDD per year.



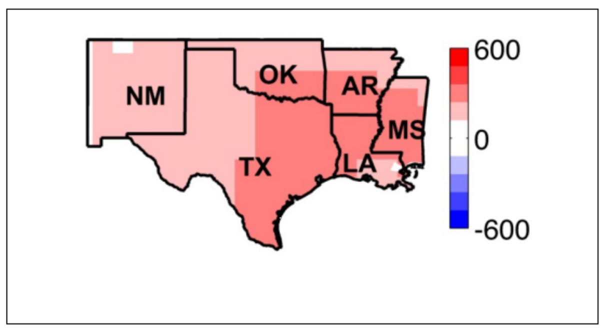


Yearly Accumulation of Degree-Days



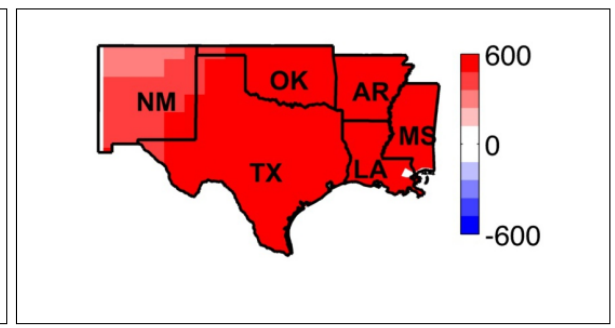
2010 (Baseline)

Change from Baseline in Yearly Accumulation of Degree-Days



2030 (Median)

Change from Baseline in Yearly Accumulation of Degree-Days



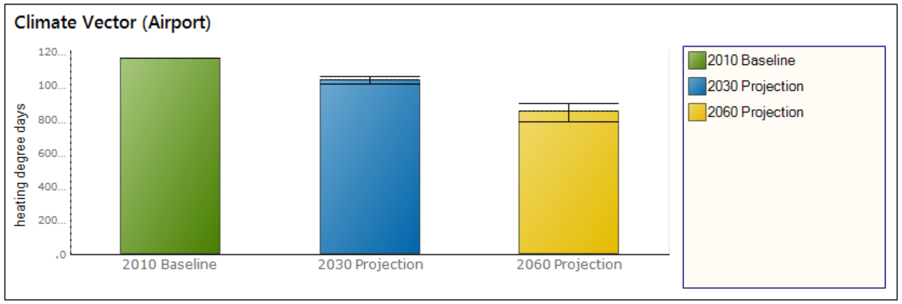
2060 (Median)

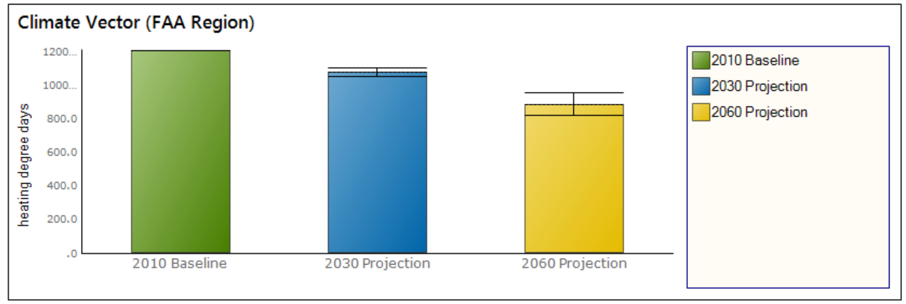
Heating Degree Days
CONFIDENCE: High

HeatingDegreeDays

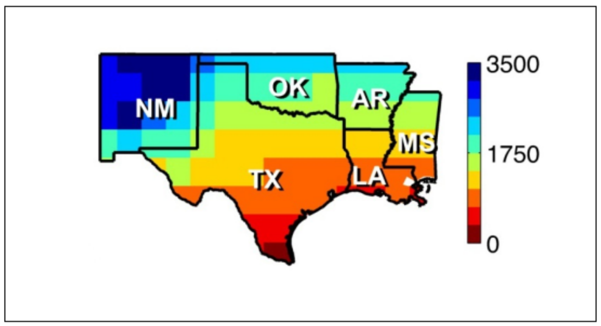
CONFIDENCE: HIGH

A Heating Degree Day (HDD) is a unit of measure that reflects the energy demand needed to heat a building. The daily HDD is calculated by subtracting the day's average temperature from 65. Daily HDDs are summed to obtain the accumulated HDD per year.



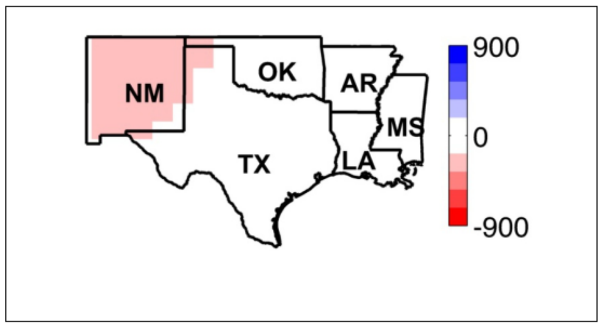


Yearly Accumulation of Degree-Days



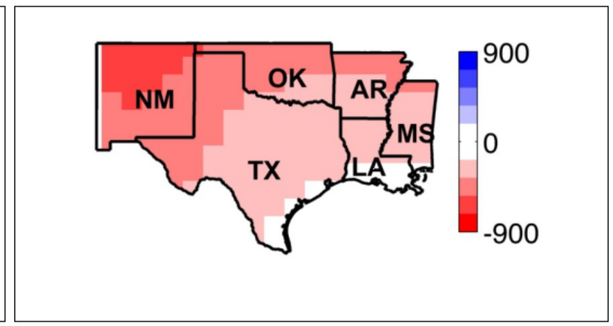
2010 (Baseline)

Change from Baseline in Yearly Accumulation of Degree-Days



2030 (Median)

Change from Baseline in Yearly Accumulation of Degree-Days



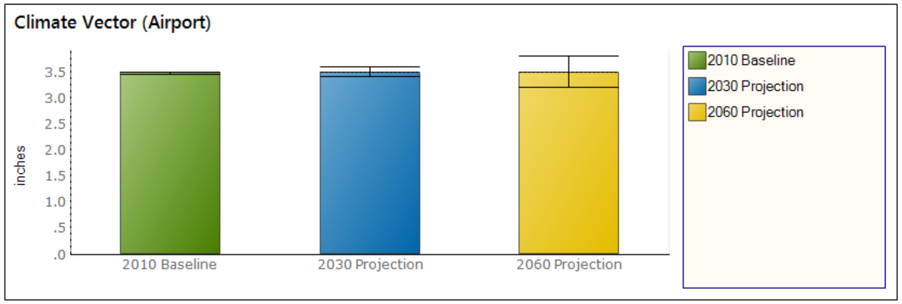
2060 (Median)

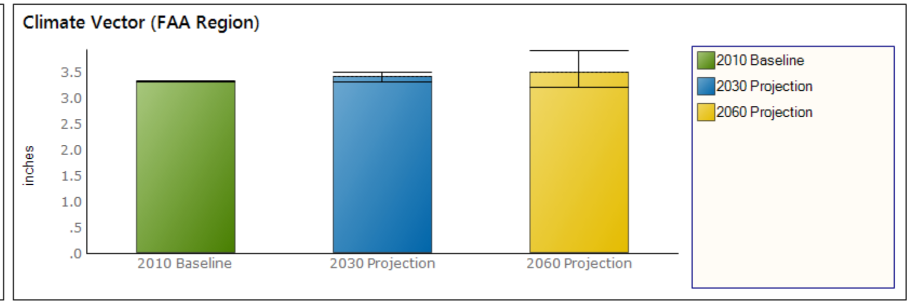
Heavy Rain (5 Day)
CONFIDENCE: Low

HeavyRain5Day

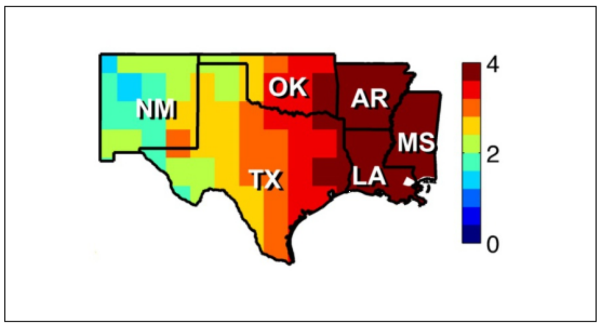
CONFIDENCE: LOW

Five-Day Heavy Rain is a measure of the maximum amount of rainfall that accumulates, in inches, over a five day period.



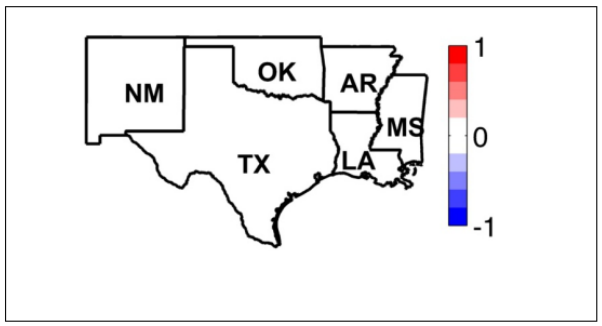


Inches of Rainfall



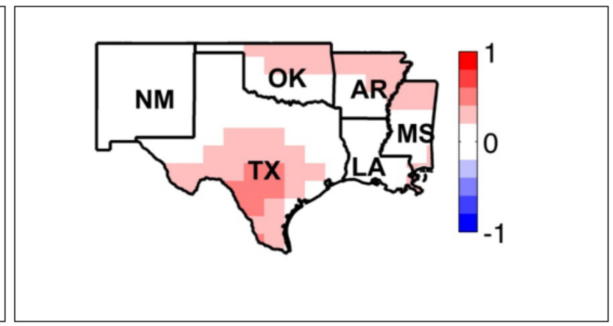
2010 (Baseline)

Change from Baseline in Inches of Rainfall



2030 (Median)

Change from Baseline in Inches of Rainfall



2060 (Median)

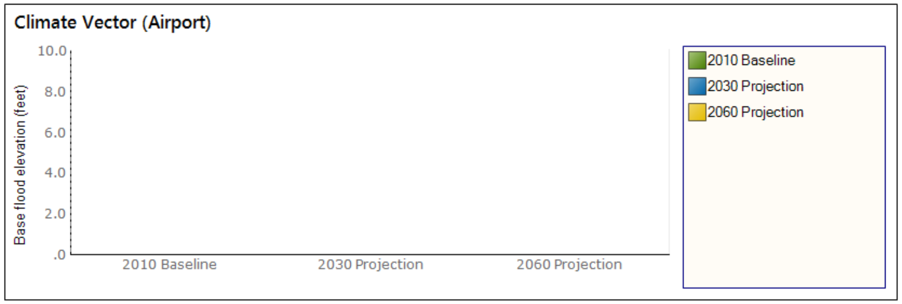
Sea Level Rise BFE

CONFIDENCE: High

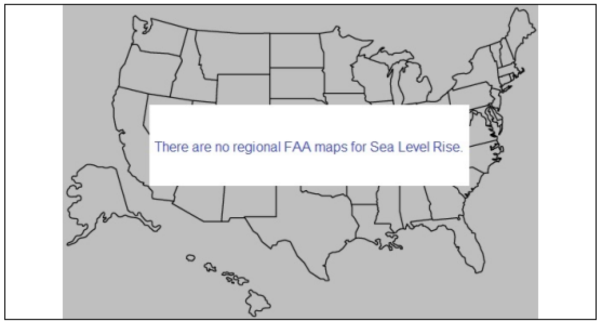
SeaLevelRise_BaseFloodElevation

CONFIDENCE: HIGH

The Base Flood Elevation (BFE) estimates the height to which floodwater is anticipated to rise during a 100-year flood event. BFE is measured in feet relative to the North American Vertical Datum of 1988 (NAVD88).

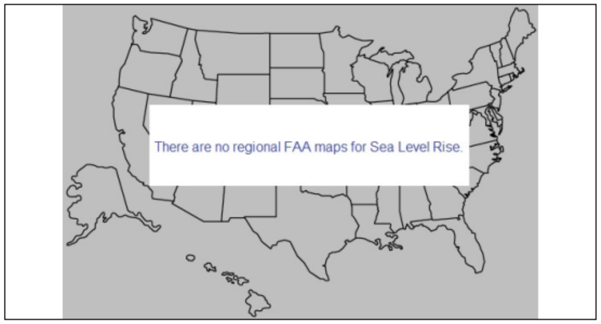


Base flood elevation (feet)



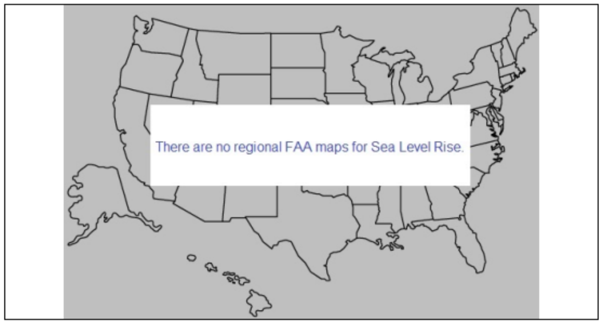
2010 (Baseline)

Change from Baseline in Base flood elevation (feet)



2030 (Median)

Change from Baseline in Base flood elevation (feet)



2060 (Median)

SCREENING

Relative to the selected airport, risk is categorized as:

= High Risk = Medium Risk = Low Risk

Section II: Risk (2030)

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Ground Access, Circulation, and Parking					Parking Facilities
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
		3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	1	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
		3	1	HotDays	Increased Pavement Temperature	• Offer More Covered Parking Facilities
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Ground Access, Circulation, and Parking					Access Roads
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
		3	2	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
		3	1	HotDays	Thermal Expansion	• Replace Expansion Joints
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🔴	**Utilities**					**On-Site Electrical Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🔴	2	3	HotDays	Insufficient Capacity Due to Increased Demand	• Generate Power Onsite • Increase Size of Electrical Service • Use Demand-Limiting Measures
	🔴	2	3	HotDays	Decreased Reliability of External Utility	• Add a Secondary Feed from an Additional Utility • Add or Increase Capacity for Onsite Generation • Arrange An Uninterruptable Power Rate • Use Demand-Limiting Measures
	🟡	2	2	VeryHotDays	Transformer Failure	• Install Supplemental Fans • De-Rate and Replace Or Supplement Transformer
	🔵	2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
	🔵	2	2	DryDays	Soil Expansion-Contraction	• Modify Fill Material at Underground Utilities to Alleviate Expansion

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🔴	**General Aviation Facilities**					**Aircraft Parking Aprons**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🔴	3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	🔵	3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🔴	**Commercial Passenger Terminal Facilities**					**Commercial Passenger Terminal Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***

	🔴	3	2	HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
	🔴	3	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	🔴	3	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	🔴	3	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	🔴	3	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	🔴	3	2	DryDays HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	🔵	3	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	🔵	3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🔴	**Commercial Passenger Terminal Facilities**					**Curbside Amenities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🔴	3	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections

						• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	3	1	HotDays DryDays	Reduced Visibility	• Increase Lighting
	●	3	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
	●	3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**General Aviation Facilities**					**Transient Aircraft Parking Apron Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	●	2	1	DryDays	Water-Reliant Maintenance Curtailed	• Install Gray Water Systems • Develop Water Conservation Protocols
	●	2	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Commercial Passenger Terminal Facilities**					**Gates (Passenger Boarding Bridges)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials,	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)

					External Seals) and / Or Mold Vulnerability	
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Airport Maintenance Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	HotDays	Roofing Material and Exterior Seals (Roof and	• Upgrade Roof with High Heat and Reflective Products

					Walls) Degradation	
		2	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	1	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Airport Administrative Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing	• Schedule More Frequent Inspections

					Materials, External Seals) and / Or Mold Vulnerability	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	General Aviation Facilities					**Loading and Unloading Equipment / Operation**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays DryDays	Wildfire Smoke	• Develop Personal Protective Strategies • Limit Activities During Poor Air Quality
		2	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Aircraft / GSE					**Demand and Capacity**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays DryDays CoolingDays	Reduced Throughput Capacity (Number of Planes Operating Out of the Facility)	• Plan for Fluctuations in Throughput Capacity
		2	1	HotDays HotNights HumidDays DryDays CoolingDays	Change in Tourism and Seasonal Enplanements	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	VeryHotDays	Increased Fire Hazards May Impede Flight Operations	• Plan for Increases in Fires • Assess Fire Main Capacity
		2	1	HotDays	Reduced Ability of Some Airports to	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

					Take Certain Aircraft	

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Apron**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Aircraft Rescue and Fire Fighting (ARFF)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	1	HotDays	Increase in Emergency Medical Situations	• Optimize Accessibility to Emergency Personnel
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Regional Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays	Thermal Expansion	• Cooperate with Regional Planners to Adjust Height Restrictions
		2	1	DryDays	Subsidence of Foundations	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	HotDays	Reduced Rate of Climb	• Cooperate with Regional Planners to Adjust Height Restrictions

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	Other					Grounds and Landscaping
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	1	2	DryDays HotDays	Increased Water Demand for Landscaping	• Modify Landscaping Methods and Elements

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	Environmental and Safety					Environmental (Noise, Air Quality, Water Quality and Quantity)
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	2	1	DryDays	Reduced Streamflow May Result in More Stringent Environmental Discharge Standards	• Improvements to BMP and Deicing Treatment System Performance
	●	2	1	HotDays	More Stringent GHG Emission Reduction Standards	• Transition GSE Fleet to Alternate Fuel Equipment
	●	2	1	HotDays	Noise Complaints Due to Increased Thrust	• Assess Noise Impacts
	●	2	1	HotDays HotNights HumidDays DryDays CoolingDays	Increases in Invasive Species	• Use Appropriate Wildlife and Landscape Management Techniques
	●	2	1	DryDays	Increased Fire Hazard With Droughts	• Plan for Increases in Fires • Assess Fire Main Capacity
	●	2	1	HotDays HotNights HumidDays DryDays CoolingDays	Number of Endangered Species Increases	• Use Appropriate Wildlife and Landscape Management Techniques

		2	1	HotDays	Ozone Pollution and Poor Air Quality	• Research and Improve Air Quality Reduction Policies and Procedures
		2	1	HotDays HotNights	Dryer Soils Lead to Reduced Vegetation and Increased Erosion	• Improvements to BMP Resiliency
		2	1	HotDays	Difficulties Re-Establishing Vegetation	• Use Appropriate Wildlife and Landscape Management Techniques

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Construction Activities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	HotDays DryDays	Construction Delays	• Schedule Work Around The Forecast • Schedule Work to Start and End Earlier in The Day

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Airfield / Airspace					**Runways, Taxiways, and Holding Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Lengthen Runway • Reduce Payload
		2	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		2	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Personnel and Passengers**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***

		2	1	HotDays	Heat Exposure	• Educate Employees about Heat Injuries • Schedule Cooling Breaks • Improve Temperature Control and Monitoring Strategies (Shades on Windows, Window Films, Covered Waiting Area, Misting Station, setc.) •
		2	1	HotDays	Limitation on Outdoor Maintenance and Services	• Use Longer Season to Absorb Work Delays Due to Weather and Air Quality
		2	1	HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
		2	1	HotDays	Change in Tourism and Seasonal Enplanements	• Plan for Changes in Magnitude and Timing of Passenger Travel
		2	1	HotDays HotNights HumidDays DryDays CoolingDays	Human Migration	• Plan for Changes in Magnitude and Timing of Passenger Travel

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Stormwater Drainage**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	DryDays	Permit Compliance Issues	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
		2	1	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		2	1	DryDays	Dryer Soils Lead to Reduced Vegetation and Increased Erosion	• Replace Vegetation With Drought Resistant Vegetation Or Structural BMPs.
		2	1	HotDays	Permit Compliance Issues Due to High Pollutant Loads	• Monitor and Adjust Outdoor Water Use With Respect to Pollutant Loading

	●	2	1	DryDays	Decreased Discharge Quantity and Impaired Quality	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Support Facilities**					**Flight Kitchens**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	1	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	1	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	1	HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
	●	1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs
	●	1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling

						• Improve Building Envelope • Replace Equipment According to Climate Zone
		1	1	HotDays	Increased Water Demand	• Plan for Increased Water Consumption
		1	2	DryDays HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Aircraft / GSE					**Ground Service Equipment**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays	Non-Attainment of Air Quality Standards	• Transition GSE Fleet to Alternate Fuel Equipment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Aircraft / GSE					**Aircraft Performance**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays	Weathering of Fleet (Tires)	• Change Tires More Frequently • Clean Runways More Frequently
		2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
		2	1	HotDays	Foreign Object Damage (Tires and Deteriorated Pavement)	• Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Aircraft Fuel Storage / Fueling**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	1	DryDays	Subsidence of Foundations	• Modify Fill Material

		1	1	VeryHotDays	Potential Increase In Fire Risks (Flashpoint of Aviation Fuel Is 100°F)	• Plan for Increases in Fires • Assess Fire Main Capacity
		1	1	HotDays HotNights	Increased Fuel Consumption	• Expand On-Site Storage Capacity

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Water Distribution Systems**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	1	DryDays	Reduced Water Availability Due to Drought	• Utilize Water Conserving Fixtures and Landscaping
		3	1	DryDays	Less Water Main Flushing	• Continue Monitoring and Disinfection of Water Supply System
		3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Sanitary Sewer**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Communications**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Airfield / Airspace					**Navigational Aids**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	DryDays	Soil Expansion-Contraction	• Replace NAVAID Foundations

Section II: Risk (2060)

OVERALL RISK	SERVICE:				ASSET/OPERATION:
	Ground Access, Circulation, and Parking				**Parking Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	1	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
		3	1	HotDays	Increased Pavement Temperature	• Offer More Covered Parking Facilities
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	SERVICE:				ASSET/OPERATION:
	Ground Access, Circulation, and Parking				**Access Roads**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
		3	1	HotDays	Thermal Expansion	• Replace Expansion Joints
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	SERVICE:	ASSET/OPERATION:

	General Aviation Facilities					**Aircraft Parking Aprons**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**On-Site Electrical Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	3	HotDays	Insufficient Capacity Due to Increased Demand	• Generate Power Onsite • Increase Size of Electrical Service • Use Demand-Limiting Measures
		2	3	HotDays	Decreased Reliability of External Utility	• Add a Secondary Feed from an Additional Utility • Add or Increase Capacity for Onsite Generation • Arrange An Uninterruptable Power Rate • Use Demand-Limiting Measures
		2	2	VeryHotDays	Transformer Failure	• Install Supplemental Fans • De-Rate and Replace Or Supplement Transformer
		2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		2	2	DryDays	Soil Expansion-Contraction	• Modify Fill Material at Underground Utilities to Alleviate Expansion

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Commercial Passenger Terminal Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies

		3	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		3	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		3	2	DryDays HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		3	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Curbside Amenities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	1	HotDays DryDays	Reduced Visibility	• Increase Lighting

		3	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Airport Maintenance Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	1	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems

						• Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	General Aviation Facilities					**Loading and Unloading Equipment / Operation**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays DryDays	Wildfire Smoke	• Develop Personal Protective Strategies • Limit Activities During Poor Air Quality
		2	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Gates (Passenger Boarding Bridges)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems

						• Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🟡	**General Aviation Facilities**					**Transient Aircraft Parking Apron Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	2	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	🔵	2	1	DryDays	Water-Reliant Maintenance Curtailed	• Install Gray Water Systems • Develop Water Conservation Protocols
	🔵	2	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🟡	**Support Facilities**					**Airport Administrative Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	🟡	2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	🟡	2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	🟡	2	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	🔵	2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan

		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Aircraft / GSE					**Demand and Capacity**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays DryDays CoolingDays	Reduced Throughput Capacity (Number of Planes Operating Out of the Facility)	• Plan for Fluctuations in Throughput Capacity
		2	1	HotDays HotNights HumidDays DryDays CoolingDays	Change in Tourism and Seasonal Enplanements	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	VeryHotDays	Increased Fire Hazards May Impede Flight Operations	• Plan for Increases in Fires • Assess Fire Main Capacity
		2	1	HotDays	Reduced Ability of Some Airports to Take Certain Aircraft	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Apron**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement

		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Aircraft Rescue and Fire Fighting (ARFF)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	1	HotDays	Increase in Emergency Medical Situations	• Optimize Accessibility to Emergency Personnel
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Stormwater Drainage**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	DryDays	Permit Compliance Issues	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
		2	1	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		2	1	DryDays	Dryer Soils Lead to Reduced Vegetation and Increased Erosion	• Replace Vegetation With Drought Resistant Vegetation Or Structural BMPs.
		2	1	HotDays	Permit Compliance Issues Due to High Pollutant Loads	• Monitor and Adjust Outdoor Water Use With Respect to Pollutant Loading
		2	1	DryDays	Decreased Discharge Quantity and Impaired Quality	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Regional Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***

	●	2	1	HotDays	Thermal Expansion	• Cooperate with Regional Planners to Adjust Height Restrictions
	●	2	1	DryDays	Subsidence of Foundations	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	●	2	1	HotDays	Reduced Rate of Climb	• Cooperate with Regional Planners to Adjust Height Restrictions

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Other**					**Personnel and Passengers**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	HotDays	Heat Exposure	• Educate Employees about Heat Injuries • Schedule Cooling Breaks • Improve Temperature Control and Monitoring Strategies (Shades on Windows, Window Films, Covered Waiting Area, Misting Station, setc.) •
	●	2	1	HotDays	Limitation on Outdoor Maintenance and Services	• Use Longer Season to Absorb Work Delays Due to Weather and Air Quality
	●	2	1	HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
	●	2	1	HotDays	Change in Tourism and Seasonal Enplanements	• Plan for Changes in Magnitude and Timing of Passenger Travel
	●	2	1	HotDays HotNights HumidDays DryDays CoolingDays	Human Migration	• Plan for Changes in Magnitude and Timing of Passenger Travel

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Aircraft / GSE**					**Ground Service Equipment**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	HotDays	Non-Attainment of Air Quality Standards	• Transition GSE Fleet to Alternate Fuel Equipment

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	**Support Facilities**					**Flight Kitchens**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	1	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	1	2	HumidDays	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	1	HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
	●	1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs
	●	1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	1	1	HotDays	Increased Water Demand	• Plan for Increased Water Consumption
	●	1	2	DryDays HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Grounds and Landscaping**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	DryDays HotDays	Increased Water Demand for Landscaping	• Modify Landscaping Methods and Elements

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Construction Activities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	HotDays DryDays	Construction Delays	• Schedule Work Around The Forecast • Schedule Work to Start and End Earlier in The Day

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Airfield / Airspace					**Runways, Taxiways, and Holding Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Lengthen Runway • Reduce Payload
		2	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		2	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Environmental and Safety					**Environmental (Noise, Air Quality, Water Quality and Quantity)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***

	●	2	1	DryDays	Reduced Streamflow May Result in More Stringent Environmental Discharge Standards	• Improvements to BMP and Deicing Treatment System Performance
	●	2	1	HotDays	More Stringent GHG Emission Reduction Standards	• Transition GSE Fleet to Alternate Fuel Equipment
	●	2	1	HotDays	Noise Complaints Due to Increased Thrust	• Assess Noise Impacts
	●	2	1	HotDays HotNights HumidDays DryDays CoolingDays	Increases in Invasive Species	• Use Appropriate Wildlife and Landscape Management Techniques
	●	2	1	DryDays	Increased Fire Hazard With Droughts	• Plan for Increases in Fires • Assess Fire Main Capacity
	●	2	1	HotDays HotNights HumidDays DryDays CoolingDays	Number of Endangered Species Increases	• Use Appropriate Wildlife and Landscape Management Techniques
	●	2	1	HotDays	Ozone Pollution and Poor Air Quality	• Research and Improve Air Quality Reduction Policies and Procedures
	●	2	1	HotDays HotNights	Dryer Soils Lead to Reduced Vegetation and Increased Erosion	• Improvements to BMP Resiliency
	●	2	1	HotDays	Difficulties Re-Establishing Vegetation	• Use Appropriate Wildlife and Landscape Management Techniques

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Aircraft / GSE**					**Aircraft Performance**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	HotDays	Weathering of Fleet (Tires)	• Change Tires More Frequently • Clean Runways More Frequently
	●	2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
	●	2	1	HotDays	Foreign Object Damage (Tires and Deteriorated Pavement)	• Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	Support Facilities					Aircraft Fuel Storage / Fueling
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	1	1	DryDays	Subsidence of Foundations	• Modify Fill Material
	●	1	1	VeryHotDays	Potential Increase In Fire Risks (Flashpoint of Aviation Fuel Is 100°F)	• Plan for Increases in Fires • Assess Fire Main Capacity
	●	1	1	HotDays HotNights	Increased Fuel Consumption	• Expand On-Site Storage Capacity

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	Utilities					Water Distribution Systems
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	3	1	DryDays	Reduced Water Availability Due to Drought	• Utilize Water Conserving Fixtures and Landscaping
	●	3	1	DryDays	Less Water Main Flushing	• Continue Monitoring and Disinfection of Water Supply System
	●	3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	Utilities					Sanitary Sewer
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	SERVICE:	ASSET/OPERATION:
●	Utilities	Communications

	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
		2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Airfield / Airspace					**Navigational Aids**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	DryDays	Soil Expansion-Contraction	• Replace NAVAID Foundations

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Mud Springs Creek
Watershed
PROTECT OUR RIVERS

STORMWATER MANAGEMENT PROGRAM

DFW
DALLAS
FORT WORTH
INTERNATIONAL
AIRPORT

August 2021

CDM Smith

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Signature and Certification

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Table of Contents

List of Figures

List of Tables

Appendices

Acronyms

A/E	Architecture/ Engineering
AC	Advisory Circular
ACROS	Airport Climate Risk Operational Screening
ACRP	Airport Cooperative Research Program
AOA	Airport Operations Area
ARFF	Aircraft Rescue and Fire Fighting Road
BMP	Best Management Practices
CAD	Computer-Aided Design
CBOD	Carbonaceous Biochemical Oxygen Demand
CEQ	Council on Environmental Qualities
CFS	Cubic Feet per Second
CIMM	Center for Infrastructure Modeling and Management
CIP	Capital Improvement Program
CLOMR	Conditional Letter of Map Revision
CWA	Clean Water Act
DCM	Design Criteria Manual
DFWIA	Dallas Fort Worth International Airport
EISA	Energy Independence and Security Act
EMC	Event Mean Concentration
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
ETAM	Energy, Transportation, & Asset Management
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FIRMs	Flood Insurance Rate Maps
FIS	Flood Insurance Study
fps	Feet per Second
FHA	Federal Highway Administration
GCM	Global Climate Models
GIS	Geographic Information Systems
GSI	Green Stormwater Infrastructure
H&H	Hydrologic and Hydraulic
HEC	Hydrologic Engineering Center
HVAC	Heating, Ventilation, and Air Conditioning
IDDE	Illicit Discharge Detection and Elimination
iSWM	Integrated Stormwater Management by NCTCOG
ILS	Instrumentation Landing System
LID	Low-Impact Development

LiDAR	Light Detection and Ranging
LOMR	Letter of Map Revision
LOS	Level of Service
MCM	Minimum Control Measure
MSGP	Multi-Sector General Permit
MS4	Municipal Separate Storm Sewer System
NAVD88	North American Vertical Datum of 1988
NAS	National Academy of Sciences
NCTCOG	North Central Texas Council of Governments
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination Systems
NRCS	Natural Resources Conservation Service
O&M	Operation and Maintenance
PSMS	Primary Stormwater Management System
RAS	River Analysis System
SDMP	Stormwater Drainage Master Plan
SOP	Standard Operating Procedures
SWMM	EPA Stormwater Management Model
SWMP	Stormwater Management Program
SWP3	Stormwater Pollution Prevention Plan
SWPTP	DFWIA Stormwater Pretreatment Plant
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollutant Discharge Elimination System
TPH	Total Petroleum Hydrocarbons
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation
UNT	University of North Texas
USACE	U.S. Army Corps of Engineers
USDA SCS	United States Department of Agriculture Soil Conservation Service
WOTUS	Waters of the United States
WQ_V	Water Quality Volume
WSM	Watershed Management

Section 1

Program Overview

1.1 Introduction

The purpose of the Dallas Fort Worth International Airport (DFWIA) Stormwater Management Program (the Program) is to establish the policies, procedures, and practices for an effective stormwater management plan. The Program will provide a process for the Stormwater Drainage Master Plan (SDMP) to be updated periodically and recalibrated based on future development, regulatory changes, and/or organizational priorities. The Program will be used by the DFWIA Energy, Transportation, & Asset Management (ETAM)/Systems Performance/Watershed Management (ETAM/WSM) group as a guiding document to maintain the SDMP. The Program formalizes the process for compiling, submitting, and updating data associated with stormwater management including Geographic Information Systems (GIS) spatial data, design documents, and hydrologic and hydraulic [H&H] model data sets.

This document also establishes an integrated approach for the operation and maintenance (O&M) of the stormwater drainage system components as well as site-specific Green Stormwater Infrastructure (GSI) guidelines. DFWIA property leasees will continue to be responsible for providing updated site information and operating and maintaining their respective stormwater facilities. For these facilities, ETAM requires that access be provided to ensure continuous operational capability of the system, confirmed via periodic inspections by DFWIA staff. The airport will review the design and construction of these features, but it will not accept ownership of private drainage facilities.

Section 2

Transfer of Data from Stormwater Drainage Master Plan

2.1 General

DFWIA has GIS spatial data and existing SWMM models to provide designers with the most up-to-date information established in the SDMP. Any reliance on this data is at the designers' own risk, and all data should be verified by the designer.

GIS Data and SWMM models will be shared with external entities based on the following criteria:

- Only geographical subset areas will be distributed, not entire GIS datasets. The base GIS dataset will be stored separately for protection against potential malware.
- Distribution will be made in the form of geodatabases and United States Environmental Protection Agency (EPA) Stormwater Management Model (SWMM), version 5+. The base SWMMs will be stored separately for reference to established primary stormwater management system (PSMS) features and results.
- Distribution of data will be controlled to prevent a threat to security and shall not be shared for use on other projects.

All data transfers are to be made through ETAM via an Information Request Form. In addition to the form, the watershed(s) should be referenced and a shapefile or geodatabase showing the geographical location of the area under consideration should also be provided. Once received, the Information Request Form will be evaluated by the DFWIA GIS/SWMM manager to verify the request. The GIS manager will then extract the geographical area containing relevant information, which will then be provided to the designer.

2.1.1 GIS Data

Once an Information Request Form is processed, the GIS manager will extract the available data and send it to the requester.

- The following geodatabases may be provided to the requestor:
  - Land Use Areas
  - Impervious Areas (Current)
  - Impervious Areas (Date at Time of SDMP Development)
  - Soil Classification(s)
  - DFWIA GIS Geodatabase of all Relevant Stormwater Infrastructure
  - Watershed Boundaries

- Floodplain Inundation and Buffer Boundaries
- Major Infrastructure–Buildings, Light Rail, etc.

The developer may find some limits to the data developed by the SDMP. SWMM models are at a master plan level and generally pipes 36 inches and larger were modeled to represent the Primary Stormwater Management System (PSMS). Smaller pipes are in the GIS but not in the models of the stormwater system. For this reason, the GIS geodatabase of all existing stormwater infrastructure in the area of interest will be provided to the developer to allow them to develop more detailed, design-level models.

2.1.2 FEMA Floodplain and SDMP Inundation Maps

FEMA floodplain maps as well as the conceptual inundation maps developed using SWMM results as part of SDMP will be distributed to developers in the form of shapefiles or a geodatabase. On-site flood inundation maps have been developed as part of this SDMP and are presented as part of each watershed study. The DFWIA SDMP design event inundation maps do not replace the FEMA Flood Insurance Rate Maps (FIRMs) as the effective regulatory floodplain document, with respect to elevations and areas. They are intended to identify problem areas and assist with identification of flood reduction benefits for mitigative measures. These inundation maps may be used as a guide by DFWIA to advance or limit development of the two boundaries where the SDMP models show higher flood stages and greater areas of inundation. Development is regulated within regulatory FEMA floodplain limits by FEMA requirements and regulated by ETAM within SDMP inundation limits, or FEMA/SDMP buffer areas. Compensatory storage for the 100-year inundation floodplain volume must be provided onsite and connected to the PSMS in addition to attenuation for increased runoff and flows and treatment as required by the TPDES MS4 permit. Additionally, it is the responsibility of the developer to compare to FEMA floodplain regulations and the ETAM DFWIA SDMP inundation maps for calculations of compensatory storage.

2.1.3 Models

Modeling of the PSMS was performed using the EPA SWMM, version 5. Refer to the SDMP for a detailed description of modeling efforts. These models may be requested for informational use and used to provide baseline H&H conditions for the eight watersheds in the airport. Models also will be used to help establish model inflows as well as tailwater boundary conditions in the development of detailed design models. The eight existing watershed models will be updated as needed after the creation of the SDMP. The developer will verify that data received for their area of interest is up to date before proceeding with design.

2.1.4 Post-SDMP Revisions

Since the creation of the SDMP, development may have occurred that is not reflected in the watershed models of the PSMS, as they were based on a land use condition representative of May 2017. A preliminary list of constructed developments will be provided to the developer (Section 2.1.1), but the developer must verify that data is up to date.

2.2 Data Submittal Requirements

For DFWIA to maintain the SDMP, developers will be required to demonstrate clearly that their proposed project results in no increases in peak discharge rate for the entire range of storm events (the 1-, 5-, 10-, 25, 100-, and 500-yr 24-hour design storms), no increase in on-site or off-site stages, and no adverse off-site impacts. The developer will be required to provide as-builts in the form of construction as-built drawings, revised geodatabases, inundation maps, site-specific stormwater models, and watershed masterplan models (if applicable.) All data provided will follow standardized naming conventions and format established as a part of the SDMP. Both the modeling efforts and future needs will rely on accurate, complete, and fully attributed GIS data being provided back to DFWIA. The GIS Enterprise Geodatabase is enabled with editor tracking that will record the creation of new features or any edits to existing features. This function will record both the time of the creation/edit/update as well as the user. If needed, DFWIA, can query updates from any point in the time desired. Data submittal will be coordinated through the following email as the contact point from ETAM:

etam_wsm@dfwairport.com

2.2.1 GIS Data

2.2.1.1 Drainage Areas

The developer will provide updated drainage areas and the longest flow-paths in geodatabase format. ETAM then will use these parameters to establish SWMM subcatchment attributes.

2.2.1.2 Drainage Structures

The developer will provide back to the airport any updates to stormwater infrastructure, including the following:

- Pipes
- Culverts
- Inlets
- Junctions
- Detention Basins or Ponds
- Open Channels (Including Cross Sections)
- Control Structures
- Energy Dissipation Structures
- GSI Best Management Practices (BMPs)
- Other Stormwater Infrastructure

2.2.1.3 Land Use Areas

The developer will provide any updated land use and impervious area information in geodatabase format back to the airport. The geodatabase should only include the areas updated from development to clearly demonstrate where changes have been made.

2.2.2 Annotated SDMP Inundation Maps

If, in the course of development, discrepancies between the models and existing site conditions are found, developers will also be required to provide updated stormwater system and/or topographic information shown on annotated inundation/floodplain maps. In the event that proposed development modifies FEMA regulatory boundaries the developer will be responsible for coordinating with FEMA and submitting a required Letter of Map Revision (LOMR) or Conditional Letter of Map Revision (CLOMR) through ETAM/WSM for approval prior and submittal to FEMA. The developer is responsible for all FEMA CLOMR/LOMR costs associated with their development, including FEMA permitting fees.

Section 3

Operations and Maintenance

3.1 Reasons for Stormwater Facility Maintenance

3.1.1 Compliance with DFWIA Guidelines

DFWIA is required to meet regulatory standards for stormwater quality from the following three essential organizations: EPA, whose Clean Water Act (CWA) is enforced through the Texas Council on Environmental Quality (TCEQ) and the TPDES permit; the Council on Environmental Qualities (CEQ). Additionally water quantity and hazardous land use protection requirements must be met as defined through guidance and Advisory Circulars (ACs) by the Federal Aviation Administration (FAA), including Clear Zone and Airport instrumentation landing system (ILS) and lighting system protections; design storm rainfall and limitations on stormwater ponding along runways, taxiways, and emergency facilities; limitations on fog and bird attractant land uses; and BMPs.

The TCEQ is the organization responsible for enforcing DFWIA's compliance of the CWA. The DFWIA 2021 GSI Manual, prepared by the University of Texas's Center for Infrastructure Modeling and Management (CIMM) indicates that compliance with the CWA "includes the Municipal Separate Storm Sewer System (MS4) permitting process" (CIMM 2021). The boundaries of DFWIA have been categorized as MS4 and require the necessary permitting to classify it as such. The MS4 permits, in turn, require treatment of the stormwater entering DFWIA. "DFWIA is required to address the quality of stormwater discharged from new developments and significant redevelopments to the maximum extent practicable" (CIMM 2021).

"…DFWIA has received and continues to receive federal funding for the airport, [because of this] they are subject to the National Environmental Policy Act (NEPA)" (CIMM 2021). The NEPA is enforced through TCEQ and, through this enforcement, they have required DFWIA to complete Environmental Impact Statements (EISs) whenever construction is done on the property, from pre-construction of the airport to current expansions. "NEPA requires where a potential environmental impact is likely that, that impact must be mitigated. NEPA [also] requires that water quality impacts from developed areas be mitigated to protect [the] waters of the U.S." (CIMM 2021).

The FAA has released Advisory Circulars, such as AC series 150, that provide guidance in meeting and addressing criteria and issues that are highlighted by the National Academy of Sciences (NAS) and their corresponding Transportation Research Board (TRB) in Airport Cooperative Research Program (ACRP) studies. These reports call attention to following the standards set by the CWA as well as managing stormwater through GSI.

3.1.2 Preventative Measures to Reduce Maintenance Costs

GSI and stormwater collection and conveyance mechanisms are the two primary treatment practices discussed in this manual. For each of these elements of the stormwater infrastructure system, there are two foundational reasons for a robust inspection and maintenance program:

- Inspection and maintenance of existing facilities reduce long-term costs by preventing the need for early replacement of infrastructure in disrepair.
- Routine maintenance of the stormwater system is necessary to maintain functionality and, therefore, is required as a part of the DFWIA National Pollutant Discharge Elimination Systems (NPDES) MS4 permit to improve water quality to the maximum extent practicable.

Frequent inspection and maintenance tend to result in nominal annual maintenance costs and a lower life-cycle cost by reducing the need for costly repairs or replacement of infrastructure by proactively addressing issues as they develop rather than when they become problems. Routine maintenance generally does not require the planning, design, material costs, and extensive construction labor costs associated with extensive repairs. For example, remediation of minor erosion and its resulting downstream sedimentation can prevent the need to completely replace culverts, bridges, roads, embankments, or fouled water quality media.

In addition to reducing life-cycle costs, routine maintenance maximizes the effectiveness of stormwater infrastructure. This is particularly important with regard to GSI components of the stormwater system that rely upon engineered media and vegetation to accomplish the intended improvements to water quality.

3.2 Stormwater Management Facilities

As discussed in Section 3.1.1, GSI and stormwater collection and conveyance mechanisms are the primary stormwater management facilities discussed in this manual. Stormwater collection and conveyance infrastructure are conventionally used when managing runoff from storm events. The predominant stormwater collection and conveyance mechanisms are inlets, outfalls, swales, grass filter strips, and channels, each of which is discussed subsequently. GSI, also commonly referred to as BMPs, are less common. However, BMPs are still very effective and offer benefits that extend beyond traditional stormwater management, such as improving water quality. The GSI discussed in this manual includes rain gardens (bioretention basins), sand filters, extended (dry) detention basins, vegetative filter strips, grass swales, and permeable or porous pavers. As appropriate, references to applicability for airside and/or landside areas are referenced consistent with AC series 150 requirements.

3.2.1 Stormwater Collection and Conveyance

3.2.1.1 Inlets

Stormwater inlets are structures that are purposed to collect runoff from storm events from paved surfaces, parks, and landscaped and open space areas, and then carry it to below ground pipe drains. Storm drain inlets are to be cleaned, repaired, or replaced as needed to prevent failure of the device and the potentially resultant flooding. A functioning inlet is foundational to preventing unanticipated inundation of nearby land and infrastructure. Routine cleaning of inlets, therefore, is paramount to maintaining a functioning system. Inlets can also become structurally inadequate due to excessive loads or impacts from vehicles or equipment, losing functionality and becoming a safety hazard for vehicular and pedestrian traffic. The maintenance cycles provided below are minimums. Structures will be maintained on a more frequent basis as needed.

Any inlets that are in operation during construction should be protected to keep debris, sediment, and untreated stormwater from entering the system. Inlet protection devices, which are added to inlets during construction to keep them stabilized and prevent erosion, will be removed at the conclusion of the project. Inlets and catch basins must be maintained and properly cleaned to prevent sediments from passing into the drainage control system.

An Inlet Inspection Checklist is provided in Appendix A.

Table 3-1 Inlet Maintenance Items

Inlet Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Clean and remove sediment, leaves, trash, and debris.													*
Repair and re-vegetate eroded areas near the inlet. Provide additional armoring as necessary.													*
Trim vegetation.													*
Repair frames, grates, and structure.													*

*As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year.

3.2.1.2 Outfalls

Outfalls are devices used to control the physical conditions as runoff exits one element of the stormwater system and is conveyed into a downstream component of the stormwater system. Some examples of outfalls include pipes, culverts, headwalls, and overflow weirs. The immediately adjacent reach of the downstream system, such as a swale, ditch, or channel also functions as a part of the outfall system. The O&M of outfall structures requires maintenance of the outfall device as well as the prevention of erosion in the downstream receiving system. If left unattended, minor erosion in the downstream system can undermine the structural integrity of the outfall, increase the transport of sediment downstream, and pose risks to adjacent infrastructure. Early correction of erosive conditions is essential to prevent more costly repairs in the future. Maintenance often includes placing fill and re-vegetating eroded areas, identifying and eliminating the source of the erosion, or providing additional soft or hard armoring measures to mitigate the threat of continued erosion. Larger-scale erosion due to head-cutting in a downstream channel can also place outfall infrastructure at risk. The maintenance cycles provided below are minimums. Outfalls shall be maintained on a more frequent basis as needed. Outlets should also be checked frequently after storm events to ensure that no debris or pollutants are obstructing the structure from appropriately conveying stormwater.

An Outfall Inspection Checklist is provided in Appendix A.

Table 3-2 Outfall Maintenance Items

Outfall Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Clean and remove sediment, leaves, trash, and debris.													*
Repair and re-vegetate eroded areas near the outfall. Provide additional armoring as necessary.													*
Trim vegetation.													*
Repair damaged structural elements.													*

*As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year

3.2.1.3 Channels

Stormwater conveyance channels are permanent waterways, natural or constructed, which convey stormwater runoff. Channels, similar to outfalls, require well-built stabilizing structures to prevent erosion of the channel bed and banks. Maintenance of channel erosion begins with assessing the root cause of the erosion. Only after determining the cause can a proper maintenance plan be developed. Like most stormwater maintenance activities, early routine maintenance can prevent more costly repairs that occur when an issue is left unattended.

Preventing erosion of the streambank toe of slope is a key to preventing erosion of the channel bank. Threats to the stability of the toe of slope include head-cutting within the channel, excessive shear stress, particularly on the outside bend of a channel, localized erosion from adjacent outfalls, inadequate vegetative cover caused by high velocities, drought, and localized or global geotechnical stability failures that are often a result of rapid drawdown on the tail end of high flows in the channel. Inspection of channels by a multi-disciplined team enhances the ability to identify the root causes of streambank erosion.

There are many methods that can be used to stabilize a channel; instream structures such as vane structures, erosion control matting, and root wads are a few of many options that can be implemented. Beyond adding bioengineered structures to a channel, a more aesthetically conducive way the banks can be stabilized is by establishing a strong riparian buffer. Following construction of a channel is when the streambanks are at their most vulnerable and is often when sudden erosion occurs. This vulnerability is due to the roots of the riparian vegetation being not yet foundationally established in the streambank soils.

Natural solutions are preferred to hard armoring because they are often a more sustainable practice, generally cost less, and provide better water quality benefits. As the threat to infrastructure and the public is increased due to close proximity to an erosive channel, the reliance on natural solutions typically diminishes and reliance on hard armoring becomes more appropriate.

The maintenance cycles provided in Table 3-3 are minimums. Channels shall be maintained on a more frequent basis as needed. A Channel Inspection Checklist is provided in Appendix A.

Table 3-3 Channel Maintenance Items

Channel Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Replace eroded soil and re-vegetate as necessary.										1			1
Install bioengineering remedies such as root wads, vanes, and engineered vegetation plans, as determined by an inter-disciplined team.			1										1
Install structures such as channel-grade control, riprap, grouted riprap, or walls as necessary.			1										1
Remove all trash, debris, fallen branches, or trees.			1										1
Remove sediment buildup.			1										1
Mow non-native sodded turf grasses to 2-inch height and bag turf clippings to prevent thatch and drain feature choking/clogging.				1			1			1			3 or *
Mow native grasses and perennials (wildflowers) to no less than 5- to 7-inch height and bag clippings to prevent thatch and drain feature choking/clogging.	1						1						2

*As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year

3.2.2 Green Stormwater Infrastructure

3.2.2.1 Sand Filters–Landside

3.2.2.1.1 Description

Sand filters and other types of media filters purify stormwater by sifting out pollutants. As seen in Figure 3-1, there are two main components of sand filters: the sediment forebay and the filtration chamber. As mentioned by CIMM in their 2021 GSI Manual, "The sediment forebay should be included for sand filters with drainage areas over 2-acres and can be included in smaller sand filters to remove floatables, large materials, and sediment before [it is] filtered through the sand or other media" (CIMM 2021).

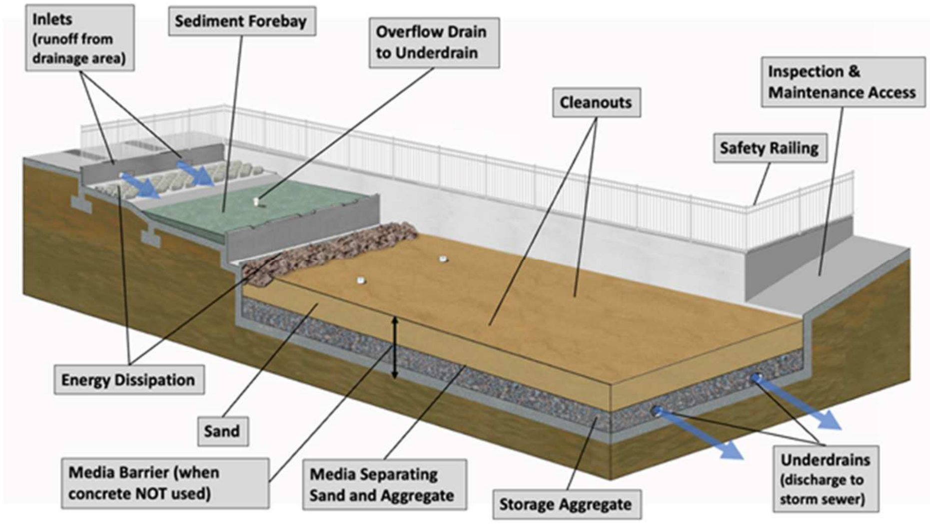

Figure 3-1 Conceptual Rendering of a Sand Filter using Concrete (Adapted from TRWD 2018)

3.2.2.1.2 Function

The key function of sand filters is to remove pollutants from stormwater. Relying on gravity, sand filters force heavy sediments to settle, which then allows the structure to remove any fine sediments and pollutants from the stormwater via filtration. Sand filters are often enacted to treat stormwater runoff in relatively large areas, "…generally up to 10-acre[s]" (CIMM 2021).

3.2.2.1.3 Inspection and Maintenance Cycles

Inspection and infiltration testing of all sand filter facilities will occur on an annual basis. Additionally, inspections will occur within 48 hours of all rainfall events recorded at the DFWIA rain gauge that meet or exceed 1.0inches in 24 hours.

The maintenance cycles provided in Table 3-4 are minimums. Sand filters will be maintained on a more frequent basis as needed. A Sand Filter Inspection Checklist is provided in Appendix A.

Table 3-4 Sand Filter Maintenance Items

Sand Filter Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Hand weed beds – do not allow invasive weeds to seed or seedling shrubs/trees to establish and mature; do not spread seeds or spores.			2	2	2	2	2	2	2	2	1		17

Sand Filter Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Install temporary closures at curb inlet/splash pad/forebay openings for 6 to 9 months to allow root establishment and prevent washout of turf grasses. If seeded or sodded, remove closure, clean and remove silt/ sediments and trash/debris regularly.	1	1	1	1	1	1	1	1	1	1	1	1	12
Clean and remove sediment, leaves, weeds, logs, branches, and debris, and repair/restore aggregate energy dissipation areas.	1	1	1	1	1	1	1	1	1	1	1	1	12
Remove all trash, debris, fallen branches, trimmings, and thatch from sand/grass areas.	1	1	1	1	1	1	1	1	1	1	1	1	12
Scrape away sediment and debris off top and replace with clean sand filtration media		1						1					2
Perform double ring infiltrometer test (ASTM D3385)once every 3 years.		1											1 or *
Apply only approved organic insecticide,		1						1					2

Sand Filter Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
fungicide, or herbicide.													
Treat and remove ant beds with approved organic insecticide to prevent mound fines from silting and choking surfaces.		1						1					2
Mow non-native sodded turf grasses to 2-inch height and bag turf clippings to prevent thatch and drain feature choking/clogging.				1			1			1			3 or *
Mow native grasses and perennials (wildflowers) to no less than 5- to 7-inch height and bag clippings to prevent thatch and drain feature choking/clogging.	1						1						2
Blow trash, sediments, grass cuttings, and leaves away from feature and bag to prevent washing into GSI practices.				1			1			1			3 or *
Underdrain systems – inspect, remove debris, clean out a minimum of 3 times per year)			1		1						1		3 and *

*As needed with inspection after storm events of 0.5 to 1.0 inch or greater, or at least twice per year

3.2.2.2 Rain Gardens (Bioretention Basins)–Landside

3.2.2.2.1 Description

Rain gardens, also commonly referred to as biofilters or bioretention basins, utilize a distribution of microscale stormwater treatment devices to take advantage of the biological, chemical, and physical processes of plants, microbes, and soils to eliminate pollutants that are accumulated within stormwater runoff. There are two main types of bioretention basins: centralized and distributive. As discussed in the DFWIA 2021 GSI Manual, "centralized bioretention basins are implemented for larger drainage areas and include a two cell system… [while distributive basins] can be implemented for drainage areas of one-acre or less. These are smaller and shallower than the centralized systems and are often placed adjacent to the impervious cover runoff source" (CIMM 2021).

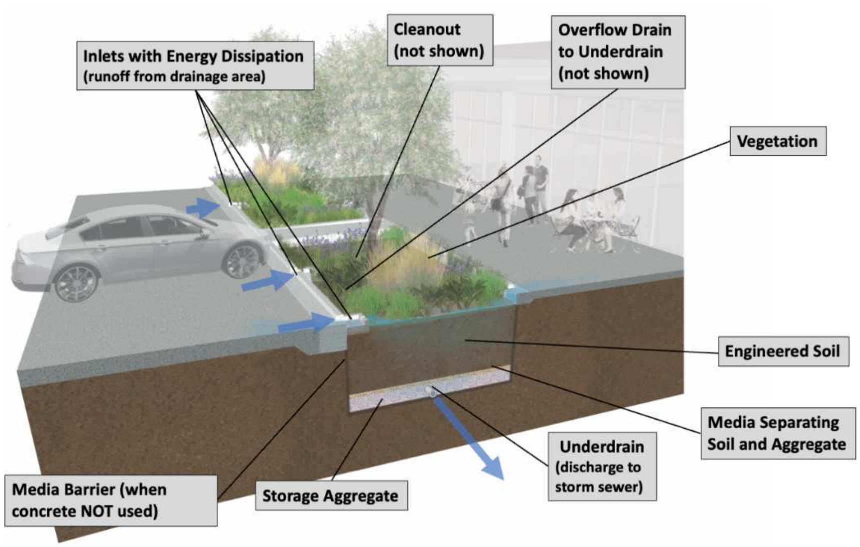

Figure 3-2 Conceptual Rendering of a Distributive Rain Garden (Adapted from TRWD 2018)

3.2.2.2.2 Function

A key component to the function of bioretention basins is the filter medium. Hsieh and Davis's 2005 work, "Evaluation and Optimization of Bioretention Media for Treatment of Urban Storm Water Runoff," defines the filter medium as, "an engineered mix of highly-permeable natural media, which are usually [a] mixture of soil, sand, and organic matter that facilitate pollutant removal via sedimentation, filtration, sorption, and precipitation"(Hsieh and Davis 2005). The addition and homogenization of the organic components (i.e., the plants and microorganisms) and the filter medium provides additional runoff treatment. "Plants help sustain the permeability of the medium for longer periods and enhance removal of pollutants" (Hsieh and Davis 2005).

3.2.2.2.3 Inspection and Maintenance Cycles

Inspection and infiltration testing of all bioretention facilities will occur on an annual basis. Additionally, inspections will occur within 48 hours of all rainfall events recorded at the DFWIA rain gauge that meet or exceed 1.0 inches in 24 hours.

The maintenance cycles provided in Table 3-5 are minimums. Rain gardens will be maintained on a more frequent basis as needed. A Rain Garden Inspection Checklist is provided in Appendix A.

Table 3-5 Rain Garden Maintenance Items

Rain Garden Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Prune tree to remove dead wood, suckers, maintain clearances, and aesthetic character; remove soil and ant beds from root flare base.										1			1
Hand weed beds – do not allow invasive weeds to seed or seedling shrubs/trees to establish and mature; do not spread seeds or spores.			2	2	2	2	2	2	2	2	1		17
Trim/cut back warm season ornamental grasses (if necessary) to one-third of plant height – 1 time every 2 years, remove all trimmings from area		1											0.5
Trim/cut back cool season sedges to 1/3rd plant height – 1 time every 2 years, remove all trimmings from area.									1				0.5
Shrubs & groundcovers – pick prune if necessary, remove and dispose of all trimmings; maintain character and visibility clearances.										1			1
Trim spent yucca, hesperaloe, or other bloom stalks and remove dead lower foliage if it easily releases from plant base; remove and dispose.		1											1
Perennials in rain garden – trim or prune by hand; remove and dispose of all trimmings.		1							1				2
Remove and replace dead, diseased, and overgrown or declining plants.		1							1				2
Install temporary closures at curb inlet/splash pad/forebay openings for 6 to 9 months to allow root	*	*	*	*	*	*	*	*	*	*	*	*	*

Rain Garden Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
establishment and prevent washout of plants; remove closure, clean, and remove sediments regularly.													
Remove aged mulch and apply fresh single grind interlocking mulch at drain structures base or open areas where plants are not established.			1							1			2
Clean and remove sediment, leaves, weeds, logs, branches, and debris; repair/restore aggregate surfaces and/or aggregate energy dissipation areas.		1								1			2
Remove all trash, debris, fallen branches, trimmings, and thatch from areas.		1			1			1			1		4
Replenish engineered media/infiltration media.		1						1					2 or *
Perform double ring infiltrometer test (ASTM D3385) once every 3 years.		1											1 Or *
Apply only approved organic fertilizer.		1						1					2
Apply only approved organic insecticide, fungicide, or herbicide.		1						1					2
Treat and remove ant beds with approved organic insecticide to prevent mound fines from silting and choking surfaces.		1						1					2
Mow embankment non-native sodded turf grasses to 2-inch height and bag turf clippings to prevent thatch and drain feature choking/clogging.				1	1	1	1	1	1				6 or *
Mow embankment native grasses and perennials (wildflowers) to no less than 5- to 7-inch height and bag clippings to prevent thatch and	1						1						2

Rain Garden Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
drain feature choking/clogging.													
Blow sediments, grass cuttings, and leaves away from and bag to prevent wash into GSI practices.				1	1	1	1	1	1				6 or *
Underdrain systems – inspect, remove debris, and clean out a minimum 3 times per year.			1		1						1		3 and *
Permanent supplemental irrigation system – inspect, adjust, repair, and monitor.		1						1					2

* As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year

3.2.2.3 Enhanced Dry Detention–Landside

3.2.2.3.1 Description

Enhanced dry detention basins are a subset of basins that similarly store and treat stormwater runoff, but they require modifications to the low-flow channel crossing the basin. The modification of the low-flow channel is what allows for an enhanced dry detention basin to incorporate additional water quality elements that further treat stormwater. The modifications to the channel are made to give a preferential pathway and additional time for granular pollutants to settle out of the runoff for lower flow events, those typically associated with the water quality control volume (WQCv). The enhanced dry detention basin incorporates higher infiltration media that allows for a greater volume of runoff to be treated through the consolidated features and enhanced filter media. A visual representation of an enhanced (dry) detention basin can be seen in **Figure 3-3**.

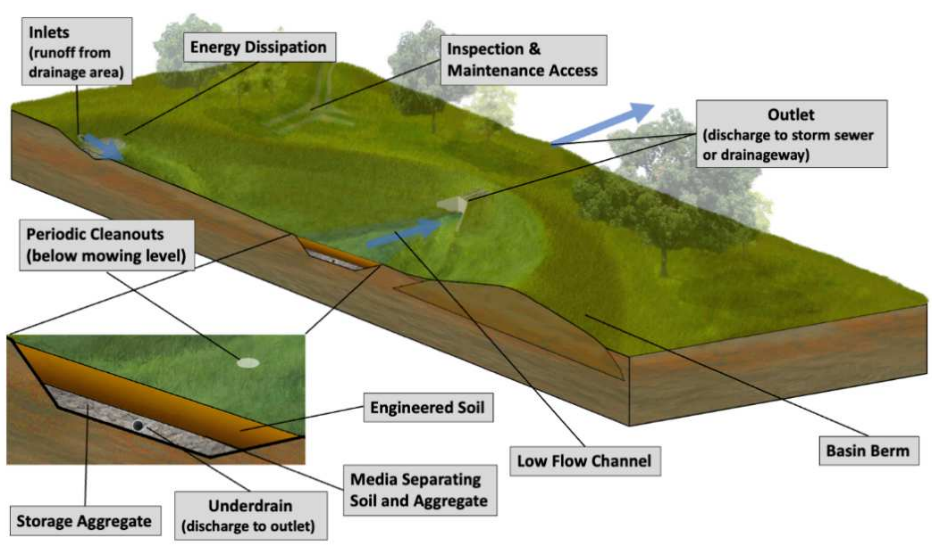

Figure 3-3 Conceptual Rendering of an Enhanced Detention Basin

3.2.2.3.2 Function

Unlike traditional detention basins, which, while providing some water quality benefits, are generally more focused on flood mitigation. The modified features as mentioned above allow for enhanced dry detention basins to provide increased water quality benefits. "By enhancing the aspects of the basin [and] adding key features that improve water quality, these systems are effective at reducing pollutants." (CIMM 2021).

3.2.2.3.3 Inspection and Maintenance Cycles

Inspection of all dry detention facilities will occur on an annual basis. Additionally, inspections shall occur within 48 hours of all rainfall events recorded at the DFWIA rain gauge that meet or exceed 1.0 inches in 24 hours.

The maintenance cycles provided in Table 3-6 are minimums. Dry detention facilities will be maintained on a more frequent basis as needed. A Dry Detention Inspection Checklist is provided in Appendix A.

Table 3-6 Enhanced Detention Maintenance Items

Enhanced Detention Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Prune trees to remove dead wood, suckers, maintain clearances, and aesthetic character; remove soil and ant beds from root flare base to prevent wash into basin.										1			1
Hand weed pond and embankments – do not allow invasive weeds to seed or seedling shrubs/trees to establish and mature; do not spread seeds or spores.			2	2	2	2	2	2	2	2	1		17
Trim/cut back upper embankment warm season ornamental grasses (If necessary) to one-third of plant height – 1 time every 2 years, remove all trimmings from area.		1											0.5
Trim/cut back cool season									1				0.5

Enhanced Detention Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
sedges to one-third plant height – 1 time every 2 years, remove all trimmings from area.													
Remove and replace dead or diseased plants and areas of turf grasses.		1							1				2
Install temporary closures at curb inlet/splash pad/forebay openings for 6 to 9 months to allow root establishment and prevent washout of turf and grasses, remove closure, and clean and remove sediments regularly.	*	*	*	*	*	*	*	*	*	*	*	*	*
Clean and remove sediment, leaves, weeds, logs, branches and debris, and repair/restore aggregate areas.	1	1	1	1	1	1	1	1	1	1	1	1	12
Remove all trash, debris, fallen branches, trimmings, and thatch from areas.	1	1	1	1	1	1	1	1	1	1	1	1	12
Replenish engineered media/infiltration media.		1						1					2 Or *
Perform double ring infiltrometer test (ASTM D3385) once every 3 years.		1											1 or *
Apply only approved organic fertilizer.		1						1					2
Apply only approved organic insecticide, fungicide, or herbicide.		1						1					2

Enhanced Detention Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Treat and remove ant beds with approved organic insecticide to prevent mound fines from silting and choking surfaces.		1						1					2
Mow non-native sodded turf grasses to 2-inch height and bag turf clippings to prevent thatch and drain feature choking/clogging.				1			1			1			3 or *
Mow native grasses and perennials (wildflowers) to no less than 5- to 7-inch height and bag clippings to prevent thatch and drain feature choking/clogging.	1						1						2
Blow sediments, grass cuttings, and leaves away from basin and bag to prevent wash into GSI practices.				1			1			1			3 or *

* As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year

3.2.2.4 Pervious Interlocking Pavers

3.2.2.4.1 Description

Pervious interlocking pavers allow for stormwater to filter through them and into an underlying stone aggregate storage reservoir before the water is infiltrated into the subgrade or conveyed to a pipe. There are a number of surfaces that can be used to achieve the pervious interlocking paver GSI, such as porous concrete, porous asphalt, and grassed modular systems. There are many types of permeable interlocking pavers systems available today. Manufacturer's recommendations should be strictly followed, unless they are modified by an engineer’s signed and sealed design. An illustration of a pervious paver can be seen in **Figure 3-4**.

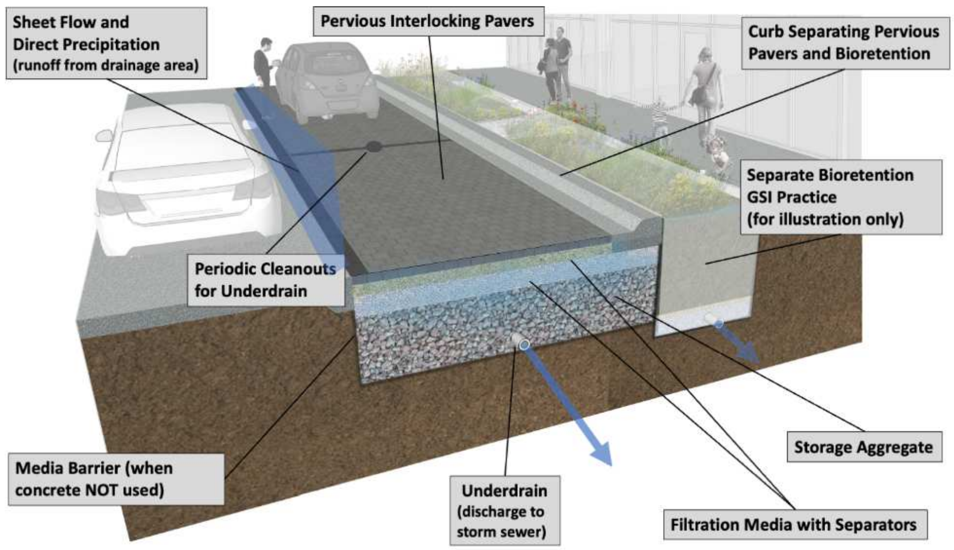

Figure 3-4 Conceptual Rendering of Pervious Pavers (adapted from TRWD 2018)

3.2.2.4.2 Function

Below the surface of pervious interlocking pavers are often several layers of aggregate, each providing storage and a level of filtration for the stormwater passing through it. Beyond treating and filtering out pollutants through the aggregate filters, however, permeable interlocking pavers also limit stormwater runoff at the source. They are able to do this through the functionality of their design, allowing stormwater to filter through the surface into the underlying storage reservoir, reducing the overall runoff volume.

3.2.2.4.3 Inspection and Maintenance Cycles

Inspection and infiltration testing of all pervious interlocking paver facilities will occur on an annual basis. Additionally, inspections will occur within 48 hours of all rainfall events recorded at the DFWIA rain gauge that meet or exceed 1.0 inches in 24 hours.

The maintenance cycles provided in Table 3-7 are minimums. Pervious interlocking paver systems will be maintained on a more frequent basis as needed. A Pervious Interlocking Paver Inspection Checklist is provided in Appendix A.

Table 3-7 Pervious Paver Maintenance Items

Pervious Paver Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Treat and remove ant beds with approved organic insecticide to prevent mound fines from silting and choking surfaces.		1						1					2
Blow debris, silt/sediments, and leaves away from and bag to prevent wash onto paver surface.		1						1					2
Blow grass cuttings away from and bag to prevent wash onto paver surface.		1						1					2

Pervious Paver Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Underdrain systems, inlets/outlets, and observation wells – inspect, remove debris, clean out; repair observation well components depending on condition.			1		1						1		3
Remove trash, gum, cigarette butts, and blow clean.		1						1					2
Remove weeds and moss.		1											1
Remove snow, ice, and sand from paver areas after snow/ice storm event.	*	*									*	*	*
Inspect and test surface infiltration rate per ASTM C1781 at different locations and applications.		1											1
Use regenerative air machine vacuum to clean pavers in street, parking, or sidewalk once every 2 years.		1											0.5
Repair and replace cracked, broken, or deteriorated pavers.		1											1
Repair and level pavers if ½ inch in parking or if ¼ inch for ADA access areas/routes.		1											1
Replenish paving jointing aggregate affecting accessibility of surface and structural integrity.		1											1
Replace/repair leveling base or subbase aggregate of pavers.		1											1

* As needed

3.2.2.5 Vegetative Filter Strips with Underdrains–Landside or Airside

3.2.2.5.1 Description

Vegetated filter strips are slightly sloped structures that are generally placed perpendicular to the path of runoff to receive and filter sheet flow from a paved surface. As stated by Washington's King County report, *Surface Water Design Manual*, "[vegetated filter strips are] designed to receive and maintain sheet flow over the entire width of the strip" (King County 2016). A detailed rendering of a vegetated filter strip can be seen in **Figure 3-5**.

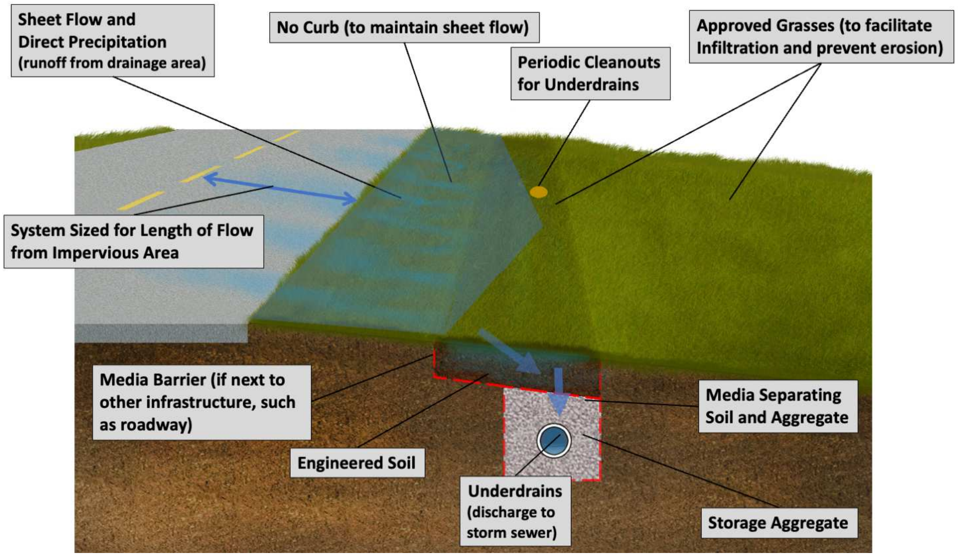

Figure 3-5 Conceptual Rendering of a Vegetated Filter Strip (GDOT n.d.)

3.2.2.5.2 Function

The primary function of vegetative filter strips is to treat and reduce the velocity of stormwater runoff. “[They] are used most effectively in areas with low density impervious cover or linear impervious cover or as pre- or post-treatment for other water quality GSI practices” (CIMM 2020). Vegetative filter strips use three main processes—sedimentation, filtration, and infiltration.

3.2.2.5.3 Inspection and Maintenance Cycles

Inspection of all vegetated filter strips will occur on an annual basis. Additionally, inspections will occur within 48 hours of all rainfall events recorded at the DFWIA rain gauge that meet or exceed 1.0 inches in 24 hours.

The maintenance cycles provided in Table 3-8 are minimums. Vegetated filter strips will be maintained on a more frequent basis as needed. A Vegetated Filter Strip Inspection Checklist is provided in Appendix A.

Table 3-8 Filter Strip Maintenance Items

Filter Strip Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Hand weed areas – do not allow invasive weeds to seed or seedling trees to establish and mature; do not spread seeds or spores.			2	2	2	2	2	2	2	2	1		17
Clean, remove sediment, leaves, weeds, logs, branches and debris; repair/restore aggregate areas.	1	1	1	1	1	1	1	1	1	1	1	1	12

Filter Strip Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Remove all trash, debris, fallen branches, trimmings, and thatch from areas.	1	1	1	1	1	1	1	1	1	1	1	1	12
Replenish engineered media/filtration media.		1						1					2 or *
Perform double ring infiltrometer test (ASTM D3385) once every 3 years.		1											1 or *
Remove and replace dead or diseased grass areas to prevent erosion.		1						1					2
Apply only approved organic fertilizer.		1						1					2
Apply only approved organic insecticide, fungicide, or herbicide.		1						1					2
Treat and remove ant beds with approved organic insecticide to prevent mound fines from silting and choking surfaces.		1						*					2
Mow non-native sodded turf grasses to 2-inch height and bag turf clippings to prevent thatch and drain feature choking/clogging.				1			1			1			3 or *
Mow native grasses and perennials (wildflowers) to no less than 5- to 7-inch height and bag clippings to prevent thatch and drain feature choking/clogging.	1						1						2
Trim/cut back/mow cool season sedges to one-third plant height – 1 time every 2 years, remove all trimmings from area.									1				0.5
Blow grass cuttings and leaves away from and bag to prevent wash into GSI practices.				1			1			1			3 or *
Underdrain systems – inspect, remove debris, clean out (min. 3 times per year).			1		1						1		3 and *

* As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year

3.2.2.6 Grass Swale – Landside or Airside

3.2.2.6.1 Description

Grass swales are easy to construct and maintain, and when properly sized for low level retention or detention based on flow rate, volume and length to width ratio. They can provide both treatment and flood attenuation benefits, especially for airside systems consistent with AC series 150.They can also be implemented as a secondary GSI used to receive and offer pre/post-treatment to stormwater as it is conveyed to/from a primary GSI; however, "if a grass swale GSI practice system is used within close proximity to small, low density impervious areas the WQCv for this area can be treated" (CIMM, 2021). An illustration of a grass swale can be seen in **Figure 3-6**.

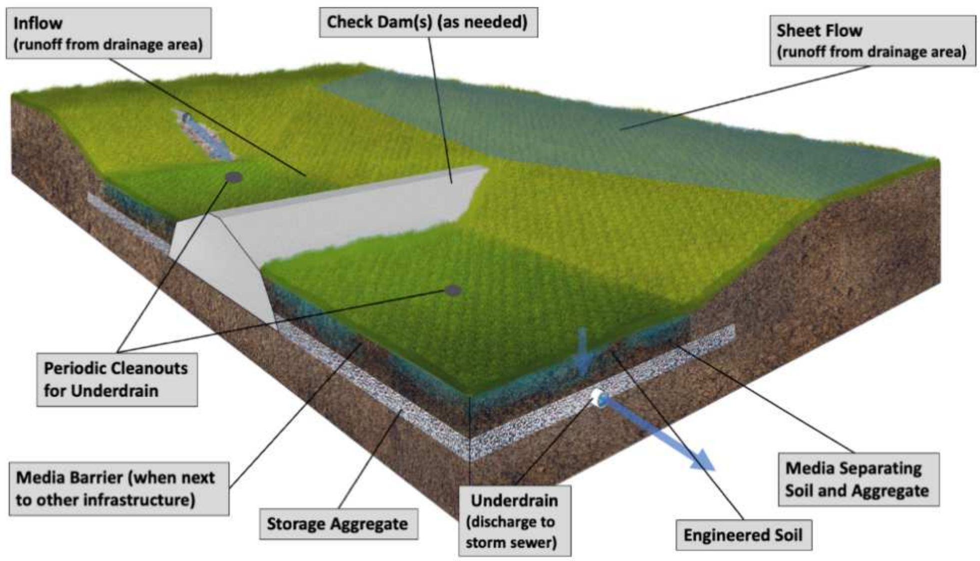

Figure 3-6 Conceptual Rendering of the Components of a Grass Swale (Adapted from GDOT n.d.)

3.2.2.6.2 Function

Grass swales are designed to collect, convey and attenuate flows and remove pollutants by routing shallow flow through a favorable length to width ration with stable vegetation, specifically vegetation that promotes infiltration, particle settling, or sedimentation. To be considered a water quality treatment device, the swale must be designed based on specific geometric criteria, including a relatively flat bottom, gentle side slopes, and a mild longitudinal bed slope.

Similar to the vegetative filter strip, grass swales can be utilized on either the landside or airside of DFWIA; there are, however, some factors that must be considered when applying the grass swales to either of these areas. For instance, "on the landside they are used most effectively in areas with low density impervious cover or linear impervious cover, such as roadways or sidewalks, or as pre- or post- treatment for other water quality GSI practices…[however] on the airside, where space for surface GSI practices is often limited, grass swales can provide a useful means to achieve stormwater flow attenuation and quality treatment based principally on infiltration and interception of pollutants in the vegetative matrix where most pollutants decompose or are bound up to soil particles" (CIMM 2021).

3.2.2.6.3 Inspection and Maintenance Cycles

Inspection of all grass swale facilities will occur on an annual basis. Additionally, inspections will occur within 48 hours of all rainfall events recorded at the DFWIA rain gage that meet or exceed 1.0 inches in 24 hours.

The maintenance cycles provided in Table 3-9 are minimums. Grass swales will be maintained on a more frequent basis as needed. A Grass Swale Inspection Checklist is provided in Appendix A.

Table 3-9 Grass Swale Maintenance Items

Grass Swale Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Adjacent Trees: prune to remove dead wood, suckers, maintain clearances, and aesthetic character; remove soil and ant beds from root flare base to prevent wash into swale.										1			1
Hand weed areas – do not allow invasive weeds to seed or seedling trees to establish and mature; do not spread seeds or spores.			2	2	2	2	2	2	2	2	1		17
Trim/cut back warm season ornamental grasses (if necessary) to one-third of plant height – 1 time every 2 years, remove all trimmings from area.		1											0.5
Trim/cut back cool season sedges to one-third plant height – 1 time every 2 years, remove all trimmings from area.									1				0.5
Remove and replace dead or diseased grass areas to prevent erosion.		1						1					2
Install temporary closures at curb inlet/splash pad/forebay openings for 6 to 9 months to allow root establishment and prevent	1	1	1	1	1	1	1	1	1	1	1	1	12

Grass Swale Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
washout of plants, remove closure, and clean and remove sediments regularly.													
Remove aged mulch and apply fresh single grind interlocking mulch at drain structures base or open areas where plants are not established.			1							1			2
Clean and remove sediment, leaves, weeds, logs, branches, and debris, and repair/restore aggregate areas.	1	1	1	1	1	1	1	1	1	1	1	1	12
Remove all trash, debris, fallen branches, trimmings, and thatch from areas.		1			1			1			1		4
Replenish engineered media/filtration media.		1						1					2 or *
Perform double ring infiltrometer test (ASTM D3385) once every 3 years.		1											1 And *
Apply only approved organic fertilizer.		1						1					2
Apply only approved organic insecticide, fungicide, or herbicide.		1						1					2
Treat and remove ant beds with approved organic insecticide to prevent mound fines from silting and choking surfaces.		1						1					2
Mow non-native sodded turf grasses to 2-inch height and bag turf clippings to prevent thatch and drain feature choking/clogging.				1			1			1			3 or *
Mow native grasses and perennials (wildflowers) to no	1						1						2

Grass Swale Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
less than 5- to 7-inch height and bag clippings to prevent thatch and drain feature choking/clogging.													
Blow grass cuttings and leaves away from and bag to prevent wash into GSI practices.				1			1			1			3 or *
Blow grass cuttings away from permeable interlocking pavers.				1			1			1			3 or *

* As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year

3.2.3 First Flush Systems

3.2.3.1 Description

While first flush treatment systems are not traditionally classified as a GSI practice, they are frequently used throughout the airside of DFWIA, and thus, are included in this report. FFSs are intended principally as an airside practice, but may find applications on the landside, such as situations where less common pollutants of concern (e.g., oils and greases) can be most cost-effectively handled with this practice. First flush treatment systems collect the first flow of stormwater—often it is the section of flow that collects the most pollutants. Once stormwater is captured into the system, a controlled volume is released from an outlet to the downstream wastewater treatment plan or to a storm sewer. The first flush systems incorporates Type D and Type B-1 inlets as well as fuel separators. The design of a fuel separator as part of the first flush system can be visualized in **Figure 3-7**.

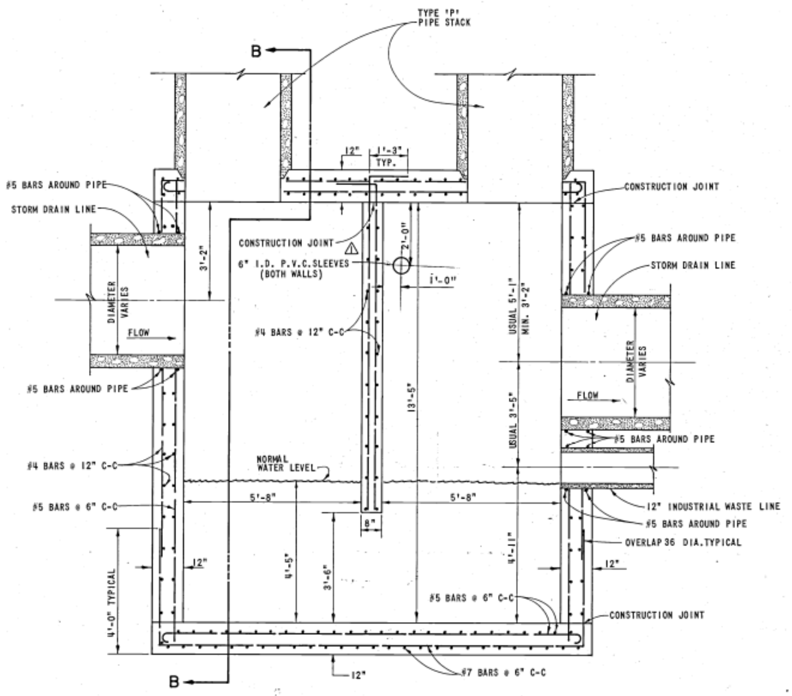

Figure 3-7 Cross Section of a Typical First Flush System (FFS) for Existing Airside Fuel Separators

3.2.3.2 Function

First flush treatment systems function to capture and treat pollutants that are caught by stormwater in the initial runoff from a rainfall event. Throughout DFWIA they are principally used as an airside practice, but there may be applications on the landside of DFWIA. "DWIA has numerous underground first flush facilities, [illustrated in **Figure 3-7**], in the airport operations area with the principal intent to capture sediment and chemical compounds…" (CIMM 2021).

3.2.3.3 Inspection and Maintenance Cycles

Inspection of all fuel separators and Type B-1 inlets occurs every quarter and Type D inlets will occur on an annual basis.

Table 3-10 First Flush Maintenance Items

Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	No	Dec	
Type B1 ramp inlets on the Airport Operations Area (AOA) around terminals:													
Inspect inlets		1			1			1			1		4
Document condition of each inlet during inspection for the following: trash and debris, petroleum hydrocarbon sheen exceeding 3/8-inch (0.375-inch) thickness, glycol and petroleum odors, condition of all		1			1			1			1		4

Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	No	Dec	
make-up water devices (operational).													
Remove excess sediment and debris.		1			1			1			1		4
Remove make-up water contaminated with excess hydrocarbons by vacuuming until no measurable sheen is detected, or less than 3/8-inch (0.375-inch) thickness.		1			1			1			1		4
Check for strong glycol odors.		1			1			1			1		4
Remove make-up water contaminated with glycol by vacuuming.		1			1			1			1		4
Document estimated volumes of sediment, debris, hydrocarbons, and water removed during cleaning activities.		1			1			1			1		4
Type D1 ramp inlets on the Airport Operations Area (AOA) around terminals:													
Inspect inlets						1							1
Document condition of each inlet during inspection for the following: trash and debris, petroleum hydrocarbon sheen exceeding 3/8-inch (0.375-inch) thickness, glycol and petroleum odors, condition of all make-up water devices (operational).						1							1
Remove excess sediment and debris.						1							1
Remove make-up water contaminated with excess hydrocarbons by vacuuming until no measurable sheen is detected, or less than 3/8-inch (0.375-inch) thickness.						1							1
Check for strong glycol odors.						1							1
Remove make-up water contaminated with glycol by vacuuming.						1							1
Document estimated volumes of sediment, debris, hydrocarbons,						1							1

Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	No	Dec	
and water removed during cleaning activities.													
Fuel Separators:													
Inspections (conducted on dry weather days only and not following heavy precipitation events)		1			1			1			1		4
Document condition of fuel separator during inspection.		1			1			1			1		4
Preventative maintenance of diverter boxes					1								0.5 or *
Remove excess sediment and debris once every 2 years.					1								0.5 or *
Remove make-up water contaminated with excess hydrocarbons by vacuuming until no measurable sheen is detected, or less than 3/8-inch (0.375-inch) thickness once every 2 years.					1								0.5 or *
Check for strong glycol odors once every 2 years.					1								0.5 or *
Remove make-up water contaminated with glycol by vacuuming once every 2 years.					1								0.5 or *
Comprehensively clean all fuel separators to remove debris, remove standing water, and remove sediment to less than 1/2-inch (0.50-inch) thickness once every 2 years.					1								0.5 or *
Document estimated volumes of sediment, debris, hydrocarbons, and standing water removed during cleaning activities once every 2 years.					1								0.5 or *
Disposal methods to be determined during cleaning activities. Off-site disposal may be required. No process waters will enter the DFWIA storm water collection system. (Once every 2 years)					1								0.5 or *

Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	No	Dec	
Add make-up water manually with non-operational make-up water devices once every 2 years					1								0.5 or *

* As needed with inspection after storm events of 1.0 inch or greater, or at least twice per year
Type D inlet: Ramp storm water inlets draining to fuel interceptors
Type B1 inlet: Storm water inlet directly connected to the IW System and the storm sewer
Gasoline fueling common areas include Terminal A North GSE, Terminal A South GSE, and Terminal C South GSE

3.3 Other Treatment Facilities

3.3.1 Proprietary- Point to Manufacturers Guidelines for Specific Design

If using a proprietary system, developers must demonstrate equivalent treatment and/or flow attenuation required to manage flows, stages, velocities, and pollutants. The developer must follow the maintenance and inspection procedures defined by the manufacturer of the proprietary system. The developer will provide a copy of the proprietor's maintenance recommendations to ETAM.

3.4 Underground Stormwater Storage Facilities

Stormwater storage facilities, also commonly referred to as underground stormwater retention/detention, are made to mimic predevelopment conditions and capture and store runoff gathered from surrounding impervious areas. They accomplish this by guiding runoff through storm sewer systems and leading it to subsurface vaults of interconnected storage pipes or chambers to increase overall system stormwater storage capacity. The stormwater is then released through an outlet pipe once system capacity is restored. Stormwater storage facilities are not designed to provide high levels of water quality benefits, but, instead, made to be coupled with GSIs, detaining water to allow the GSI practices to function longer, treating more runoff. They also are designed for a handful of other benefits, such as reducing the flow of runoff, providing a durable design made to last over a number of years, allowing for stormwater storage in areas of high density or low land availability, and allowing for a controlled release of collected runoff.

There are a number of factors that should be considered when approaching safety and maintenance on an underground storage facility. These factors include protections and controls for spills, proper venting for potential explosive materials, safe access for maintenance staff and equipment, periodic inspections of inlets and outlets to confirm that they are functioning as designed and to clear out any debris that may have accumulated due to storm events. Similarly, proprietary sediment traps within the system should be cleaned and cleared to avoid accumulation and the potential loss of functionality. A detailed list of maintenance considerations can be found in Table 3-11.

3.4.1 Inspection Cycle

Table 3-11 Underground Storage Maintenance Items

Underground Storage Maintenance Items	Frequency												Per Yr.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Inspect, clean, remove sediment, leaves, and debris.								1					1
Inspect elements added for erosion prevention and structure stabilization.								1					1

Section 4
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Appendix A
Stormwater Management Facilities Inspection Checklists

Inlet Checklist

Date: ________________________ **Work Order #** _ ________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ________________________ **Inspector(s):** _ _____

GPS Latitude: ________________ **GPS Longitude:** _ __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Drains operational and clear			
Trash and debris accumulation			
Fallen leaves, branches, trimmings, or thatch to be removed			
Broken or missing area protection			
Signs of erosion or scouring 3 feet around inlet			
Aggregate condition (if used on-site) to be cleaned and restored			
Vegetation trimmed and maintained properly per maintenance guidelines			
Broken/cracked frames, grates, and structure			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Outfall Checklist

Date: ______________________ **Work Order #** _ ________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** _ _____

GPS Latitude: ________________ **GPS Longitude:** _ __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Drains operational and clear			
Trash and debris accumulation			
Fallen leaves, branches, trimmings, or thatch to be removed			
Signs of erosion or scouring at outfall			
Aggregate condition (if used on-site) to be cleaned and restored			
Tree / Vegetation trimmed and maintained properly per maintenance guidelines			
Invasive species, weeds, or seedling trees or other to be removed			
Excessive or overgrown vegetation			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Damaged structural elements			
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Channel Checklist

Date: ______________________ **Work Order #** _ _______

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** _ _____

GPS Latitude: ________________ **GPS Longitude:** _ __________

Sequence	Equipment	Description	Notes	Follow-up	Date Updated	Error Message	Result Finding
10		Culvert / Outfall Condition		Yes/No			Good, Fair, Poor, N/A
20		Header Condition		Yes/No			Good, Fair, Poor, N/A
30		Skirting Condition		Yes/No			Good, Fair, Poor, N/A
40		Pad Condition		Yes/No			Good, Fair, Poor, N/A
50		Other Structure Condition		Yes/No			Good, Fair, Poor, N/A
60		Sediment Build Up		Yes/No			Minor, Moderate, Severe, N/A
70		Plant Grow / Debris		Yes/No			Minor, Mild, Moderate, Severe
80		Ponding		Yes/No			Minor, Mild, Moderate, Severe
90		Trash Present		Yes/No			Minor, Moderate, Severe
100		Erosion		Yes/No			Minor, Moderate, Severe
110		Animal Activity		Yes/No			Yes/No

Sequence	Equipment	Description	Notes	Follow-up	Date Updated	Error Message	Result Finding
120		Channel Condition		Yes/No			Good, Fair, Poor, N/A
130		Plant Coverage		Yes/No			25-35%, 50-60%, 75-85%, 80-90%
140		Plant Height (Ft.)		Yes/No			Less than 1 Ft, Greater than 3 ft, Less than 3 ft
150		Dams		Yes/No			Yes/No

Sand Filter – Landside Inspection Checklist

Date: ______________________ **Work Order #** ______________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** ____________

GPS Latitude: ________________ **GPS Longitude:** ___________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Foul odors or insects such as mosquitos			
Standing water after design drawdown subsequent to a storm event			
Inlets clogged with debris			
Drains (outlets) operational and clear			
Clean-outs operational and clear			
Surface drain or underdrain pipe corrosion, break, or disconnection			
Accumulated debris, sediment, or silt in sediment forebay or aggregate energy dissipation area			
Accumulated sediment or debris in basin higher than limit			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Trash and debris accumulation			
Fallen leaves, branches, logs, trimmings, or thatch (from grass cuttings) to be removed			
Broken or missing area protection			
Signs of erosion or scouring			
Banks or slope eroded			
Aggregate condition at energy dissipation (if used on-site) to be cleaned and restored			
Fungus or mold growth on top of sand filtration media			
Poor grass health, dead, or diseased to be removed and replaced (if applicable)			
Excessive or overgrown grasses (if applicable)			
Invasive species, weeds, or seedling trees or other to be removed			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Ant mounds to be treated and removed to prevent silt			
Infiltration testing			
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Rain Garden (Bioretention Basins) - Landside Inspection Checklist

Date: ______________________ **Work Order #** ________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** _____

GPS Latitude: ________________ **GPS Longitude:** __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Foul odors or insects such as mosquitos			
Standing water after design drawdown subsequent to a storm event			
Underdrains operational and clear			
Drains operational and clear			
Clean-outs operational and clear			
Surface drain or underdrain pipe corrosion, break, or disconnection			
Accumulated sediment/debris in forebay or at aggregate energy dissipation area			
Trash and debris accumulation			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Fallen leaves, branches, trimmings, or thatch to be removed			
Broken or missing area protection			
Signs of erosion or scouring			
Banks or slope eroded			
Mulch condition (if used on-site) to be removed from drain area and replenished			
Aggregate condition (if used on-site) to be cleaned and restored			
Tree / Vegetation trimmed and maintained properly per maintenance guidelines			
Poor vegetative health, dead, or diseased to be removed and replaced			
Invasive species, weeds, or seedling trees or other to be removed			
Desired volunteer vegetation that can remain in feature (example: bluebonnets)			
Excessive or overgrown vegetation			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Permanent supplemental irrigation operational, damaged, or in need of repair			
Ant mounds to be treated and removed to prevent silt			
Infiltration testing – to be performed by a trained professional			
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Enhanced Dry Detention - Landside Inspection Checklist

Date: ______________________ **Work Order #** __________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** __________

GPS Latitude: ________________ **GPS Longitude:** __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Foul odors or insects such as mosquitos			
Standing water after design drawdown subsequent to a storm event			
Underdrains operational and clear			
Inlets and Outlets operational and clear			
Clean-outs operational and clear			
Surface drain or underdrain pipe corrosion, break, or disconnection			
Structural components damaged or compromised			
Accumulated sediment and debris at energy dissipation area			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Trash and debris accumulation			
Fallen leaves, branches, trimmings, or thatch to be removed			
Broken or missing area protection (e.g. curbs, edges, bollards etc.)			
Condition of basin structure			
Signs of erosion or scouring			
Banks or slopes eroded			
Aggregate condition (if used on-site) to be cleaned and restored			
Vegetation cut, trimmed, and maintained properly per maintenance guidelines			
Poor vegetative health, dead, or diseased to be removed and replaced			
Invasive species, weeds, or seedling trees or other to be removed			
Desired volunteer vegetation that can remain in feature (example: bluebonnets)			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Excessive or overgrown vegetation			
Ant mounds to be treated and removed to prevent silt			
Infiltration testing – to be performed by a trained professional			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Pervious Interlocking Pavers Inspection Checklist

Date: ______________________ **Work Order #** ____________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** ____________

GPS Latitude: ________________ **GPS Longitude:** __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Foul odors or insects such as mosquitos			
Standing water after design drawdown subsequent to a storm event			
Underdrains operational and clear			
Inlets/outlets operational and clear			
Observation wells and clean-outs operational and clear			
Surface drain or underdrain pipe corrosion, break, or disconnection			
Accumulated sediment, silt, or debris over surface of pavers			
Trash and debris accumulation (along with gum and cigarette butts)			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Fallen leaves, branches, trimmings, or thatch (grass cuttings)			
Broken or missing area protection			
Paver settlement or un-level surface			
Chipped, cracked, broken, or deteriorated pavers			
Separation of pavers jointing affecting structural integrity			
Loss of jointing aggregate to top of paver chamfer			
Integrity of edge constraints (curbs, bands, edging)			
Weeds and moss			
Ant mounds treated and removed to prevent silt			
Regenerative air machine vacuum cleaning			
Effect of materials storage (if applicable) over surface of pavers			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Infiltration testing – to be performed by a trained professional			
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Vegetative Filter Strips with Underdrains –Landside or Airside Inspection Checklist

Date: ______________________ **Work Order #** ___________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** __________

GPS Latitude: ________________ **GPS Longitude:** __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Foul odors or insects such as mosquitos			
Standing water after design drawdown subsequent to a storm event			
Underdrains operational and clear and at design gradient			
Observation well or clean-outs operational and clear			
Surface drain or underdrain pipe corrosion, break, or disconnection			
Sediment and debris accumulation			
Trash and debris accumulation			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Fallen leaves, branches, trimmings, or thatch to be removed			
Missing area protection while turf or grasses/perennials are establishing roots			
Settlement or up-heaving			
Signs of erosion or scouring			
Grasses/perennials or turf cut, trimmed, and bagged properly per maintenance guidelines			
Poor vegetation health, dead, or diseased to be removed and replaced			
Invasive species, weeds, or seedling trees or other to be removed			
Excessive or overgrown vegetation			
Ant mounds to be treated and removed to prevent silt			
Infiltration testing – to be performed by a trained professional			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

Grass Swale Inspection Checklist – Landside or Airside

Date: ______________________ **Work Order #** ____________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** ____________

GPS Latitude: ______________ **GPS Longitude:** __________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Foul odors or insects such as mosquitos			
Standing water after design drawdown subsequent to a storm event			
Underdrains operational and clear			
Inlets and Outlets operational and clear			
Clean-outs operational and clear (if applicable)			
Surface drain or underdrain pipe corrosion, break, or disconnection			
Structural components (check dam) damaged or compromised			
Accumulated sediment and debris at energy dissipation area			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Trash and debris accumulation			
Fallen leaves, branches, trimmings, or thatch to be removed			
Broken or missing area protection			
Settlement or up-heaving of swale			
Signs of erosion or scouring			
Banks or slopes eroded			
Aggregate condition (if used on-site) to be cleaned and restored			
Grasses or turf cut, trimmed, and bagged properly per maintenance guidelines			
Poor grass or turf health, dead, or diseased to be removed and replaced			
Invasive species, weeds, or seedling trees or other to be removed			
Excessive or overgrown vegetation			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Ant mounds to be treated and removed to prevent silt			
Infiltration testing – to be performed by a trained professional			
Animal Activity			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance was performed same day, 2 if maintenance is needed.

First Flush System Inspection Checklist

Date: ______________________ **Work Order #** _ ____________

Type of Inspection: **Post-storm** ☐ **Annual** ☐ **Routine** ☐

Facility: ______________________ **Inspector(s):** _ ____________

GPS Latitude: ________________ **GPS Longitude:** _ ___________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Type D Ramp Inlets:			
Trash and debris			
Petroleum hydrocarbon sheen exceeding 3/8-inch thickness			
Glycol odors			
Petroleum odors			
Condition of make-up water devices (operational)			
Sediment			
Sediment removed by cleaning			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Make-up water contaminated with hydrocarbons removed by vacuuming			
Strong glycol odors			
Make-up water contaminated with glycol removed by vacuuming			
Estimated volumes of sediment, debris, hydrocarbons, and water removed during cleaning			
Type B1 Ramp Inlets:			
Trash and debris			
Petroleum hydrocarbon sheen exceeding 3/8-inch thickness			
Glycol odors			
Petroleum odors			
Condition of make-up water devices (operational)			
Sediment			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Sediment removed by cleaning			
Make-up water contaminated with hydrocarbons removed by vacuuming			
Strong glycol odors			
Make-up water contaminated with glycol removed by vacuuming			
Estimated volumes of sediment, debris, hydrocarbons, and water removed during cleaning			
Fuel Separators:			
Inspection conducted on dry weather day only and not following heavy precipitation event			
Fuel separator condition			
Diverter boxes – preventative maintenance			
Excess sediment and debris removed by cleaning			
Make-up water contaminated with excess hydrocarbon removed by vacuuming until no measurable sheen is detected (<3/8-inch)			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Strong glycol odors			
Make-up water contaminated with glycol removed by vacuuming			
Comprehensive cleaning to remove debris and standing water and sediment to <1/2-inch			
Estimated volumes of sediment, hydrocarbons, and standing water removed during cleaning			
Disposal methods determined			
Make-up water added manually			
General:			
Outlets operational and clear to wastewater system			
Inspection plates operational and clear			
Structural components damaged or compromised			
Records – all submittals submitted by Owner to DFWIA			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Comments or Action(s) Taken to Resolve Issue
Detailed inspection reports kept on site as well as records of maintenance activities			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed, 2 if maintenance was performed same day.


Mud Springs Creek
Watershed
PROTECT OUR RIVERS