ALAN PLUMMER ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERS AND SCIENTISTS

FINAL REPORT

STORMWATER HARVESTING GUIDANCE DOCUMENT
FOR
TEXAS WATER DEVELOPMENT BOARD

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MIYA WATER
DR. JAMES P. HEANEY

MARCH 2010

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MARCH 2010

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LIST OF ABBREVIATIONS

ac........................... Acres
ac-ft....................... Acre-feet
ac-ft/yr................... Acre-feet per year
AMC .... Antecedent moisture conditions
ARI........................ Average recurrence interval
ASBS..................... Area of Special Biological Significance
ASCE .... American Society of Civil Engineers
ASR....................... Aquifer storage and retrieval
BCS....................... Borger Color System
BMP .... Best Management Practice
BOD .... Biochemical oxygen demand
BOD_5..................... Five-day biochemical oxygen demand
$CaCO_3$ .... Calcium carbonate
CERP..................... Comprehensive Everglades Restoration Plan
CFU....................... Colony-forming units
Cl_2 .... Chlorine
COD .... Carbonaceous oxygen demand
CP.......................... Control point
ºC.......................... Degrees Celsius
DAR .... Drainage-area-ratio
deg F...................... Degrees Fahrenheit
EIA........................ Equivalent impervious area
ENR....................... *Engineering News-Record*
EPA .... Environmental Protection Agency
FD record .... Flow distribution record
gal.......................... Gallons
gal/acre.................. Gallons per acre
gal/acre/month....... Gallons per acre per month
GPT .... Gross pollutant trap
GCD .... Groundwater Conservation District

GIS .... Geographic information system
gpm .... Gallons per minute
in .... Inches
in/yr .... Inches per year
IN record .... Inflow record
lb .... Pounds
LID .... Low impact development
LOI .... Location of interest
meq/l .... Milliequivalents per liter
MG .... Million gallons
mg/l .... Milligrams per liter
min .... Minutes
ml .... Millileters
mm .... Millimeters
MPN .... Most Probable Numbers
MS4 .... Municipal Separate Storm Sewer System
MSD .... Municipal Setting Designation
MUSIC .... Model for Urban Stormwater Improvement Conceptualisation
NA .... Not available
NRCS .... Natural Resources Conservation Service
NSW .... New South Wales
NTU .... Nephelometric turbidity units
NURP .... National Urban Runoff Program
O&M .... Operation and maintenance
REV .... Rate-Efficiency-Volume
RSC .... Residual sodium carbonate
S.U. .... Standard units
SAR .... Sodium adsorption ratio
SCADA .... System Control and Data Acquisition
SMURRF .... Santa Monica Urban Runoff Recycling Facility
sq mi .... Square miles
SWMP .... Stormwater Management Plan
TAC .... Texas Administrative Code

TBL .... Triple bottom line
TCEQ .... Texas Commission on Environmental Quality
TDS .... Total dissolved solids
TNRIS .... Texas Natural Resources Information System
TPDES .... Texas Pollutant Discharge Elimination System
TRHEC .... Texas Rainwater Harvesting Evaluation Committee
TWDB .... Texas Water Development Board
UIC .... Underground Injection Control
UV .... Ultraviolet radiation
UWRRC .... Urban Water Resources Research Council
WAM .... Water Availability Model
WERF .... Water Environment Research Foundation
WP record .... Watershed parameter record
WRAP .... Water Rights Analysis Package
WSUD .... Water-sensitive urban design
WUG .... Water User Group
μS/cm .... Microsiemens per centimeter

ES. Executive Summary

Surface water supplies, which primarily originate from rainfall runoff (stormwater), are the primary source of water for cities in Texas. As of 2007, approximately 64 percent of municipal water demands were met with surface water, and 36 percent of municipal demands were met with groundwater.[(1)] Between 2010 and 2060, the Texas population is projected to grow from almost 25 million people to more than 45 million people, creating water supply and stormwater management challenges, particularly in urbanizing areas of the state.[a,(1)] This large increase in population will be accompanied by a significant increase in impervious area that will substantially increase the amount of stormwater runoff and the quantity of surface water available for water supply.

Stormwater can be captured over a wide range of scales, from small-scale rainwater harvesting projects, where water is collected from rooftops, to large-scale diversion of stormwater from streams and reservoirs. The Texas Water Development Board (TWDB) previously developed *The Texas Manual on Rainwater Harvesting*, and diversion of stormwater from streams and reservoirs is well-regulated and widely practiced.[(2)] This document provides guidance on intermediate-scale stormwater harvesting: the use of stormwater collected from overland flow and stormwater collection systems prior to entering a natural watercourse, primarily in urban areas.

ES.1. Purpose of this Document

Many issues related to implementation of stormwater harvesting in Texas are neither well-documented nor well-understood. These include legal issues associated with water rights and associated permitting, as well as technical issues associated with evaluation of water availability, storage requirements, and treatment requirements. This guidance document is the product of a research study funded by the TWDB to develop information necessary for planners and designers to:

- Assess these Texas-specific issues,
- Evaluate the feasibility of stormwater harvesting as a water management strategy in Texas, and
- Develop and implement stormwater harvesting projects.

The information provided in this document was developed through the following research tasks:

- Perform a literature search to identify and document the current state of technology and applicable legal issues related to stormwater harvesting.

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[a] Bibliographic references in this document are shown with superscript numbers in parentheses. The bibliography is shown in Appendix A.

- Develop an approach for determining the probable quantities of historical and future stormwater.
- Develop information regarding practices and technology for harvesting stormwater including health and reliability issues as a water supply.
- Develop information regarding alternative practices and technologies for treatment and use of the stormwater.
- Define legal issues related to harvesting of the historical and future stormwater.
- Define issues related to the potential impacts of reusing stormwater on downstream ecology.
- Identify regions in Texas with the greatest potential for stormwater harvesting projects.
- Discuss the issues and implications associated with various scales and forms of stormwater harvesting strategies.

ES.2. Guide to this Document

Stormwater harvesting includes the collection, storage, treatment, distribution, and use of stormwater runoff for beneficial purposes. This document provides guidance for planning, designing, and operating stormwater harvesting projects (Chapters 2, 6, and 7). Planning a stormwater harvesting project involves:

- Identifying project objectives;
- Identifying site and watershed characteristics;
- Identifying potential users and demands;
- Determining whether a water right permit would be required for the project;
- Quantifying stormwater availability;
- Evaluating environmental issues, including downstream ecology;
- Assessing potential health issues;
- Managing potential risks;
- Determining water quality and treatment requirements;
- Planning for public education and awareness; and
- Considering costs and benefits.

This document provides Texas-specific guidance for planning topics such as determining whether a water right permit is required for a stormwater harvesting project (Chapter 3), how to estimate stormwater availability for a project (Chapter 4), and which of the 16 water planning regions in Texas have the greatest potential for stormwater harvesting in Texas (Chapter 5).

The design of collection and distribution facilities depends on water flowrates, and the design of storage facilities depends on water volumes. Sizing of storage capacity involves a tradeoff between maximizing supply reliability and minimizing storage size and cost. In addition to surface storage, aquifer storage and retrieval (ASR) is a potential storage method. This document provides information about the potential for ASR within the 16 water planning regions in Texas. The regulatory requirements for implementing an ASR project are also discussed.

Design of treatment facilities must consider the quality of the captured stormwater and the quality requirements of the intended water use. For many uses, the required quality can be achieved through traditional stormwater best management practices, such as grassy swales, settling basins, etc. Frequently, such measures can be designed based on limited stormwater quality data and based on information provided in the literature. Other uses may have more restrictive water quality requirements that require a higher degree of treatment. In these cases, stormwater quality should be more fully characterized, and probable effectiveness of the selected treatment processes must be carefully assessed. This document provides potential treatment quality goals for different uses and guidance on stormwater treatment technologies.

Stormwater harvesting is a viable strategy for meeting water needs in Texas. Successful stormwater harvesting projects have been implemented in the United States, as well as other countries, particularly Australia. Selected case studies are presented in Chapter 8. The TWDB should promote and encourage the implementation of stormwater harvesting as a water management strategy through training programs and grant funding.

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1. Introduction

Between 2010 and 2060, the Texas population is projected to grow from almost 25 million people to more than 45 million people, creating water supply and stormwater management challenges, particularly in urbanizing areas of the state.[b,(1)] Development of new water supplies in Texas is becoming more difficult and more costly, and water planners and providers are looking to alternative practices, such as conservation and reuse, which make more efficient use of existing supplies. In addition, urbanization tends to degrade stormwater quality and change the hydrology of watersheds, increasing runoff volume, accelerating the time of concentration, increasing the magnitude of the peak flow, and increasing the frequency and severity of flooding. These changes contribute to degraded aquatic ecosystems and bed and bank erosion. Stormwater harvesting can address both water supply and stormwater management challenges.

Stormwater harvesting includes the collection, storage, treatment, distribution, and use of stormwater runoff for beneficial purposes.[c] Stormwater harvesting can occur over a wide range of scales, from small-scale rainwater harvesting projects, where water is collected from rooftops, to large-scale diversion and use of stormwater from streams and reservoirs. The Texas Water Development Board (TWDB) previously developed *The Texas Manual on Rainwater Harvesting*, and use of stormwater from streams and reservoirs is well-regulated and widely practiced.[(2)] This document provides guidance on intermediate-scale stormwater harvesting: the use of stormwater collected from overland flow and stormwater collection systems prior to entering a natural watercourse, primarily in urban areas. In the remainder of this document, the word “stormwater” generally refers to water that can be harvested from overland flow or from stormwater collection systems prior to entering a natural watercourse.[d]

Stormwater harvesting is practiced as a water management strategy in other regions of the United States and internationally, particularly in Australia. Stormwater harvesting integrates elements of traditional stormwater management (collection and treatment best management practices), potable water systems (treatment technologies and distribution systems), wastewater treatment (treatment technologies), and treated wastewater effluent reuse (non-potable water demands, treatment technologies, and distribution systems), and other fields. There are excellent general references in these fields, including:

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[b] Bibliographic references in this document are shown with superscript numbers in parentheses. The bibliography is shown in Appendix A.

[c] Stormwater harvesting is sometimes called “stormwater reuse.”However, the word “reuse” is also used to describe the use of treated wastewater effluent. To avoid possible confusion, the phrase “stormwater harvesting” is used in this report.

[d] As discussed in Section 3.1, stormwater collected from overland flow and stormwater collection systems prior to entering a natural watercourse is “diffused surface water” belonging to the surface owner and is not “state water” subject to appropriation and permitting under the Texas Water Code. Therefore, this document focuses on stormwater projects that will not require water right permits. A determination of whether a stormwater harvesting project requires a water right permit should be made during the planning process (Chapter 2).

- Heaney, J. P., Pitt, R., Field, R., 1998, Innovative Urban Wet-Weather Flow Management Systems: prepared for the United States Environmental Protection Agency, EPA/600/R-99/029.(3)
- Strecker, E. and others, 2005, Critical Assessment of Stormwater Treatment and Control Selection Issues: prepared for the Water Environment Research Foundation, WERF Publication 02-SW-1.(4)
- Florida Department of Environmental Protection and Water Management Districts, Environmental Resource Permit Stormwater Quality Applicant's Handbook: Design Requirements for Stormwater Treatment Systems in Florida: March 2010 Draft.(5)
- Prince George's County, Maryland Department of Environmental Resources Programs and Planning Division, 1999a, Low-Impact Development Design Strategies: An Integrated Design Approach, prepared for the United States Environmental Protection Agency, EPA Publication 841-B-00-003.(6)
- Urban Drainage and Flood Control District, 2008, Urban Storm Drainage Criteria Manual: Denver, Colorado.(7)
- American Water Works Association and American Society of Civil Engineers, 2005, Water Treatment Plant Design: Fourth Edition, McGraw-Hill, New York.(8)
- Mays, L., 2000, Water Distribution Systems Handbook: McGraw-Hill, New York.(9)
- Metcalf and Eddy, Inc., 2003, Wastewater Engineering: Treatment and Reuse, 4th Edition, McGraw-Hill, New York.(10)
- Camp, Dresser & McKee, Inc., 2004, Guidelines for Water Reuse: prepared for the United States Environmental Protection Agency, EPA/625/R-04/108.(11)
- Asano and others, 2007, Water Reuse: Issues, Technologies, and Applications: McGraw Hill, New York.(12)

However, no comprehensive United States stormwater harvesting guidance document was identified that ties all of these elements together. Two comprehensive Australian stormwater harvesting guidance documents are available and should be consulted on general stormwater harvesting issues:

- As part of the Australian Guidelines for Water Recycling, the National Resource Management Ministerial Council, the Environment Protection and Heritage Council, and the National Health and Medical Research Council published a guidance document in July 2009 titled National Water Quality Management Strategy – Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2): Stormwater Harvesting and Reuse.(13)
- In 2006, the Department of Environment and Conservation in New South Wales published a guidance document titled Managing Urban Stormwater: Harvesting and Reuse.(14)

The Australian guidance documents are excellent references containing general principles that can be applied to any stormwater harvesting project, but there are differences between the

Australian and Texas regulations that apply to stormwater harvesting, and there is a need for additional, Texas-specific guidance. Many issues related to implementation of stormwater harvesting in Texas are neither well-documented nor well-understood. These include legal issues associated with water rights and associated permitting, as well as technical issues associated with evaluation of water availability, storage requirements, and treatment requirements. This guidance document assesses these Texas-specific issues and provides information necessary to evaluate the feasibility of stormwater harvesting as a water management strategy in Texas and to develop and implement stormwater harvesting projects.

This guidance document is organized into the following chapters:

- Planning of Stormwater Harvesting Projects (Chapter 2),
- Legal and Regulatory Issues in Texas (Chapter 3),
- Stormwater Availability in Texas (Chapter 4),
- Potential for Stormwater Harvesting in Texas (Chapter 5),
- Design of Stormwater Harvesting Projects (Chapter 6),
- Operation of Stormwater Harvesting Projects (Chapter 7), and
- Case Studies (Chapter 8).

A bibliography of literature sources is presented in Appendix A.

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2. Planning of Stormwater Harvesting Projects

Planning a stormwater harvesting project should begin with identifying all steps necessary to develop and screen various stormwater harvesting alternatives. Mitchell and others suggest a flowchart (Figure 2-1) of the tasks involved in planning a stormwater harvesting project in Australia.[(15)] Some items in this flowchart require additional explanation:

- "Stormwater quantity and quality" in the Site Investigation (Step 2) means estimating total stormwater availability and stormwater quality at the project site. This estimate provides an upper bound for the stormwater quantity that is available to the project. Project infrastructure may be sized to use all of the available stormwater or only a portion. The "project yield analysis" during Analysis and Conceptual Design (Step 5) refers to an estimate of the water available to end users given the conceptual design (sizing) of the project infrastructure. The quantity of water available to end users will be less than or equal to the total quantity of stormwater available to the project.
- "Flood and stream health protection" is listed as a Site-Specific Objective (Step 3). This is meant to address potential flooding and downstream ecology concerns.

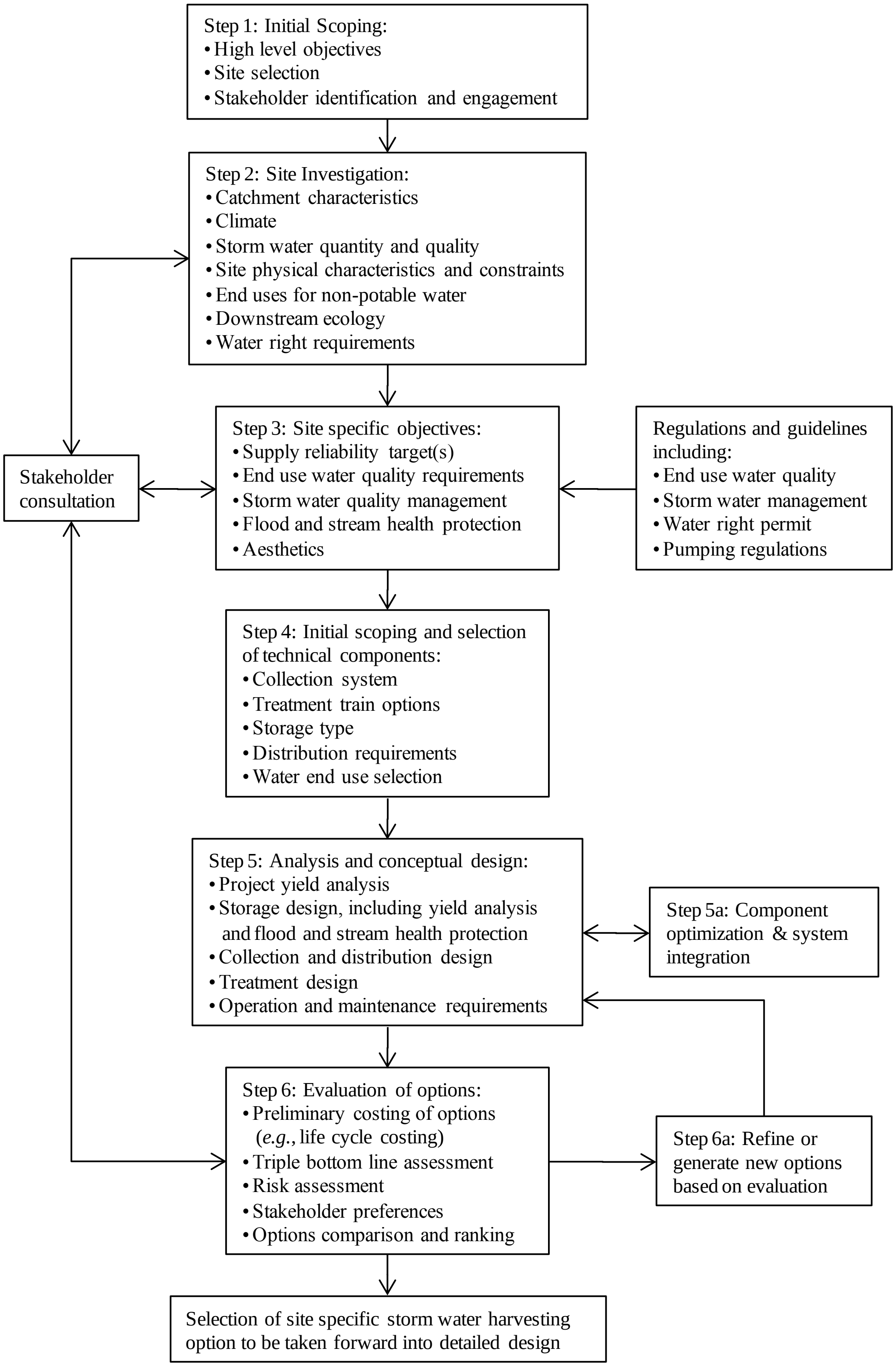
The Mitchell and others flowchart may need to be customized for a specific stormwater harvesting project in Texas. At a minimum, the customized flowchart should include the following tasks:

- Identifying project objectives;
- Identifying site and watershed characteristics;
- Identifying potential users and demands;
- Determining whether a water right permit would be required for the project;[e]
- Quantifying stormwater availability;
- Evaluating environmental issues, including downstream ecology;
- Assessing potential health issues;
- Managing potential risks;
- Determining water quality and treatment requirements;
- Planning for public education and awareness; and
- Considering costs and benefits.

Each of these topics is addressed in this chapter.

[e] Section 3.1 in this document discusses ownership of stormwater and when stormwater is "state water" that is subject to appropriation (and water rights permitting) under Texas Water Code Chapter 11.

Figure 2-1: Developing and Screening of Australian Stormwater Harvesting Projects



Adapted from Mitchell and others[15]

2.1. Project Objectives and Performance Measures

The first task in planning a stormwater harvesting project is to identify the project objectives. These objectives will influence all other planning, design, and operational decisions. Generally, project objectives can be divided into two sets: primary objectives that are the reason(s) to consider a stormwater harvesting project and secondary objectives that are related to successful implementation and operation of a stormwater harvesting project. Primary objectives may include:

- Reduction in potable water demand (including peak demands),
- Reduction in stormwater volume, flowrate, and frequency,
- Restoration of the predevelopment flow regime,
- Reduction in erosion and scouring,
- Reduction in stormwater pollutant loads entering local watercourses,
- Reduction of downstream flooding and erosion,
- Development of an additional local water supply, and
- Reduction in demands on an aquifer.

Secondary objectives may include:

- Managing public health and safety risks,
- Managing environmental risks,
- Meeting end user water requirements regarding quality, quantity, and reliability,
- Providing cost-effective treatment,
- Minimizing water supply infrastructure requirements,
- Providing a public amenity or recreational opportunities,
- Compliance with regulations,
- Conjunctive use of stormwater and other sources,
- Raising public awareness of stormwater pollution,
- Aesthetics, and
- Wildlife habitat enhancement.

Performance measures are used to determine whether project objectives have been achieved. Depending on the project, performance measures could include:(15,16)

- Stormwater runoff quantity and quality,
- End use water quantity and quality,
- Receiving water quantity and quality,
- Potable water consumption (total and per capita),
- Stormwater consumption (total and per capita),
- Supply reliability (percentage of demand met with stormwater harvesting),
- The percentage of new dwellings that incorporate low impact development (LID) principles,
- Percentage of stormwater used versus the amount available,
- Awareness levels/social acceptance, and
- Cost-effectiveness.

Other project objectives and performance measures may be appropriate for a given project. It is important to the success of a stormwater harvesting project to identify the project objectives at the outset of project planning. Likewise, performance measures should be identified early in the process so that they can be incorporated into the design of the project.

2.2. Site and Watershed Characteristics

Site and watershed characteristics can constrain the selection of a project site. At a minimum, the following characteristics should be investigated to aid in the selection of an appropriate site:[f,(13,14)]

- Topography
- Land use
- Environmental flows
- Vegetation
- Sensitive ecosystems
- Existing water management infrastructure
- Regulatory constraints
- Sewer overflows
- Stormwater quality
- Stormwater availability
- Potential stormwater uses
- On-site sewage management systems
- Groundwater vulnerability
- Soil characteristics

If aquifer storage and retrieval (ASR) or groundwater recharge is a possibility, aquifer characteristics such as depth, thickness, composition, hydraulic conductivity, transmissivity, fracture zones, hydraulic interaction with other aquifers, local groundwater quality, and hydraulic gradient should also be investigated.[g,h]

Stormwater quality may vary greatly from one watershed to another and between storm events.[(13)] Stormwater quality depends on watershed characteristics, pollutant sources, climate, and watershed infrastructure.[(15)] Unexpected events, such as chemical spills, can also have a significant impact on stormwater quality.

Different land uses have different impacts on stormwater quality. Despite the variability in concentrations, the following trends have been observed for urban stormwater:[(14,17,18 referenced in 17)]

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[f] Some of these characteristics are discussed in other sections of this chapter.

[g] Aquifer storage and retrieval projects are also sometimes called “aquifer storage and recovery” projects. Texas Administrative Code Title 30, Chapter 297 defines an ASR project as: “A project … that anticipates the use of a Class V aquifer storage well … for injection into a geologic formation, group of formations, or part of a formation that is capable of underground storage of appropriated surface water for subsequent retrieval and beneficial use…” In this guidance document, the definition of an ASR project is expanded beyond “appropriated surface water” to include privately-owned water that is not subject to appropriation.

[h] Groundwater recharge involves injection of water into an aquifer through wells (as in ASR) or infiltration of water through the soil column. Purposes of groundwater recharge may include: later recovery of the water for beneficial use (as in ASR), prevention of a salt water intrusion, enhancement of spring flows, or other purposes.

- The presence of industrial land uses and paved roads with high traffic volumes increases the likelihood of chemical pollution of the stormwater.
- Stormwater from commercial and industrial watersheds generally has lower concentrations of nutrients and higher concentrations of heavy metals than stormwater from residential watersheds.
- High volumes/frequencies of sewer overflows increase the likelihood of pathogens in stormwater runoff.
- Stormwater from residential watersheds tends to have greater coliform levels by one order of magnitude than stormwater from commercial and industrial watersheds, due to the presence of domestic animals.
- Stormwater from totally urbanized watersheds is likely to have higher chemical concentrations than stormwater from partially urbanized watersheds.

Table 2-1 lists some of the pollutant sources that can contribute to urban stormwater contamination. Literature sources of stormwater quality data are presented in Appendix B.

Table 2-1: Potential Urban Stormwater Pollutant Sources

Pollutant Source	**Solids**	**Nutrients**	**Microorganisms**	**DO Demands**	**Metals**	**Oils**	**Synthetic Organics**
Soil erosion	x	x		x	x		
Cleared land	x	x	x				
Fertilizers		x			x		
Human waste	x	x	x	x			
Animal waste	x	x	x	x	x		
Vehicle fuels and fluids	x		x	x	x		
Fuel combustion		x			x	x	
Vehicle wear	x				x		
Industrial and household chemicals	x	x			x	x	x
Industrial processes	x	x			x	x	x
Paint and preservatives					x	x	
Pesticides					x	x	x

Mitchell and others adapted from Livingston[15,19]

2.3. Potential Users and Demands

A review of stormwater harvesting systems in Australia found that stormwater harvesting has been implemented mostly on small scales, and the water has been used mostly for urban irrigation.[20 referenced in 21] Other potential uses of stormwater include:[13,14,22,23,24]

- Vehicle washing
- Toilet flushing
- Industrial and commercial uses
- Ornamental ponds, water features, or wetlands
- Aquifer storage and retrieval
- Evaporative cooling water
- Boiler feed water
- Process water
- Washdown water
- Dust suppression
- Fire fighting
- Commercial food crops
- Non-food crops (trees, turf, flowers, etc)
- Street cleaning
- Groundwater recharge
- Enhancement of environmental flows

With the exceptions of aquifer storage and retrieval and groundwater recharge, these are exclusively non-potable uses.

2.4. Stormwater Availability

Stormwater availability and timing should be assessed to determine whether there will be sufficient stormwater to meet projected demands and to provide basic information for the design of stormwater storage and treatment facilities. Section 3.1 discusses ownership of stormwater and when stormwater is "state water" that is subject to appropriation (and water right permitting) under Texas Water Code Chapter 11. Stormwater availability in Texas is discussed in detail in Chapter 4.

If stormwater is not projected to be a reliable supply for a given project, it may be feasible to use stormwater as a supplement to water from another source. Out of 17 systems (mostly located in Australia), several collect and recycle treated wastewater effluent in addition to stormwater.[23] Most of the 17 systems are supplemented with potable water as a backup during periods of low rainfall.

2.5. Environmental Impacts

Potential environmental impacts associated with stormwater harvesting can include changes to environmental flows, an increased chance of upstream flooding, the potential for pollution of surface water or groundwater, and other case-specific issues. This section is intended to identify potential issues, and project planners should conduct site-specific investigations as necessary for management of environmental impacts from individual stormwater harvesting projects.

Environmental Flows

Harvesting of stormwater can reduce the runoff volumes and peak flows that enter a natural watercourse, reducing pollutant loadings and the potential for erosion. In watersheds where development has taken place, stormwater harvesting can help restore flow regime indicators such as runoff frequency and peak flow to their pre-development levels.[(15)] This can enhance downstream aquatic ecosystems and reduce downstream erosion. However, too much change to instream flows can adversely affect aquatic ecosystems. For example, a project that is designed to capture stormwater before it enters a natural stream when flow in the stream is already low should consider the impact on environmental flows.[(25)] Ecosystem sensitivity, existing and projected flows, and project objectives should be assessed during the design phase of a project to determine appropriate project yield and pass-through quantities.

Flooding Hazards

In cases where weirs, embankments, or other modifications are utilized to store water in or capture water from a stormwater collection system, stormwater may back up in the collection system, causing an increased chance of upstream flooding. Flooding hazards should be assessed during the design phase of a project in order to appropriately mitigate risks to surrounding areas.

Potential for Pollution

The potential for a stormwater harvesting project to cause pollution of surface water, groundwater, or soil will depend on the influent stormwater quality, the provided level of treatment, and the uses of the stormwater. These topics and associated risks are discussed in other sections.[i]

Capturing stormwater before it enters a natural watercourse may also impact downstream pollutant concentrations and the health of downstream aquatic ecosystems. Currently, there are no known monitoring data or studies that show these impacts.[(21)] Ecosystem sensitivity, existing and projected water quality, and project objectives should be assessed during the design phase of a project to determine appropriate project water quality requirements.

Impact on Soil and Plant Systems

Without sufficient treatment and careful application, use of stormwater for irrigation may adversely impact soil and plant systems. An excessive hydraulic loading rate can result in runoff from irrigated areas, low oxygen levels in soil, and decreased crop yield. Stormwater may contain nutrients, and it is important to understand whether the concentrations are compatible with the plant system (elevated nitrogen concentrations may be associated with decreased crop yield). It will also be important to determine if the concentration could have impacts on underlying groundwater. Finally, when present in excess, salinity, chlorine disinfection residuals,

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[i] Sources of stormwater quality data are presented in Appendix B. Stormwater treatment methods are discussed in Section 6.3. Risk management is discussed in Section 2.7.

chlorides, sodium, boron, copper, zinc, and herbicides can inhibit plant growth.[j,(13)] Where stormwater is used for irrigation, treatment systems and operational guidelines should be developed to control potential adverse impacts on soil and plant systems.

Special care should be taken in stormwater irrigation applications in order to avoid contamination of groundwater. The risk of groundwater contamination can be controlled through appropriate stormwater application rates.

2.6. Public Health Issues

Public health issues should be addressed during the risk management (Section 2.7) and design (Chapter 6) phases of a stormwater project. Potential health concerns associated with stormwater harvesting can be divided into two major categories of concern: water quality risks and water storage hazards. Descriptions of common public health considerations are provided below and should not be considered all-inclusive.

Water Quality Risks to Public Health

Water quality risks to public health should be evaluated based on the intended end use and the degree of human contact. Public health risks may be associated with pathogens, inorganic chemicals, and/or organic chemicals in stormwater.

Based on a literature review for the Water Environment Research Foundation, Olivieri and others identified the following pathogens as most important when considering human exposure to stormwater: Norwalk-like viruses, Hepatitis A, Astrovirus, and rotavirus (human viruses); *Cryptosporidium parvum*, *Giardia lamblia*, *Entamoeba histolytica*, and *Toxoplasma gondii* (protozoa); and *Campylobacter*, *Salmonella*, *Shigella*, and *E. coli* (bacteria).[(26)] This list was compiled from the Centers for Disease Control’s estimated disease burden in the United States, U.S. Environmental Protection Agency studies on combined and sanitary sewer overflows, and pathogens known to be present in wastewater. If there is potential for human exposure to pathogens in the stormwater, planners should consider analyzing stormwater for the presence of these pathogens and, if necessary, designing treatment facilities to control public health risks from pathogens.

Typical organic or inorganic chemical pollutants associated with stormwater include: metals, sediment, nutrients, chlorides, pesticides, oil and grease, toxic organics, and hydrocarbons.[(27,28)] Stormwater treatment is used to reduce water quality risks to public health. Water quality and treatment goals for stormwater harvesting are discussed in Section 2.8.

Accidental spills, industrial discharges, and other unforeseen changes in watershed water quality may increase the risk to public safety. If the potential exists for sudden changes to stormwater quality, planners should incorporate design elements such as low-flow bypasses and/or retention

[j] Water quality and treatment goals are discussed in Section 2.8.

ponds into stormwater collection and storage facilities to protect the quality of the produced water and may recommend additional monitoring measures.

Water Storage Hazards for Public Safety

Water storage hazards associated with stormwater harvesting include injury or drowning in stormwater storage facilities, and other public safety issues, such as cross connections with the potable water supply and embankment failure/overtopping. In addition, open storage facilities can become a vector habitat (including mosquitoes) if not properly controlled. Water storage hazards and mitigation should be evaluated during the design phase of a stormwater harvesting project. Where possible, consideration should be given to measures to minimize the uncontrolled access of the public to stormwater storage facilities.

2.7. Risk Management

Throughout the planning, design, and operation phases of a stormwater harvesting project, a systematic risk management approach, such as shown in Table 2-2, should be adopted to identify and manage risks to public health and to the environment. A defined risk evaluation process should create treatment, storage, and delivery goals that are incorporated into project design or operational procedures. A systematic approach to risk management will help to control hazards, improve reliability, incorporate redundancy, and enhance the overall performance of a stormwater harvesting system. The approach should include risk mitigation measures during the capture, treatment, storage, and delivery phases of the project.

In addition to defining a systematic risk management approach, risk management for stormwater harvesting projects can be addressed through establishment of stormwater harvesting quality goals, screening investigations, and project design. These topics are addressed below.

Risk Management through Stormwater Harvesting Quality Goals

The Texas Surface Water Quality Standards require that "pollution in stormwater shall not impair existing or designated uses," including water supply.[(29)] Typically, stormwater discharge permits under the Texas Pollutant Discharge Elimination System (TPDES) do not contain numerical concentration limits. Instead, stormwater discharge permits require a stormwater management plan (SWMP) that is designed to control pollution through structural and non-structural best management practices, rather than treating the stormwater prior to discharge. SWMPs generally contain best management practices that prevent or effectively reduce exposure of stormwater to pollution.[(30)] Similarly, concentration limits for non-potable stormwater harvesting are unregulated in Texas.[k]

[k] Potable stormwater harvesting must conform to state and federal drinking water standards.

Table 2-2: Risk Management Framework

<table>
<tr><th>Tenet</th><th>Action</th><th>Procedure</th></tr>
<tr><td rowspan="2">Commitment</td><td>Develop</td><td rowspan="2">▪ Involve appropriate regulatory agencies.
▪ Construct a team of qualified individuals.
▪ Comply with applicable regulations.
▪ Engage stakeholders.
▪ Develop appropriate organizational policy.</td></tr>
<tr><td>Manage</td></tr>
<tr><td rowspan="2">Assessment</td><td>Identify</td><td rowspan="2">▪ All sources, uses, and exposure routes.
▪ Hazards, risks, and appropriate risk levels.</td></tr>
<tr><td>Assess</td></tr>
<tr><td rowspan="2">Prevention</td><td>Identify</td><td rowspan="2">▪ Preventive measures to mitigate risks.
▪ Critical control points.</td></tr>
<tr><td>Implement</td></tr>
<tr><td rowspan="4">Procedures</td><td>Identify</td><td rowspan="4">▪ Operation and maintenance procedures.
▪ Monitoring protocol.
▪ Operational performance goals.
▪ Appropriate materials/equipment throughout system.</td></tr>
<tr><td>Develop</td></tr>
<tr><td>Establish</td></tr>
<tr><td>Ensure</td></tr>
<tr><td rowspan="4">Verification</td><td>Develop</td><td rowspan="4">▪ Goals for treated stormwater quality.
▪ Water quality monitoring plan for system.
▪ Plans for individual users.
▪ System for managing issues.</td></tr>
<tr><td>Collect</td></tr>
<tr><td>Review</td></tr>
<tr><td>Implement</td></tr>
<tr><td rowspan="2">Emergency Management</td><td>Establish</td><td rowspan="2">▪ Communication procedure.
▪ Protocol during emergencies and incidents.
▪ Develop corrective action procedures.</td></tr>
<tr><td>Implement</td></tr>
<tr><td rowspan="2">Education</td><td>Develop</td><td rowspan="2">▪ Employee awareness and training.
▪ Public education and communication.</td></tr>
<tr><td>Provide</td></tr>
<tr><td rowspan="2">Documentation</td><td>Manage</td><td rowspan="2">▪ Appropriate record documentation and submittal.
▪ Reports for internal and external stakeholders.</td></tr>
<tr><td>Produce</td></tr>
<tr><td rowspan="3">Evaluation and Improvement</td><td>Conduct</td><td rowspan="3">▪ Review processes and procedures.
▪ Review additions to system to ensure they comply with procedures.
▪ Long-term data to assess performance.
▪ Management review of systems and procedures.
▪ New technologies.</td></tr>
<tr><td>Develop</td></tr>
<tr><td>Validate</td></tr>
</table>

Department of Environment and Conservation NSW[14]

To reduce or mitigate hazards as part of a risk management plan, quantitative and/or qualitative water quality objectives should be identified. As discussed in Section 2.8, several literature sources proposed stormwater harvesting quality goals to manage risks associated with public health, to reduce algal blooms in stormwater storage, and to provide appropriate irrigation water quality. These proposed goals are shown in Tables 2-4 through 2-8 in Section 2.8.

Risk Management through Screening Investigations

Planners should conduct screening investigations to help identify potential risks.[13,14] The watershed should be reviewed for non-residential land use that could contribute agricultural or industrial contaminants and for historical sewer overflows that could indicate the presence of pathogens. Various investigations and follow-up actions may be appropriate for watersheds with industrial land use or major roads, agricultural land use, on-site sewage management systems, and/or wastewater treatment plants (Table 2-3). In watersheds where the sewer overflow frequency is unknown or moderate to high (approximately 0.23 to 0.80 overflows per mile per year), Australian guidelines suggest that a 1-log reduction in pathogens using treatment or exposure controls may be appropriate.[13] In watersheds where the sewer overflow frequency is high, the same guidelines suggest calculation of additional health risks due to raw sewage entering the stormwater and increase of log reduction requirements accordingly.

The screening process should assess whether the proposed types of water use are suitable for stormwater harvesting based on water quality goals established for the project. For example, stormwater quality should be screened for salinity concentrations that could adversely impact plant productivity and soil structure and for constituents that could adversely impact groundwater quality. Characteristics of proposed irrigated areas should be screened for the likelihood of excessive runoff or erosion, restricted plant growth, soil saturation, or other adverse impacts. The volume and frequency of stormwater diversions should be screened for potential impacts to environmental flows. The location and design of stormwater storage should consider the risks of animal inputs of fecal matter, mosquito breeding, public safety, algal blooms, turbidity, and mixing of dissimilar waters. This list of screening investigations is not comprehensive and is meant to serve as a starting point. Other site and watershed characteristics that should be screened during site selection are discussed in Section 2.2.

For stormwater ASR or groundwater recharge projects, National Resource Management Ministerial Council[1] and others discussed four stages of risk assessment and management.[22] In Stage 1, the entry-level evaluation, readily available information is gathered, and a first assessment is performed of the project viability and project degree of difficulty. The entry-level viability assessment includes evaluating whether there is:

- Sufficient demand for water,
- Adequate available stormwater
- A suitable aquifer for storage of the stormwater, and
- Sufficient space available for stormwater collection, storage, and treatment facilities.

[1] The National Resource Management Ministerial Council includes the Australian/State/Territory and New Zealand government ministers responsible for primary industries, natural resources, environment, and water policy.

Table 2-3: Screening Investigations for Stormwater Harvesting Projects Capturing Water from Non-Residential Watersheds

Source	Potential Hazard	Investigations
Industrial land use or major roads/freeways	Hydrocarbons Metals	▪ Appropriately designed stormwater treatment measures are present ▪ Stormwater quality controls are appropriately operated and maintained ▪ Treatment measures are managed by an organized commercial and/or government entity subject to regulation and audit
Agricultural land use	Pathogens Nutrients	▪ Agricultural land uses are not expected to produce poor stormwater quality (*i.e.*, no significant fertilizer application, manure generation or forestry activities) ▪ Where agricultural land uses could produce poor stormwater quality, appropriate stormwater quality management practices are in place and appropriately maintained.
On-site sewage management systems	Pathogens	▪ Regulatory authority requires appropriate design of on-site sewage management systems ▪ Regulatory authority audits on-site sewage management systems
Wastewater treatment plants	Pathogens Pollutants	▪ Wastewater treatment plant is appropriately designed, operated and maintained ▪ Treatment measures are managed by an organized commercial and/or government entity subject to regulation and audit ▪ Regulatory authority regulates and audits treatment plant water quality performance ▪ Treatment plant includes disinfection

National Resource Management Ministerial Council and others[13]

The entry-level degree of difficulty assessment considers available information on stormwater quality, groundwater quality, proximity of other groundwater users, aquifer characteristics, and experience with similar projects. It serves as a preliminary indicator of human health and environmental risks and informs the extent of the investigations likely to be required in Stage 2.

Stage 2 may involve site-specific investigations, estimation of maximal risk and uncertainty, and hazard identification and identification of preventive measures. Site-specific investigations may include source water and groundwater sampling and analysis, hydrogeological studies, watershed studies, groundwater modeling, and geochemical evaluation. Estimation of risks and uncertainties may include assessment of inactivation rates for pathogens in aquifers, assessment of environmental fate data for organic chemicals, and prediction of the fate of pathogens and organic chemicals in groundwater and recovered water. The site-specific investigations and risk and uncertainty estimation will enable hazard and preventive measure identification.

Stage 3 consists of validation of the preventive measures after design and construction and residual risk assessment. Finally, Stage 4 consists of an ongoing operation and maintenance plan that addresses residual risks.

The following parameters may be of concern for stormwater ASR projects: pathogens, arsenic, iron, manganese, hydrogen sulfide, salinity, sodicity, nutrients, trace organic compounds, turbidity and particulates, and radionuclides.[m,(22)] Design factors that must be considered include: pressure, flow rates, volumes, and groundwater levels; contaminant migration in fractured rock and karstic aquifers; aquifer dissolution and well and aquitard stability; aquifer and groundwater-dependent ecosystems; and energy and greenhouse gas impacts. If the ASR project involves infiltration instead of injection, the filtration of the stormwater through the soil will provide additional treatment.

Water quality issues could occur at the interface between dissimilar waters that are mixed in an aquifer. For example, certain potable ASR sites in Florida mobilized arsenic from pyrite-rich limestone into the groundwater due to differences in the dissolved oxygen concentrations between the injected water and native groundwater.[(31)] The arsenic issue was not seen in native groundwater withdrawals because the physico-chemical conditions were not conducive to arsenic mobilization.

In Texas, the Carrizo sandstone is reported to have elevated pyrite content near the East Texas salt domes. In addition, the Gulf Coast and Ogallala aquifers have existing arsenic concerns. These aquifers would need to be investigated on a local level to be considered for stormwater ASR for potable use.

Risk Management through Project Design

Potential risks identified through screening investigations can be managed through proactive design of stormwater treatment facilities and operational measures such as limiting hydraulic loading rates, limiting public access to project facilities, and monitoring of constituents of concern. Stormwater projects can also minimize public health risks through segregation of waters having different qualities. For example, Hatt and others documented 6 systems that collect, treat, and use roof runoff separately from general runoff, using the roof runoff for purposes that have greater potential for human contact.[(23)] Design of stormwater projects is discussed in more detail in Chapter 6.

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[m] Trace organic compounds include pesticides, hydrocarbons, algal toxins, disinfection byproducts, and emerging constituents of concern.

2.8. *Water Quality and Treatment Goals*

As discussed in Section 2.7, concentration limits for non-potable stormwater harvesting are unregulated in Texas.[n] Few water quality guidelines have been proposed specifically for stormwater harvesting. As a result, guidelines or regulations for treated wastewater effluent reuse and drinking water quality have often been used as an end use water quality target.[(20 referenced in 21)] In particular, federal and state drinking water quality standards may be too conservative for stormwater harvesting scenarios that involve non-potable applications.

The potential for human contact should be a primary consideration when developing treatment guidelines. Similar to the Texas reclaimed water use regulations, applications for which human contact is likely should require more stringent treatment standards. [o,(32)] The Texas reclaimed water use regulations provide water quality criteria for turbidity, fecal coliform, and BOD_5, based on potential for human contact.[(33)]

It is important to match the water quality goal with the water use. Several literature sources proposed stormwater harvesting quality goals to manage risks associated with public health, to reduce algal blooms in stormwater storage, and to provide appropriate irrigation water quality:

- National Resource Management Ministerial Council and others identified treatment goals for different stormwater uses for management of public health risks (Table 2-4) and for management of operational risks (Table 2-5).[(13)]
- The Texas Rainwater Harvesting Evaluation Committee recommended minimum water quality guidelines for the indoor use of collected rainwater (Table 2-6).[(34)] Although these guidelines only apply to water collected from rooftops (while stormwater may be collected from overland flow or stormwater collection systems), they are presented here for comparison to other information.
- Melbourne Water recommended maximum storage detention times to reduce the risk of algal blooms (Table 2-7).[(35 referenced in 14)] These detention times assume that there are no light or nutrient limitations.
- Table 2-8, compiled from several sources, shows guidelines for evaluation of irrigation water quality for selected parameters.

[n] Potable stormwater harvesting must conform to state and federal drinking water standards.

[o] Reclaimed water is defined as highly treated wastewater that is used for beneficial purposes.

Table 2-4: Australian Guidelines for Stormwater Treatment to Manage Public Health Risks by Type of Use and Public Access Control

<table>
<tr><th>Type of Use</th><th>Public Access Control</th><th>Stormwater Treatment Criteria</th></tr>
<tr><td rowspan="2">Municipal use: open space, sports grounds, golf courses, dust suppression
<u>OR</u>
Irrigation of non-food crops</td><td>Unrestricted</td><td>Disinfection to achieve:
▪ > 1.5 $\log_{10}$ reduction (96 percent) of viruses and bacteria
▪ > 0.8 $\log_{10}$ reduction (82 percent) of protozoan parasites
▪ E. coli <10 CFU/100 ml (median)

Turbidity:
▪ < 25 NTU (median)
▪ < 100 NTU (95th percentile)

provided the disinfection system is designed for such water quality and that, during operation, the disinfection system can maintain an effective dose by using up all disinfectant demand and providing free disinfectant residual and/or provides adequate UV dose even in the presence of elevated turbidity and UV absorbing materials

Iron:
▪ < 9.6 mg/l (median)</td></tr>
<tr><td>Restricted</td><td>No treatment required</td></tr>
<tr><td>Public drip irrigation or subsurface irrigation</td><td>Unrestricted</td><td>No treatment required</td></tr>
<tr><td>Dual distribution system with indoor and outdoor use
<u>OR</u>
Irrigation of commercial food crops</td><td>Unrestricted</td><td>Disinfection to achieve:
▪ > 4 $\log_{10}$ reduction of viruses, parasites and bacteria
▪ E. coli <1 CFU/100 ml

Turbidity:
▪ < 2 NTU (target)
▪ < 10 NTU (95th percentile) and
▪ < 25 NTU (maximum)</td></tr>
</table>

National Resource Management Ministerial Council and others[13]

Table 2-5: Australian Guidelines for Stormwater Treatment to Manage Operational Risks for Public Spray Irrigation

Parameter	Stormwater Treatment Criteria	
	Design Life up to 20 Years	**Design Life up to 100 Years**
Suspended solids	< 50 mg/l	< 30 mg/l
Coarse particles	< 2 mm diameter	< 1 mm diameter
Iron (total)	< 10 mg/l	< 0.2 mg/l
Phosphorus (total)	< 0.8 mg/l	< 0.05 mg/l
Nitrogen (total)	< 25 mg/l	< 5 mg/l
Hardness ($CaCO_3$)	< 350 mg/l	< 350 mg/l

National Resource Management Ministerial Council and others[13]
Department of Environment and Conservation NSW[14]

Table 2-6: Texas Minimum Water Quality Guidelines for Indoor Use of Rainwater

Category of Use	Rainwater Quality for Non-Potable Indoor Use	Rainwater Quality for Potable Uses
Single-Family Households	Total coliforms < 500 CFU/100 ml Fecal coliforms < 100 CFU/100 ml Turbidity < 10 NTU Water testing recommended annually	Total coliforms – 0 Fecal coliforms – 0 Protozoan cysts – 0 Viruses – 0 Turbidity ≤ 1 NTU Water testing recommended every 3 months
Community or Public Water System	Total coliforms < 500 CFU/100 ml Fecal coliforms < 100 CFU/100 ml Water testing recommended annually	Total coliforms – 0 Fecal coliforms – 0 Protozoan cysts – 0 Viruses – 0 Turbidity ≤ 0.3 NTU Water testing required monthly In addition, the water must meet all other public water supply regulations and water testing requirements per Texas Administrative Code Title 30, Chapter 290.

Texas Rainwater Harvesting Evaluation Committee[34]

Table 2-7: Suggested Maximum Detention Times to Reduce the Risk of Algal Blooms

Maximum Detention Time* (days)	Average Daily Temperature (ºC)
50	15
30	20
20	25

Melbourne Water[35 referenced in 14]

* 20th percentile value. Assumes no light or nutrient limitations.

Irrigation

Water quality goals for irrigation applications should be developed on a case-by-case basis using site-specific information. Tables 2-4, 2-5, and 2-8 provide examples of stormwater quality objectives for irrigation applications. Typical suspended solids and nutrient concentrations in stormwater may result in blockages in irrigation equipment due to direct clogging or biofouling. Maximum concentrations to prevent operational problems for conventional spray irrigation systems are presented in Table 2-5.

When present in excess, salinity, chlorine disinfection residuals, chlorides, sodium, boron, copper, zinc, and herbicides can be toxic to plants and/or inhibit plant growth.(13)

Industrial Use

Water quality goals for individual industrial applications should be developed with consideration of the intended use and site-specific data. Appropriate treatment should be provided to address potential stormwater quality concerns for industrial uses, including the following general categories:(14)

- Pathogen levels (health risks to public and workers)
- Chemical quality (corrosion of pipes and machinery, scale formation, foaming, etc.)
- Physical quality (solids deposition, fouling, blockages)
- Nutrients (slime formation, microbial growth)

Prior to the implementation of stormwater harvesting in industrial applications, a detailed evaluation of potential water quality issues and points of exposure should be performed.

Table 2-8: Guidelines for Evaluation of Irrigation Water Quality for Selected Parameters

Constituent	Units	Degree of Restriction on Use			Comment	References
		None	Slight to Moderate	Severe		
TDS	mg/l	<450	450-2,000	>2,000		(36)
TDS	mg/l	<800	800-2,000	>2,000		(37)
TDS	mg/l	100-1,000	1,000-2,000	>2,000		(38)
SAR	-	<3	3-9	>9		(36)
SAR	-	<6	6-9	>9	2:1 Clay Type or Sand and TDS<960 mg/l	(39)
SAR	-	<16	16-24	>24	1:1 Clay Type or Sand and TDS >960 mg/l	(39)
SAR	-	1-10	10-18	>18		(40)
RSC	meq/l	<0	0-2.5	>2.5		(39)
RSC	meq/l	<1.25	1.25-2.5	>2.5		(37)
Chlorides	mg/l	<70	70-355	>355	Soil accumulation and root toxicity for sensitive trees and shrubs	(39)
Chlorides	mg/l	<100	>100	NA	Foliage contact with sensitive ornamental plants	(39)
Boron	mg/l	<0.7	0.7-3.0	>3.0		(36)
Boron	mg/l	<0.5	0.5-1.0	>1.0		(41)
Boron	mg/l	NA	NA	>1.0	Landscape plants	(37)
Copper	mg/l	NA	NA	>0.2		(39)
Selenium	mg/l	NA	NA	>0.02		(40)
Nitrogen	mg/l	<5	5-30	>30		(36)
Zinc	mg/l	NA	NA	>5		(39)
pH	S.U.	6.5-8.4	NA	NA		(36)
pH	S.U.	6.5-7.0	7.0-8.4	NA		(37)

TDS = total dissolved solids
SAR = sodium adsorption ratio
RSC = residual sodium carbonate
NA = not available
mg/l = milligrams per liter
meq/l = milliequivalents per liter
S.U. = standard units

Potable Surface Water Supply Augmentation

Potable surface water supply augmentation with stormwater would consist of a discharge of captured stormwater to a surface water body with a TCEQ-designated water supply use. Augmentation of a surface water body used for potable water supply with stormwater may require a new or amended TPDES water quality permit.[p] As discussed in Section 2.7, the Texas Surface Water Quality Standards require that "pollution in storm water shall not impair existing or designated uses," including water supply.[(29)] In general, this requirement is met not through numerical concentration limits but through implementation of best management practices that prevent or effectively reduce exposure of stormwater to pollution.[(30)]

Aquifer Storage and Retrieval

Currently, all stormwater injected into a Texas aquifer must be treated to meet state primary and secondary drinking water standards prior to injection, regardless of the ambient water quality in the aquifer or the uses of water from the aquifer.[(42,43)] If the stormwater is recovered for potable use, it must be treated to the same standards after retrieval, if necessary.

There are no known projects in Texas that augment a drinking water aquifer with harvested stormwater, but the following projects augment aquifers used for drinking water with water from other sources:

- The El Paso Public Utilities Board recharges the Hueco Bolson aquifer with reclaimed water that has been treated to drinking water standards. In 2008, El Paso injected (through wells) and infiltrated (through spreading basins) about 460 million gallons of reclaimed water into the aquifer.[(44)]
- During low-demand periods, the City of Kerrville treats surface water from the Guadalupe River to drinking water standards and stores it in the Trinity Aquifer for later use during high-demand periods.
- During wet or low-demand periods, the San Antonio Water System stores groundwater from the Edwards Aquifer in the Carrizo Aquifer for use during high-demand periods or when Edwards Aquifer withdrawal permits are curtailed.

Example stormwater ASR irrigation projects include recharge of the Blaine Aquifer in southwestern Oklahoma and Andrews Farm in South Australia. [(45,46)]

An example of aquifer-stored water being used for environmental flows is the Comprehensive Everglades Restoration Plan (CERP). This project, while not in full operation, is designed to include 333 ASR wells with a total capacity of more than 1.6 billion gallons per day. It includes almost 36,000 acres of constructed stormwater treatment wetlands to ensure water adequate

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[p] In addition, a new or amended water right permit may be required to divert the stormwater from the water body downstream of the stormwater discharge.

water quality for the Everglades, to improve conditions in Lake Okeechobee, and prevent excessive releases of fresh water to coastal estuaries.[47,48]

2.9. Public Education and Awareness

Community attitudes toward stormwater harvesting depend on the following community and project characteristics:[15,49]

- Community Characteristics:
  - Community income and education
  - Level of knowledge of urban water issues
  - Knowledge of water quality
  - Frequency and severity of potable water restrictions
  - Familiarity/experience with alternative water sources
  - Confidence in the water provider
  - Advocacy by water authorities, government agencies, and researchers
  - Assurances that there is no unacceptable health risk

- Project Characteristics:
  - Proposed uses of stormwater
  - Amount of water to be supplied
  - Projected cost of the water
  - Degree of human contact with the water
  - Public health and safety measures
  - Strong conservation or environmental justification for stormwater use

Significant public education about project impacts, costs, risks, and benefits may be necessary. Owners should involve stakeholders from project conception through project planning, design, and implementation. Designing a public education program to build support for stormwater harvesting requires understanding existing public attitudes towards stormwater projects and understanding potential barriers to project implementation. Australian research on these topics is summarized in the following sections.

Public Support for Various Uses

The public may be predisposed to support stormwater harvesting for non-potable purposes rather than potable purposes. Surveys in Perth, Western Australia, found the following levels of support for various uses of treated stormwater:[50 referenced in 49]

- Irrigation of residential gardens: 96 percent
- Toilet flushing: 95 percent
- Laundry: 68 percent
- Personal washing: 50 percent
- Drinking water: 29 percent

A telephone survey of approximately 2,500 householders from 7 Australian cities with water restrictions (Adelaide, Brisbane, Canberra, Hobart, Melbourne, Perth and Sydney) was conducted in late 2004 and early 2005.[51] Based on this survey, Table 2-9 summarizes the willingness of urban residents in Australia to use stormwater for various uses.

Table 2-9: Willingness to Use Stormwater in Australian Cities (Percent)

<table>
<tr><th>Willingness/ Confidence Level</th><th>Toilet Flushing</th><th>All Household Uses</th><th>Showering</th><th>Cooking</th><th>Drinking</th></tr>
<tr><td>Without hesitation/ great confidence</td><td>84.9</td><td>25.1</td><td rowspan="2">81.9</td><td rowspan="2">58.7</td><td rowspan="2">48.4</td></tr>
<tr><td>Some qualifications/ moderate confidence</td><td>11.6</td><td>50.3</td></tr>
<tr><td>Not willing</td><td>3.5</td><td>24.6</td><td>not reported</td><td>not reported</td><td>not reported</td></tr>
</table>

Calculated from data presented in Marks[51]

In addition, public willingness to consider stormwater harvesting for potable purposes appears to depend on the availability of other water supplies. In Perth, Western Australia, 1999 to 2005 was a time of increasing concern over water resources. Two-day-per-week watering restrictions were implemented in 2001 and still remain in effect.[52] During this time, support for the use of treated stormwater as drinking water increased from 29 percent to 49.6 percent, and support for the use of treated stormwater for personal washing/showering increased from 50 percent to 84.2 percent.[50 referenced in 49,51]

Public Support and Project Scale

In Australia, the public is more accepting of household scale stormwater harvesting projects or large, centralized projects rather than neighborhood scale projects. The public finds stormwater from their own homes to be more acceptable than stormwater from their neighbors' homes and perceives that a high level of regulation and risk management will ensure suitable water quality for large-scale projects. In addition, the public is more accepting of using rainwater for garden watering rather than stormwater and more accepting of stormwater harvesting rather than reuse of treated wastewater effluent.[14,21,49,53]

Implementation Issues

Interviews with 36 private industry and government water professionals in southeast Queensland, Australia, revealed the following barriers to implementation of water-sensitive urban design (WSUD), which includes stormwater harvesting: [q,(16)]

[q] "Low impact development" (LID) is used in the United States to describe water-sensitive urban design principles.

- State and local governments do not provide policy direction, regulations, and guidelines or sufficient detail in the approval and administrative process.
- Capital and maintenance costs for building, maintaining, and replacing infrastructure related to water-sensitive urban design (low impact development) are perceived to be too high.
- Stakeholders and the community are not aware of the benefits and practicalities of water sensitive urban design, do not receive training, and do not have access to relevant information.
- Consumers do not demand water sensitive design developments, and appropriate marketing about their costs, benefits and rewards does not occur.

Lesser barriers to implementation include:(16)

- Lack of technical expertise and information,
- Lack of incentives,
- Health and safety concerns,
- Lack of political and senior management support, and
- Lack of sharing of ideas and information.

In addition, concern over prohibitive storage requirements and whether large storage facilities can be retrofit into the urban environment is a barrier to stormwater harvesting.(15)

Other barriers may include:(20 referenced in 21,21,23)

- Long negotiation, assessment, and approval processes for stormwater projects.
- Lack of experience in the water industry and among the relevant authorities with stormwater harvesting and associated policies.
- Inadequate methodologies for objectively assessing the costs and benefits of stormwater harvesting projects.
- Lack of standard protocols for the collection of life-cycle costs for stormwater harvesting systems.

Although this research took place in Australia, it is likely that the same barriers to implementation exist in Texas. Recommended remedies for surmounting barriers to implementation of stormwater harvesting include:(16)

- A centralized, comprehensive information service to disseminate specific town planning controls, best practice guidelines, case studies of successful demonstration sites, estimated costs to build and maintain assets over 10 years, and an educational database.
- Education and training programs for stakeholders, community groups, developers and water practitioners. This education and training should take place continuously from project conception through project planning, design, and implementation.
- Production of technical manuals, demonstration sites, and promotional materials.

- A pool of experts that can assist local councils with design and implementation of water conservation or treatment projects.
- Evaluation of water-sensitive urban design (low impact development) during regional planning.

2.10. Costs and Benefits

Stormwater harvesting projects often have multiple economic, social, and environmental objectives. It can be difficult to quantify social and environmental impacts and objectives in monetary terms, so an economic analysis of project alternatives may not provide sufficient information for decision-making. A "triple-bottom-line" (TBL) assessment method that includes developing criteria for assessing the multiple objectives, developing a scoring matrix to evaluate the likely impact of different project alternatives on the assessment criteria, and selecting preferred alternatives should be used to assess costs and benefits. Taylor presented example TBL assessments for two stormwater harvesting projects.(54)

One element of the TBL approach is life-cycle costing, which includes capital costs, acquisition costs, maintenance costs, renewal/adaptation costs, and costs for taking the project out of service at the end of its life.(15) The TBL approach should also include the following economic benefits:(15,14,25)

- Savings from purchasing less potable water
- Income from sale of the stormwater
- Savings from reduction in downstream stormwater facility sizes
- Savings from avoiding the need for nutrient removal
- Savings in fertilizer application
- Income benefits to the end user
- Financial benefits from increased amenity and aesthetics

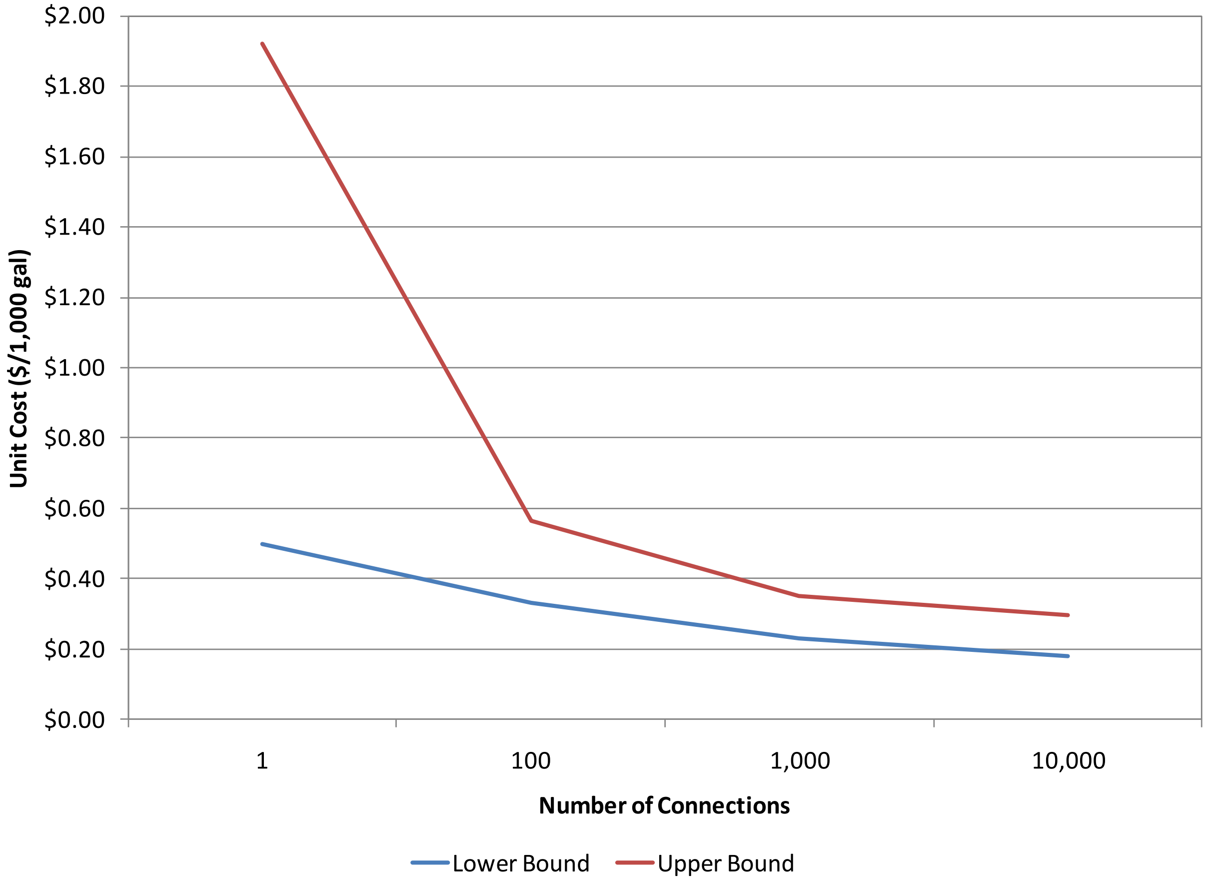
Smaller stormwater harvesting projects may not appear economical when compared with potable water rates.(25) In such cases, economic benefits, such as those listed above, and non-economic benefits (*e.g.*, reductions in point source pollutant loads) should be considered.

Costs

Few data are available regarding the capital and operating costs of stormwater harvesting systems.(21) Actual costs and planning-level costs from literature sources are reported in this section.

The unit cost of the produced water tends to decrease with the yield of the project. Mitchell and others estimated life cycle costs of rainwater and stormwater harvesting in Melbourne, Australia, for various system sizes (Figure 2-2).(53) The systems included collection, storage, "minimal" treatment, and distribution facilities. The estimates included acquisition, renewal, and decommissioning for 50 years, with a discount rate of 5.2 percent per year.

Figure 2-2: Life Cycle Cost of Rain Water and Stormwater Harvesting for a Range of Residential Stormwater Harvesting Scales[r]



Adapted from Fletcher and others and Mitchell and others[21,53]

In a study focused on Adelaide, South Australia, Kellogg Brown & Root presented capital and O&M costs for various stormwater harvesting storage capacities for the City of Adelaide, showing an economy of scale (Figures 2-3 and 2-4).[25]

The capital cost of a stormwater harvesting system is related to the watershed size, the treatment method, land characteristics, and storage type.[20 referenced in 21] Hatt and others summarized capital costs, operating costs, user prices, and benefits (reduced potable demand, pollution control, and reduced runoff volume) for 17 stormwater harvesting projects, mostly located in Australia.[23] Table 2-10 shows updated cost and performance data for 7 of these systems.[20 referenced in 21] The Homebush Bay project produced water with a unit cost twice that of potable water, but the water was sold for 85 percent of the potable water price to encourage use. The Parafield project produced water at 30 percent of the cost of the raw water alternative.

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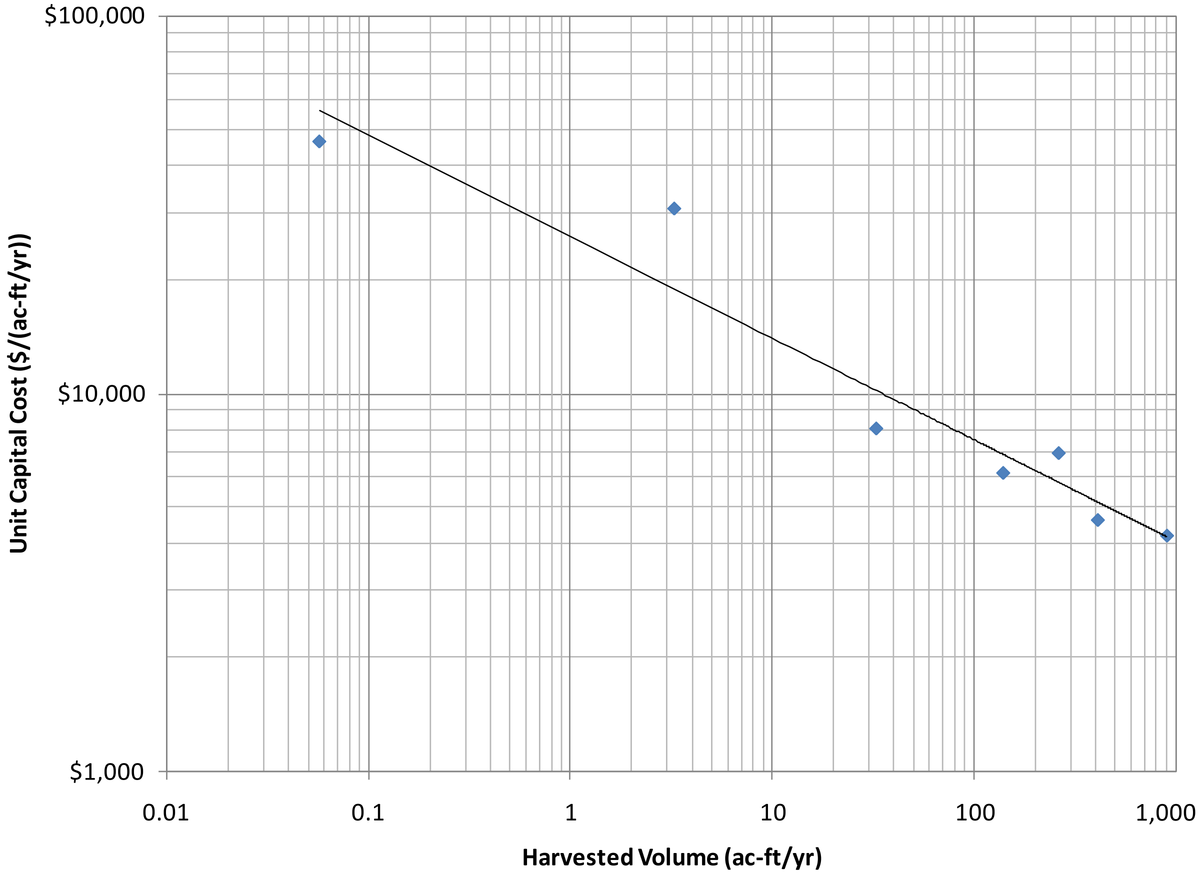
[r] Conversion to 2009 U. S. dollars based on 2005 average exchange rate of 0.762 U. S. dollars per Australian dollar and *Engineering News-Record* (ENR) Construction Cost Indices of 8564 (August 2009) and 7479 (August 2005).

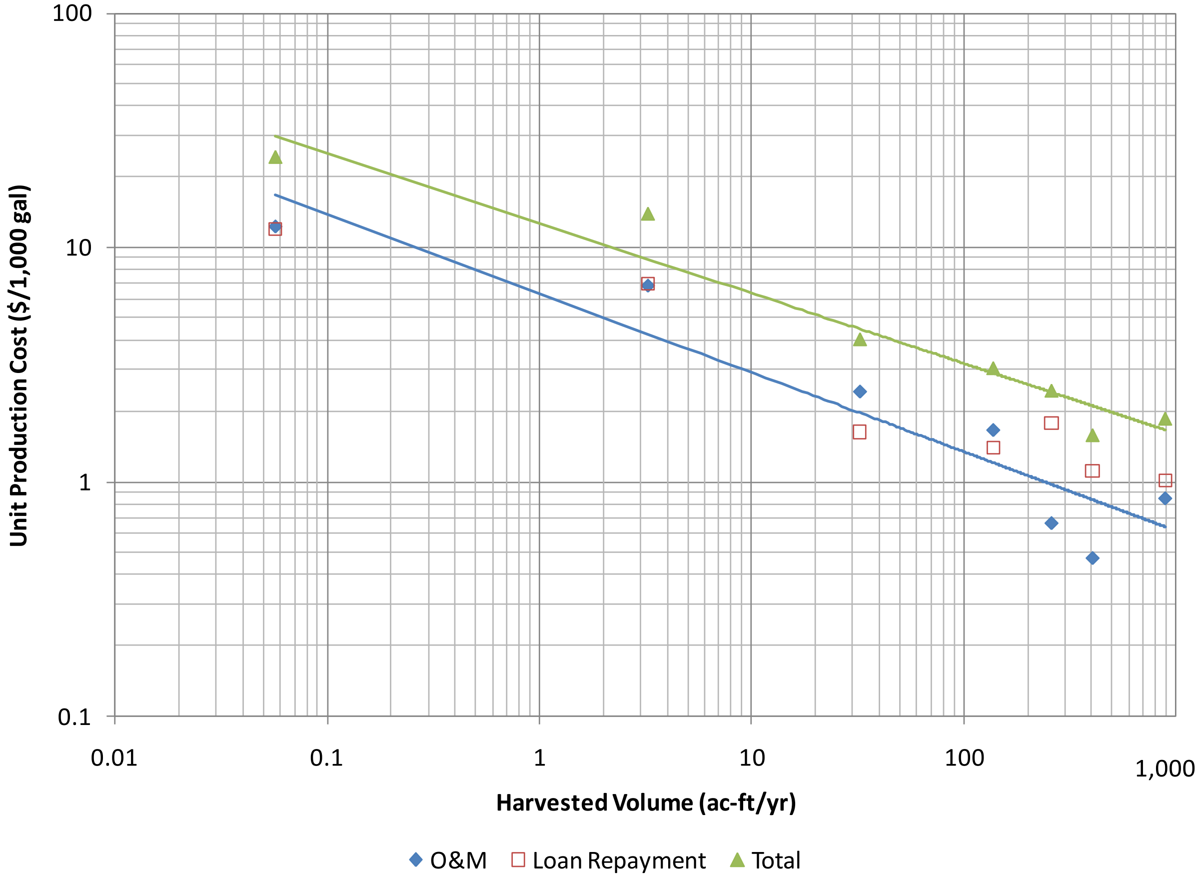
Figure 2-3: Projected Unit Capital Cost of Stormwater Harvesting in Adelaide, South Australia[s]



Adapted from Kellogg Brown & Root.[25]

[s] Costs converted to 2009 U. S. dollars using annual average exchange rate for the year the project was constructed and August *Engineering News-Record* (ENR) Construction Cost Indices to bring the costs forward from the construction year.

Figure 2-4: Projected Unit Production Cost of Stormwater Harvesting in Adelaide, South Australia[t]



Adapted from Kellogg Brown & Root.(25)

[t] Costs converted to 2009 U. S. dollars using annual average exchange rate for the year the project was constructed and August *Engineering News-Record* (ENR) Construction Cost Indices to bring the costs forward from the construction year.

Table 2-10: Performance Data for Seven Stormwater Harvesting Systems

Site	Capital Cost* ($)	Mean Annual Runoff (acre-feet)	Runoff Collected (% of Mean Annual Runoff)	Storage Volume (% of Mean Annual Runoff)	Potable Water Use Reduction (%)	Potable Water Cost Savings (% of Capital Cost)	Total Nitrogen Prevented from Entering Stream** (lb)	Equivalent Wetland Cost for Total Nitrogen Removal*,*** (% of Capital Cost)
Inkerman Oasis****	360,000	6.2	20	1	30	0.1	2.4-20	0.2-1.7
Figtree Place	100,000	5.1	83	5	65	1.4	8.2-68	2.6-22.5
Kogarah	522,000	7.6	85	15	17	0.4	12-106	0.7-6.0
Oaklands Park	79,000	61	100	65	n/a	30.8	117-992	56.6-485.2
Hawkesbury****	3,234,000	649	50	11	28	3.1	617-5,292	5.7-48.4
Homebush Bay****	12,624,000	956	100	42	50	2.2	1,819-15,598	4.1-35.2
Parafield	3,732,000	1,792	100	29	n/a	14.7	3,411-29,243	27.1-231.9

Fletcher and others, adapted from Hatt and others; Hatt and others(21,20,23)

* Costs converted to 2009 U. S. dollars using annual average exchange rate for the year the project was constructed and August *Engineering News-Record* (ENR) Construction Cost Indices to bring the costs forward from the construction year.

** Range based on volume of stormwater used multiplied by estimated low and high total nitrogen concentrations for influent stormwater (0.7 mg/l and 6 mg/l, respectively).

*** The equivalent cost for total nitrogen reduction is based on the equivalent cost of constructing a stormwater treatment wetland to remove the given mass of total nitrogen (assumed to be $296 per pound of total nitrogen removed).

**** Includes capital costs for both stormwater and wastewater recycling.

Fletcher and others presented capital and maintenance costs for various stormwater treatment best management practices including gross pollutant traps; vegetated swales and filter strips; infiltration and bioretention systems; rainwater tanks; ponds, wetlands, and sediment basins; and porous pavements.(55) Olivieri and others presented capital and maintenance costs for stormwater treatment best management practices including detention basins, retention ponds, infiltration basins and trenches, vegetated swales, stormwater wetlands, sand filters, and advanced treatment and disinfection.(26) Finally, Mitchell and others presented extensive capital and maintenance cost information.(49)

Additional cost information is presented in the case studies in Chapter 8.

Benefits

Benefits of stormwater harvesting may include:

- Reduction in potable water demand (including peak demands),
- Reduction in stormwater volume, flowrate, and frequency,
- Reproduction of the predevelopment flow regime,
- Reduction in erosion and scouring,
- Reduction in stormwater pollutant loads entering local watercourses,
- Reduction of downstream flooding and erosion,
- Development of an additional local water supply, and
- Reduction in demands on an aquifer.
- Distributed water supply sources and reduced water distribution costs
- Matching of water quality with water uses
- Low energy requirements
- Natural treatment processes
- Public amenity

Due to limited experience and lack of monitoring data, it is difficult to assess actual potable water savings and environmental and human health risks, and it is difficult to quantify environmental and other benefits for existing and future stormwater harvesting projects.(21) Most studies of the environmental benefits of stormwater harvesting rely on modeling to project the impacts.

Hatt and others compared the costs for 17 stormwater harvesting projects to the cost of equivalent potable water supply (assumed to be $1.00 per thousand gallons) and to the cost of equivalent nitrogen removal (assumed to be $314 per kilogram of total nitrogen removal).[u],(23) For several of the projects, the benefits of potable water savings and nitrogen removal balance a substantial portion of the project capital cost (Table 2-10). Reductions in potable water use ranged from 17 to 65 percent (Table 2-10).

[u] Conversion to 2009 U. S. dollars based on 2004 average exchange rate of 0.736 U. S. dollars per Australian dollar and *Engineering News-Record* (ENR) Construction Cost Indices of 8564 (August 2009) and 7188 (August 2004).

In a 22-lot subdivision where the housing contained water-efficient appliances, harvested rainwater accounted for 56 percent of water use.[56 referenced 21]

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3. Legal and Regulatory Issues in Texas

Legal and regulatory issues include water ownership and permitting issues for stormwater harvesting projects.

3.1. Stormwater Ownership

Ownership of stormwater on the surface and stormwater stored in an aquifer is discussed in the following sections.

Stormwater on the Surface

Water law in the State of Texas continues to evolve, especially as new water supply technologies and strategies develop. Stormwater harvesting and rainwater harvesting may eventually result in further evolution of the law. A review of how water law has evolved and its current status in Texas (presented below) is required to fully understand possible legal complexities surrounding stormwater harvesting.

Historical Overview

Texas water law derives its origins from the Spanish and Mexican civil law water rights system, the English doctrine of riparian water rights, and the western American doctrine of appropriative rights.(57) During the settlement of Texas, Spain and Mexico often granted land titles that expressly included grants to water rights.(58) Between 1840 and 1895, Texas relied on the riparian water law doctrine, in which water rights are determined according to ownership of land adjacent to watercourses.(59) Under the riparian doctrine, water rights are inherent in ownership of land adjacent to or bordering a natural river or stream.(60) In Texas, the riparian doctrine began to merge with the prior appropriation water law doctrine from 1889 to 1967 for the management of uses of Texas surface water resources.(60) This merger began with the passing of the Irrigation Acts of 1889, 1895, and 1913, which declared all unappropriated water to be property of the state and available for appropriation by the state on a "first in time, first in right" (*i.e.*, the "prior appropriation doctrine") basis.(61) However, these acts did not abolish existing riparian rights, creating a conflicting dual legal approach for managing surface water in Texas.(60) In 1967, the Legislature combined these two legal doctrines through the passage of the Water Rights Adjudication Act (Act), through which the State reduced all then-existing Certified Filings and Permits (except for domestic and livestock claims) to Certificates of Adjudication.(62) The Act mandated that any person claiming a riparian water right must file a claim for such right with the Texas Water Commission by 1969.(60) Prior to the Act, a riparian water right holder was not required to file any claim for water.(60) Therefore, the Act unified rights granted under the riparian doctrine with permits granted under the prior appropriations doctrine into one water permit system.(60) Today, any party seeking a water right must comply with the Texas Water Code (Water Code) and the Texas prior appropriation system for allocating water rights.

Current Legal Framework

Water Code Chapter 11 provides the foundation for surface water rights in Texas. The Legislature outlined in Chapter 11 the requirements to apply for a surface water right and established the prior appropriation doctrine for managing surface water rights in Texas. The statutes found in Chapter 11 are supplemented by rules adopted by the Texas Commission on Environmental Quality (TCEQ) in Title 30, Chapters 295 and 297 of the Texas Administrative Code (TAC).

Water Code Section 11.021 provides that all "water of the ordinary flow, underflow, and tides of every flowing river, natural stream, and lake, and of every bay or arm of the Gulf of Mexico, and the storm water, floodwater, and rainwater of every river, natural stream, canyon, ravine, depression, and watershed in the state is the property of the state."(63) Under TAC, Title 30, Section 297.1, a similar definition of "state water" is provided, but it includes water in a "watercourse in the state."(64) The definition of "state water" identifies that almost all surface water within the state is owned and held in trust by the state. However, the definition of "state water" specifically excludes percolating groundwater, "diffuse surface rainfall runoff, groundwater seepage, or springwater before it reaches a watercourse."(64)

Although state water is considered to be the property of the state, Texas allows the use of state water under the prior appropriation doctrine codified in the Water Code. Under Water Code Section 11.022, the "right to the use of state water may be acquired by appropriation," and when such a right of use "is lawfully acquired, it may be taken or diverted from its natural channel."(65) However, what exactly is considered state water subject to appropriation requires clarification because Texas law does not consider "diffused surface water" to be "state water," even though "state water" generally includes surface water, and "diffused water" is *water on the surface* (in places other than watercourses).(64) The distinction between how the law views state water as opposed to diffused water will help establish a clear criterion for whether stormwater harvesting and rainwater harvesting projects may be subject to appropriation under Water Code Chapter 11.

<u>State Water vs. Diffused Surface Water</u>

Water Code Section 11.021 is not clear as to how water is classified as state water but instead provides a list of water types and water bodies that qualify as state water. Because of this ambiguity, Texas courts have been called upon to clarify how to determine whether surface water is state water or diffused surface water. Diffused surface water is water found on the surface that has not yet entered a watercourse, belonging to the surface owner and not subject to appropriation.(64)

The capstone case of *Hoefs v. Short* established the test for determining whether water constitutes state water subject to appropriation or diffused water that belongs to the surface owner and not subject to appropriation.(66) In *Hoefs*, the plaintiff sought an injunction to stop an adjoining landowner from damming a creek at the point where the creek began to cross the plaintiff's property.(66) The adjoining landowner asserted that the waters being dammed were diffused surface water. In its analysis, the court distinguished between diffused surface waters and waters that reached a natural watercourse.(66) The court held that if the water is in a diffused state the owner could capture such water, but that once the water reached a natural watercourse the landowner could no longer capture such waters. In so holding, the court's decision turned on how it defined a "watercourse."(66) The court set forth three elements for determining whether a watercourse exists: (1) a well-defined bed and banks; (2) a current of water; and (3) flow from a definite and permanent source of supply.(66)

<u>Watercourse: Natural or Artificial?</u>

The court-created definition of "watercourse" in *Hoefs* is now included under Section 297.1(59) of the TAC, defining a "watercourse" as a "definite channel of a stream in which water flows within a defined bed and banks, originating from a definite source or sources. (The water may flow continuously or intermittently, and if the latter with some degree of regularity, depending on the characteristics of the sources.)"(64)

What is absent from this definition is that a watercourse must be a *natural* watercourse. This appears to leave open for debate whether water in any channel meeting the above definition of "watercourse," whether a natural channel or not, would then be considered state water. If this were the case, then water in drainage ditches or culverts that channel into natural streams would constitute state water subject to appropriation *prior* to entering the stream. But Texas case law, when discussing watercourses in the context of the appropriation of state water, makes clear that watercourses must be natural for the water to be considered state water.[v] In *Hoefs*, the court stated that "[w]hen it is said that a stream in order to be a *natural* water course to which water rights attach must have bed, banks, a current of water, and a permanent source of water supply."(66)

Subsequent to the decision in *Hoefs*, the Texas Supreme Court, in determining liability for escape of salt water from defendant's land onto plaintiff's property, discussed a prior statute regarding water that qualifies as property of the state in *Turner vs. Big Lake Oil Company*.(67) The statute indicates that "the right to use [water] may be acquired by appropriation in the manner and for the uses and purposes…and may be taken or diverted from its natural channel."(67) In a more recent case, the Austin Court of Appeals, citing to *Turner*, stated that "[d]iffuse surface water belongs to the owner of the land on which it gathers, so long as it remains on that land prior to its passage into a natural watercourse."(68) The case law, therefore,

[v] Cases addressing the criminal offense of discharging pollution in violation of Chapter 26 of the TWC turn on the terms "water in the state" when examining whether the discharge is a violation. *See Watts v. State,* 140 S.W.3d 860, 866 (Tex. App.—Houston[14th Dist.] 2004, pet. denied). "Water in the state" is different from "state water" in that the definition of "water in the state" specifies that it includes the bed and banks of *all* watercourses, including artificial water courses. *Id.*; *see* Tex. Water Code § 26.001(5) (Vernon 2008) (defining "water" or "water in the state" as "including the beds and banks of all watercourses and bodies of surface water."). The definition of "state water" does not specify that it includes *all* watercourses, and case law establishes that natural water courses are required for a finding of "state water."

seems to make quite clear that a watercourse must be *natural* in order to qualify as state water subject to appropriation.[w]

Stormwater as State Water

From the definitions of state water and diffused water, it becomes clear as to how water may or may not be subject to appropriation. Because state water will not be held to exist unless it is within a "natural watercourse," conveyance of stormwater through artificial structures such as ditches, culverts, and stormwater drains will not cause the water to be subject to appropriation as state water. Only upon entering what is considered to be a natural watercourse that has (1) a well-defined bed and banks; (2) a current of water; and (3) flow from a definite and permanent source of supply will water become state water.

In the context of stormwater harvesting then, if an entity has a permit to discharge stormwater -- for construction activities, industrial facilities, or Municipal Separate Storm Sewer Systems (MS4s) -- the stormwater is diffused surface water prior to entering into a natural watercourse and belongs to the surface owner or the owner of the artificial structure conveying the diffused surface water. Likewise, in the context of rainwater harvesting, water collected would also qualify as diffused surface water, not state water subject to appropriation, if it does not enter a natural watercourse prior to use. Recent legislation on the harvesting of rainwater appears to support this finding by allowing harvesting without any requirement for compliance with the appropriation and permitting rules established under Water Code Chapter 11 for state water. In 2007, the 80th Legislature passed House Bill 4 which allowed for the use of harvested rainwater indoors for non-potable applications.[(69)] House Bill 4 also provides that on-site water reclamation systems, such as rainwater harvesting systems, will become standard for new state buildings after September 1, 2009.[(70)] Therefore, as long as either stormwater or harvested rainwater is restricted from entering a natural watercourse (that meets the three part definition above) prior to use, then such water belongs to the surface owner as diffused surface water and will not be subject to appropriation and permitting under the Water Code as state water.

Stormwater Stored in an Aquifer

Aquifer storage and retrieval (ASR) involves injecting water into a geologic formation, group of formations, or part of a formation that is capable of underground storage of water for subsequent retrieval and use.[(71)] As discussed in the previous section, stormwater on the surface constitutes privately-owned water before it enters a natural watercourse with a defined bed and banks. However, once this privately-owned stormwater is injected into an aquifer, it is subject to different rules of ownership and use.

In Texas, "groundwater" is defined as "water under the surface of the ground other than underflow of a stream and underground streams, whatever may be the geologic structure in

[w] TCEQ has issued water right permits with diversion points located on drainage ditches or canals, and reasons that these artificial watercourses have come to be considered natural watercourses (Appendix E, Pages E-3 and E-12). No case law exists that addresses when an artificial watercourse becomes a natural watercourse.

which it is standing or moving."[72] According to this definition, once privately-owned water is injected into an aquifer, it becomes groundwater.[x,y] The "rule of capture," the controlling law on groundwater in the State of Texas, provides that a landowner may pump from under his land as much groundwater as needed for his intended beneficial use as long as he is not negligent in causing subsidence of a neighbor's land, willfully wasteful, or malicious.[73] Without intervening regulation, the rule of capture would seemingly allow a landowner overlying the aquifer to withdraw not only the groundwater, but also the stormwater contained therein, subject only to the subsidence, waste, and malice exceptions noted above.

Groundwater Conservation Districts

If the aquifer storage of stormwater is located within a groundwater conservation district (GCD) that is acting under Chapter 36 of the Texas Water Code, then the entity seeking to store stormwater within the aquifer would have to comply with the GCD's regulations and Chapter 36.[z] Provisions under Chapter 36 make it illegal to drill a well, alter the size of a well or well pump, or operate a well without first obtaining a permit from a GCD.[74] These regulations could help ensure that the stormwater stored by an entity within the aquifer is protected from withdrawal by other landowners via permits issued by the GCD pursuant to Chapter 36 and the GCD's rules.

Municipal Regulations

A municipality may regulate "the pumping, extraction, and use of groundwater by persons other than retail public utilities … for the purpose of preventing the use or contact with groundwater that presents an actual or potential threat to human health" within the city or its extraterritorial jurisdiction.[75] Such a regulation is often implemented as part of the process for obtaining a Municipal Setting Designation (MSD) from the TCEQ for a property that has contaminated groundwater.[76] The purpose of an MSD is "to limit the scope of or eliminate the need for investigation of or response actions addressing contaminant impacts to groundwater that has been restricted from use as potable water by ordinance or restrictive covenant."[77]

If a stormwater aquifer storage and retrieval project is located in an area that is subject to municipal limitations on groundwater use, these limitations could help restrict access to the stored water. However, care should be taken to ensure that the water quality of the water retrieved from aquifer storage is suitable for the intended uses.

---

[x] Assuming that the injection location is not close to an underground stream or underflow of a stream.

[y] State water is treated differently from privately-owned water, as "state water injected into the ground for an aquifer storage and recovery project remains state water."[78]

[z] GCD web sites and contact addresses are listed at http://www.tceq.state.tx.us/assets/public/permitting/watersupply/groundwater/gcd/gcdcontactlist.pdf.

3.2. *Permitting*

Permitting issues may arise in the process of developing a stormwater harvesting project, depending on the specific application and conditions of the project. Potential issues discussed in this section include water rights, stormwater discharge permits, Chapter 404 permits, and aquifer storage and retrieval permits.

Water Right Permits

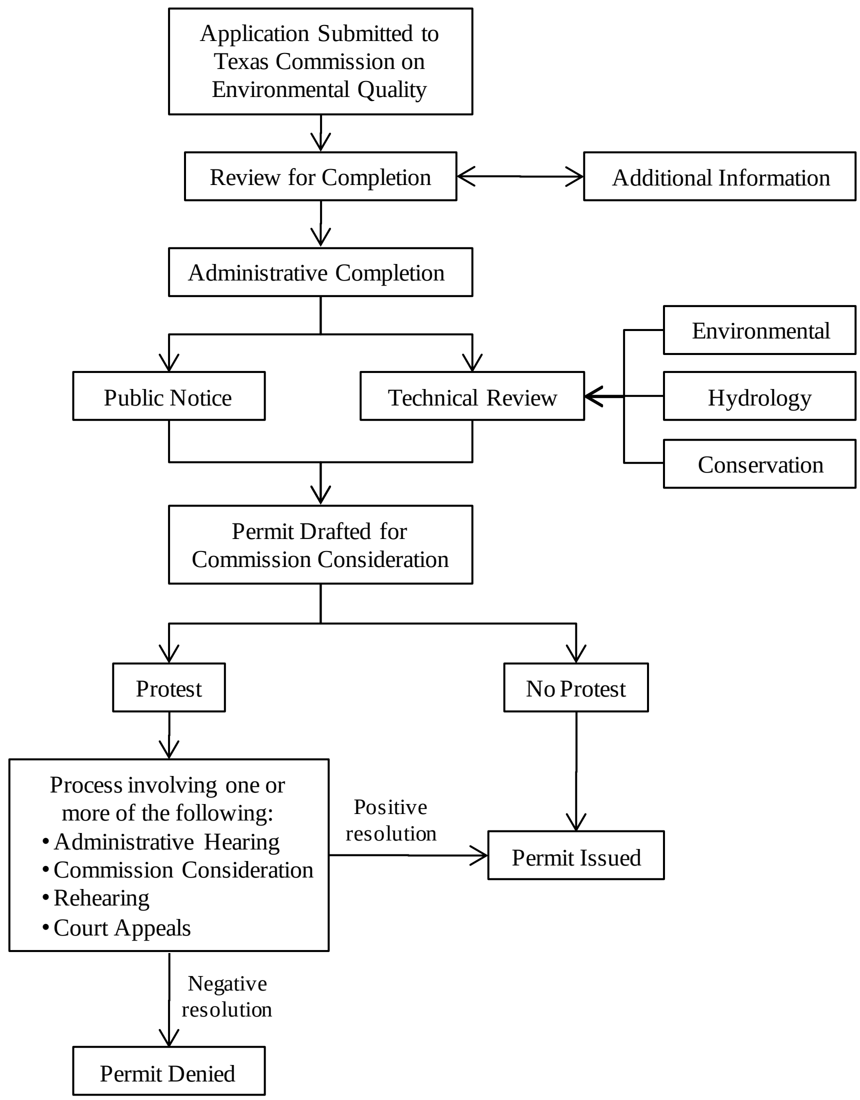
If stormwater is harvested from overland flow or from a stormwater collection system prior to discharge to a natural watercourse (i.e., is not "state water"), no water right is necessary (as discussed in Section 3.1). If it is determined that the water to be used is "state water," a water right permit must be secured for the stormwater harvesting project. An applicant for a water right permit must comply with Water Code Chapter 11 and the rules adopted by the TCEQ under Title 30, Chapters 295 and 297 of TAC, addressing the procedural and substantive requirements of water right applications, respectively. Figure 3-1 provides a diagram of the water right permitting application process in Texas.

In many Texas river basins, there may be little to no water available for appropriation under a water right permit. Water available for appropriation in a particular basin can be assessed using the Water Availability Model (WAM) for that basin.[(79)] WAMs are discussed in more detail in Section 4.1.

Chapter 402 and 404 Permits

Stormwater collection projects generally gather stormwater into storage for beneficial use. Conceivably, the construction phase of a stormwater project could implicate the permitting requirements under Sections 402 and 404 of the Clean Water Act. The project's subsequent beneficial use of the stormwater would not implicate the permitting requirements.[(80)] The 404 permitting requirement would not be implicated because the nature of stormwater harvesting would not involve dredged or fill material that would change the bottom elevation of a receiving water body. [(81)] If construction of the project causes a discharge of any "dredged or fill material" into jurisdictional waters, then a corresponding "Section 404" permit must be acquired from the Army Corps of Engineers under the Clean Water Act.[(82)] If construction of the project causes a discharge of any pollutant into jurisdictional waters (other than dredge or fill material), then a corresponding "Section 402" National Pollutant Discharge Elimination System (NPDES) permit must be acquired from the U.S. Environmental Protection Agency (EPA).[(83)] If construction activity implicates the Section 402 NPDES permitting scheme, a general permit may be secured to cover the 402 permitting requirement.[(84)]

Figure 3-1: Water Right Permitting Application Process in Texas



Aquifer Storage and Retrieval

Required permits for a stormwater ASR project may include injection well permits, permits from a groundwater conservation district, and water right permits (if the water is "state water").

Injection Well Permits

An injection well permit from the Underground Injection Control (UIC) group within the Texas Commission on Environmental Quality (TCEQ) is required for all ASR injection wells.[85] Since ASR injection wells are considered Class V injection wells under 30 TAC § 331, these wells are subject to Class V construction and closure standards.[86] ASR injection wells are also subject to construction, closure, operating, monitoring, and water quality requirements.[43, 85] The Underground Injection Control rules at 30 TAC § 331 include regulations governing construction details for pressurized wells and monitoring requirements to assess the migration of injected fluids.[85]

Groundwater Conservation District Permits

If the aquifer storage of stormwater is located within a groundwater conservation district (GCD) that is acting under Chapter 36 of the Texas Water Code, then the entity seeking to store stormwater within the aquifer would have to comply with the GCD's regulations and Chapter 36. Provisions under Chapter 36 make it illegal to drill a well, alter the size of a well or well pump, or operate a well without first obtaining a permit from a GCD.[74]

Water Right Permits for "State Water"

Water Code Chapter 11, and the corresponding TCEQ regulations under Chapters 295 and 297 of TAC, set forth water right permitting and reporting requirements. These water right permitting requirements are probably not triggered for ASR stormwater projects, because these projects contain unappropriated stormwater owned by the landowner. ASR projects, as defined under 30 TAC § 297.1(5), do not involve unappropriated stormwater, and instead involve the aquifer storage and retrieval of "*appropriated* surface water." Similarly, the ASR project permitting procedure and requirements under Sections 11.153 and 11.154 of the Texas Water Code apply only for "*appropriated* water."

4. Stormwater Availability in Texas

Methods to estimate stormwater availability vary, depending on whether the purpose for the project is water supply or flood control. Methods for estimating stormwater availability for each objective are discussed in the following sections.

4.1. Stormwater Availability for Water Supply

From 1997 through 2004, TCEQ commissioned Water Availability Model (WAM) data sets for the 23 river basins in the state using the Water Rights Analysis Package (WRAP) executable.[(87)] A WAM simulates management of the water resources in a river basin under the Texas system of priority-based water rights. The WAM can be used to assess hydrologic and institutional water availability and reliability. This section describes use of a WAM to assess stormwater availability.[aa]

The WAMs use monthly naturalized flows, defined as the flows that would have occurred in the absence of human influences such as reservoir development, diversions, and return flows. During development of the WAMs, naturalized flows were estimated at many locations (called primary control points) in each river basin by adjusting historical hydrologic records for upstream diversions, return flows, reservoir storage, and reservoir evaporation. In each WAM, the naturalized flows and historical evaporation data are available for a long period that includes the drought of the 1950s.[bb] A typical period of record is 1940 through 1996.

The WAMs contain several methods for use in estimating flows at ungaged control points (CPs) from flows at gaged CPs, including a drainage-area-ratio (DAR) method and a modified Natural Resources Conservation Service (NRCS) curve number method. The DAR method simply distributes runoff that occurs between gaged CPs across the drainage area uniformly. The modified curve number method distributes this runoff using relative watershed characteristics (curve numbers) and mean annual precipitation. The TCEQ no longer uses the modified curve number method in determining water availability due to issues with the underlying datasets and issues related to aggregation of curve numbers. The DAR method is used almost exclusively in the 21 WAMs available for download from the TCEQ.[(79)] Therefore, the DAR method is currently recommended for projecting stormwater availability.

The WAMs include drainage areas for the large majority of CPs. Using these data and the historical climate information, the DAR method can be used to estimate monthly stormwater availability for any location in the state over a large range of historical climatic conditions. Instructions for estimating monthly stormwater availability are presented below, along with example calculations.

[aa] WAMs are typically used to assess the quantity of water that is available for appropriation under a water right permit, As used here, however, “stormwater availability” means the availability of stormwater that is “diffuse surface rainfall runoff” and can be captured prior to becoming “state water.” This water would not be subject to appropriation or require a water right permit.[(64)]

[bb] These data contain estimates to fill in missing data.

For a location of interest (LOI), the necessary steps include:

1. Identify the appropriate river basin (Figure 4-1).

2. Obtain WAM files for that river basin (both WRAP model and GIS shapefiles) from the TCEQ.[79] GIS shapefiles are currently available online for the Brazos, Canadian, Cypress, Neches-Trinity, Neches, Red, Sulphur, Trinity-San Jacinto, and Trinity River Basins. GIS shapefiles for other river basins can be obtained by requesting them from the TCEQ.

3. Identify the nearest CP downstream of the LOI (B4995A in Figure 4-1). For the basins where GIS shapefiles are available, this can be accomplished by viewing the CP locations for the river basin with GIS software (such as ArcGIS or MapWindow), identifying the LOI, and determining the nearest downstream CP. For better context, themes such as roads, rivers, political boundaries, etc., can be added to the map. For basins without available GIS shapefiles, this step may require consultation with the TCEQ, as it can be difficult to determine control point locations from the WAM files.

4. For the nearest downstream CP, identify the upstream and downstream gaged CPs from the appropriate flow distribution (FD) record in the flow distribution (*.dis) file.[88] A flow distribution record looks like:

   ```
   FDB4995A   8RIRI      1   8RIDA
   ```

   For the above example, Field 1 indicates the record type (FD), Field 2 is the name of the control point of interest (B4995A), Field 3 is the name of the downstream gaged CP (8RIRI), Field 4 shows that there is one upstream gaged CP, and Field 5 is the name of the upstream gaged CP (8RIDA).

5. Obtain drainage areas for the relevant CPs from the appropriate watershed parameter (WP) records in the flow distribution (*.dis) file.[88] Watershed parameter records look like:

   ```
   WP 8RIDA 333.385  73.970  35.500
   WPB4995A 537.695  71.890  35.910
   WP 8RIRI 731.390  70.650  36.270
   ```

   For the watershed parameter records, Field 1 indicates the record type (WP), Field 2 is name of the control point (e.g., “8RIDA” in the first line of the above example), Field 3 is the associated drainage area (e.g., 333.385 square miles), Field 4 is the curve number for the drainage area (e.g., 73.970), and Field 5 is the associated mean annual precipitation (e.g., 35.500 inches).

6. Calculate the monthly naturalized flow contributed by runoff from the watersheds between the gaged CPs (Figures 4-1 and 4-2).

Figure 4-1
Watersheds for Example Calculation

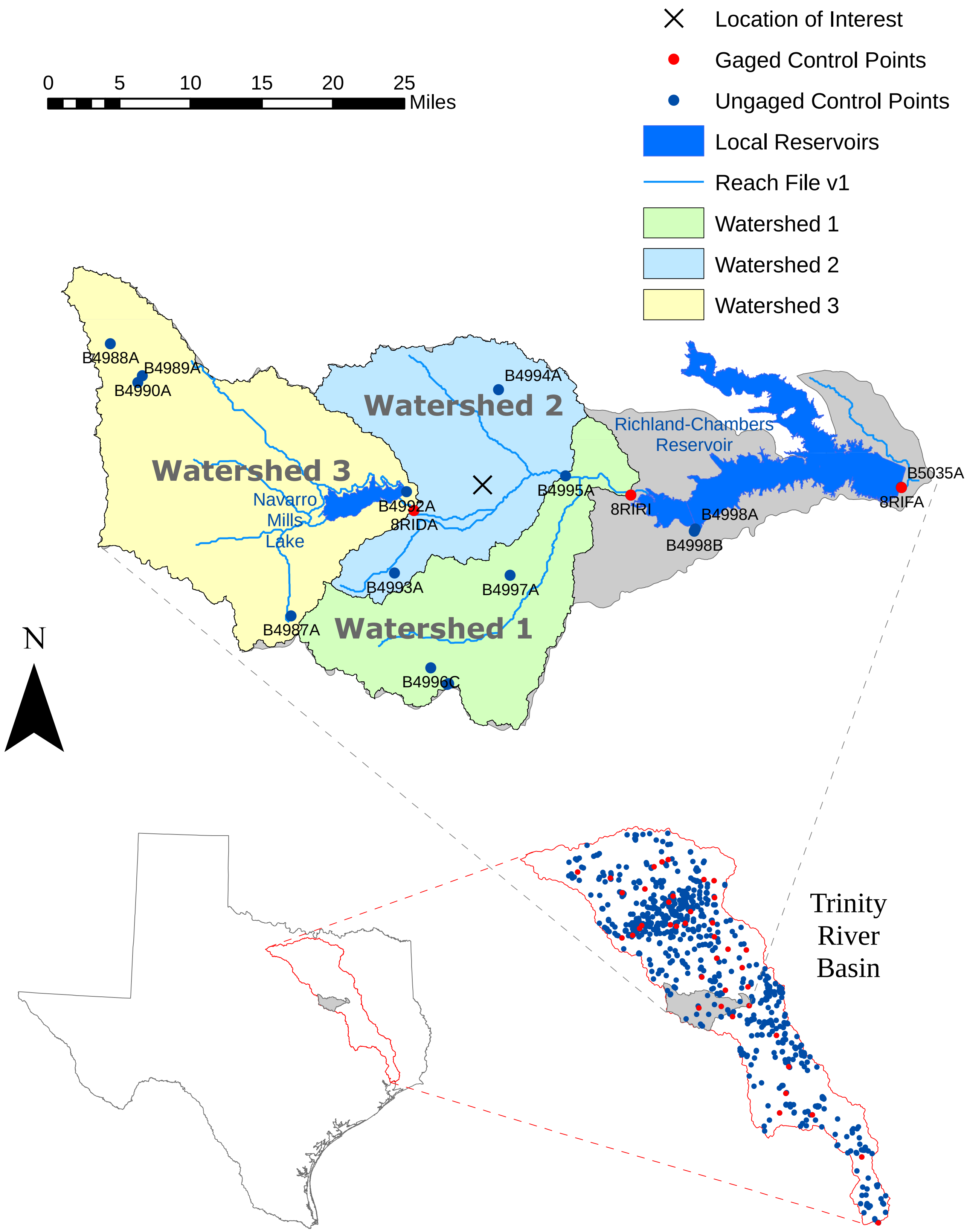


Figure 4-2: Drainage Area Ratio Monthly Flow Distribution Method Example

	Control Points		
	8RIRI	**B4995A**	**8RIDA**
Gaged?	Yes	No	Yes
Drainage Area [A] (sq mi)	731.390	537.695	333.385

	Watersheds			
	1	**2**	**3**	**1 and 2**
Downstream Control Point	8RIRI	B4995A	8RIDA	8RIRI
Upstream Control Point	B4995A	8RIDA	n/a	8RIDA
Area [A] (sq mi)	193.695	204.310	333.385	398.005

[1] Year	**[2] Month**	**[3] 8RIRI Naturalized Flow Volume (ac-ft)**	**[4] 8RIDA Naturalized Flow Volume (ac-ft)**	**[5] Naturalized Flow Volume from Watersheds 1 and 2 (ac-ft)**	**[6] Naturalized Flow Volume from Watershed 2 (ac-ft)**	**[7] Naturalized Flow Volume from Watershed 2 (in)**
Formulas:				**max(0,[3]-[4])**	$\frac{[5]*A2}{(A1+A2)}$	$\frac{[6]}{(A2)*53.333}$
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
1962	1	3,459	2,590	869	446.1	0.04
1962	2	11,305	4,210	7,095	3,642.1	0.33
1962	3	5,033	2,100	2,933	1,505.6	0.14
1962	4	30,569	5,270	25,299	12,986.9	1.19
1962	5	7,098	4,620	2,478	1,272.0	0.12
1962	6	30,040	30,680	0	0.0	0.00
1962	7	2,929	980	1,949	1,000.5	0.09
1962	8	5	2	3	1.5	0.00
1962	9	4,283	1,865	2,418	1,241.2	0.11
1962	10	32,081	11,744	20,337	10,439.7	0.96
1962	11	1,769	490	1,279	656.6	0.06
1962	12	2,421	2,424	0	0.0	0.00
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.

NOTES:

1) Drainage area, mean precipitation, and curve number obtained for each control point from "WP" records in the Trinity River Basin WAM file trin8.dis.
2) Naturalized flows for gaged control points obtained from "IN" records in the Trinity River Basin WAM file trin8.inf.
3) Assumes storm water project located in Watershed 2.
4) Multiply runoff for Watershed 2 (Column [7]) by the storm water project area and a conversion factor (53.333) to calculate runoff volume for the storm water project area.
5) There are cases where the upstream naturalized flow is greater than the downstream naturalized flow (e.g., June 1962). It is recommended that the runoff in intermediate areas be set to zero for such cases.

7. Use the calculated watershed characteristics to distribute the runoff to the intermediate watersheds. An example calculation is shown in Figure 4-2. Additional documentation is presented in the WRAP Modeling System Reference Manual.[87]

8. Project monthly stormwater availability for the LOI by multiplying the watershed-scale stormwater runoff in inches (Column [7] in Figure 4-2) by the local drainage area.

Figures 4-3 and 4-4 show example results for the LOI in Figure 4-1. The projected monthly stormwater availability is highly variable during the period of record, ranging from 0 gallons per acre (gal/acre) to more than 275,000 gal/acre (Figure 4-3). To estimate the monthly stormwater volume available to a stormwater harvesting project at the LOI, the monthly stormwater availability in Figure 4-3 should be multiplied by the drainage area that contributes flow to the project.[cc] Figure 4-4 shows the frequencies with which various runoff volumes are available. For example, stormwater runoff of at least 994 gal/acre/month is projected to be available 60.6 percent of the time. The frequency graph could also be modified to reflect availability during a critical period (*e.g.*, summer months).

The discussion in this section focuses on using the WAM data to estimate stormwater availability. The primary advantages of this method are that the data are available for virtually any location in the State of Texas and that the resulting estimate of stormwater availability can be scaled to a wide range of project sizes. However, should a project planner identify more appropriate models, data, and/or stormwater availability estimates for a specific site, use of such information in project planning and design is encouraged.

Stormwater availability estimated from the WAMs will generally be limited to monthly projections. In addition, the projections encompass a wide range of climatic and watershed conditions. Such projections are suitable for use in designing storage for water supply (including aquifer storage). However, designing storage for flood control will require projections of stormwater runoff on a much finer time scale (*e.g.*, storm-based hourly hydrographs) and may require consideration of antecedent soil moisture conditions. Estimation of stormwater runoff for flood control is discussed in Section 4.2.

In this section, it has been assumed that the stormwater would be "diffuse surface rainfall runoff," captured prior to becoming "state water," and would not require a water right or be subject to an appropriative water right.[64] Legal issues associated with stormwater harvesting are discussed in Chapter 3.

[cc] Stormwater that is intercepted and used prior to entering a natural watercourse (and is not subject to appropriation and permitting under the Water Code as state water) may result in reduced water availability for downstream water rights.

Figure 4-3: Projected Monthly Stormwater Availability from Example Calculation

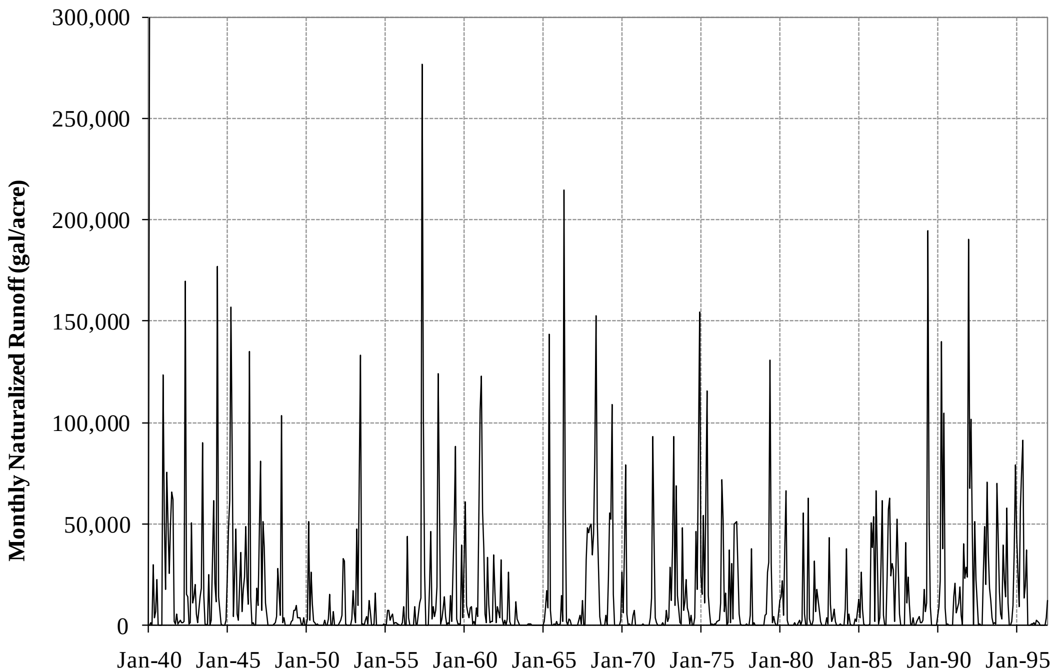
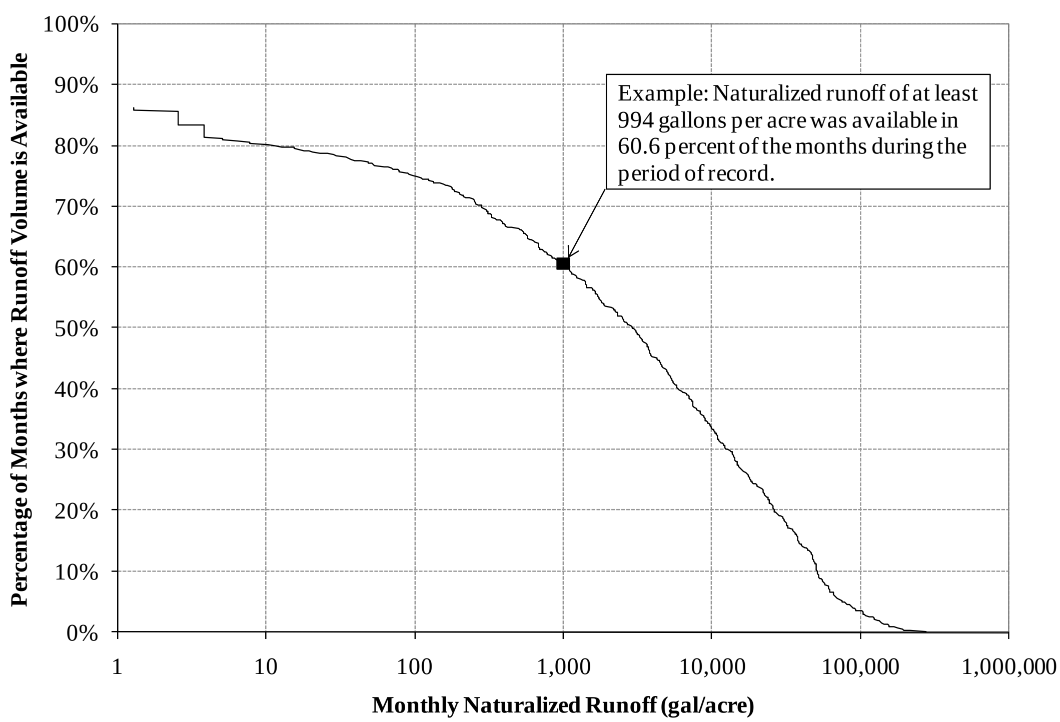


Figure 4-4: Projected Frequency of Stormwater Availability from Example Calculation



Both urbanization and climate change could impact stormwater availability. As increased development takes place, a watershed may become less pervious, leading to more stormwater runoff. As precipitation decreases (or increases) due to climate change, available stormwater should also decrease (or increase). In the WAMs, stormwater runoff is not calculated from climatic conditions (*e.g.*, precipitation) or watershed characteristics (*e.g.*, curve number) but is determined by distributing naturalized flows from gaged CPs to ungaged locations. Estimation of naturalized flows from historical hydrologic records was conducted during WAM development, and the naturalized flows are specified in the IN records in the inflow (*.inf) file.[88] Therefore, the existing WAMs do not appear to be suitable for assessing potential impacts of urbanization or climate change on stormwater availability for water supply.

4.2. Stormwater Runoff for Flood Control

If flood control is a project objective, then stormwater storage should be designed based on the projected stormwater runoff from a design storm event (rather than from monthly flows as in the WAMs). Stormwater hydrographs can be estimated using the Rational Method or the Natural Resources Conservation Service Curve Number Method.[89,90] Example stormwater runoff hydrographs are projected below with the curve number method for the location of interest (LOI) used in the previous example (Figure 4-1).

Assumed characteristics of the example project include:

- 20 acres with a 1 percent slope.
- Flow drains in the lengthwise direction, and the length is 3 times the width.
- Curve numbers were obtained from the Trinity River Basin WAM from Field 4 in the watershed parameter (WP) records in the flow distribution (*.dis) file, and an area-weighted curve number of 68.5 was estimated for Watershed 2 (Figure 4-1).[dd,(88)]
- Grassland with 50 to 75 percent ground cover and not heavily grazed. Soil with a moderate infiltration rate (0.15 to 0.30 inches per hour). These assumptions roughly correspond to the estimated curve number.
- Design storm of 2-year frequency and 24-hour duration.

Because the focus of this analysis is flood control, the curve number was adjusted from typical antecedent moisture conditions (AMC II) to saturated antecedent moisture conditions (AMC III); this will generate the maximum amount of stormwater runoff.[90] The direct runoff volume was estimated using the curve number method, and the time of concentration was estimated from a nomograph of watercourse slope, land cover type, and flow velocity.[90] Finally, the direct runoff

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[dd] The drainage area contributing to control point B4995A (Figure 4-1) is 537.695 square miles (from Item 5 on page 4-2), and the curve number for this area is 71.89. The drainage area contributing to control point 8RIDA (Figure 4-1) is 333.385 square miles (from Item 5 on page 4-2), and the curve number for this area is 73.97. Therefore, the area-weighted curve number for Watershed 2, located between these control points is:

$$\frac{[(537.695 \text{ square miles})(71.89) - (333.385 \text{ square miles})(73.97)]}{(537.695 \text{ square miles} - 333.385 \text{ square miles})} = 68.5$$

volume was multiplied by interpolated Natural Resources Conservation Service unit hydrographs for Type III storms to obtain projected storm hydrographs (Figure 4-5).[89]

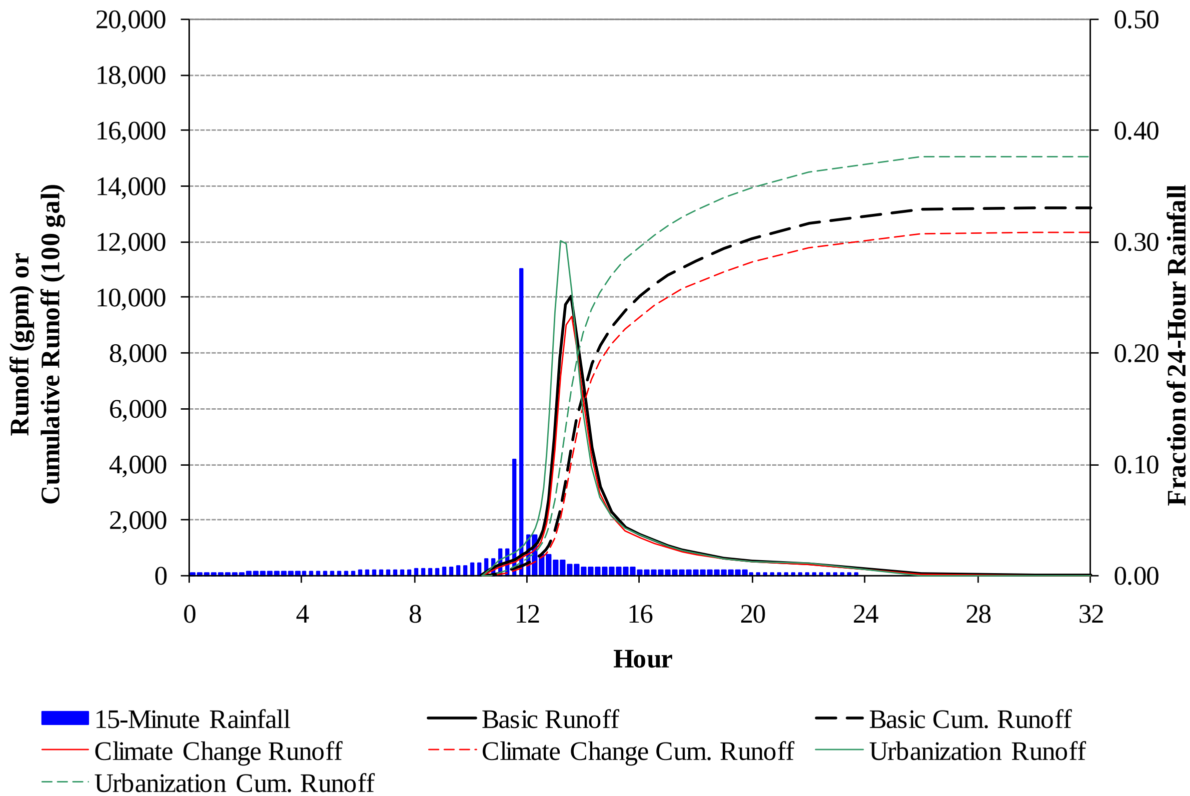
Example calculations were also performed to demonstrate how the projected storm hydrographs could change due to climate change or urbanization. Climate change could either increase or reduce the precipitation from the 2-year, 24-hour storm. In this case, it was assumed that the precipitation would be reduced from 4.2 inches to 4.0 inches. This 4.8 percent reduction in precipitation translated to a 7.4 percent reduction in the projected peak flow and a 7.0 percent reduction in the projected runoff volume (Figure 4-5).

The potential impact of urbanization was represented by changing the curve number from 68.5 to 75 to reflect a change in land cover type from grassland to a residential subdivision with quarter-acre lots.[90] This change resulted in a 19.8 percent increase in the projected peak flow, a 13.9 percent increase in projected runoff volume, and a decrease in the projected time-to-peak of 24 minutes (Figure 4-5).

The discussion in this section shows a method for estimation of stormwater hydrographs. Should a project planner identify more appropriate models, data, and/or hydrographs for a specific site, use of such information in project planning and design is encouraged.

Figure 4-5: Example Storm Hydrographs

Quantity	Basic	Climate Change	Urbanization	Reference
Cover Type	Grassland	Grassland	Residential	
Drainage Area [A] (ac)	20	20	20	Assumed
2-Yr., 24-Hr. Rainfall (in)	4.2	4.0	4.2	(89)
Typical Curve Number	68.5	68.5	75.0	Estimated from Trinity River Basin WAM
Saturated Soils Curve Number	83.3	83.3	87.3	(90)
Soil Storage Capacity (in)	2.00	2.00	1.45	(90)
Direct Runoff [R] (in)	2.49	2.31	2.85	(90)
Direct Runoff Volume (gal)	1,352,303	1,257,056	1,549,301	[A]*[R]*325,851/12
Time of Concentration (min)	44.9	44.9	38.5	(90)
Rainfall Distribution Type	III	III	III	(89)



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5. Potential for Municipal Stormwater Harvesting in Texas

In this section, factors that affect the regional potential for municipal stormwater harvesting are discussed, relevant data are reported by region, and the overall potential for municipal stormwater harvesting is assessed by region.

5.1. Factors Affecting the Regional Potential for Municipal Stormwater Harvesting

Supply, demand, implementation, and other factors may affect the regional potential for stormwater harvesting (Table 5-1).

Table 5-1: Factors Affecting Regional Potential for Stormwater Harvesting

Factor Type	Factor	Available Data
Supply	Rainfall volume	Annual average
	Rainfall frequency	Number of rainfall days
	Rainfall timing	Monthly average rainfall volume Design storm rainfall volume
	Runoff potential	Soil types Land use/land cover
	Evaporative losses	Annual average
Demand	Municipal water needs	Projected municipal water needs
	Water demand timing	No data source identified
	Air temperature	Monthly average
Implementation	Cost of municipal alternatives	Projected municipal water management strategies
	Aquifer storage and retrieval potential	Well logs Hydraulic conductivity Transmissivity Groundwater levels
Other	Stormwater quality	Comprehensive regional data sources not identified
	Environmental impacts	
	Environmental flow needs	
	Public health risks	
	Public uncertainty	
	Water availability for downstream water rights[ee]	

[ee] Stormwater that is intercepted and used prior to entering a natural watercourse (and is not subject to appropriation and permitting under the Water Code as state water) may result in reduced water availability for downstream water rights.

Supply Factors

Factors affecting the supply of stormwater include rainfall volume, rainfall frequency, rainfall timing, and runoff potential. Each of these is discussed below.

Rainfall Volume

Available stormwater increases with increasing annual rainfall. Annual average rainfall volumes for the period 1961-1990 were obtained from the Texas Natural Resources Information System (TNRIS). In Texas, annual average rainfall increases from west to east (Figure 5-1), with as little as 9 inches per year in the west and as much as 59 inches per year in the southeast. Figure 5-2 shows the annual average rainfall volume for each of the 16 water planning regions, as calculated from the TNRIS annual average rainfall data.

Rainfall Frequency

Areas with frequent rainfall will likely require smaller storage volumes than areas with infrequent rainfall. Smaller storage volumes generally cost less than larger storage volumes, increasing the potential for stormwater harvesting.[ff]

The average number of rainfall days per year (using data through 1993) was obtained from the University of Utah Department of Atmospheric Sciences for Abilene, Amarillo, Austin, Brownsville, Corpus Christi, Dallas-Fort Worth, Del Rio, El Paso, Galveston, Houston, Lubbock, Midland-Odessa, Port Arthur, San Angelo, San Antonio, Victoria, Waco, and Wichita Falls.[(91)] Similar data for El Campo, Greenville, Longview, and Texarkana were obtained from other sources.[(92,93)] At least one of the cities listed above is located in each planning region.

The average number of rainfall days for each region (Figure 5-3) was estimated by dividing the cities listed above into their respective planning regions and averaging the data for the cities in each region. The number of rainfall days generally increases from west to east. There is also some north-south variation.

Rainfall Timing

For stormwater harvesting projects that supply seasonal water demands, such as irrigation and cooling, areas with significant rainfall in the summer will likely require smaller storage volumes than areas without significant rainfall in the summer.

[ff] This logic can also be adapted to ASR facilities.

Figure 5-1: 1961-1990 Annual Average Rainfall in Texas

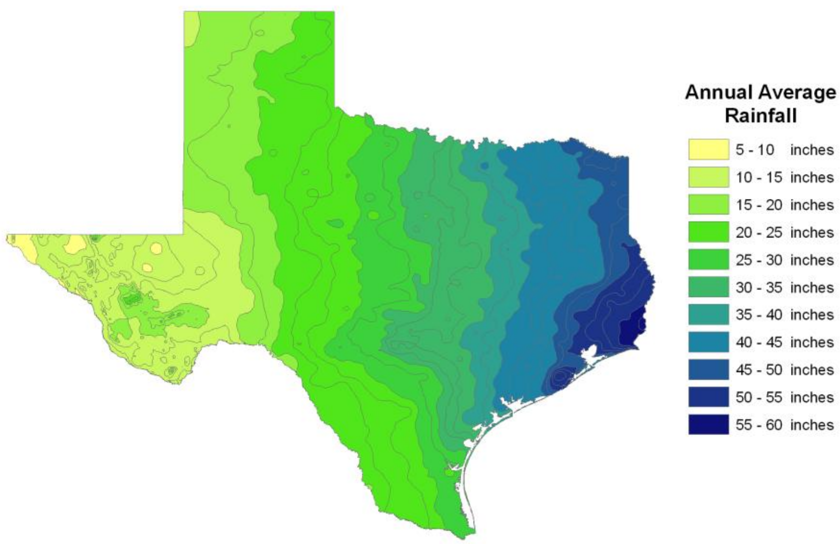


Figure 5-2: 1961-1990 Annual Average Rainfall by Region

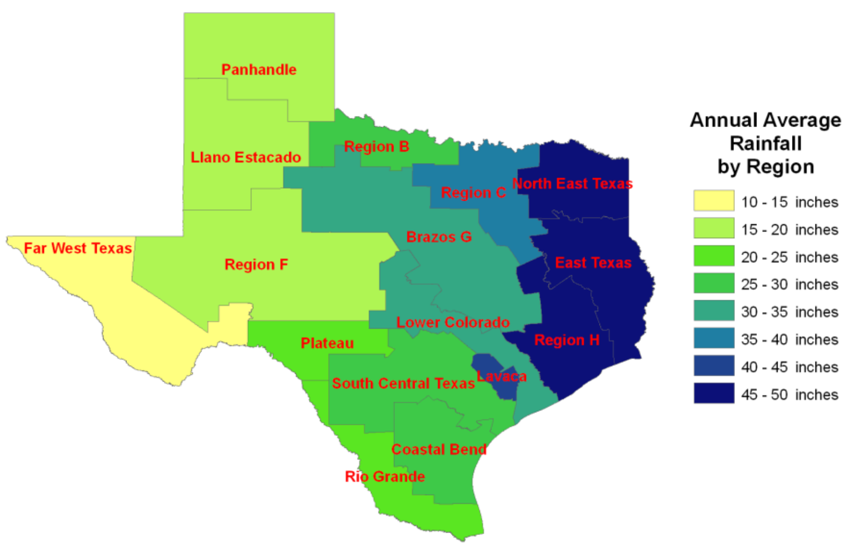
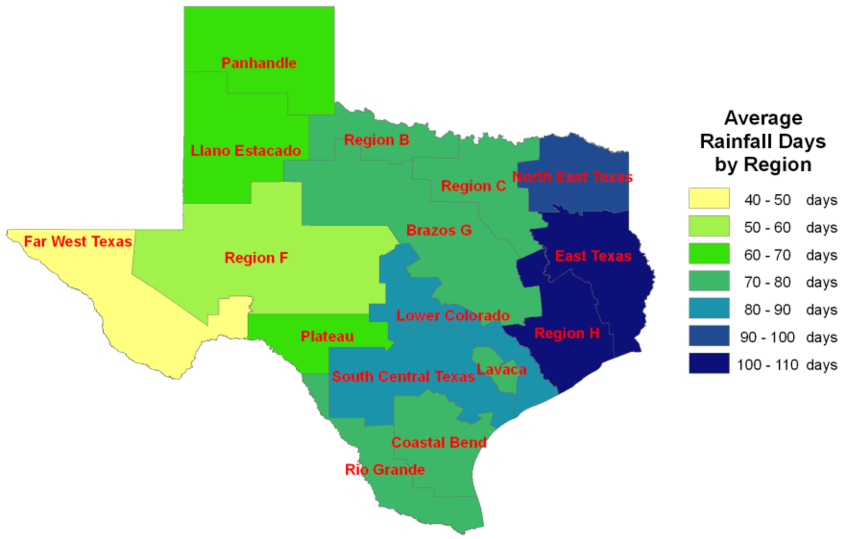


Figure 5-3: Annual Average Rainfall Days by Region



Monthly average rainfall volumes for the period 1940-2007 were obtained for each 1-degree rectangle in Texas from the TWDB. The monthly averages for May through September were added together to estimate the warm season average rainfall volume. Finally, the estimated warm season average rainfall was compared to the annual average rainfall. In Texas, the percentage of annual rainfall that occurs during the warm season generally decreases from west to east (Figure 5-4), with the highest percentage (71 percent) in the northwest corner of the Panhandle. One exception is that the El Paso area has a slightly lower percentage than the Trans-Pecos area. Figure 5-5, calculated using area-weighted averages of the data shown in Figure 5-4, shows the estimated warm season average rainfall percentage for each of the 16 water planning regions.

Design storm rainfall volumes compared to average annual rainfall can also give an indication of rainfall timing. Areas where a given design storm represents a larger percentage of the annual rainfall volume tend to experience more of their annual rainfall during fewer events. Such areas may require larger storage volumes and may have a decreased potential for stormwater harvesting.

Figure 5-4: Estimated May-September Average Rainfall Percentage in Texas

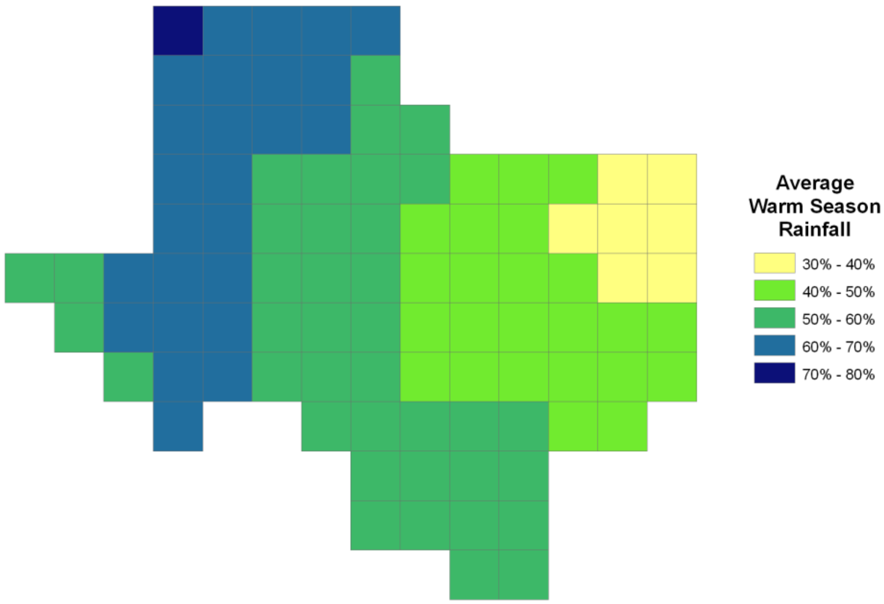
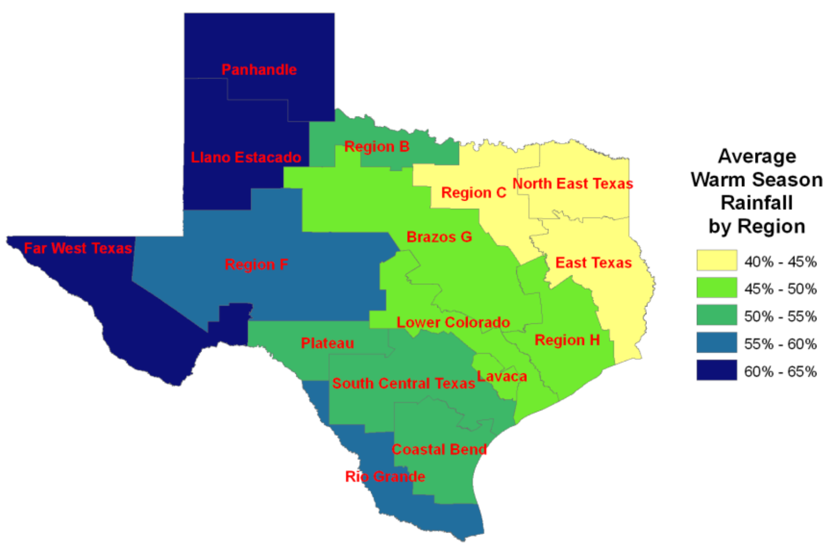


Figure 5-5: Estimated May-September Average Rainfall Percentage by Region



For estimation of the regional potential for stormwater harvesting, a one-year frequency, 24-hour duration design storm was chosen.[gg] One-year frequency, 24-hour duration rainfall volumes were obtained from National Weather Service Technical Publication 40.[(94)] In Texas, the design volumes increase from west to east (Figure 5-6). These design storm volumes were averaged by planning region and compared to the annual average rainfall volume (Figure 5-7). The resulting percentage tends to increase from northeast to southwest, indicating that the southern and western regions tend to experience a greater percentage of their rainfall from fewer events.

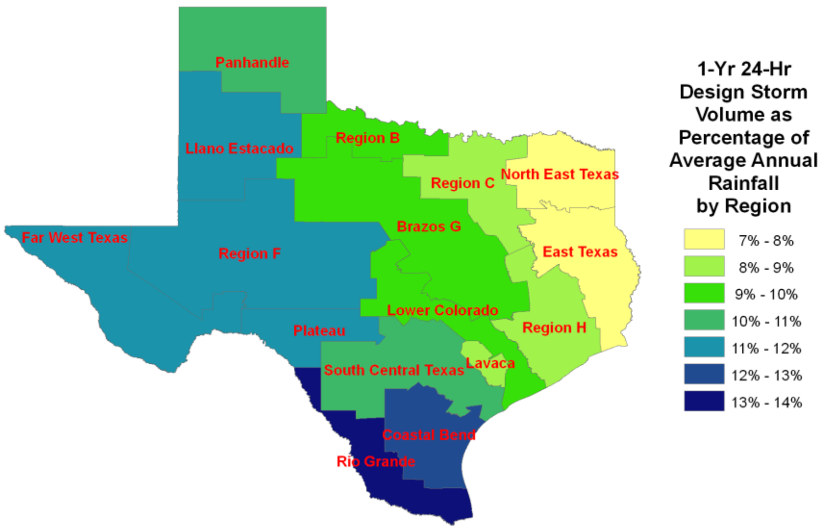
Figure 5-6: One-Year Frequency, 24-Hour Duration Design Rainfall Volumes in Texas

Runoff Potential

Natural Resources Conservation Service curve numbers can be used to estimate runoff based on soil and land use characteristics. Areas with higher curve numbers typically have lower infiltration rates and/or greater development density/paved area than areas with smaller curve numbers, and areas with higher curve numbers generate more stormwater runoff for a given storm event. In addition, storage construction costs may be lower if native clay soils can be used to limit infiltration.

[gg] This represents the 24-hour rainfall amount for which, on average, one year is expected to elapse between rainfall events of equal or greater magnitude.

Figure 5-7: Comparison of 1-Year Frequency, 24-Hour Duration Design Rainfall Volumes to Average Annual Rainfall by Region



As discussed in Chapter 4, Natural Resources Conservation Service curve numbers are available for each control point in the TCEQ Water Availability Models (WAMs) for each river basin in Texas. These curve numbers represent the average curve number for the entire drainage area upstream of each control point. While these curve numbers could be useful for evaluation of stormwater harvesting projects on a local basis, it is difficult to disaggregate them for individual areas. The curve number data for the WAMs are not available in GIS format from the TCEQ since curve numbers are not used in the WAMs (see discussion of the modified curve number method on Page 4-1). The locations of drainage areas in relationship to the control points in the WAMs can be determined by requesting the appropriate GIS data sets from TCEQ. Therefore, curve numbers were estimated from other data sources, as discussed below.

The General Soil Map for Texas was obtained from the National Resources Conservation Service and used to identify the hydrologic group for each soil unit in Texas. The 2001 National Land Cover Database for Texas was obtained from the Natural Resources Conservation Service and used to identify land use/land cover types for Texas. For a given location, the curve number was obtained from a lookup table based on land use/land cover type and soil hydrologic group (Table 5-2). In this manner curve numbers were developed for the entire state (Figure 5-8).

The regions with the greatest stormwater runoff potential, as measured by regionally-averaged curve numbers, are Region H, Plateau, Lavaca, East Texas, and Lower Colorado (Figure 5-9).

Table 5-2: Natural Resources Conservation Service Curve Number Lookup Table

Land Use/ Land Cover Type	Description	Soil Hydrologic Group			
		A	B	C	D
11	Open Water	100	100	100	100
21	Developed, Open Space	51	68	79	84
22	Developed, Low Intensity	61	75	83	87
23	Developed, Medium Intensity	77	85	90	92
24	Developed, High Intensity	89	92	94	95
31	Barren Land (Rock/Sand/Clay)	77	85	90	92
41	Deciduous Forest	55	66	74	79
42	Evergreen Forest	60	75	85	89
43	Mixed Forest	57	73	82	86
52	Shrub/Scrub	55	67	80	85
71	Grassland/Herbaceous	49	69	79	84
81	Pasture/Hay	49	69	79	84
82	Cultivated Crops	64	75	82	85
90	Woody Wetlands	100	100	100	100
95	Emergent Herbaceous Wetlands	100	100	100	100

This table was developed based on similar tables found in Bao and others and Stukey and others.[95,96]

Figure 5-8: Natural Resources Conservation Service Curve Numbers in Texas

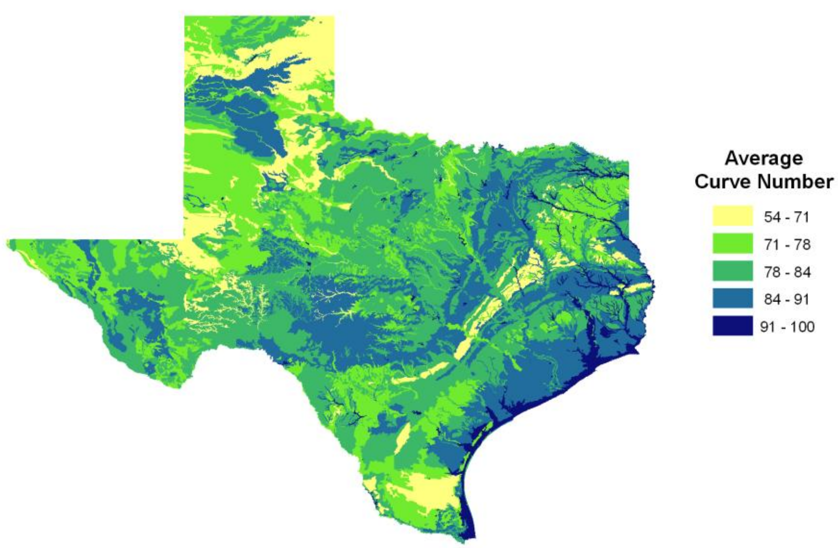
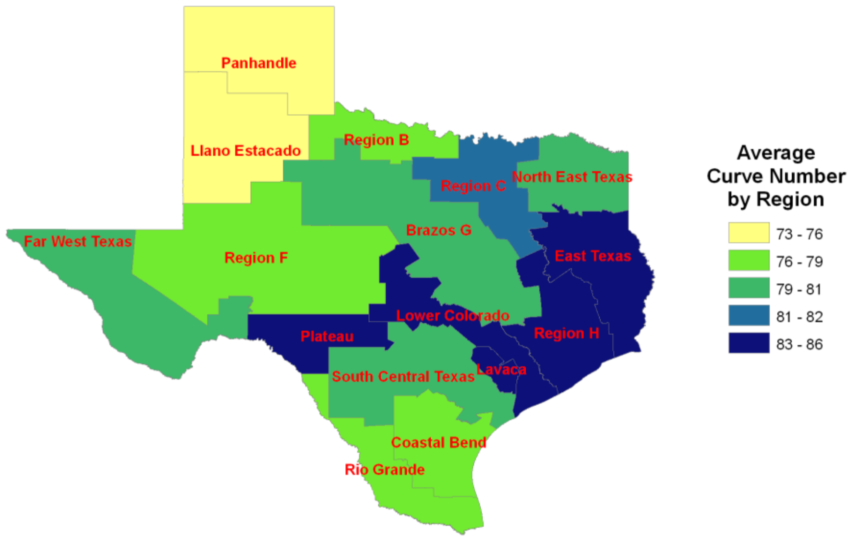


Figure 5-9: Average Natural Resources Conservation Service Curve Number by Region



Evaporative Losses

Areas with greater evaporation will likely require larger storage volumes than areas with lesser evaporation.

Monthly average lake evaporation volumes for the period 1954-2007 were obtained for each 1-degree rectangle in Texas from the TWDB. The monthly averages were added to estimate the annual average lake evaporation volume. In Texas, the annual lake evaporation generally decreases from west to east (Figure 5-10), although there are some exceptions (*e.g.*, in mountainous areas), and there are some north-south variations as well. The regional averages reflect a similar pattern, with highest evaporation in the western half of the state and lowest evaporation in the southeast part of the state (Figure 5-11).

Figure 5-10: Annual Average Lake Evaporation in Texas

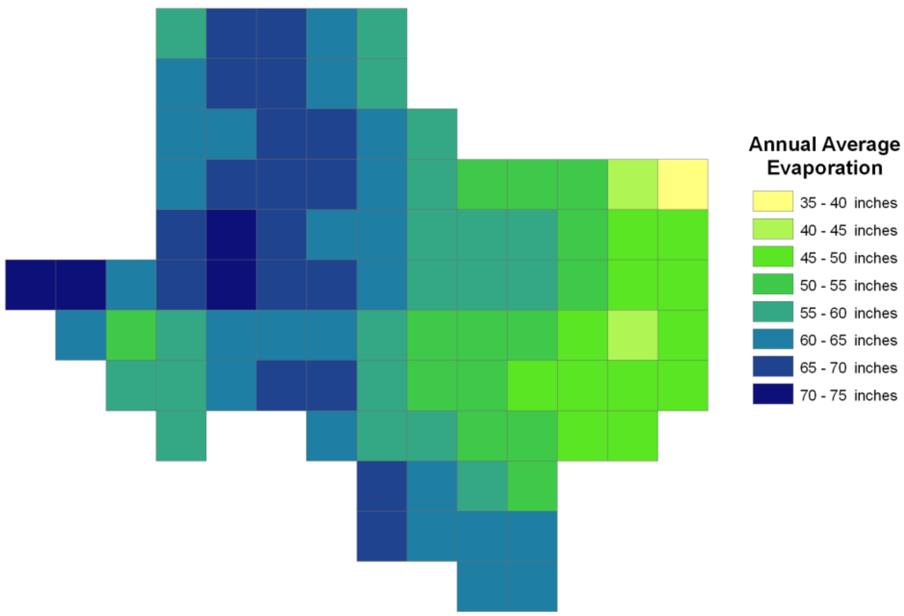
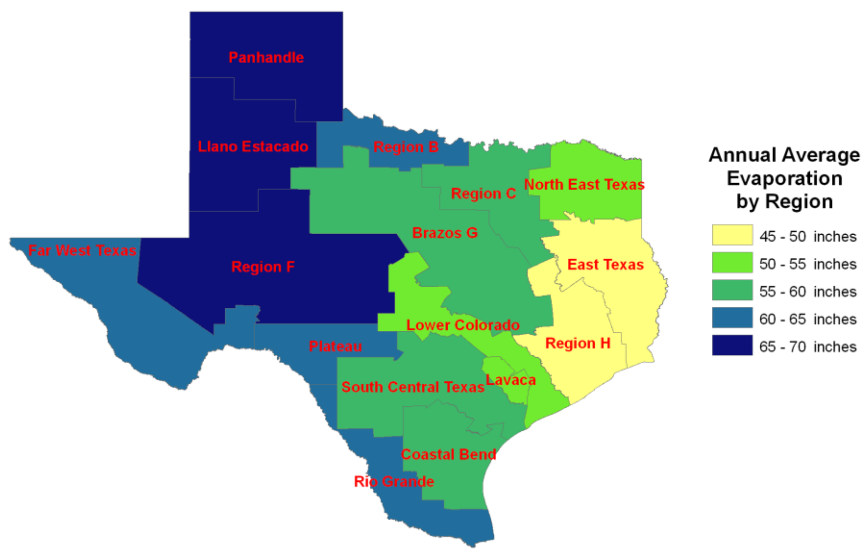


Figure 5-11: Annual Average Lake Evaporation by Region



Demand Factors

Factors affecting the demand for stormwater include water needs, water demand timing, and air temperature. Each of these is discussed below.

Municipal Water Needs

The potential for stormwater harvesting increases with increasing water needs. During development of the 2006 regional water plans, future water demands and currently available water supplies were projected for every municipal water user group (WUG) in Texas.[hh] For each municipal WUG, the projected water need by decade was estimated as the difference between the projected water demand and the currently available water supply.[ii]

The 2030 projected water needs were totaled for all municipal WUGs in each region (Figure 5-12). The Region C projected 2030 municipal water need (829,522 acre-feet per year) is almost 6 times as great as the next largest projected 2030 municipal water need (Region H at 139,268 acre-feet per year). Although 9 of the 16 planning regions have projected municipal water surpluses in 2030, there may be cities within these regions that have significant projected water shortages.

Water Demand Timing

In general, stormwater harvesting is more feasible when the demand and the supply are closely spaced in time. Near coincidence of demand and supply leads to smaller storage volume requirements, less required land area to meet project needs, greater supply reliability (less reliance on backup supplies), and possibly to smaller changes in stored water levels (better aesthetic appearance).

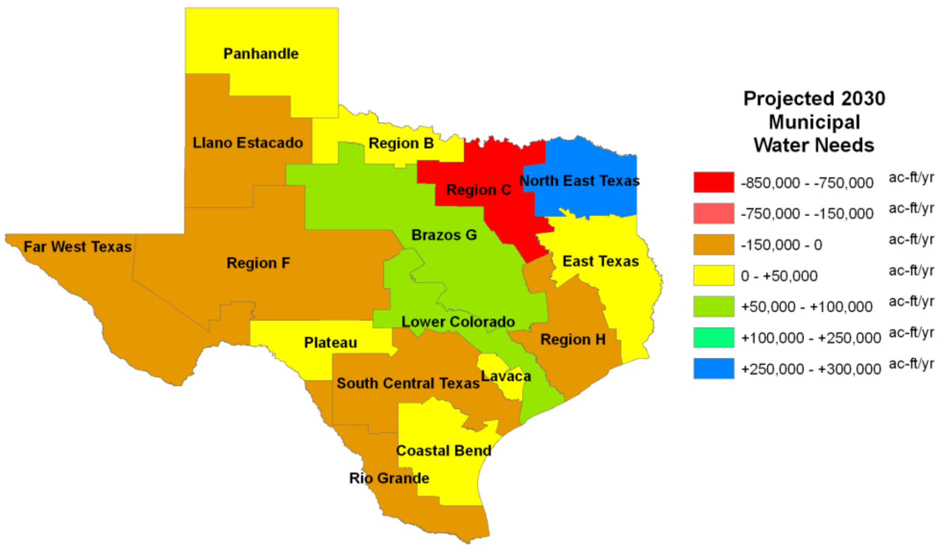
Seasonal uses (*e.g.*, irrigation and cooling) have larger demands in the summer and smaller demands in the winter. Areas where a higher percentage of the annual rainfall occurs during the warm season may have a higher potential to use harvested stormwater for seasonal uses. Non-seasonal uses (*e.g.*, toilet flushing and commercial uses) are relatively constant throughout the year. Areas where the annual rainfall is somewhat evenly distributed throughout the year may have a higher potential to use harvested stormwater for non-seasonal uses.

No regional data were identified regarding the timing of water demands.

[hh] A municipal water user group is a city with a population of 500 people or more or a water supplier with a projected average day demand of 0.25 mgd or greater.

[ii] Stormwater that is intercepted and used prior to entering a natural watercourse (and is not subject to appropriation and permitting under the Water Code as state water) may result in reduced water availability for downstream water rights. This may reduce the “currently available water supply” for a municipal WUG.

Figure 5-12: Projected 2030 Municipal Water Needs by Region



NOTE: Negative values indicate projected water needs. Positive values indicate projected water surpluses.

Air Temperature

For stormwater harvesting projects that supply seasonal water demands, such as irrigation and cooling, areas with higher air temperatures in the summer will likely have greater demands than areas with lower summer temperatures.

Monthly average temperatures for the period 1971-2000 were obtained from the TWDB's Digital Climatic Atlas of Texas.[97] The monthly averages for May through September were averaged to estimate warm season average temperatures for Texas. The highest average warm season temperatures occurred in the southern portion of the state, and the lowest average warm season temperatures occurred in the Panhandle and in the Davis Mountains (Figure 5-13). The warm season average temperature for each of the water planning regions is shown in Figure 5-14.

Figure 5-13: May-September Average Air Temperature

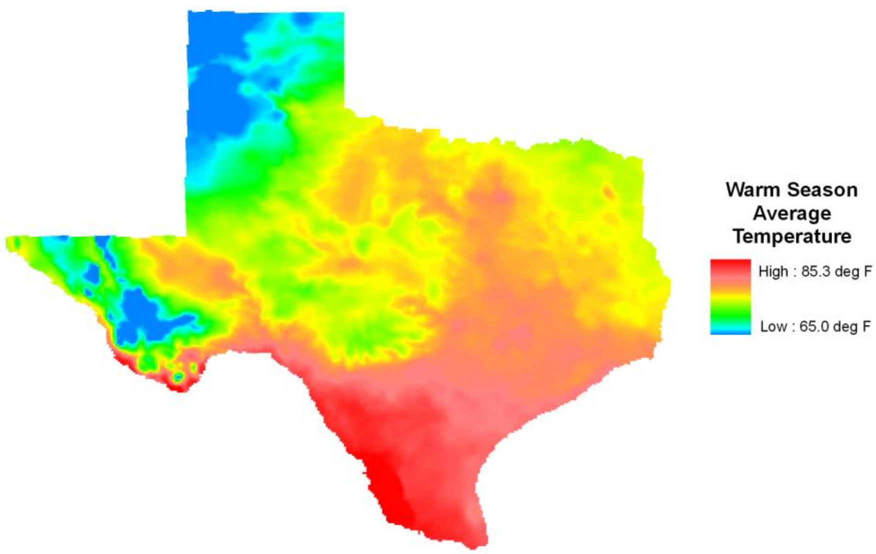
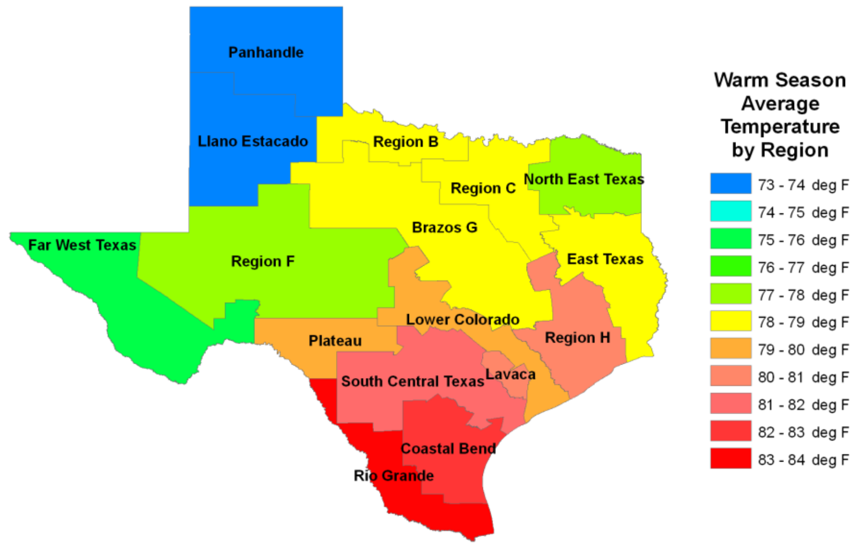


Figure 5-14: May-September Average Air Temperature by Region



Project Implementation Factors

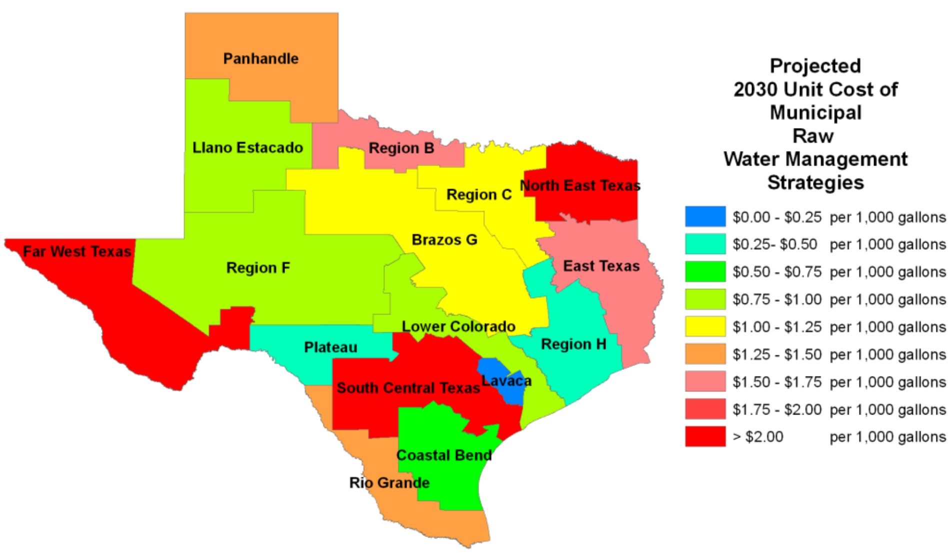
Factors affecting the feasibility of stormwater projects include the unit cost of water supply alternatives and the potential for aquifer storage and retrieval (ASR). Each of these is discussed below.

Unit Cost of Municipal Water Supply Alternatives

The potential for stormwater harvesting increases with increasing unit cost of alternative sources of supply. During development of the 2006 regional water plans, the regional water planning groups recommended water management strategies to meet projected municipal water needs. The planning groups reported estimated annual costs (in second quarter 2002 dollars) and water supply amounts for these strategies.

For each region, the annual costs and water supply amounts were totaled for municipal raw water management strategies. The projected 2030 unit cost of additional municipal raw water was estimated as the total projected 2030 annual cost for the water management strategies divided by the total projected 2030 supply associated with the water management strategies (Figure 5-15). Generally speaking, lower costs for additional municipal raw water are found in the central and coastal parts of the state, while higher costs for additional municipal raw water are found along the borders of the state and in South Central Texas.

Figure 5-15: Projected 2030 Unit Cost of Proposed Municipal Raw Water Management Strategies



Aquifer Storage and Retrieval

Aquifer storage capacity, injection rate, aquifer transmissivity, aquifer depth, and groundwater quality affect the potential for using ASR in conjunction with stormwater harvesting. Each of these parameters is discussed below:

- Aquifer storage capacity depends on the presence or absence of candidate aquifers and the thickness and porosity of the aquifer(s). The potential for ASR increases with increasing aquifer storage capacity.
- The permissible injection and withdrawal rates depend on the aquifer transmissivity/ permeability, depth, and thickness. The potential for ASR increases with increased injection rate.
- Aquifer transmissivity/permeability is a measure of how fast water can move through the aquifer. Higher transmissivity/permeability allows increased injection rates but also allows the injected water to move away from the injection location more quickly.
- Deeper aquifers require deeper wells, higher injection pressures, and larger pumps than shallow aquifers. Therefore, with increasing aquifer depth, ASR costs increase and the potential for ASR decreases.
- The required level of stormwater treatment depends on the existing groundwater quality, the intended end use, and designated aquifer uses. Stormwater harvesting costs increase with more stringent stormwater treatment requirements.

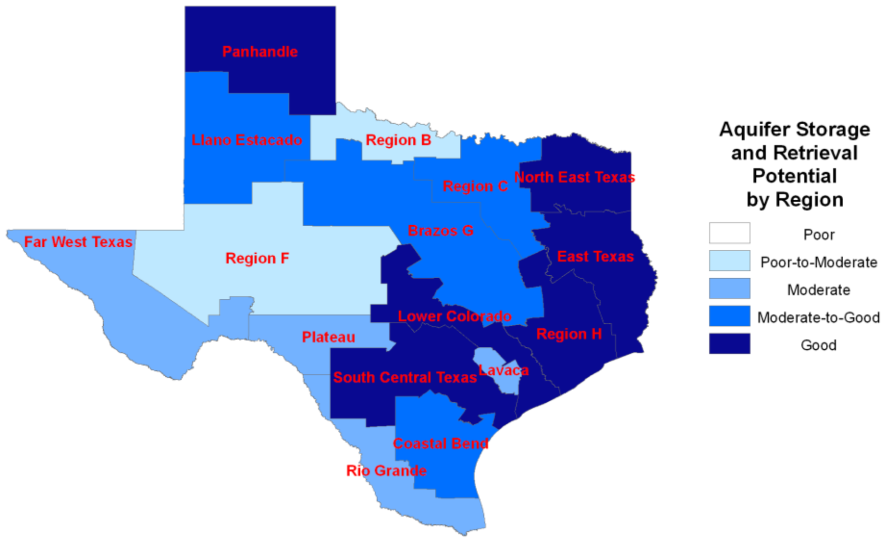
The Texas aquifers that would allow direct injection of large volumes from a small number of sites or wells would be the karstic units in the Edwards Aquifer, the Blaine Aquifer, and some of the West Texas aquifers such as the Capitan Reef. However, these aquifers also have very high transmission capacities (hydraulic conductivity and transmissivity), so the stored stormwater would quickly move away from the injection well. Therefore, in these aquifer units, the stored stormwater could be used to meet water demands over a relatively large area.

Highly porous sandstone aquifers such as the Hueco Bolson, Carrizo-Wilcox, Gulf Coast, and Trinity Aquifers would allow moderate to large volumes of stormwater to be injected. These aquifers do have significant variability in their characteristics, but in general:

- They can store large amounts of water,
- They have regional areas which have undergone groundwater level declines and have available storage, and
- They have moderate to low transmission capacity, so the injected stormwater should remain in the vicinity of the injection wells.

Based on a qualitative evaluation, most of the water planning regions have moderate to good potential for ASR (Figure 5-16). The regions with the lowest potential are Region B and Region F. These findings are based on the regional evaluations presented in Appendix C. Local conditions should be evaluated for an individual project.

Figure 5-16: Projected Aquifer Storage and Retrieval Potential by Region



Other Factors

Other factors that may impact the potential for stormwater harvesting include stormwater quality, environmental impacts, environmental flow needs, public health risks, public awareness, and water availability for downstream water rights. These factors are site- or project-specific and/or difficult to summarize on a regional basis. Therefore, no assessment has been made of the impact of these factors on the regional potential for stormwater harvesting.

5.2. Qualitative Evaluation of Municipal Stormwater Harvesting Potential by Region

For each of the factors discussed in the previous section, a piecewise comparison was performed to rank the factors that most impact the potential for municipal stormwater harvesting. Using the results of the piecewise comparison, factor weights from 1 to 10 were assigned, where 10 represents the greatest impact and 1 represents the least impact (Table 5-3). For example, public health risks (factor weight of 8) are judged to be more important to the potential for municipal stormwater harvesting than public uncertainty (factor weight of 2). Though somewhat subjective, the factor weights were assigned based on experience and literature review.

Table 5-3: Factor Weights

Factor Type	Factor	Factor Weight*
Supply	Rainfall volume	6
	Rainfall frequency	5
	Rainfall timing	5
	Runoff potential	5
	Evaporative losses	5
Demand	Municipal water needs	4
	Water demand timing	5
	Air temperature	5
Implementation	Cost of municipal alternatives	6
	Aquifer storage potential	3
Other	Stormwater quality	6
	Environmental impacts	6
	Environmental flow needs	4
	Public health risks	8
	Public uncertainty	2
	Water availability for downstream water rights	2

* Factor weights range from 1 to 10. A greater number means that the factor is more important for evaluating the potential for stormwater harvesting.

In addition, regional weights were assigned to represent the geographic influence of each factor (Table 5-4) on municipal stormwater harvesting potential. The regional weights also range from 1 to 10, where 10 represents the greatest potential and 1 represents the least potential. For example, North East Texas, East Texas, and Region H each receive average annual rainfall of 45 to 50 inches per year, while Far West Texas receives 10 to 15 inches per year. Therefore, based solely on rainfall volume, the potential for stormwater harvesting is much greater in North East Texas, East Texas, and Region H than in Far West Texas. The regional weights for each factor are based on the relative values for each factor and each region and have been assigned so that the average regional weight is approximately 5. To conclude the example, the regional weights for rainfall volume are 8 for North East Texas, East Texas, and Region H and 1 for Far West Texas.

For a given region, the overall potential for municipal stormwater harvesting is the sum of the multiples of the factor weights and the regional weights (Table 5-5). Regions were divided into five groups based on overall potential (Figure 5-17). Based on this rating system, East Texas has the greatest potential for municipal stormwater harvesting, followed by South Central Texas, North East Texas, Region H, and Region C. The largest contributing factors to the potential for municipal stormwater harvesting in these regions are rainfall volume (East Texas, Region H), the cost of municipal water supply alternatives (South Central Texas, North East Texas) and municipal water needs (Region C).

Table 5-4: Regional Weights

Factor*	Regional Weight**															
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
Rainfall volume	2	4	6	8	1	2	5	8	8	3	5	4	3	4	2	7
Rainfall frequency	5	5	6	7	3	3	5	8	8	4	6	6	5	5	4	5
Rainfall timing	7	6	4	3	7	6	5	4	3	5	4	5	6	5	7	4
Runoff potential	5	5	6	5	5	5	5	6	6	6	6	5	5	5	5	6
Evaporative losses	4	5	6	6	5	4	5	7	7	5	6	6	4	5	4	6
Water needs	4	4	10	2	5	5	4	6	4	4	4	6	5	4	4	4
Water demand timing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Air temperature	5	5	5	5	5	5	5	6	5	5	6	6	6	6	5	6
Cost of alternatives	6	7	5	9	9	4	5	2	7	2	4	9	6	3	4	1
Aquifer storage potential	7	4	6	7	5	4	6	7	7	5	7	7	5	6	6	5
Stormwater quality	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Environmental impacts	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Public health risks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Public uncertainty	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water availability for downstream water rights	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Regional weights range from 1 to 10. For a given factor, a greater number means that the region has more potential for stormwater harvesting. For some factors (*e.g.*, water demand timing) no regional data were identified, and no regional weights were assigned.

** Water Planning Region letters and names

A: Panhandle
B: Region B
C: Region C
D: North East Texas
E: Far West Texas
F: Region F
G: Brazos G
H: Region H
I: East Texas
J: Plateau
K: Lower Colorado
L: South Central Texas
M: Rio Grande
N: Coastal Bend
O: Llano Estacado
P: Lavaca

Table 5-5: Regional Potential for Municipal Stormwater Harvesting

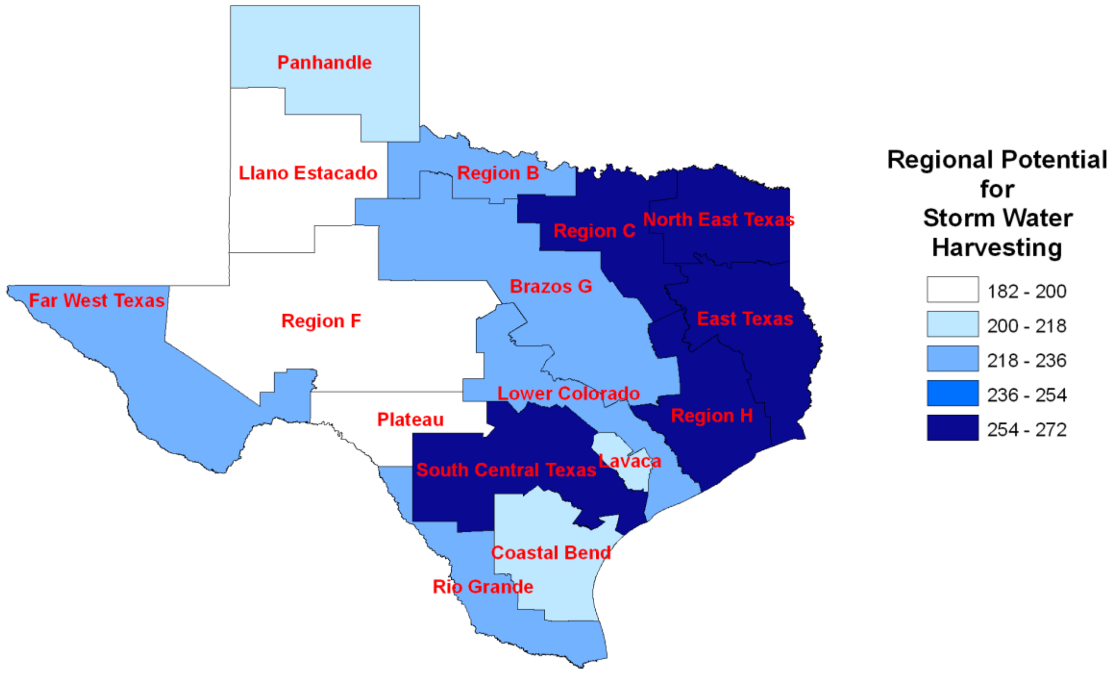
Factor*	Regional Potential Score**															
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
Rainfall volume	**12**	24	36	**48**	**6**	**12**	30	**48**	**48**	18	30	24	18	24	**12**	**42**
Rainfall frequency	25	25	30	35	15	15	25	40	40	20	30	30	25	25	20	25
Rainfall timing	**35**	30	20	15	35	30	25	**20**	**15**	25	20	25	30	25	**35**	20
Runoff potential	25	25	30	25	25	25	25	30	30	**30**	30	25	25	25	25	30
Evaporative losses	20	25	30	30	25	20	25	35	35	25	30	30	20	25	20	30
Water needs	16	16	**40**	**8**	20	20	16	24	16	16	**16**	24	20	16	16	16
Water demand timing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Air temperature	25	25	25	25	25	25	25	30	25	25	30	30	30	30	25	30
Cost of alternatives	**36**	**42**	30	**54**	**54**	24	**30**	**12**	42	**12**	24	**54**	**36**	18	24	**6**
Aquifer storage potential	21	**12**	**18**	21	15	**12**	18	21	21	**15**	21	**21**	**15**	18	18	15
Stormwater quality	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Environmental impacts	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Public health risks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Public uncertainty	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water availability for downstream water rights	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	**215**	**224**	**259**	**261**	**220**	**183**	**219**	**260**	**272**	**186**	**231**	**263**	**219**	**206**	**195**	**214**

* A higher regional potential score means that the region has more potential for stormwater harvesting. For some factors (*e.g.*, water demand timing) no regional data were identified, and no regional potential scores were calculated. For each region, bold green text shows the factor(s) that contributed the most to the regional potential, and bold red text shows the factor(s) that contributed the least to the regional potential.

** Water Planning Region letters and names

A: Panhandle
B: Region B
C: Region C
D: North East Texas
E: Far West Texas
F: Region F
G: Brazos G
H: Region H
I: East Texas
J: Plateau
K: Lower Colorado
L: South Central Texas
M: Rio Grande
N: Coastal Bend
O: Llano Estacado
P: Lavaca

Figure 5-17: Relative Potential for Stormwater Harvesting by Region



Note: A higher regional potential score means that the region has more potential for stormwater harvesting.

This evaluation of potential for municipal stormwater harvesting is generalized across the 16 water planning regions and may not adequately reflect localized conditions. Individual projects should be evaluated using site-specific information.

Sensitivity Analysis for Aquifer Storage and Retrieval

ASR was assigned a relatively low factor weight in comparison to other factors. A sensitivity analysis was performed to see how increasing the ASR factor weight (while holding all other factors constant) would change the overall potential for municipal stormwater harvesting. The results are reported in terms of whether changes to the ASR factor weight caused a region to change groups in Figure 5-17.

With an ASR factor weight of 4, all regions remain in the same group. With an ASR factor weight of 5, Rio Grande (M) moved down in relative potential by one group. With an ASR factor weight of 6, Panhandle (A) moved up in relative potential by one group.

Potential for Other Uses

The potential for stormwater harvesting for other uses can be assessed in a similar fashion. To assess the potential for stormwater harvesting for irrigation, for example, municipal water needs and the cost of municipal water supply alternatives should be replaced with irrigation water needs and the cost of irrigation water supply alternatives. It may also be necessary to revise some of the factor and regional weights.

5.3. Quantitative Evaluation of Municipal Stormwater Harvesting Potential by Region

The Texas Rainwater Harvesting Evaluation Committee (TRHEC) reported that, based on the statewide average precipitation of 28 inches per year, capturing rainfall from 10 percent of the roof area in Texas would produce 120,000 acre-feet of water per year.[(34)] This amount equals about 0.03 percent of the statewide rainfall volume and about 0.3 percent of total streamflow entering the Gulf of Mexico. The TRHEC concluded that this would have little or no impact on total streamflow.[(34)]

A similar "back-of-the-envelope" quantitative estimate of the statewide potential for municipal stormwater harvesting is possible. Based on the 2001 National Land Cover Database for Texas obtained from the Natural Resources Conservation Service, approximately 667 square miles are classified as "Developed, High Intensity," and approximately 1,538 square miles are classified as "Developed, Medium Intensity." The average annual rainfall for these areas can be estimated by overlaying the land use data with the annual rainfall data (Figure 5-1). Assuming an average runoff coefficient of 0.5, harvesting 10 percent of the stormwater runoff from developed areas (high and medium intensities) would produce approximately 218,000 acre-feet per year.[jj]

[jj] There is some degree of overlap with the estimate for rainwater harvesting, since some roof area has been included in the estimate. In addition, stormwater that is intercepted and used prior to entering a natural watercourse (and is not subject to appropriation and permitting under the Water Code as state water) may result in reduced water availability for downstream water rights, so much of the supply of harvested stormwater may be offset by reductions in downstream water supplies.

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6. Design of Stormwater Harvesting Projects

In traditional stormwater management, collection, storage, and treatment facilities are relatively independent, and each serve separate functions. However, in stormwater harvesting systems that are based on low impact development (LID) principles, many of the collection and storage facilities also provide significant treatment. Although background information is presented for collection, storage, and treatment facilities in separate sections below, there is significant overlap between categories.

It is relatively simple to incorporate design and construction of a stormwater harvesting system into a new development, but there are many more constraints to design and construction of stormwater harvesting systems in developed, urban areas. There is a need for technologies that allow stormwater harvesting systems to be retrofitted into existing urban areas.[(21)]

6.1. Collection

Collection facilities may consist of traditional gutter/pipe/channel systems or LID conveyance systems such as grass buffer strips, swales, porous pavements, and biofilters.[(15,6, 98,7)] Traditional systems convey water with minimal losses but do not provide treatment. LID conveyance systems collect and treat water at the same time but could result in water losses.[kk] LID conveyance systems are projected to lose minimal amounts of water through evapotranspiration (ET) and larger amounts due to infiltration of water into the soil, depending on the soil type.

Wanielista and others discussed the hydraulics of stormwater control structures (*e.g.*, ditches, canals, partially filled pipes, gutters, inlets, orifices, gates, weirs, and culverts).[(99)]

6.2. Storage

Potential storage types include open storage, aboveground tanks, underground tanks, and aquifers. Advantages and disadvantages for each storage type are presented in Table 6-1.

Sizing of storage and other design considerations are discussed in the following sections.

[kk] Treatment is discussed in Section 6.3.

Table 6-1: Potential Advantages and Disadvantages of Storage Types

Storage Type	Potential Advantages	Potential Disadvantages
Open storage	▪ Low capital and maintenance cost	▪ Public safety ▪ Mosquito breeding potential ▪ Higher potential for eutrophication ▪ Aesthetic issues with fluctuating water levels
Aboveground tank	▪ Moderate capital and maintenance costs ▪ No public safety issues	▪ Aesthetic issues
Underground tank	▪ No visual issues ▪ No public safety issues	▪ Higher capital cost ▪ Higher maintenance costs ▪ Small storage volumes
Aquifer	▪ Little space required ▪ Cost-effective ▪ Prevents saltwater intrusions into aquifer ▪ Avoids evaporation losses	▪ Requires suitable geology ▪ Potential to pollute groundwater unless pre-treated ▪ May not recover all water

Department of Environment and Conservation NSW[14]

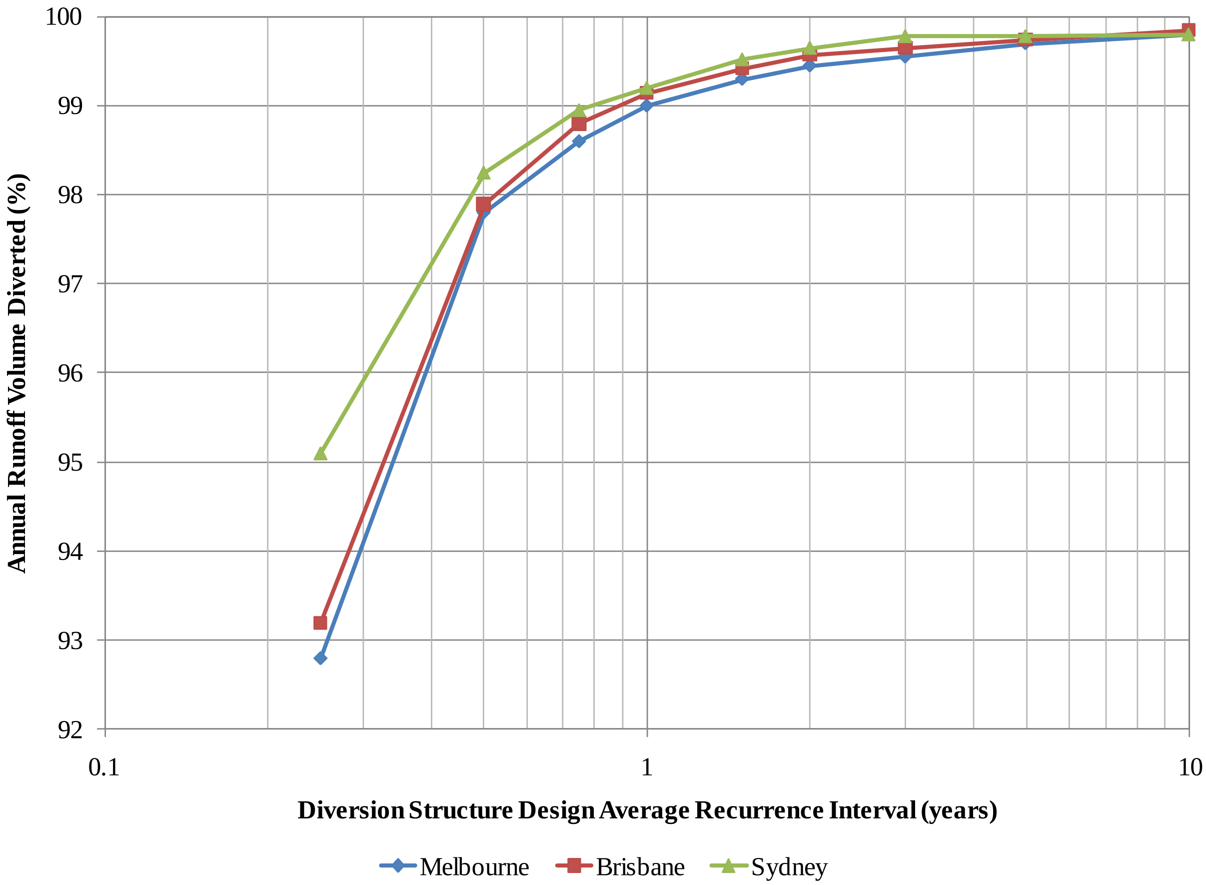
Storage Sizing

Sizing of storage for stormwater harvesting depends on the temporal pattern and volume of stormwater runoff, the temporal pattern and size of the water demand, and the required degree of supply reliability.[100,101,102] Stormwater harvesting projects are generally designed to capture runoff from low average recurrence interval (ARI) storm events (*e.g.*, a 3-month average recurrence interval), since these storm events comprise most of the annual runoff volume.[14] There is a point of diminishing returns between the design average recurrence interval and the proportion of the annual volume that is captured (Figure 6-1). Similarly, there is a point of diminishing returns between the storage capacity and yield reliability (Figure 6-2).

Sizing of storage capacity involves a tradeoff between maximizing supply reliability and minimizing storage size and cost (Figures 6-1 and 6-2).[15] Relatively small storage capacities can substantially reduce potable water use. Seepage losses should be minimized, because they can significantly impact stormwater yield from storage. Net evaporative losses have a minor impact on yield, so closed storage does not appear to be necessary for supply reliability reasons.

Using 15 years of rainfall data, Wanielista and others developed stormwater storage design curves similar to Figure 6-1 for 17 locations in Florida.[101] Different design curves are specified based on different time periods between rainfall events. The design minimum time period between rainfall events should be consistent with times required for treatment (infiltration, chemical precipitation, sediment removal, biological assimilation, or other method) and conveyance of stormwater to the user.[101]

Figure 6-1: Relationship between Design Average Recurrence Interval and Proportion of Annual Runoff Volume Captured

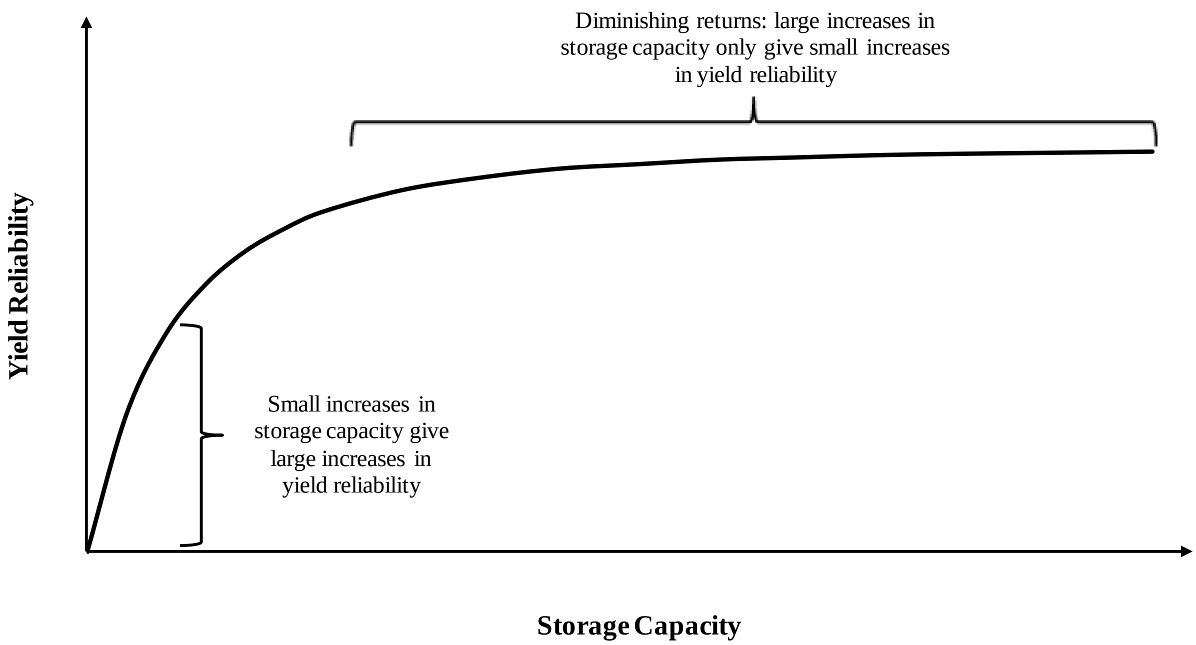


Department of Environment and Conservation NSW, after Wong and others(14,103)

Using results from a water balance model of stormwater harvesting storage, Wanielista and others developed sets of rate-efficiency-volume (REV) curves for 25 locations in Florida (Figure 6-3 shows the curves for Orlando, Florida).[ll,(102)] The water balance model accounted for historical rainfall patterns and allowed for variation in storage volume and water demand rate. The work of Wanielista and others could be used as a model to develop storage design curves for sites in Texas.(101,102)

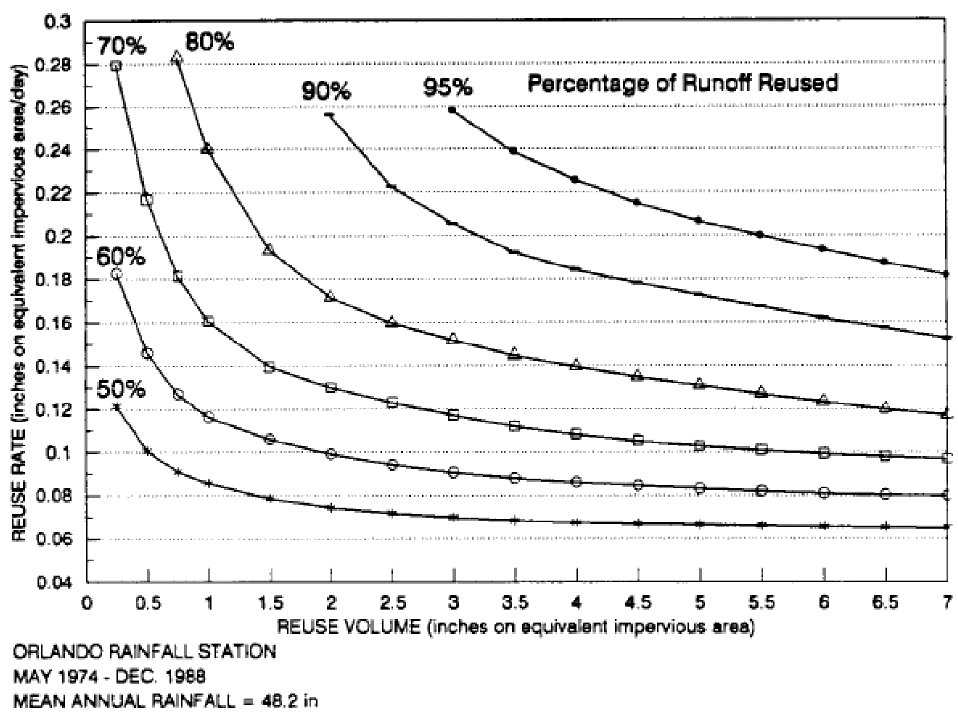
[ll] The "Reuse Volume" label on the X axis in Figure 6-3 means the volume of the stormwater storage facility. The "Reuse Rate" label on the Y axis means the water demand rate.

Figure 6-2: Relationship between Storage Capacity and Yield Reliability



Adapted from Mitchell and others[15]

Figure 6-3: Rate-Efficiency-Volume (REV) Design Curves for Orlando, Florida



Wanielista and others[102]

The REV curves show the use efficiency (the percentage of the captured stormwater runoff that is used) for different combinations of storage volume and water demand rate. Given a target use efficiency, a REV curve allows a project designer to identify the storage size necessary to meet projected water demands. In Figure 6-3, the water demand rate and the stormwater storage volume are both normalized by equivalent impervious area (EIA), which is the watershed area multiplied by the watershed runoff coefficient. In addition to REV curves, other design curves could be developed to show the percentage of the water demand met by stormwater harvesting for different combinations of water demand rate and stormwater storage volume.

Wanielista and others presented an example calculation for a stormwater storage volume of 3 inches and a water demand rate of 0.2 inches per day.[mm,(102)] They modeled inflows to and outflows from a stormwater storage facility using the Orlando, Florida, rainfall record from May 1974 through December 1988. During this period, they found that inflows to storage[nn] balanced outflows from storage[oo] and that the use efficiency was 89.3 percent.[pp] Over the same period, approximately 66 percent of the water demand was met by stormwater harvesting.[qq]

From Figure 6-3, maintaining the user water demand rate of 0.2 inches EIA per day and increasing the storage volume from 3 inches EIA to 5.5 inches EIA would increase the use efficiency to about 95 percent. Similarly, maintaining the storage volume of 3 inches EIA and increasing the user water demand rate from 0.2 inches EIA per day to 0.26 inches EIA per day would increase the use efficiency to about 95 percent.

In some applications, stormwater storage may be used for flood control as well as for water supply. To properly size storage for these dual purposes, the additional costs to increase the storage size for flood control and the benefits of the additional flood storage must be taken into account. For a dual purpose application, continuous simulation modeling should be performed to evaluate optimal operating policies for water supply and flood control.

Impacts of the design average recurrence interval for stormwater capture on downstream stormwater flow should also be quantified.[(15)] Designing facilities to harvest flows with a relatively short average recurrence interval means that harvesting will not significantly reduce peak flows from flood events.[(25)]

A review of stormwater harvesting systems in Australia found that these projects sometimes made use of available storage in existing ponds and lakes rather than sizing storage to meet demand.[(20 referenced in 21)] In Texas, if stormwater is introduced into a natural watercourse, a water

---

[mm] All water demand rates and storage volumes in this example are normalized by the equivalent impervious area, as defined above.

[nn] 706.88 inches of captured stormwater runoff and 439.24 inches of water supplemented from another source.

[oo] 1,070.40 inches of water demand and 75.72 inches discharged from storage.

[pp] (706.88 inches of captured stormwater runoff - 75.72 inches discharged from storage)/706.88 inches of captured stormwater runoff.

[qq] 706.88 inches of captured stormwater runoff/1,070.40 inches of water demand.

right permit (or permit amendment) would be necessary to divert this water from the natural watercourse.

Other Considerations

Other storage design considerations include management of public health risks, management of algal blooms, and operational considerations.[15,14,35 referenced in 14] Public access to the storage area could be restricted to prevent drowning. Covering the storage facility minimizes fecal inputs from animals and water birds, minimizes mosquito breeding, and prevents algal blooms. If the facility is not covered, it could be designed with steep sides and no macrophytes planted on the fringe to make it less hospitable to wildlife and minimize fecal inputs. A relatively low detention time also helps prevent algal blooms (Table 2-7). In addition, the storage facility should be designed to facilitate removal of accumulated sediments, and wet ponds may need to be lined if the native soil does not have sufficiently low hydraulic conductivity.

Infected mosquitoes can spread the West Nile virus, and mosquitoes need standing water to breed. In Denton, Texas, for example, the principal vector of West Nile virus is a highly domesticated mosquito species that uses the “transient waters common to the urban environment” as larval habitat.[104] Mosquito breeding can be prevented by designing stormwater collection and treatment facilities so that all standing water is discharged or infiltrated within 72 hours, so that tight-fitting covers denying mosquitoes access to standing water, and so that the habitat is less suitable for breeding.[105] Such design practices may include:[105]

- Avoiding orifices that can become easily clogged.
- Using the site’s hydraulic grade line to allow gravity flow through the stormwater collection and treatment facilities and complete draining of distribution piping and containment basins.
- Avoiding use of loose riprap, concrete depressions, barriers, diversions, or flow spreaders that can hold standing water.
- Completely sealing structures that retain water for more than 72 hours.
- Using submerged inlets and outlets.
- Providing appropriate pumping, piping, valves, or other equipment necessary to dewater the facilities.

Coordination of Storage Design with Aquifer Storage and Retrieval

Large amounts of treated stormwater can be stored by injection into an aquifer, but some surface storage is necessary to balance stormwater inflow and operation of the injection wells. Given a design hydrograph for stormwater inflow, it may be technically feasible to inject stormwater into an aquifer with a large number of injection wells and small surface storage, with a small number of injection wells and large surface storage, or with some intermediate design. Identification of the optimal configuration will depend on local maximum injection rates, aquifer depth, and the relative costs of injection wells and surface storage.

6.3. *Treatment*

The focus of stormwater treatment is evolving from protection of receiving water quality to new technologies aimed specifically at providing stormwater for various uses.[(21)] The necessary level of water treatment depends on the stormwater end uses and the potential for human contact (Figure 6-4). Potential levels of treatment include pretreatment technologies, stormwater treatment technologies, advanced water treatment technologies, and disinfection. Each of these technologies is described in the next sections, followed by a discussion of the factors involved in selecting treatment techniques and general treatment effectiveness for the different technologies.[rr]

Stormwater for all end uses should receive at least pretreatment and stormwater treatment (Figure 6-4). Treatment technologies for a stormwater harvesting project should be evaluated on a case-by-case basis.

Pretreatment Technologies

Pretreatment technologies may include the use of gross pollutant traps, such as racks, screens, baskets, booms, pits, grinders, grit chambers, oil/water separators, etc., to remove large debris, coarse sediment, floating matter, and oil and grease. Pretreatment facilities may also include a low-flow bypass structure designed to bypass the “first flush” of stormwater that may contain pollutants that have accumulated between storms and/or a high-flow bypass structure designed to prevent high-velocity flows from resuspending settled particulates.

Advantages

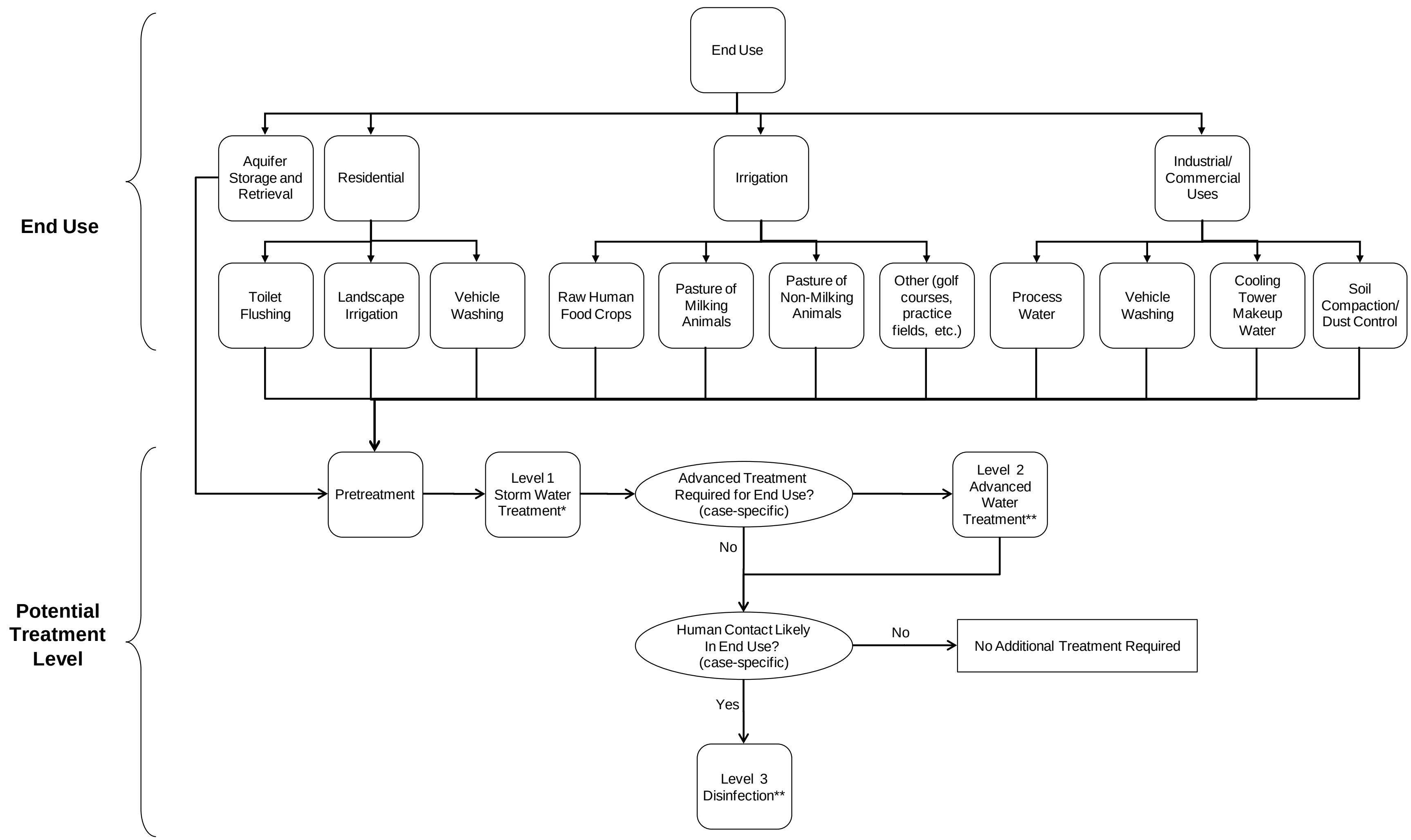
1. These methods may be suitable for retrofitting in existing systems.
2. These methods reduce downstream maintenance requirements.
3. These methods do not require large land areas.

Disadvantages

1. Potential odor problems associated with litter.
2. Not suitable for removal of dissolved pollutants.
3. Mosquito breeding problems, if not maintained properly.
4. Regular maintenance necessary.

[rr] Limited treatment information is presented for each case study in Chapter 8.

Figure 6-4: Potential Stormwater Uses and Associated Levels of Treatment



* Design treatment facilities based on limited site-specific water quality data and reported typical water quality characteristics.

** Design treatment facilities based on site-specific sampling and water quality testing.

Stormwater Treatment Technologies

Stormwater treatment technologies may be classified as vegetative practices, detention facilities, infiltration facilities, and filtration practices. The degree of treatment needed will depend on the end use of the harvested stormwater.

Table 6-2 lists other criteria essential for selecting a stormwater treatment technology, including typical contributing land uses, treatment land requirements, typical drainage area sizes, desired soil conditions, and groundwater elevation.

Vegetative Practices

Vegetative systems such as grass swales and filter strips are used to increase pervious surfaces in urban areas and to convey and treat stormwater runoff. These systems enhance infiltration and solids removal. They are used as an alternative to curb-and-gutter and stormwater conveyance systems. These systems may be used upstream of other stormwater treatment technologies. Generally native vegetation is preferred as it requires less site preparation and maintenance.

Grassed Swales

A grassed swale, also called vegetated swale, grassed channel, biofilter, or retention swale, is a shallow, broad channel that has dense vegetation on the side slopes and on the bottom.(6,7,106,107,108, 109) Grassed swales slowly convey stormwater runoff, trapping suspended solids and metals, promoting infiltration, and reducing runoff velocities. Through infiltration, grassed swales can achieve low-to-moderate removal of suspended solids, nitrogen, phosphorus, and metals. Grassed swales provide little removal of dissolved pollutants, such as nutrients. Both dry and wet swale configurations are possible. Dry swales are typically seen in residential areas where a standing pool of water is not suitable, while wet swales can be used where standing water is not a nuisance. Grassed swales can be used as a stand-alone treatment method or in conjunction with wet ponds and wetlands. A grassed swale is shown in Figure 6-5.

Advantages

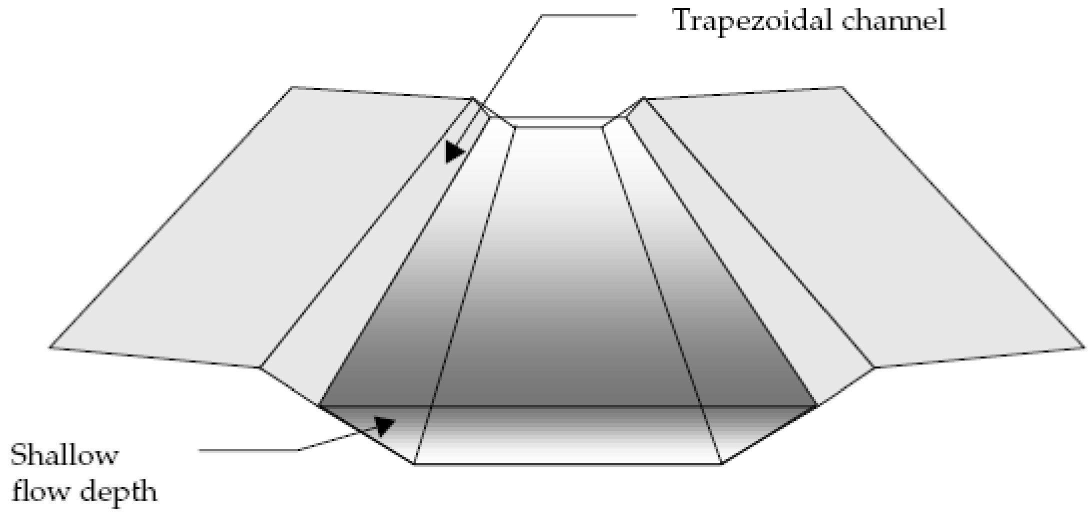
1. Easy to design.
2. More aesthetically pleasing than conventional stormwater conveyance systems.
3. Typically have lower capital costs than concrete channels.
4. Provides some reduction in runoff volume from small storms.

Table 6-2: Other Criteria for Selection of Stormwater Treatment Technologies

Stormwater Treatment Measure	Typical Contributing Land Use	Relative Area Required	Typical Drainage Area Size (acres)	Desired Soil Conditions	Ground-Water Elevation
Vegetative Practices					
Grassed Swales	Rural commercial, residential, industrial, some urban types	Small	< 10	Permeable	Below facility
Vegetated Filter Strips	Rural commercial, residential, industrial, some urban types	Varies	< 10	Depends on type	Depends on type
Detention Facilities					
Detention Basins	Urban commercial, residential, industrial	Large	10 to 40	Permeable	Below facility
Retention Ponds	Urban commercial, residential, industrial	Large	10 to 40	Impermeable	Near surface
Constructed Wetlands	Urban commercial, residential, industrial	Large	> 40	Impermeable	Near surface
Infiltration Facilities					
Infiltration Basins	Urban commercial, residential, industrial	Large	< 10	Permeable	Below facility
Infiltration Trenches/ Wells	Urban commercial, residential	Small	< 10	Permeable	Below facility
Porous Pavements	Urban commercial areas with low vehicular traffic	Not applicable	< 10	Permeable	Below facility
Filtration Practices					
Sand Filters	Urban commercial, residential	Varies	< 10	Depends on type	Depends on type
Bioretention Systems	Urban commercial, residential, industrial	Large	10 to 40	Permeable	Below facility

United States Environmental Protection Agency[106]

Figure 6-5: Grassed Swale



NSW Environment Protection Authority[110]

Disadvantages

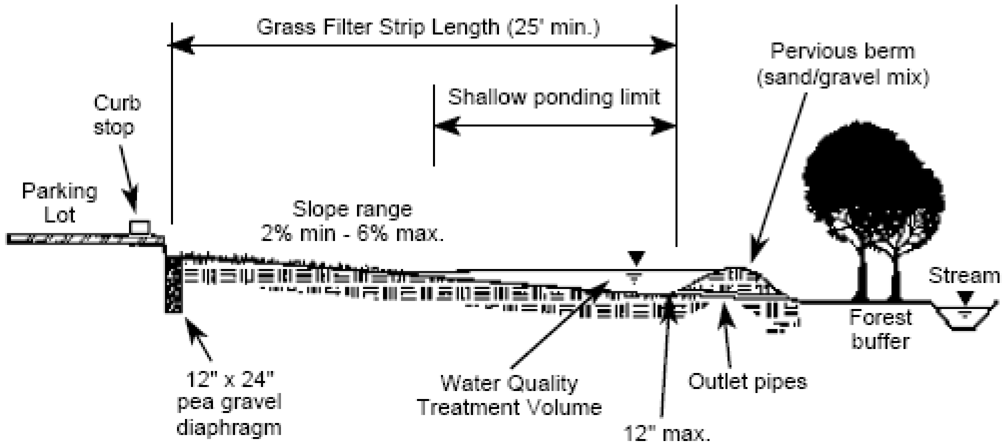
1. Generally not effective in removing dissolved pollutants such as nutrients.
2. Only suitable in areas with low slopes and with soils not susceptible to erosion.
3. Adequate sunlight needed.
4. May require permanent irrigation.
5. Not suitable for large peak flows and velocities.
6. Potential for mosquito breeding and odor problems.
7. May require more right-of-way than conventional stormwater conveyance systems.

Vegetated Filter Strips

Vegetated filter strips are uniformly graded, densely vegetated areas that treat overland flow before the flow enters a conveyance system.[6,7,106,107, 109] A flow spreader (porous pavement or other structure) is used to uniformly spread the flow across the filter strip, and flow is perpendicular to the strip. Through straining of the flow through grasses and through settling, filter strips can provide moderate-to-high removal of particulate suspended solids, nitrogen, phosphorus, and metals. Biological uptake of pollutants and infiltration are minor pollutant removal mechanisms. Pollutant removal depends on the filter strip's dimensions, slope, and soil permeability. Filter strips are less effective at removal of dissolved pollutants, such as nutrients.

Filter strips can be used upstream of treatment processes like sand filters and bioretention systems. Filter strips are also used in conjunction with riparian buffers in treating overland flows. A vegetated filter strip is shown in Figure 6-6.

Figure 6-6: Filter Strip



United States Environmental Protection Agency, from Claytor and Schueler[107,111 referenced in 107]

Advantages

1. Filter strips can effectively remove pollutants such as suspended solids, organics, and some trace metals.
2. Provides aesthetically pleasing green space.
3. May provide some reduction in runoff volume from small storms.

Disadvantages

1. Generally not effective in removing dissolved pollutants such as nutrients.
2. Only suitable in areas with stable slopes, soils, and vegetation; otherwise, channelization occurs.
3. Contributing area may be limited in order to maintain uniform distribution of sheet flow over the strip.
4. Requires additional land area compared to traditional stormwater management systems.
5. Requires periodic removal and replacement as sediment accumulates.
6. May require permanent irrigation.
7. Adequate sunlight is needed.
8. Can provide wildlife habitat.

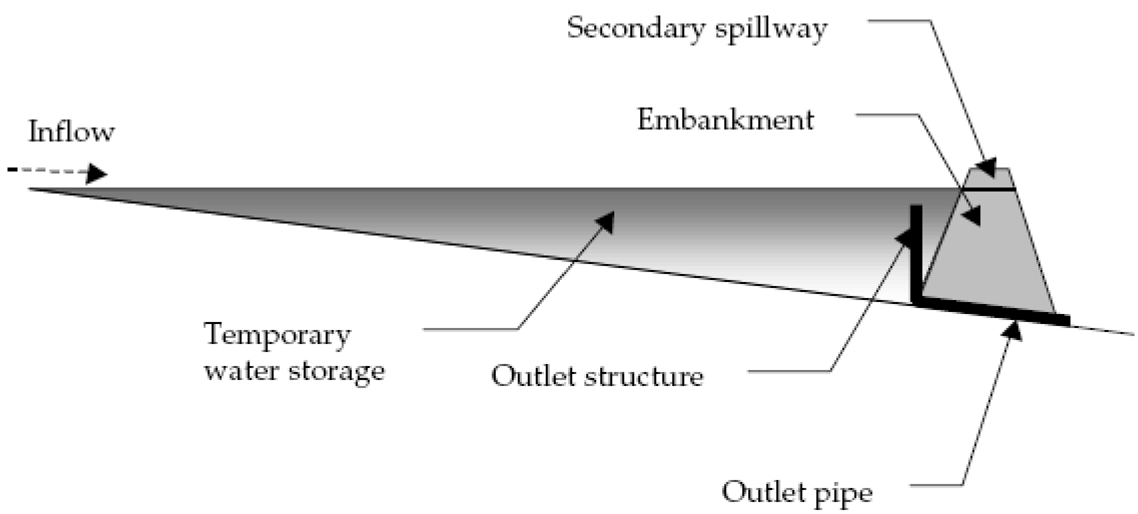
Detention Facilities

Detention facilities are structural methods used for controlling urban runoff and reducing pollutant loading. Detention facilities intercept and store stormwater runoff and release it to receiving water bodies in a controlled manner, reducing peak flow velocities. The main mechanism of pollutant removal in these methods is settling, but filtration, adsorption, microbial action, and vegetative uptake can occur in some cases. The main types of detention facilities are detention basins, retention ponds, and constructed wetlands.

Detention Basins

Detention basins (also known as dry ponds, extended detention basins, detention ponds, and extended detention ponds) operate by detaining stormwater runoff for a short period and then releasing it after the storm event.[4,26,106,107, 109] These basins are designed to completely empty under dry conditions and are also used for flood control purposes (Figure 6-7). Through gravity settling, detention basins provide moderate-to-high removal of suspended solids and metals and low-to-moderate removal of nutrients. Detention basins are less effective at removing dissolved pollutants and microorganisms. Pollutant removal increases with increased detention time. Treatment efficiency can also be improved by including a pre-settling chamber to collect coarse sediment. Vegetation can remove contaminants by filtration and vegetative uptake. A typical detention basin is shown in Figure 6-7.

Figure 6-7: Typical Detention Basin



NSW Environment Protection Authority[110]

Advantages

1. Reduces downstream scour and loss of aquatic habitat.
2. May provide some reduction in runoff volume.
3. Can mitigate the effects of isolated pollution events in the drainage area.
4. Construction costs are generally less expensive (on a cost per unit area basis) than retention basins or constructed wetlands, with the chief expense being excavation of the site.
5. May be part of an aquifer storage and retrieval system.
6. Can provide recreational and open space opportunities.

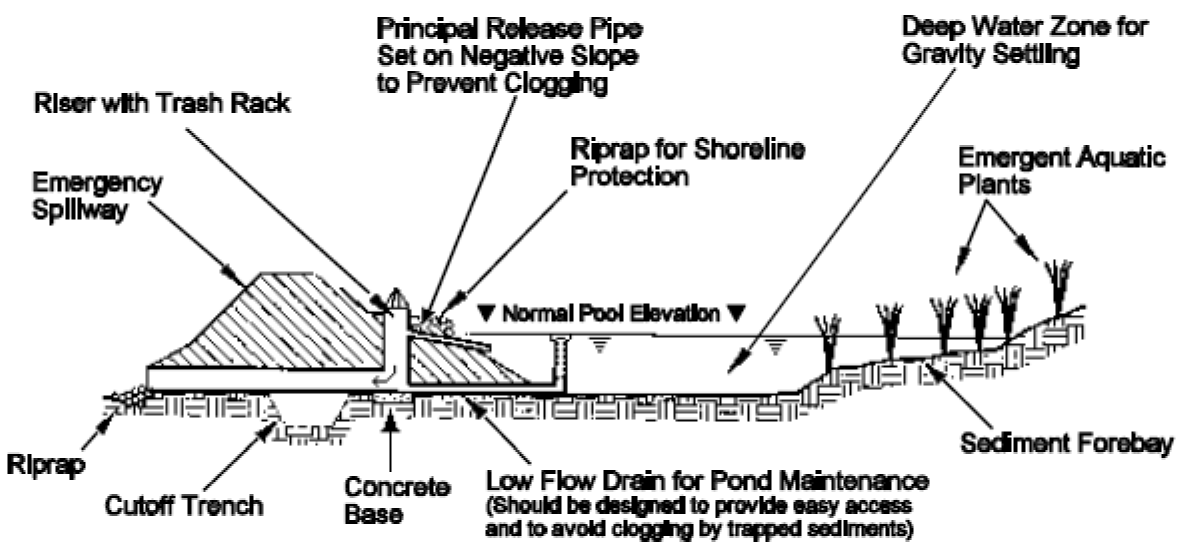
Disadvantages

1. Detention ponds require large land areas, typically 0.5 to 2.0 percent of the contributing area.
2. Requires periodic sediment removal.
3. May not be suitable with high groundwater levels, as a permanent pool may occur.

<u>Retention Ponds</u>

Retention ponds (also known as wet ponds, retention basins, stormwater ponds, and retention extended detention ponds) have a similar design to dry detention ponds but maintain a permanent pool of water, which is replaced in part or total by a subsequent storm event.[ss,(4,7,26,106,107,108, 109)] A temporary detention volume is provided above the permanent pool to temporarily detain additional stormwater and to enhance sedimentation. Through gravity settling and biological uptake, wet ponds provide moderate-to-high removal of suspended solids and metals and moderate nutrient removal. As in wetlands, native emergent aquatic plants and microorganisms help in pollutant removal by vegetative uptake and degradation, respectively. A typical retention basin is shown in Figure 6-8.

Figure 6-8: Typical Retention Pond



United States Environmental Protection Agency, from Northern Virginia Planning District Commission[(107,112 referenced in 107)]

[ss] A water right permit would be required to locate a retention pond "on-channel" (i.e., on a natural watercourse).

Advantages

1. Reduces downstream scour and loss of aquatic habitat
2. Can mitigate the effects of isolated pollution events in the drainage area.
3. May be part of an aquifer storage and retrieval system.
4. Can provide recreational, aesthetic, and open space opportunities.
5. Can provide wildlife and aquatic habitat.

Disadvantages

1. Requires dry-weather base flow to maintain the permanent pool.
2. Requires periodic sediment removal.
3. May experience problems with litter, scum, algal blooms, nuisance odors, and mosquito breeding.
4. Retention ponds require large land areas, typically 0.5 to 2.0 percent of the contributing area.
5. May attract waterfowl and wildlife, resulting in increased bacteria and nutrient concentrations in the retained water.
6. High water infiltration rates may make it difficult to maintain a permanent pool.

<u>Constructed Wetlands</u>

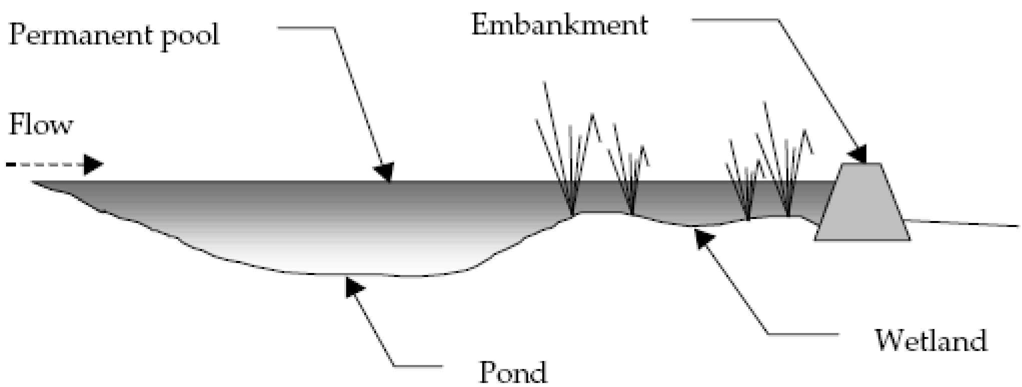
Constructed wetlands (also known as stormwater wetlands, wetland basins, extended detention wetlands, and shallow marshes) are similar to retention basins but have more than half of their surface area covered by emergent wetland vegetation.[tt,(7,26,106,107,108,113)] Constructed wetlands are much shallower than retention basins, averaging 1 to 1.5 feet in depth, but temporary flood storage can be provided above this level. Typical contaminant removal processes include sedimentation, volatilization, filtration, adsorption, microbial decomposition, vegetative uptake, and inactivation via sunlight. Constructed wetlands provide moderate-to-high removal of suspended solids and metals and low-to-moderate removal of nutrients and pathogens. Constructed wetland systems require pretreatment in the form of a sediment forebay to remove coarse sediment. A typical constructed wetland is shown in Figure 6-9.

Advantages

1. Reduces downstream scour and loss of aquatic habitat
2. Can mitigate the effects of isolated pollution events in the drainage area.
3. May be part of an aquifer storage and retrieval system.
4. Can provide recreational, aesthetic, and open space opportunities.
5. Can provide wildlife and aquatic habitat.

[tt] Depending on the project specifics, a water right permit may be required to divert water from constructed wetlands.

Figure 6-9: Typical Constructed Wetland



NSW Environment Protection Authority[110]

Disadvantages

1. Requires near-zero land slope.
2. Requires dry-weather base flow to maintain the permanent pool.
3. Requires periodic sediment removal.
4. Constructed wetlands require large land areas.
5. May attract waterfowl and wildlife, resulting in increased bacteria and nutrient concentrations in the retained water and destruction of wetland plants.
6. High water infiltration rates may make it difficult to maintain a permanent pool.
7. Treatment wetlands are complex and require a thorough understanding of the contaminants of concern and related removal mechanisms. With improper design, there is a risk of water quality impairment.

Infiltration Facilities

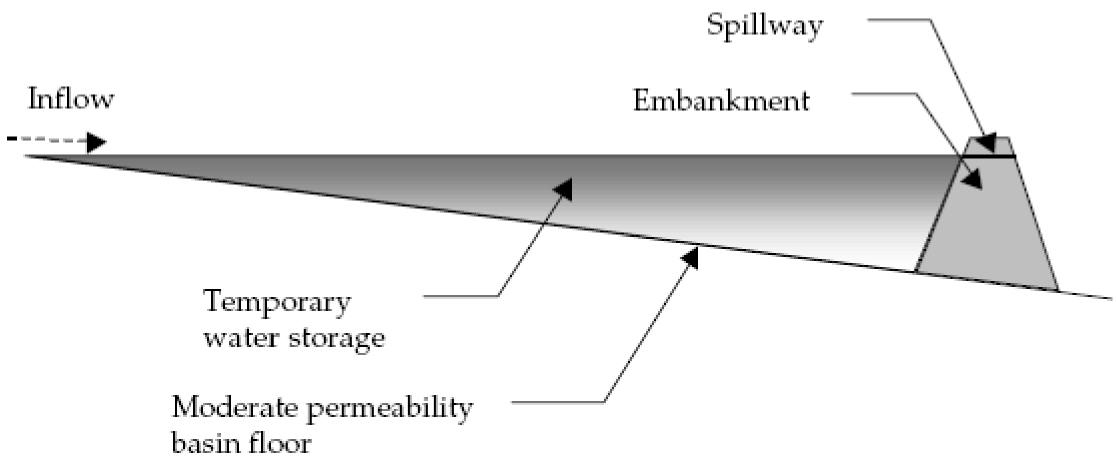
Infiltration facilities operate by permanently capturing stormwater runoff and infiltrating the water into the ground. The main types of infiltration systems are infiltration basins, infiltration trenches/wells, and porous pavements.

<u>Infiltration Basins</u>

Infiltration basins are impoundments designed to capture, hold, and infiltrate the water into the ground.[4,6,7, 98,106,107, 109] They are similar to dry ponds, but they only have a spillway structure and no standard outlet structure. Moderate-to-high removal of suspended solids, nutrients, pathogens, and metals is achieved by a combination of filtration, adsorption, and biological conversion. Infiltration basins are less effective at removal of dissolved pollutants, some toxics, and chlorides.

The efficiency of an infiltration basin can be improved by using vegetative systems, which help remove soluble nutrients, prevent migration of pollutants, and increase the permeability of the soils. Pretreatment is required to prevent sediments from clogging the infiltration surface. A typical infiltration basin is shown in Figure 6-10.

Figure 6-10: Typical Infiltration Basin



NSW Environment Protection Authority[110]

Advantages

1. Reduces downstream scour and loss of aquatic habitat
2. Reduces runoff volume.
3. May be part of an aquifer storage and retrieval system.
4. Contributes to groundwater recharge and may increase base flow in nearby streams.

Disadvantages

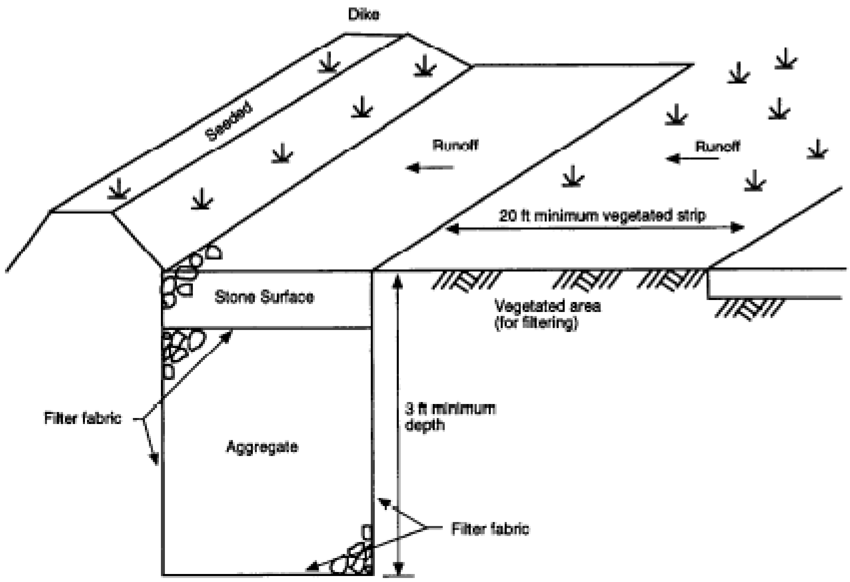
1. Potential for groundwater contamination.
2. Only suitable for areas with permeable soils.
3. Requires periodic sediment removal to maintain infiltrative capacity.
4. Infiltration basins require large land areas.
5. Unless other vector mitigation measures are employed, the system should be designed to infiltrate all stored water within 72 hours, preventing mosquito breeding and other odor problems.[105,107]
6. Groundwater levels should be at least 2 to 4 feet below the bottom of the basin.

<u>Infiltration Trenches/Wells</u>

Infiltration trenches are shallow trenches filled with gravel where runoff is collected and then infiltrated into the ground.[4,106,107,108] Due to their limited storage area, infiltration trenches can only treat a portion of the runoff, mostly the first flush from a rainfall event. Moderate-to-high removal of suspended solids, nitrogen, pathogens, and metals and low-to-moderate removal of nitrogen is achieved through filtration, adsorption, and microbial decomposition. Infiltration trenches are less effective at removal of dissolved pollutants, such as nutrients.

Infiltration trenches are sometimes used in conjunction with other treatment methods like detention ponds to control peak flows. Pretreatment is typically required to prevent sediments from clogging the infiltration surface. An infiltration trench is shown in Figure 6-11.

Figure 6-11: Infiltration Trench



United States Environmental Protection Agency, from Livingston and others[106,114 referenced in 106]

Advantages

1. Reduces downstream scour and loss of aquatic habitat
2. Reduces runoff volume.
3. May contribute to groundwater recharge and may increase base flow in nearby streams.
4. Infiltration trenches do not require large land areas as in the case of infiltration basins.

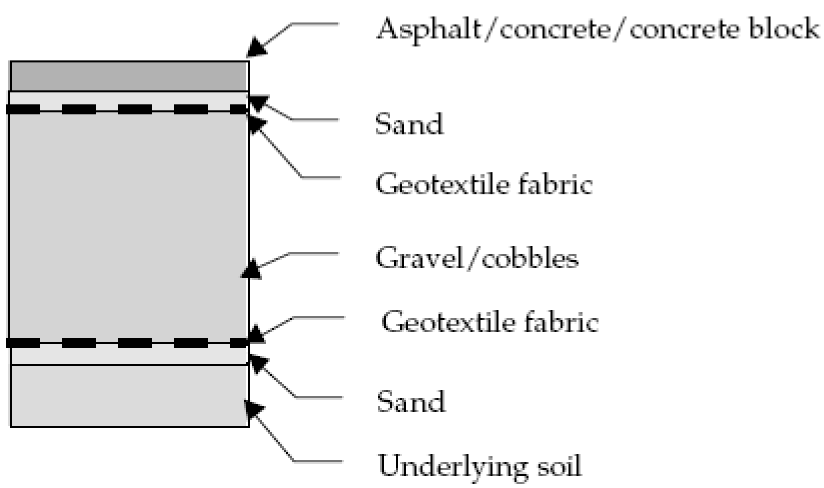
Disadvantages

1. Groundwater levels should be at least 2 feet below the bottom of the trench.
2. Potential for groundwater contamination.
3. Only suitable for areas with permeable soils.
4. Not suitable in cold climates, due to the possibility of freezing of the trench surface, thus preventing the runoff from reaching the trench.
5. Not suitable in areas with steep slopes and in areas with fill.
6. With inadequate pretreatment, infiltration trenches/wells are prone to clogging. Periodic maintenance, such as sediment removal, is required to keep pretreatment facilities operating effectively. If clogging does occur, rehabilitation of the infiltration trench/well through replacement of topsoil and/or filters will be necessary.

Porous Pavements

Porous pavement systems allow stormwater runoff to drain through a permeable pavement layer into an underground gravel bed.[4,7, 98,106,107] The permeable layer may be porous asphalt, porous concrete, concrete blocks, and reinforced/stabilized turf. In combination with infiltration into the underlying soil, porous pavement can provide high removals of suspended solids, nitrogen, pathogens, and metals and moderate removal of nitrogen. Removal efficiencies depend on the surface area and the storage volume of the pavement and the soil infiltration rate. An under-drain system can collect the treated stormwater for storage. A typical porous pavement design is shown in Figure 6-12.

Figure 6-12: Typical Porous Pavement Design



NSW Environment Protection Authority, adapted from Construction Industry Research and Industry Information Association [110,115 referenced in 110]

Advantages

1. Reduces downstream scour and loss of aquatic habitat
2. Reduces runoff volume.
3. May contribute to groundwater recharge.
4. May be preferable for overflow parking lots that are not used on a daily basis.

Disadvantages

1. Potential for groundwater contamination.
2. Not suitable for high traffic volumes or use of heavy equipment.
3. High concentrations of suspended sediments may clog pavement pores.
4. Requires periodic maintenance in the form of jet-washing or vacuuming.
5. Not suitable for use of de-icing chemicals or sand.
6. Groundwater levels should be at least 2 to 4 feet below the bottom of the installation.
7. Costs more to install and maintain than traditional pavement.

8. Potential for uneven driving surface.
9. Potential inconvenience when walking on porous pavement in high-heeled shoes.

Filtration Practices

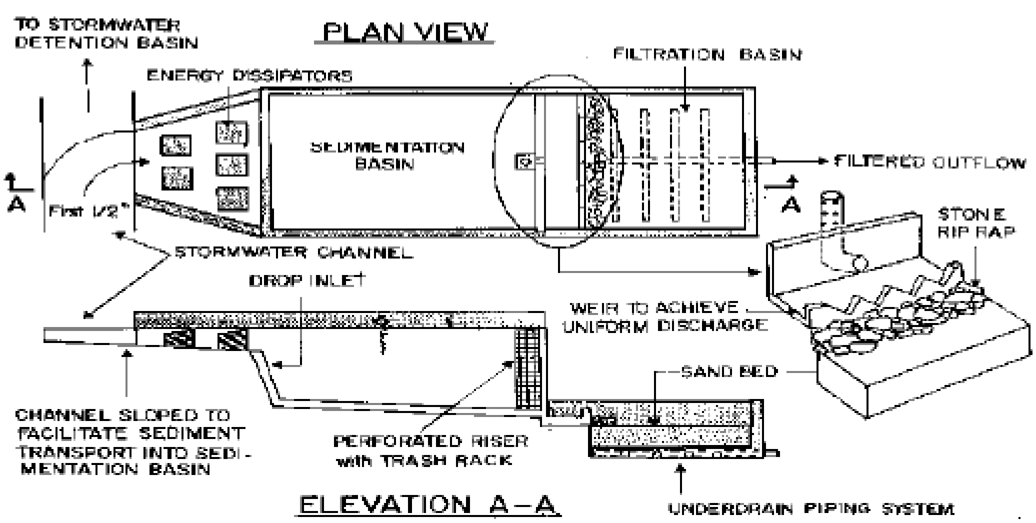
Filtration systems use a filter media such as sand, gravel, peat, or compost to remove pollutants in stormwater. Water quantity control can also be accomplished by having vertical storage above the filter bed or by allowing water to pond in the stormwater collection system before discharging to the filter. Filters are typically suited for treating runoff from parking lots and small developments and in urbanized areas where availability of land is a factor. The main types of filtration practices for stormwater treatment are sand filters and bioretention systems.

<u>Sand Filters</u>

Sand filters consist of a filter bed with a gravel and perforated pipe under-drain system.[4,7,107,108] Pretreatment must be provided to remove coarse particles. Sand filters provide high removal of suspended solids, moderate-to-high removal of particulate metals,[uu] low-to-moderate removal of nitrogen, and low removal of phosphorus and pathogens. Sand filters do not remove dissolved pollutants, such as nutrients and metals.

Sand filters can be designed in both surface and underground configurations. Three basic types of sand filters are Austin, D.C., and Delaware filters. An Austin surface sand filter is shown in Figure 6-13.

Figure 6-13: Austin Surface Sand Filter



United States Environmental Protection Agency, from Bell[107,116 referenced in 107]

[uu] Metals that have been oxidized and are in solid form.

Advantages

1. Can be placed under parking lots or building basements thus eliminating the need for large land areas.
2. Applicable in areas with high evaporation rates or in areas where soils are too pervious for the use of constructed wetlands.
3. Applicable for treating runoff from highly impervious drainage areas.

Disadvantages

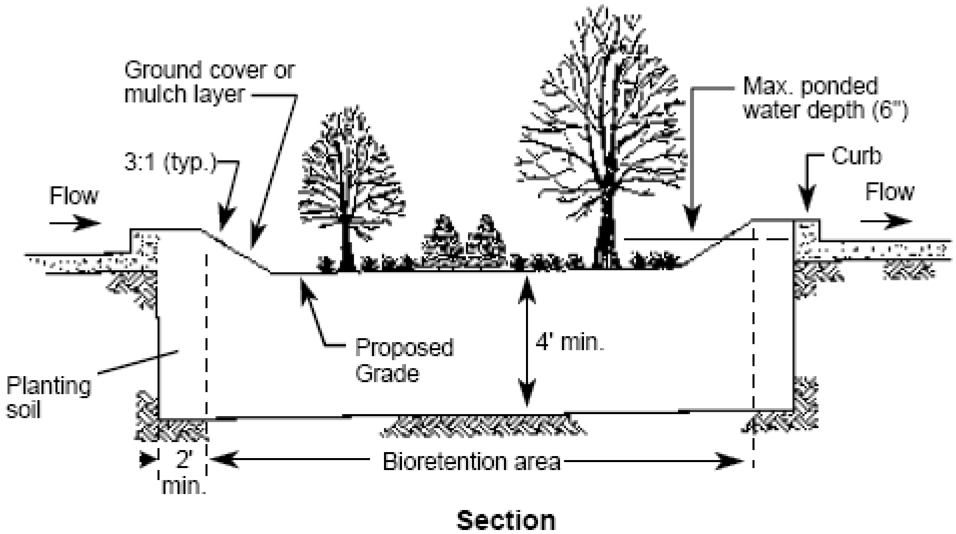
1. Potential for clogging. Forebay or pre-settling chamber needed for removal of settleable solids.
2. Requires periodic replacement of filter media.
3. Requires a flat surface area.
4. Sand filters with no grass cover may not be aesthetically acceptable in residential areas.
5. May have high head losses and low unit flow rates.
6. May require air and water backwash equipment.

Bioretention Systems

Bioretention systems use planted soil beds to remove stormwater pollutants instead of the sand media in sand filters.[4,6,7,98,107,108,109] Runoff enters the bioretention area, ponds over the surface, and infiltrates into the soil bed. A bioretention area consists of a grass buffer strip, a ponding area, an organic mulch layer, a sand bed, planting soil, and plants. The pollutant removal mechanisms include adsorption, filtration, volatilization, ion exchange, and decomposition. Bioretention is effective in removing metals, bacteria, suspended solids, nitrogen, and phosphorus. The microbial activity and plant uptake in a bioretention area will likely result in greater pollutant removals than for infiltration best management practices.

An under-drain system could be added to collect the treated runoff. Bioretention systems are applicable for impervious surfaces at commercial, residential, and industrial areas. They are suitable for treatment of runoff from median strips, parking lot islands, and swales. A typical bioretention system is shown in Figure 6-14.

Figure 6-14: Bioretention System



United States Environmental Protection Agency, from Prince George's County[107,117 referenced in 107]

Advantages

1. Reduces downstream scour and loss of aquatic habitat
2. Reduces runoff volume.
3. May contribute to groundwater recharge.
4. When properly maintained, can be aesthetically pleasing.
5. Layout can be flexible, and a wide variety of landscape designs are possible.
6. Easy to incorporate into individual residential lots.
7. Provides shade and wind breaks and absorbs noise.

Disadvantages

1. Potential for groundwater contamination.
2. Not applicable for areas where the groundwater table is within six feet of the ground surface.
3. Not applicable for areas with slopes greater than 20 percent.
4. Runoff with a high sediment load can cause clogging problems.
5. The soil may freeze in colder climates, preventing runoff from infiltration.

Advanced Water Treatment Technologies

Advanced water treatment technologies are physical, chemical, and/or biological processes commonly used in water and wastewater treatment. Possible treatment methods include dissolved air flotation, lime softening, biological nutrient removal, granular media filtration, granular activated carbon, ion exchange, microfiltration, ultrafiltration, and reverse osmosis membrane treatment. Design information for these technologies is available in the literature.[8,10,12,118]

Depending on the use and the types of contaminants removed satisfactorily by stormwater treatment methods, these advanced treatment methods may or may not be necessary. In Australia, advanced treatment techniques have generally been employed for combined stormwater harvesting/treated wastewater effluent reuse projects with end uses where human contact is intended or possible but not for projects that only use stormwater.(21)

Compared to the stormwater treatment technologies discussed in previous sections, advanced water treatment technologies have the following advantages and disadvantages:(15,21)

Advantages

1. Uses less land area.
2. More intensive control produces more consistent water quality.
3. Produces better water quality than stormwater best management practices.
4. Greater opportunity for contaminant-specific treatment.

Disadvantages

1. Generally more expensive and more complex to operate.
2. Not as visually attractive as some stormwater treatment technologies.
3. Can produce residuals that require treatment or create disposal challenges, such as brine.

Disinfection Technologies

Most stormwater treatment technologies achieve some degree of pathogen reduction, but their removal rates are highly variable.(14) For end uses where human contact is likely, disinfection is recommended. Chlorination, ultraviolet radiation, and ozonation are discussed in the following sections. The main factors to be considered in choosing a disinfection method include cost-effectiveness, treatment efficiency, and the risk to human health and the environment due to operation of the system. An examination of the stormwater quality (possibly a pilot test) may be necessary for selection of an appropriate disinfection technology.

Chlorination

Chlorination is the most common disinfection technique in water treatment.(8,12,14,108) Chlorination can be achieved through the addition of chlorine gas, hypochlorite solutions, or chloramines. Factors that influence the efficiency of chlorine disinfection include pH, type of chlorine, type of pathogens, dosing rates, contact time, water temperature, and influent quality (*e.g.*, turbidity and suspended solids concentrations).(15) Variability in flow and turbidity can make it difficult to attain the optimal dosing.

Chlorination is effective against a wide spectrum of pathogenic organisms and in oxidizing certain organic and inorganic compounds.(108) Some parasitic species are resistant to low doses, including oocysts of *Cryptosporidium parvum*, cysts of *Endamoeba histolytica* and *Giardia lamblia*, and eggs of parasitic worms.(108)

Advantages

1. Well-established technology.
2. May be more cost-effective than other disinfection methods.
3. Provides a stable and continuous disinfection.
4. Chlorine is readily available.
5. Flexible dosing control is possible.
6. Provides a chlorine residual, preventing microbial growth.

Disadvantages

1. May require dechlorination for environmental flows or other uses.
2. Chlorine is highly corrosive and toxic and poses a safety risk in transport, storage, and handling.
3. Potential for formation of harmful disinfection byproducts.
4. Increases total dissolved solids and chlorides.
5. Chlorine may react with organic matter present in the stormwater to form disinfection byproducts.

Ultraviolet Radiation

Ultraviolet radiation (UV) is the most commonly used disinfection technique for urban stormwater runoff treatment.(15) UV radiation penetrates the cell walls of an organism, destroying the cell's ability to reproduce. UV treatment is used at the Santa Monica Urban Runoff Recycling Facility in Santa Monica, California (Section 8.1); the Royal Park stormwater harvesting system in Melbourne, Australia; and the South Australian Museum in Adelaide, Australia.(15) The ease of operation and its applicability to small systems make it an attractive disinfection option. Factors that affect the efficiency of ultraviolet disinfection include influent quality, dosage, contact time, water temperature, transmissivity, and turbidity.(12,15,108)

UV disinfection is effective at inactivating most viruses, spores, and cysts, but a low dosage may not effectively inactivate some viruses, spores, and cysts.(108)

Advantages

1. Small footprint.
2. Short contact time.
3. No transport, storage, or handling of chemicals.
4. No disinfection byproducts.
5. Does not increase total dissolved solids or chlorides.
6. Easy to operate.
7. Shorter contact time compared to other disinfection methods.

Disadvantages

1. High suspended solids (> 30 mg/l) and turbidity levels impair the efficiency of ultraviolet disinfection.
2. May be energy intensive.
3. The absence of residual disinfection may result in microbial regrowth. Aquifer storage projects would still require chlorination to reduce risk of biofouling.
4. Not as cost effective as chlorination.
5. Organisms can sometimes repair and reverse the effects of UV radiation.
6. Maintenance required to prevent fouling of equipment.
7. Requires periodic replacement of lamps.

Ozonation

Ozonation, a strong oxidant and virucide, has been used for disinfection in some stormwater treatment facilities.[14,108] Due to its instability, ozone gas is generated on-site and is injected or diffused into the water stream. Factors affecting the efficiency of ozonation include ozone concentration, water temperature, contact time, pH, influent water quality, and the susceptibility of the target organisms.[15,8,12,108]

Ozonation is more effective than chlorine in destroying viruses and bacteria; however, low dosage may not effectively inactive some viruses, spores, and cysts.[8,12,108]

Advantages

1. Requires relatively short contact time.
2. Fewer shipping and handling safety risks, because ozone is generated on-site.
3. Increases the dissolved oxygen content of the treated water.

Disadvantages

1. Requires more complicated equipment than chlorination or UV.
2. High suspended solids, biochemical oxygen demand, chemical oxygen demand, or total organic carbon levels can impair the efficiency of ozonation.
3. Relatively high capital costs.
4. Can be energy-intensive.
5. Ozone is highly corrosive and reactive, requiring corrosion-resistant material such as stainless steel.
6. Off-gases from on-site generation must be destroyed to prevent worker exposure.
7. The absence of residual disinfection may result in microbial regrowth. Aquifer storage projects would still require chlorination to reduce risk of biofouling.

Site-Specific Factors in Selection of Treatment Technologies

The advantages and disadvantages of various treatment technologies are described in the preceding sections. Along with these advantages and disadvantages, site-specific factors should be considered before selecting a particular treatment method or a combination of methods for a site, including:[107]

- Drainage area
- Land requirements
- Land uses
- Average rainfall frequency, duration, and intensity
- Soil characteristics
- Groundwater elevation and quality
- Site slopes
- Geology
- Topography
- Future land use
- Safety and community acceptance
- Maintenance accessibility
- Adverse environmental effects

Stormwater quality, stormwater harvesting quality goals, and factors such as cost, design fundamentals, regulatory requirements, and aesthetics should also be addressed.

Pretreatment and stormwater treatment technologies may be designed based on limited site-specific stormwater quality data and typical stormwater quality for watershed land uses. However, a site-specific monitoring program should be undertaken prior to design of advanced water treatment technologies to properly characterize the stormwater quality.

General Treatment Effectiveness for Treatment Technologies

General ranges of pollutant removal rates for pretreatment and stormwater treatment technologies are listed in Table 6-3. Information about different stormwater treatment methods and their effectiveness is available from several literature sources (Tables 6-4 to 6-6). Publications containing stormwater treatment performance information are briefly summarized in Appendix D.[vv]

The general ranges of pollutant removal percentages must be used in conjunction with influent stormwater concentrations to project treated stormwater concentrations. Sources of influent stormwater quality data are presented in Appendix B.

[vv] As noted in Appendix E, some of these publications also contain best management practice design information.

Table 6-3: General Ranges of Pollutant Removal Rates for Pretreatment and Stormwater Treatment Technologies

Stormwater Treatment Measure	Typical Pollutant Removal (%)									
	Litter and Gross Pollutants	Coarse Sediment (> 2 mm)	Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals	Petroleum Hydrocarbons	Oxygen Demanding Substances	Turbidity
References	(110)	(110)	(14,107,110)	(14,107,110)	(14,107,110)	(14,107,110)	(14,107,108,110)	(110)	(110)	(14)
Gross Pollutant Traps										
Litter Baskets and Pits	50 to 75	10 to 50	0 to 10	0 to 10	0 to 10	0 to 10	-	0 to 10	10 to 50	0 to 70
Litter Racks	10 to 50	10 to 50	0 to 10	0 to 10	0 to 10	0 to 10	-	0 to 10	10 to 50	0 to 70
Sediment Traps	0 to 10	75 to 100	10 to 50	0 to 10	0 to 10	0 to 10	-	0 to 10	10 to 50	0 to 70
Litter Booms	10 to 50	0 to 10	0 to 10	0 to 10	0 to 10	0 to 10	-	0 to 10	10 to 50	0 to 70
Catch Basins	10 to 50	75 to 100	10 to 50	0 to 10	0 to 10	0 to 10	-	0 to 10	10 to 50	0 to 70
Vegetative Practices										
Grassed Swales	50 to 75	75 to 100	30 to 65	15 to 45	15 to 45	0 to 30	15 to 45	75 to 100	10 to 50	44 to 77
Vegetated Filter Strips	50 to 75	75 to 100	50 to 80	50 to 80	50 to 80	0 to 30	30 to 65	10 to 50	10 to 50	-
Detention Facilities										
Detention Basins	*	*	30 to 65	15 to 45	15 to 45	0 to 30	15 to 45	10 to 50	10 to 50	-
Retention Ponds	*	*	50 to 80	30 to 65	30 to 65	0 to 30	50 to 80	-	-	35 to 88
Constructed Wetlands	10 to 50	75 to 100	50 to 80	0 to 30	15 to 45	0 to 30	50 to 80	10 to 50	10 to 50	10 to 70
Infiltration Facilities										
Infiltration Basins	*	*	50 to 80	50 to 80	50 to 80	65 to 100	50 to 80	10 to 50	75 to 100	-
Infiltration Trenches/ Wells	*	*	50 to 80	50 to 80	15 to 45	65 to 100	50 to 80	10 to 50	75 to 100	-
Porous Pavements	0 to 10	0 to 10	65 to 100	65 to 100	30 to 65	65 to 100	65 to 100	50 to 75	75 to 100	-
Filtration Practices										
Sand Filters	*	*	50 to 80	0 to 30	50 to 80	0 to 30	50 to 80	50 to 75	50 to 75	55 to 90
Bioretention Systems	-	-	70 to 90	30 to 50	50 to 80	58 to 90	93 to 98	-	-	55 to 90

*Pretreatment required.
"-" means not available.

Table 6-4: Sources of More Information for Stormwater Treatment Technologies

Measure	Fletcher and others[55]	U. S. Environmental Protection Agency[108]	NSW Environment Protection Authority[110]	Mitchell and others[15]	Fletcher and others[21]	Department of Environment and Conservation NSW[14]	Prince George's County, Maryland Department of Environmental Resources Programs and Planning Division[6]	Urban Drainage and Flood Control District[7]	Strecker and others[4]	U. S. Environmental Protection Agency[109]
Grassed Swales	x	x	x			x	x		x	x
Vegetated Filter Strips	x		x				x		x	x
Detention Basins	x		x					x		x
Retention Ponds	x	x		x		x		x	x	x
Constructed Wetlands	x	x	x	x		x		x	x	
Infiltration Basins	x	x	x	x				x		x
Infiltration Trenches	x	x	x				x	x		
Porous Pavements	x		x		x			x	x	
Sand Filters		x	x	x		x		x	x	
Bioretention Systems	x	x		x	x	x	x	x		x

Table 6-5: Sources of More Information for Advanced Water Treatment Technologies

Measure	Mitchell and others[15]	National Resource Management Ministerial Council and others[13]	Asano and others[12]	American Water Works Association and American Society of Civil Engineers[8]	American Water Works Association[118]
Dissolved Air Flotation	x		x	x	x
Lime Softening	x			x	x
Biological Nutrient Removal	x		x		
Granular Media Filtration				x	x
Granular Activated Carbon			x	x	x
Ion Exchange			x	x	x
Microfiltration	x	x	x	x	x
Ultrafiltration	x	x	x	x	x
Reverse Osmosis		x	x	x	x

Table 6-6: Sources of More Information for Disinfection Treatment Technologies

Measure	U. S. Environmental Protection Agency[108]	Fletcher and others[21]	National Resource Management Ministerial Council and others[13]	Department of Environment and Conservation NSW[14]	Asano and others[12]	American Water Works Association and American Society of Civil Engineers[8]	American Water Works Association[118]	Strecker and others[4]
Chlorination	x		x	x	x	x	x	x
Ultraviolet (UV)	x	x	x	x	x	x	x	x
Ozonation	x		x	x	x	x	x	x

6.4. Distribution

With the exception of projects involving ASR, distribution facilities for treated stormwater are much the same as for other non-potable supply sources.[100] Cross-connections with the potable supply system should be avoided to protect human health. Stormwater may be more corrosive than potable water, with higher electrical conductivity and chloride levels and lower pH, so corrosion-resistant materials may need to be specified.

U.S. EPA, EPA Victoria, and Water Services Association of Australia have issued guidance for design and construction of dual distribution systems for non-potable water supplies.[11,119,120] Although these documents are primarily aimed toward distributing treated wastewater effluent, most of the design and construction principles apply to non-potable water from any source (stormwater, reclaimed water, etc.).

The TCEQ has implemented special design criteria for reclaimed water systems that distribute treated wastewater effluent.[121] Although the TCEQ has not issued rules regarding stormwater harvesting distribution systems, the Chapter 210 rules could be used as a model. These rules include requirements for signage, location of hose bibs, separation distances from potable water piping, and design standards for gravity-flow pipes and pressure pipes.

The rules also require that piping and hose bibs for reclaimed water systems must be purple, and that exposed piping must be stenciled in white lettering to say "non-potable water."[ww] Currently there are no color requirements for stormwater distribution system elements. Although it is important to communicate to the public that a stormwater distribution system contains non-potable water, to date there is no general agreement on how this should be accomplished. Some have suggested that stormwater distribution piping should be purple because the stormwater is non-potable. However, the color purple is specifically associated with reclaimed water (treated wastewater effluent) and with the associated reclaimed water quality standards.[33]

As discussed in Section 6.2, design of ASR injection or infiltration facilities should be coordinated with the design of surface storage.

[ww] Piping and hose bibs for reclaimed water systems must be manufactured in purple, painted purple, taped with purple metallic tape, or bagged in purple.

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7. Operation of Stormwater Harvesting Projects

In a survey of 17 stormwater harvesting systems, a number of systems appeared to have been neglected since completion of construction, and some operators did not have defined operation and maintenance programs, but instead took a "wait and see" approach to operation and maintenance.[23] Such an approach jeopardizes the ability of the project to meet its objectives, increases risks, and will likely increase project costs. To ensure that a stormwater harvesting project continues to meet its objectives, the project must be operated in a planned, proactive manner. This chapter presents information on proper administration, operation, maintenance, and monitoring procedures, along with sources of additional information.

7.1. Administration

The entities responsible for developing and operating a stormwater harvesting project must be willing to commit sufficient funding and resources to operation of the project, including suitably qualified and trained operations staff. Operators should be involved in the design of the project to ensure that the project will be relatively easy and cost-effective to operate and that a sufficient operations budget is provided.[14,100]

Administrators should prepare a management plan for the project and the site during the planning phase.[14] The plan should delineate the roles and responsibilities of relevant parties and provide a framework for operation and maintenance. The management plan could include the information shown in Table 7-1. The management plan should be reviewed regularly and updated as required.

7.2. Operations and Maintenance

Operators should inspect stormwater harvesting facilities regularly. The following inspections may be necessary:[14]

- Storages for the presence of cyanobacteria, particularly during warmer months
- Spillways and creeks downstream of any on-line storage after a major storm for any erosion
- Stormwater treatment systems
- Distributions systems for faults (*e.g.*, broken pipes)
- Irrigation areas for signs of erosion, under-watering, waterlogging or surface run-off.

Typical maintenance activities for a stormwater harvesting project are shown in Table 7-2.

Table 7-1: Elements of a Stormwater Harvesting Management Plan

Section	Contents
Background information	▪ Statutory requirements ▪ Relevant permits or approvals ▪ Description and flow diagram or map of the project, including the location of public warning signs and all underground pipes ▪ Treatment objectives (against which monitoring data is compared)
Roles and responsibilities	▪ How responsibilities are shared between treated stormwater suppliers and end users (if applicable) ▪ Responsibilities of any third parties (*e.g.*, councils)
Operational information	▪ Information on operating plant and equipment ▪ Information on operating the irrigation scheme (if applicable), such as loading rates, access restrictions, irrigation timing ▪ Procedures for responding to non-compliance with project objectives (*e.g.*, water quality criteria) ▪ Occupational health and safety procedures, including any associated safe work methods for operations ▪ Qualifications of personnel involved in the project's operations
Maintenance information	▪ Inspection schedules ▪ Maintenance requirements ▪ Safe work methods for maintenance ▪ Asset management procedures
Incident response/ contingency actions	▪ Incident response protocols ▪ Incident communications procedures ▪ List of key stakeholders with current contact details
Monitoring information	▪ Operational monitoring requirements, including sampling methods ▪ Reporting procedures

Department of Environment and Conservation NSW[14]

A stormwater harvesting project should be operated adaptively, with changes made to operations based on:

- Monitoring of treatment effectiveness,
- Changes to stormwater inflow concentrations,
- Operational issues, and
- Changes to public health or environmental hazards

Table 7-2: Typical Maintenance Activities for a Stormwater Harvesting Project

Element	Action Required
Collection	▪ Cleaning any blockages of or damage to diversion structures (*e.g.*, weirs) ▪ Maintenance of any pumps and rising mains
Treatment	▪ Removal of sediment and other pollutants from stormwater treatment measures ▪ Mowing and weed control for vegetated treatment systems (*e.g.*, swales) ▪ Regular inspection and maintenance of disinfection equipment in accordance with manufacturer's instructions, including removal of any sludge
Storage	▪ Removal of accumulated sediment ▪ Ensuring the integrity of any fences around open storages ▪ Ensuring the structural integrity of on-line storages (*e.g.*, downstream erosion) – an inspection of storages may be appropriate after major storm events
Distribution System	▪ Cleaning of any screens and filters in irrigation systems ▪ Maintenance of pumps and rising mains ▪ Fixing any pipe leaks or breakages

Department of Environment and Conservation NSW(14)

As mentioned in the previous section, an incident/emergency response plan is important to successful operation. Operators must be able to respond to incidents or emergencies that compromise operation of the project or present public health or environmental risks. Such incidents could include:(14)

- A chemical spill or sewer overflow in the watershed upstream of the project,
- Power failure,
- Failure of part of the treatment system (*e.g.*, disinfection),
- Electrical or mechanical equipment failure (*e.g.*, pumps),
- Vandalism or operator error,
- Algal blooms in storages, and/or
- Flooding.

Mosquitoes need standing water to breed. Mosquito breeding can be prevented by maintaining stormwater collection and treatment facilities so that all standing water is discharged or infiltrated within 72 hours, so that tight-fitting covers denying mosquitoes access to standing water, and so that the habitat is less suitable for breeding. (105) Such maintenance practices may include:(105)

- Tracking mosquito production in stormwater collection and treatment facilities.
- Unclogging standpipes, orifices, and outlet structures.
- Removing sediment accumulations.
- Maintaining mechanical devices.
- In wet ponds, maintaining sufficient water quality to support surface-feeding fish such as mosquitofish.
- Where possible, reducing emergent or floating vegetation to facilitate mosquito predators.

- Where possible, maintaining wet ponds at a depth of 4 feet or less to discourage emergent vegetation and to encourage surface disturbances and predation.
- Applying larvicide when necessary.

The United States Environmental Protection Agency and the Urban Drainage and Flood Control District have published fact sheets and documents that contain operation and maintenance information and recommendations for a number of stormwater treatment technologies (Table 6-4).[7,108]

Operation and maintenance of stormwater harvesting systems is similar to operation and maintenance of reclaimed water systems.[14] Therefore, guidance for operation and maintenance of reclaimed water systems can also be used for stormwater harvesting projects. These guidance documents include: Camp, Dresser & McKee, Inc.; Department of Environment and Conservation NSW; Queensland Government; and EPA Victoria.[11,122,123,124]

The Department of Environment and Conservation NSW devoted an entire chapter to organizational responsibilities, operations, maintenance, and monitoring and reporting related to stormwater harvesting systems.[14] Operational and maintenance topics include commissioning, watershed management, chemicals, incident response, occupational health and safety, public access control, operation of irrigation systems, inspections, system maintenance, and asset management.

Fletcher and others presented information on maintenance activities for various stormwater treatment best management practices (BMPs), including gross pollutant traps; vegetated swales and filter strips; infiltration and bioretention systems; rainwater tanks; ponds, wetlands, and sediment basins; and porous pavements.[100]

National Resource Management Ministerial Council and others discussed management of the following operational issues in an aquifer storage and retrieval system:[22]

- Clogging
- Salinity of recovered water
- Interactions with other groundwater users
- Protection against saline water intrusion
- Protection of groundwater-dependent ecosystems
- Purge water, basin scrapings, and water treatment byproducts.

7.3. Occupational Health and Safety

The owner/operator of a stormwater harvesting project must provide a safe work environment for employees. Management should:[14]

- Ensure that employees are not placed at risk through exposure to stormwater.
- Provide adequate training with regular educational programs to ensure up-to-date knowledge for employees.

- Provide well-documented work and emergency procedures and train employees in using them.
- Provide employees with appropriate personal protective equipment that will reduce their risk of exposure to the stormwater.
- Ensure the effective and safe operation of all equipment.
- Ensure maintenance of all equipment.
- Provide medical assessments of employees, if appropriate.

Owners/operators should also identify potential hazards, risk levels and controls to be implemented. To manage potential health risks to employees, management should:(14)

- Train workers (staff and contractors) on the public health risks and appropriate risk management activities.
- Immunize workers as necessary.
- Provide potable water for drinking, hand washing, etc., and prohibit use of treated stormwater for these purposes.
- Prohibit eating, drinking or smoking while working with treated stormwater. Require workers to wash their hands with soap and potable water prior to these activities.
- Require workers to promptly clean (with antiseptic) and dress any wounds.
- Require use of appropriate personal protective equipment.
- Minimize exposure to treated stormwater (e.g., minimize access to irrigation areas during irrigation).

7.4. Monitoring

When the upstream watershed has point sources of pollution, significant sewer overflows, non-residential land uses, and/or roads with high traffic volumes, a monitoring program is recommended during the planning and design phase.(14) Results from such monitoring should be used as input into the project's risk management and design elements.

In addition, monitoring should be conducted before the project supplies water to end users.(15,14) This monitoring should take place over the full range of project operating conditions and should be used to verify treatment effectiveness and the maturity of any natural systems that are part of the project. In addition, an annual, independent review of operation and maintenance should be conducted.

After implementation of a stormwater harvesting project, a long-term monitoring program should continue to verify treatment effectiveness and assess the potential for pollution of surface water, groundwater, or soil and impacts on downstream ecology. A long-term monitoring program should contain the following components:(15)

- Indicators that measure whether project objectives are being met
- Flow monitoring (at least inflow and outflow)
- Water quality monitoring at key locations (with appropriate distribution of samples between dry and wet weather and particular monitoring during and after large wet-weather events)

- Monitoring parameters aligned with project objectives
- Assessment of both loads and concentrations at each monitoring point
- Quality assurance/quality control

Table 7-3 shows suggested monitoring parameters and frequencies for protection of public health. The criteria levels should be set according to the potential uses and the operational history of the project. Table 7-4 shows suggested monitoring parameters and frequencies for projects with irrigation uses.

Table 7-3: Treated Stormwater Quality Monitoring for Public Health

Stormwater Quality Criteria	Parameter	Monitoring Frequency
Level 1	*E. coli*	Five days per week
	Turbidity	Continuous
	pH	Weekly
	Cl_2	Daily*
Level 2	*E. coli*	Weekly
	Turbidity	Continuous
	pH	Weekly
	Cl_2	Daily*
Level 3	*E. coli*	Weekly
	pH	Monthly
	Cl_2	Daily*

Department of Environment and Conservation NSW[14]

* For chlorine disinfection systems

Table 7-4: Treated Stormwater Quality Monitoring for Irrigation

Parameter	Monitoring Frequency
Suspended solids	Quarterly
Total phosphorus	Biannually
Total nitrogen	Biannually
Conductivity/total dissolved solids	Quarterly

Department of Environment and Conservation NSW[14]

Hatt and others summarized the water quality monitoring programs for 17 stormwater harvesting projects in terms of parameters, components monitored, sampling methods, and monitoring frequency.[23]

8. Case Studies

Although stormwater harvesting is relatively new to the United States, many such projects are operating in Australia. Example stormwater harvesting projects from the U.S. and Australia are presented in this chapter, covering uses such as irrigation, aquifer recharge, toilet flushing, vehicle washing, wool processing, firefighting, and environmental flows. Project objectives, design, facilities, and costs are presented.

8.1. United States

Examples of stormwater harvesting projects in the U.S. include the Santa Monica Urban Runoff Recycling Facility, the Pacific Grove Stormwater Recycling Facility, the Los Angeles County Water Augmentation Study, and several Florida stormwater harvesting projects.

Santa Monica Urban Runoff Management Program

The urban runoff management program for the City of Santa Monica, California, includes harvesting of stormwater runoff from new development, harvesting and treatment of all dry-weather runoff, and harvesting and treatment of some wet-weather runoff.[xx,(125)] Annual average precipitation in Santa Monica is approximately 12.5 inches, occurring mostly from late October through early April.

The City's Urban Runoff Pollution ordinance requires new developments to implement stormwater best management practices (*e.g.*, infiltration trenches, French drains, permeable paving, biofilters and other low-impact structures) into the post-construction design of a project.[(126)] The purpose of these best management practices is to harvest stormwater and infiltrate it into the ground, recharging aquifers and keeping urban runoff and its pollutants out of receiving waters. As of 2003, over 600 new developments (about 2.5 percent of all properties in the City) had implemented stormwater management best management practices, reducing stormwater flow by approximately 1.2 million gallons (MG) for each storm of 0.1 inches or greater in magnitude.

The Santa Monica Urban Runoff Recycling Facility (SMURRF), which began operation in February 2001, was designed to reduce pollution of Santa Monica Bay by treating and reusing dry-weather runoff, which had previously drained to the Bay. The SMURRF harvests dry-weather urban runoff from the City's two main stormwater interceptors, treats the runoff, and uses the water for landscape irrigation and indoor toilet flushing (Figure 8-1). The SMURRF harvests an annual average of 300,000 gallons per day from a drainage area of approximately 4,200 acres. The treatment capacity is 500,000 gallons per day. The treatment train consists of bar screens, flow equalization, dissolved air flotation (Figure 8-2), microfiltration, and UV disinfection.

[xx] Unless otherwise attributed, information for this case study originates from Shapiro.[(125)]

Figure 8-1: Santa Monica Urban Runoff Recycling Facility

City of Santa Monica(127)

Figure 8-2: Dissolved Air Flotation Treatment at the SMURRF

Brewer(128)

Algae grow “almost everywhere” in the SMURRF, especially in the finished water reservoir. The City is considering adding chlorine early in the treatment train to reduce algal growth.

Open to the public, the SMURRF emphasizes public art and public education.[129] The facility has colorful tile works, intriguing water features, innovative architecture, and dramatic lighting. Abstract tile mosaics show the function of the facility to passing pedestrians and motorists. Visitors can see the treated water in five locations during treatment and can view the process equipment from two overlooks. Educational materials about the facility, the local urban watershed, and pollution prevention are also presented.

Construction costs for the SMURRF and its distribution system were approximately $12 million.[129,130] Architectural components that incorporated public art and education cost approximately $750,000.[131] Examples include tile and mosaics, an area for display of educational materials, elevated equipment mounts, and special lighting. The 500,000 gallon storage tank was an expensive element ($2 million) due to site constraints.[131] Annual operation and maintenance costs are approximately $200,000.[130]

Pacific Grove Stormwater Recycling Facility Planning

Malcolm Pirnie developed a plan for a stormwater harvesting system that would capture stormwater from the Congress storm drain, provide treatment, and deliver recycled water for irrigation of a golf course (Figure 8-3), an athletic field, a cemetery, and a park in the City of Pacific Grove, California.[132] The project would reduce pollution to the Monterey Bay Area of Special Biological Significance (ASBS), develop a new local water supply, comply with the Regional Water Quality Control Board Cease and Desist Order through implementation of a structural best management practice, and enhance the critical Monarch Butterfly habitat.

Figure 8-3: Pacific Grove Golf Links

Malcolm Pirnie[130]

The project report outlined the analysis of stormwater availability, potential irrigation demands, storage requirements, runoff water quality, and treatment requirements and designed conveyance and treatment systems to meet the project objectives.[132] Irrigation water quality objectives for this project (Table 8-1) were derived from "California Department of Public Health guidelines for use of non-potable sources and best practice from other successful recycled water projects."[132]

Table 8-1: Pacific Grove Irrigation Water Quality Objectives

Constituent	Units	Maximum Concentration
Ammonia	mg/l	non-detectable
Nitrate	mg/l	5
Phosphate	mg/l	1
Turbidity	NTU	2
Total suspended solids	mg/l	2
Total dissolved solids	mg/l	500-1,000
Conductivity	µS/cm	600-1,200
Urea	µg/l	non-detectable
Detergent	mg/l	non-detectable
Chlorine	mg/l	1-2
Color	BCS	5
Copper	mg/l	0.2
Lead	mg/l	5
Zinc	mg/l	2
Oil and grease	mg/l	non-detectable
E. coli	MPN/100 ml	non-detectable
Enterococcus	MPN/100 ml	non-detectable
Total coliform	MPN/100 ml	2.2

Malcolm Pirnie[132]

Project facilities would include: a 250 gallon per minute (gpm) diversion structure, a trash and debris separator, a 250 gpm runoff pump station and 4,000 feet of 8-inch diameter force main, a 15 MG concrete storage reservoir, constructed wetlands, a 150 gpm stormwater harvesting facility (including microfiltration, ultraviolet light, disinfection with liquid hypochlorite, and a 0.5 MG clearwell), a 500 gpm recycled water pump station and 8,800 feet of 8-inch diameter force main, and turnouts to irrigation sites. The footprint of all treatment facilities (apparently including the constructed wetlands) would be approximately 0.3 acres.

The capital cost is estimated to be $15.2 million, and the annual operation and maintenance cost (not including debt service) is estimated to be $200,000. Assuming $6 million in outside funding from multiple sources, debt service on the remaining $9.2 million was estimated to cost $700,000 per year. The total annual cost of $900,000 per year would be financed with a city-wide stormwater recycling charge of $9 per dwelling unit per month.

The project is scheduled for startup operations in 2011.[130] The City Council hired a consultant for preliminary engineering and has directed staff to apply for a $1 million loan for permitting and design activities.

Los Angeles County Water Augmentation Study

Sponsored by the Los Angeles and San Gabriel Rivers Watershed Council and initiated in 2000, the Los Angeles County Water Augmentation Study is a long-term research project to explore the potential for reducing surface water pollution and increasing local water supplies by increasing infiltration of urban stormwater runoff.[133] Phases I and II involved installing stormwater infiltration best management practices ranging from simple landscaped swales to large-scale underground infiltration fields at two industrial sites, an elementary school, a commercial office building, a private residence, and a public park and monitoring of stormwater, vadose zone, and well water quality. Data collected during Phase II show no immediate impacts on groundwater quality and no apparent trends to indicate that stormwater infiltration will negatively impact groundwater at these sites.[133]

Phase III consists of the 24-home Elmer Avenue Demonstration Project, which will examine how existing local infrastructure can be retrofit to manage stormwater. The goals of Phase III are to demonstrate how stormwater best management practices can be incorporated into existing development and infrastructure and to create a model that can be replicated and expanded in the region.[133] The Elmer Avenue neighborhood, developed in the 1940s, does not have storm sewers and receives stormwater runoff from an adjacent 37-acre neighborhood. Stormwater best management practices will include:[134,135]

- Conversion to native drought-tolerant landscape,
- Bio-infiltration using vegetated swales,
- Increasing permeable surfaces,
- Installing rain gardens and rain barrels to capture runoff for infiltration or use,
- Adding more green space and habitat areas, and
- Capturing runoff from the adjacent neighborhood with catch basins that discharge to a subsurface infiltration gallery.

The project will be monitored for water quality, reduction of runoff and irrigation use, and additional benefits.[136] As of 2006, the estimated project budget was $4,125,000.[136] Construction of the Elmer Avenue project is in progress.

Florida Stormwater Harvesting Projects

Wanielista provided information on five stormwater harvesting projects in Florida.[137] Each is discussed below. Many of these projects also receive groundwater recharge, so the unit costs may not be directly transferable to Texas projects.

Orlando Tech Center

A retention pond (Figure 8-4) was constructed in 1981 to collect drainage from a 25-acre commercial area containing only 4.2 pervious acres. The pond was designed to collect 8 inches of runoff from the directly connected impervious area, and it has never gone dry or overflowed. Water from the pond is used for truck washing and lawn irrigation. The cost of the water supply is about $0.10 per thousand gallons.

Figure 8-4: Retention Pond at the Orlando Tech Center

Wanielista[137]

Winter Park Civic Center

A detention pond (Figure 8-5) was constructed in a park area to collect drainage from 3.42 acres of directly connected impervious area. The pond was designed to collect 1 inch of runoff from the impervious area. Water from the pond is used for irrigation. The cost of the system amortized over 20 years was about $0.15 per thousand gallons.

South Bay Utilities, Inc

Shallow wells are used to extract stormwater stored in a surficial aquifer and to supply water for irrigation at approximately 900 residences. The cost of the supplied water, including retrofits, is about $0.50 per thousand gallons.

Schroeder Manatee Utilities, Inc.

Horizontal wells, canals, and detention ponds are used to collect stormwater and supply approximately 4 million gallons per day (mgd) for irrigation in a 32,000-acre mixed-use area. The cost of the water supply is about $0.27 per thousand gallons.

Figure 8-5: Detention Pond at the Winter Park Civic Center

Wanielista[137]

East Central Florida Services, Inc.

Stormwater is collected from canals, surface ponds, and shallow ground water supplies, and approximately 20 mgd is supplied for irrigation in a 550,000-acre agricultural area. The cost of the water supply is about $0.19 per thousand gallons.

8.2. Australia

Examples of stormwater harvesting projects in Australia include the Parafield Stormwater Harvesting Facility, Homebush Bay/Sydney Olympic Park, and Kogarah Town Square.

Parafield Stormwater Harvesting Facility, Salisbury, South Australia

The Parafield Stormwater Harvesting Facility, located at the Parafield Airport, began operation in early 2003. It has a watershed area of approximately 6.18 square miles with residential and industrial land use. Project objectives include:[23,25]

- Flood protection
- Low cost water supply
- Water quality superior to potable water for industry and irrigation
- Reduction in potable water use
- Economic development
- Protection of water quality in Barker Inlet (breeding ground and nursery for much of South Australia’s fisheries)
- Environmental management, including habitat creation
- Recreational amenities

- Showcase conversion of stormwater from an urban nuisance and pollutant threat into a valuable resource for industry and community

Stormwater is collected using gutters, pipes, and channels. With a weir, stormwater is diverted from the Parafield Drain to a 13 MG capture basin, pumped to a 13 MG storage basin, pumped to a 5.2 acre reedbed with about a 1-foot water depth, and then distributed from the reedbed to users or injected into an aquifer for storage and later retrieval.[25] Figure 8-6 shows the position of the facilities. Sedimentation occurs in the capture and holding basins, and the reedbed provides filtration. When operating at the design limit flowrate, the average detention time is 10 days.

Figure 8-6: Construction of the Parafield Stormwater Harvesting Facility

City of Salisbury[138]

The average annual rainfall is 18.1 in/yr, generating a mean annual runoff volume of approximately 1,792 acre-feet.[23] Estimates of the percentage collected for use range from 70 percent to 100 percent.[25,23] The capture basin was designed to capture the 1-year-frequency storm, and the holding basin is the same size. The combined system can capture the 10-year-frequency storm.

The largest customer of the stormwater harvesting system is G. H. Michell & Sons, the largest wool processor in South Australia. The wool processing demand is approximately 893 acre-feet per year.[138] Approximately 405 acre-feet per year is supplied directly from the reedbed, and the remainder is drawn from aquifer storage.[23] The maximum supply capacity for the system is 1.6 mgd.[25] The project also supplies irrigation customers.

Treated stormwater in excess of customer needs is injected into an aquifer for storage and retrieval. Approximately 486 to 730 acre-feet are injected each year.(25)

The project must meet South Australia EPA water quality requirements for aquifer storage and retrieval. Table 8-2 shows the treatment effectiveness of the Parafield Stormwater Harvesting during the first year of operation.(25) Reductions of pollutant loads have averaged 74 to 90 percent. In addition, the salinity (total dissolved solids) of the stormwater supply is generally between 150 to 250 mg/l, which is less than the salinity of the potable water supply (400 mg/l or more).(23)

Table 8-2: Parafield Stormwater Harvesting Facility Treatment Effectiveness*

Parameter	Average Inflow Concentration	Average Final Concentration	Average Reduction (%)
Suspended solids (mg/l)	38	4.4	88
Turbidity (NTU)	23	2.2	90
Total nitrogen (mg/l)	1.46	0.38	74
Total phosphorus (mg/l)	0.139	0.024	83

Kellogg Brown & Root(25)

* During the first year of operation.

The capital cost of the project was $3.732 million.[yy] Operation and maintenance costs are $0.85 per thousand gallons, and loan repayment costs are $1.01 per thousand gallons. The production cost for water from the project ($1.86 per thousand gallons) is less than the price for potable water ($2.47 per thousand gallons).(25) Reduced potable water consumption saves approximately $550,000 per year, and removal of total nitrogen is worth $1.01 million to $8.66 million per year.(23)

By transferring the Michell & Sons demand to stormwater, the project has reduced potable water demand by approximately 893 acre-feet per year.(25) The project also prevents the same amount of polluted stormwater from flowing into Barker Inlet and reduces demand for raw water from the River Murray by about 405 acre-feet per year, making this water available for environmental flows.

Prior to implementation of the stormwater harvesting project, G. H. Michell & Sons was considering relocating 700 local jobs, in part due to the high cost of potable water. The lower cost of the treated stormwater has enhanced local job opportunities and economic stability.(23)

Because the system is located on airport land, open water storage presented a significant bird strike hazard.(23) To mitigate this hazard, bird-proof netting was installed over the basins and the

[yy] For costs in this paragraph, conversion to 2009 U. S. dollars based on 2003 average exchange rate of 0.652 U. S. dollars per Australian dollar and *Engineering News-Record* (ENR) Construction Cost Indices of 8564 (August 2009) and 6733 (August 2003).

reedbed to reduce the bird population around the airport (Figure 8-7). Another significant issue that had to be resolved was operator access to the facility, since airports are secure areas.[(23)]

Figure 8-7: Bird-Proof Netting over the Reedbed at the Parafield Stormwater Harvesting Facility

City of Salisbury[(139)]

Monitoring activities include:[(23,25)]

- Debris removal on a regular basis
- Annual sediment removal
- Stormwater quality in drain and basins
    - Real time monitoring of pH, total dissolved solids, and settleable solids
    - Grab and composite samples for other parameters
- Groundwater
    - Injection and extraction volumes
    - Quality
    - Monitoring of wells for clogging and sand removal
- Wildlife monitoring: macro-invertebrates, native fish, terrestrial invertebrates (mosquitoes and other insects)
- System control & data acquisition (SCADA) system linked to a central control system
- Technical Advisory Committee provides ongoing quality control provided

Homebush Bay/Sydney Olympic Park, New South Wales

The Homebush Bay site was redeveloped in advance of the 2000 Olympic Games in Sydney. The 2.7 square mile watershed includes residential and commercial land use, sporting facilities, and about 1.5 square miles of parkland. The project uses both reclaimed water and stormwater. The multiple objectives are:[zz,(23)]

[zz] Unless otherwise attributed, the information about the Homebush Bay project comes from Hatt and others.[(23)]

- Encourage development of innovative and effective wastewater treatment technologies and management practices
- Reduce potable water demand
- Reduce sewage discharge
- Improve stormwater quality

Stormwater runoff is collected from roads, pavements, and roofs with gutters, swales, and natural drainageways.[aaa] Runoff is treated with gross pollutant traps, swales, ponds, and constructed wetlands and stored in a disused brick pit (Figure 8-8). Excess reclaimed water is also stored in the brick pit. An elevated walkway with interpretive displays was constructed to allow visitors to the brick pit site.

Figure 8-8: Brick Pit Storage at Homebush Bay

Bar[(140)]

The stormwater harvesting system incorporates over 247 acres of constructed wetlands and waterways. Three water quality control ponds collect and detain the first flush runoff, allowing

[aaa] Some sporting facilities collect their own roof runoff, store it on-site, and use it for irrigation.

sedimentation. Aquatic plants throughout the system remove nutrients. High flows enter a bypass channel, which also acts as secondary storage.

From storage, the water is treated with microfiltration, reverse osmosis, chlorine disinfection, and dechlorination. After advanced treatment, the water is distributed through more than 18 miles of dual distribution system for uses such as irrigation, fire fighting, environmental flows, toilet flushing, and other outdoor uses.

The average annual rainfall at Homebush Bay is 36.2 in/yr, generating a runoff volume of approximately 954 acre-feet per year. The storage capacity in the wetland is 37 MG, and the storage capacity in the brick pit is 92 MG. The combined storage is sufficient to capture the 100-year frequency storm, although some flow is released to maintain environmental flows. In the first three years of operation, there was no need to revert to backup supplies.

On average, the project uses 567 acre-feet of reclaimed water and 162 acre-feet of stormwater per year. Use of reclaimed water and stormwater has reduced overall potable water demand by 50 percent.

The capital cost of the project was $12.62 million.[bbb] The operating cost is approximately $5.44 per thousand gallons, and the loan repayment cost is about $3.87 per thousand gallons, for a total cost of $9.32 per thousand gallons. However, the water is sold at a rate of $2.34 per thousand gallons, which is $0.45 per thousand gallons less than the potable water price. Reduced potable water consumption saves approximately $283,000 per year, and removal of total nitrogen is worth $519,000 to $4,448,000 per year.

Maintenance of the project is contracted to the construction company for 25 years. Two cross-connections with the potable water system have been detected, neither in residential dwellings.

Total suspended solids, total nitrogen, total phosphorus, bacteria, viruses, and heavy metals are monitored at 20 points throughout the system, including significant ponds and wetlands. High nutrient levels are present in water stored in the brick pit, and there is visible algae growth. Nutrient removal is being investigated.

Finally, shallow ponds surrounding the brick pit provide habitat for a local endangered frog species.

Kogarah Town Square, Kogarah, New South Wales

Kogarah Town Square is a 2.1 acre mixed-use redevelopment project that includes 193 residential apartments and 1.1 acres of retail, commercial, and library space.[23,25] The project was constructed using water-sensitive urban design principles, and stormwater runoff is used for

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[bbb] For costs in this paragraph, conversion to 2009 U. S. dollars based on 2000 average exchange rate of 0.582 U. S. dollars per Australian dollar and *Engineering News-Record* (ENR) Construction Cost Indices of 8564 (August 2009) and 6233 (August 2000).

irrigation, maintenance of a water feature, car washing, and toilet flushing.[(15)] The stormwater harvesting element of the project has been in operation since 2003. The multiple objectives are:[(23)]

- Avoidance of flooding and the need for larger stormwater facilities downstream
- Minimal impact on the receiving water
- Reduction of potable water demand
- Aesthetics
- Enhanced appreciation of water in the urban environment.

Stormwater runoff from paved areas is screened with a gross pollutant trap and collected in a series of underground "dirty water" storage tanks (Figure 8-9). The collected stormwater is used to irrigate landscaped areas. The landscaped areas contain soils that have been biologically engineered to filter first flush general runoff.[(23)] Water that filters through the soil is collected into a series of underground "clean water" storage tanks.

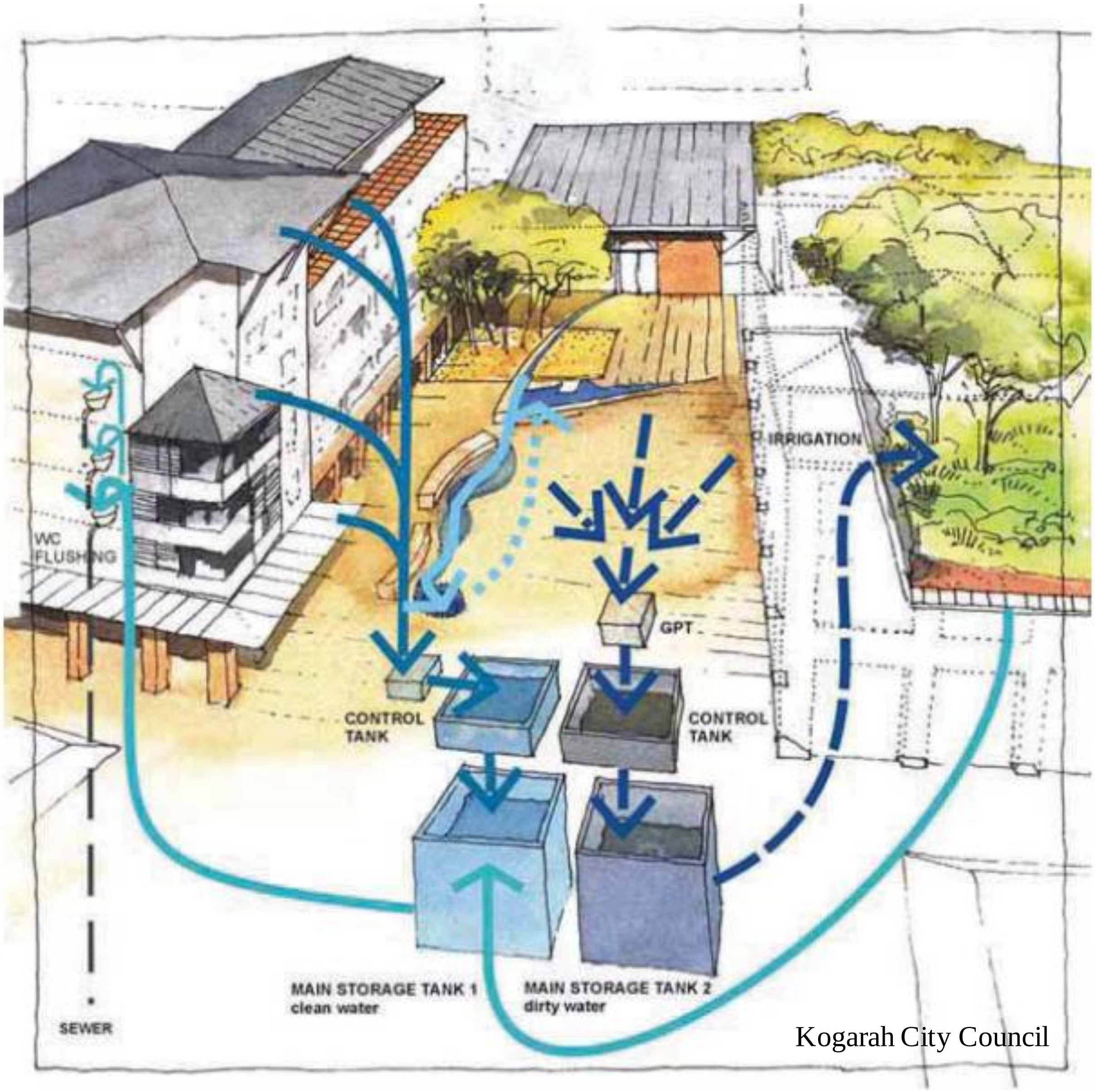
Rainwater runoff is collected from roofs and upper terraces, passed through a screen and silt trap, and collected in the "clean water" storage tanks. The clean water is used for toilet flushing and car washing. Some of the "clean water" is filtered, disinfected, and used to maintain a water feature.[(141)]

Other facts about stormwater harvesting at Kogarah Town Square include:

- During times of low rainfall, potable water is added to the water feature and to the "dirty water" tank (for irrigation).[(141)]
- The average annual rainfall at Kogarah Town Square is 43.4 in/yr, generating a runoff volume of approximately 2.17 MG, of which about 85 percent is collected for onsite use.[(141)] The storage capacity is 380,000 gallons, enough to capture the 3-month-frequency storm.
- At least 70 percent of the toilet flushing water demand is supplied with stormwater, and estimates of overall potable water savings from stormwater harvesting range from 17 percent to 25 percent.[(23,141)]
- The capital cost of the stormwater elements of the project was $522,000.[ccc] Reduced potable water consumption saves approximately $2,000 per year, and removal of total nitrogen is worth $4,000 to $31,000 per year.[(23)]
- It is expected that screen filters on the pumps will need to be cleaned once a year and that the storage and header tanks will need to be cleaned every 5 to 6 years. No water quality monitoring is performed.[(23)]

[ccc] For costs in this paragraph, conversion to 2009 U. S. dollars based on 2003 average exchange rate of 0.652 U. S. dollars per Australian dollar and *Engineering News-Record* (ENR) Construction Cost Indices of 8564 (August 2009) and 6733 (August 2003).

Figure 8-9: Water Cycle at Kogarah Town Square[ddd]



Kogarah Council[(141)]

[ddd] In Figure 8-9, "GPT" stands for gross pollutant trap.

Other

Department of Environment and Conservation NSW presented information for 12 case studies in Australia:(14)

- Barnwell Park Golf Course, Five Dock
- Sydney Smith Park, Westmead
- Bexley Municipal Golf Course, Bexley
- Black Beach foreshore park, Kiama
- Manly stormwater treatment and reuse project, Manly
- Powells Creek Park, North Strathfield
- Hawkesbury water reuse project, Richmond
- Scope Creek, Cranebrook
- Solander Park, Erskineville
- Taronga Zoo, Mosman
- Riverside Park, Chipping Norton
- Hornsby Shire Council nursery and parks depot, Hornsby.

Mitchell and others presented information on the following case studies:(15)

- Homebush Bay, Sydney, New South Wales
- Parafield Stormwater Harvesting Facility, Adelaide, South Australia
- Royal Park Wetlands, Melbourne, Victoria
- Manly Stormwater Treatment and Reuse Project, Sydney, New South Wales
- Kogarah Town Square, Sydney, New South Wales
- Inkerman D'Lux, Melbourne, Victoria

Kellogg Brown & Root presented limited information for the following stormwater harvesting case studies:(25)

- Large projects
  - Parafield Airport, Salisbury, South Australia
  - Morphettville Racecourse Facility, Morphettville, South Australia
  - Pooraka Triangle Facility, Salisbury, South Australia
  - Homebush Bay/Sydney Olympic Park, Sydney, New South Wales
- District projects
  - Northfield Residential Development, Regent Gardens, South Australia
  - Stebonheath Flow Control Park, Andrews Farm, South Australia
  - The Paddocks, Salisbury, South Australia
  - Kaurna Park, Salisbury, South Australia
- Neighborhood projects
  - Kogarah Town Square, Sydney, New South Wales
  - Tea Tree Gully Golf Club, Fairview Park, South Australia
  - Pine Lakes ASR, Salisbury, South Australia

    - New Brompton Estate, Brompton, Adelaide, South Australia
    - Fig Tree Place, Hamilton, Newcastle, New South Wales

- Individual lot projects

    - Parfitt Square, Bowden, Adelaide, South Australia
    - St. Elizabeth Church, Adelaide, South Australia
    - Plympton Anglican Church, Adelaide, South Australia

Hatt and others collected and analyzed data from 17 different stormwater harvesting systems (16 in Australia and the Santa Monica Urban Runoff Recycling Facility in the United States), showing frequencies associated with:[(23)]

- Different types of end use (irrigation, toilet flushing, environmental flows, firefighting, other)
- Collection facilities (gutter, pipe, natural drainage, channel, swales and buffers, and infiltration systems)
- Treatment facilities (advanced treatment, litter and sediment traps, infiltration facilities, wetlands, swales and buffers, disinfection, and ponds)
- Storage facilities (tanks; ponds, basins, and lakes; aquifers; and wetlands)
- Distribution facilities (irrigation systems, dual distribution systems, and pumping).

Limited design and cost information was also presented for these systems. Hatt and others also collected limited data for an additional 78 stormwater harvesting projects, including 2 in the United States: Village Homes in Davis, California, and Prairie Crossings, near Chicago, Illinois.[(23)]

Appendix A: References

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Appendix B: Sources of Stormwater Quality Data

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Sources of Stormwater Quality Data

In the United States, stormwater quality contributes directly to water quality impairments in surface and groundwater, particularly in developing and urban areas.[28] Water quality concerns may vary greatly from one watershed to another, and can be affected by watershed characteristics, pollutant sources, climate, and watershed infrastructure.[15] Soil erosion, human and animal waste, fertilizers, vehicle byproducts, fuel combustion, industrial and household chemicals, industrial processes, paint, preservatives, and pesticides can all contribute to urban stormwater contamination.[15]

Several literature sources have presented a comprehensive summary of stormwater quality data, including:

- Maestre and Pitt[142]
- International Stormwater BMP Database[143]
- United States Environmental Protection Agency[109]
- Smullen and Cave[144]
- Duncan[17]
- Fletcher and others[55]
- Department of Environment and Conservation NSW[14]
- National Resource Management Ministerial Council and others[13]
- United States Environmental Protection Agency[145]

Maestre and Pitt compiled the National Stormwater Quality Database from monitoring carried out as part of the EPA's National Pollutant Discharge Elimination System (NPDES) permitting from 1992 through 2002.[142] The database contains quality data from 3,765 events at 360 sites in 65 communities. Site-specific data (the percentage of each land use in the watershed, the total area, and the percentage of impervious cover) and event-related data (total precipitation, precipitation intensity, total runoff, and antecedent dry period) have also been included. All samples were collected at drainage outfalls. Water quality parameters in the database include conductivity, hardness, oil and grease, pH, temperature, total dissolved solids, total suspended solids, 5-day biochemical oxygen demand, chemical oxygen demand, fecal coliform, fecal streptococci, total coliform, total E. coli, ammonia, nitrate plus nitrite, total Kjeldahl nitrogen, filtered phosphorus, total phosphorus, and total and filtered metals by element.[146] The water quality data are associated with the following land uses: residential, mixed residential, commercial, mixed commercial, industrial, mixed industrial, institutional, freeways, mixed freeways, open space, and mixed open space.

The International Stormwater BMP Database project is an ongoing effort that has been collecting performance data on different stormwater best management practices (BMPs) since 1999. The project was initially funded by the U.S. EPA in association with the Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers (ASCE). The primary goal of the project was to gather scientifically valid technical information relating to the selection and performance of best management practices, helping communities to better address their stormwater problems. Influent stormwater data were collected as part of this effort. The database can be downloaded from the project web site (http://www.bmpdatabase.org).

United States Environmental Protection Agency presented the following stormwater quality data summaries:[109]

- Mean and median storm event concentrations from a number of national databases for suspended solids, nutrients, metals, BOD, oil and grease, pathogens, organics, and other constituents.
- Mean storm event concentrations for suspended solids, BOD, COD, nutrients, and some metals for various U.S. cities.
- Typical pollutant loadings of suspended solids, nutrients, BOD, and some metals from commercial, parking lot, residential, highway, industrial, park, and shopping center land uses.
- Median stormwater concentrations for suspended solids, nutrients, BOD, and some metals from residential, mixed, commercial, and open/non-urban land uses.

Smullen and Cave compiled stormwater quality statistics from the Camp, Dresser, and McKee National Stormwater Runoff Pollution Database. [144] The database included quality data from approximately 3,100 events (including the NURP data, plus additional data collected by the U.S. Geological Survey and about 30 NPDES permits).[fff] Mean and median storm event concentrations for total suspended solids, BOD, nutrients, and some metals are available.[142]

Duncan presented comprehensive stormwater quality statistics for suspended solids, total phosphorus, total nitrogen, chemical oxygen demand, biochemical oxygen demand, oil and grease, total organic carbon, pH, turbidity, total lead, total zinc, total copper, total cadmium, total chromium, total nickel, total iron, total manganese, total mercury, total coliforms, fecal coliforms, fecal and streptococci.[17] The statistics were derived from 508 data records obtained from numerous investigations reported in the literature as of 1997.

Duncan also collated watershed data, including area, impervious area, land use (urban, residential, industrial, commercial, institutional, urban open space, other urban, agricultural, forest, other rural, and roads), population density, traffic density, roof area, and mean annual rainfall.

For each constituent, Duncan presented the following information:

- Normal probability plot
- Summary of concentrations by land use
- Graphs of concentration vs. mean annual rainfall and population density for various land uses
- Summary statistics

Fletcher and others summarized stormwater quality statistics published in 17 additional studies after the Duncan review.[55] This summary included contaminant concentrations and export rates for numerous land uses (forestry, industrial, intensive animal, intensive plant, mixed, pasture,

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[fff] National Urban Runoff Program sponsored by the U.S. EPA. Summarized below.

urban, rural, natural, and others) and numerous constituents (total suspended solids, phosphorus (total and species), nitrogen (total and species), fecal coliforms, bacteria, chloride, sulfate, copper, lead, zinc, and others).[ggg] Recommended "typical values" for dry and wet weather situations are presented by land use for total suspended solids, total phosphorus, total nitrogen, fecal coliforms, zinc, lead, copper, cadmium, and oil and grease.

Department of Environment and Conservation NSW presented a relationship between fecal coliforms and *E. coli*, ranges of microorganism concentrations in stormwater, and ranges of chemicals (suspended solids, nutrients, biochemical oxygen demand, oil and grease, metals, and others) in stormwater.[(14)]

National Resource Management Ministerial Council and others provided summary statistics for stormwater contaminants in urban watersheds, including pathogens, bacteria, metals, nutrients, organics, and physicochemical indicators.[(13)]

The United States Nationwide Urban Runoff Program (NURP) was created to assess the contribution of urban runoff to water quality problems in rivers, streams, lakes, estuaries, and embankments.[(145)] At sites where monitoring data is limited, the NURP summary data may be appropriate in estimating urban runoff pollutant concentrations. Major conclusions regarding urban stormwater quality included:

- Heavy metals were frequently detected in urban stormwater and in many cases exceeded EPA ambient water quality criteria and drinking water standards.
- Organic priority pollutants were detected less frequently and at lower concentrations than heavy metals.
- Coliform bacteria were present at high levels and can be expected to exceed EPA water quality criteria during and immediately after storm events in many surface waters.
- Nutrients were generally present but, with some exceptions, did not appear to be high in comparison to other possible discharges.
- Oxygen-demanding substances were present at levels approximating those in secondary treatment plant discharges.
- Total suspended solids were fairly high in comparison to treatment plant discharges.

[ggg] An export rate is the rate at which land contributes mass of a given constituent to stormwater runoff. Export rates vary by type of land use and by the character of the storm event. Export rates are expressed in units of constituent mass per area per time.

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Appendix C: Potential for Aquifer Storage and Retrieval Potential of Stormwater by Texas Planning Region

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Potential for Aquifer Storage and Retrieval of Stormwater by Texas Planning Region

Each of the 16 regional planning areas in Texas (Figure 1) was analyzed to determine the potential for aquifer storage and retrieval (ASR). The potential was estimated using the presence of urban areas (stormwater source), receptive aquifers (storage medium), water quality considerations, and potential uses.

To conduct an initial evaluation the aquifers within each of the regions have been placed into four main groups. Each group is represented by a certain color on the figures in this appendix. The groups (and colors) are:

- Porous sand aquifers (orange)
    - Outcrop areas (stippled orange)
    - Subsurface (orange)
- Karstic aquifers (green)
- Other aquifers, such as the Igneous (brown/red)
- No aquifer is demarked in white.

These have been overlain with the respective urban centers (blue) to show the most likely areas for stormwater harvesting. Additional factors such as the depth to groundwater, storage potential, existing groundwater quality, and depth of wells have not been detailed on the figures.

A. Region A (Panhandle)

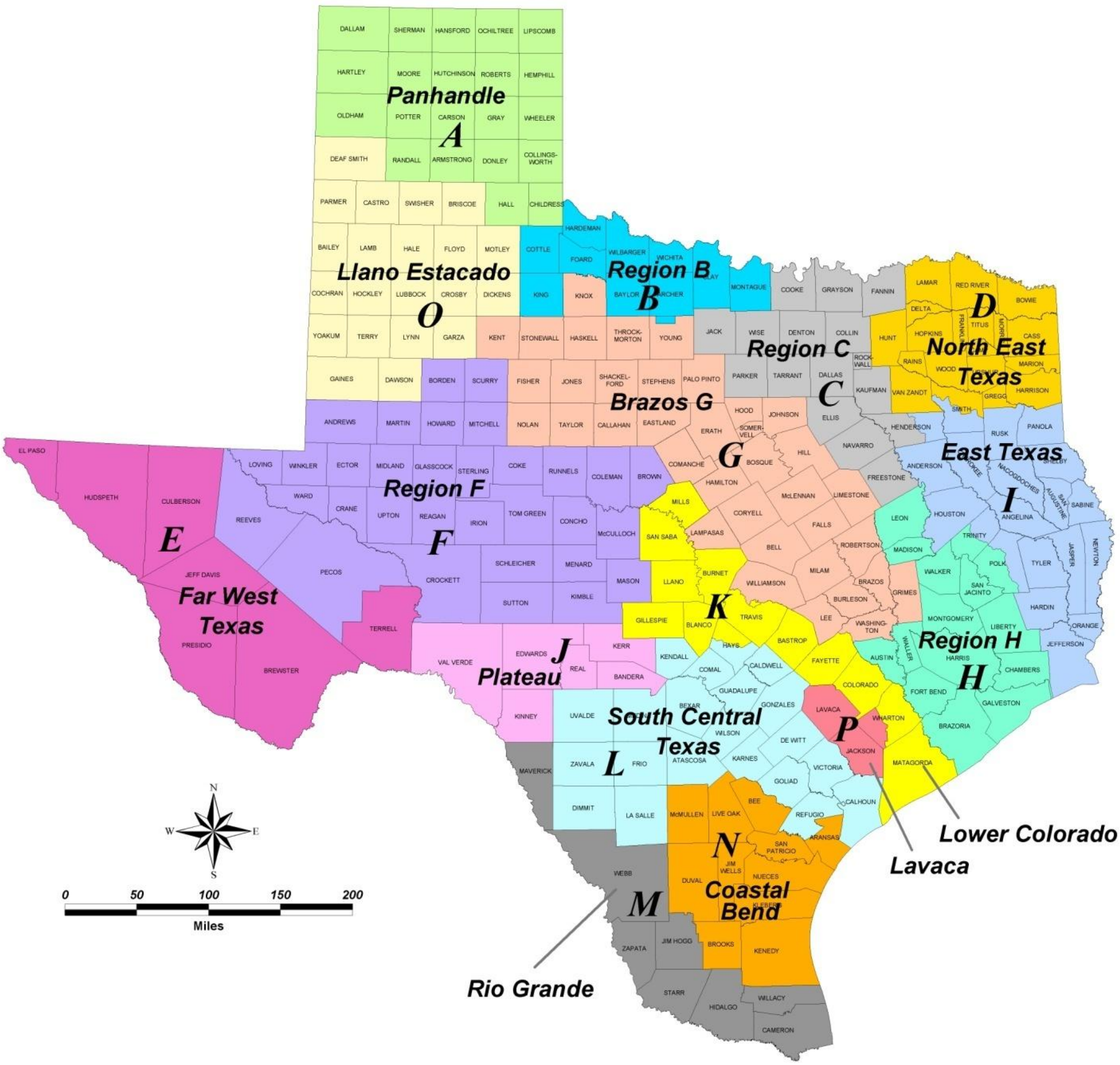
Region A is situated in the panhandle of Texas, bordering Oklahoma and New Mexico. The area includes the counties of Armstrong, Carson, Childress, Collingsworth, Dallam, Donley, Hall, Hansford, Hartley, Hemphill, Hutchinson, Gray, Lipscomb, Moore, Ochiltree, Oldham, Potter, Randall, Roberts, Sherman and Wheeler.

Region A has moderate to good potential for aquifer storage of stormwater (Figure A-1). There is significant potential in the Ogallala Aquifer and some potential in the underlying Dockum Aquifer. The Blaine Aquifer in the southeast of the region is also a possible host for ASR stormwater.

The Ogallala Aquifer is the most prolific porous sand and gravel aquifer in the state and is primarily used for irrigation. It is generally unconfined, and as such, allows use of infiltration or injection. The infiltration rates are generally good; however, due to the relatively low amounts of rainfall, very little acts as recharge. Infiltration is slightly improved to the south in Region O (Llano Estacado).

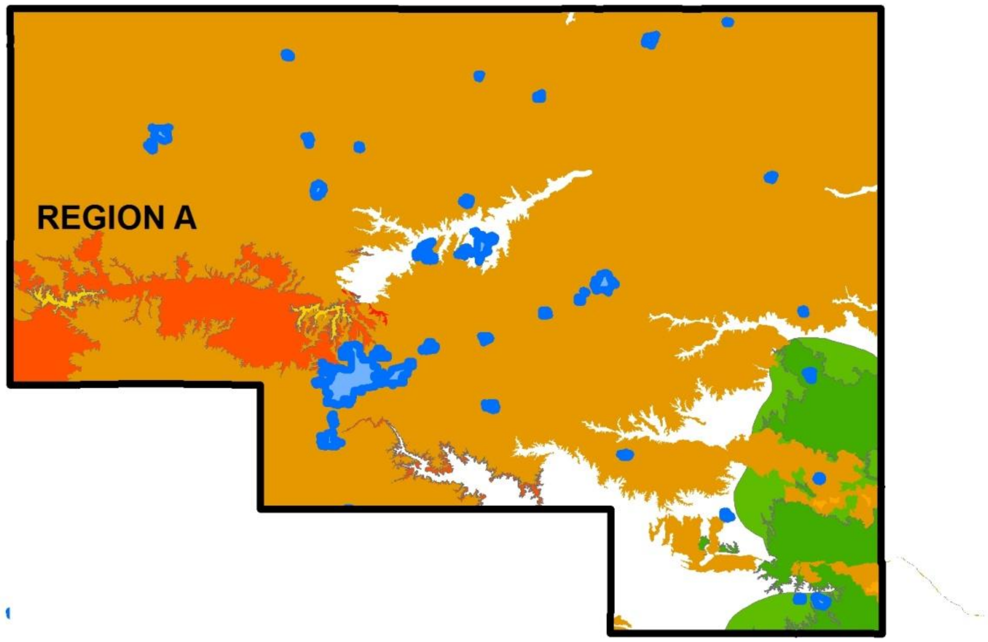
The aquifer itself has good characteristics with moderate-to-large yields and relatively shallow wells. There has been and continues to be significant mining of the resource in many areas.

Figure 1: Regional Water Planning Areas in Texas



Obtained from the Texas Water Development Board, March 2010: URL: http://www.twdb.state.tx.us/mapping/maps/jpg/sb1_groups_8x11.jpg.

Figure A-1: ASR Potential in Region A (Panhandle)



Therefore, there is a large availability for storage. While the urban centers are relatively small and spread out, there are possibilities for resource availability, especially in the area around Amarillo. Due to the porous sand and gravel nature of this aquifer, there would be good hydraulic control of any stored water. Within these units, the groundwater generally does not move at significant rates – usually only a few feet per day. This is relatively slow movement when compared with karstic limestone aquifers, which often allow water movement in the hundreds of feet per day. This makes it more advantageous for the utilities storing the water as they can keep control of the resource.

The Dockum Aquifer is often found underneath the Ogallala in the south of this region. This unit is generally confined, provides lower yields, and has water quality issues (elevated salinity). However, the Dockum Aquifer could also be used as a storage site if necessary.

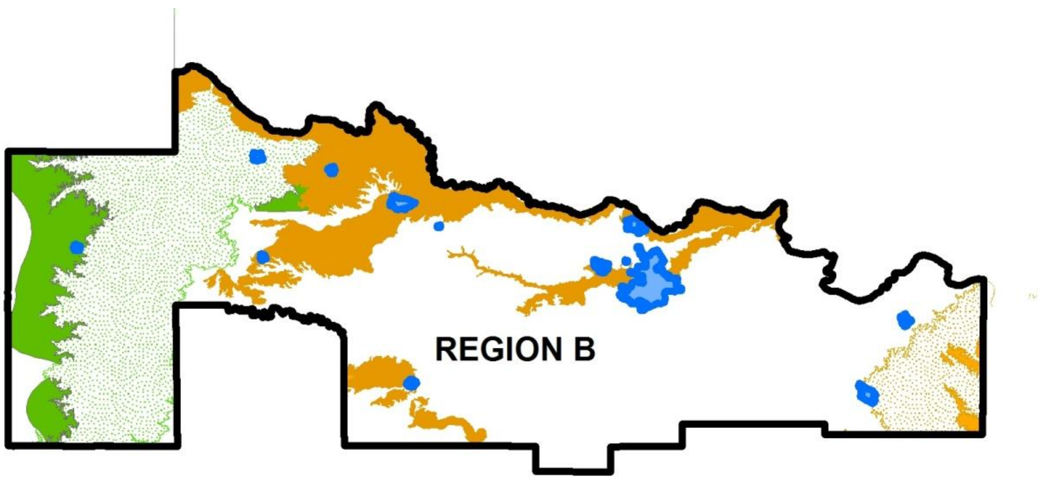
The Blaine Aquifer also crops out to the east of the region. This is a limestone/dolomite aquifer with occasional anhydrite beds. These often cause elevated salinity levels, which may be problematic for potable or irrigation use. The well yields can be moderate-to-good, which would allow reasonable infiltration/injection potential if the water quality issues could be overcome. In some cases, stormwater storage could improve water quality for spring flows which affect river systems such as the Red River. This could improve downstream water quality. However, the Blaine is not close to any of the urban centers, so available stormwater may be limited.

B. Region B

Region B is situated in north and central Texas, bordering Oklahoma. The area includes the counties of Archer, Baylor, Clay, Cottle, Foard, Hardeman, King, Montague, Wichita, Wilbarger, and part of Young.

Region B has poor-to-moderate potential for aquifer storage of stormwater (Figure B-1). There is potential in the Blaine Aquifer and in the Seymour Aquifer. However, the Seymour is very shallow, and the groundwater is unconfined. The Blaine has significant water quality issues and would need to be managed accordingly.

Figure B-1: ASR Potential in Region B



The Seymour Aquifer within the region is very shallow – often less than 50 feet below the ground surface. There have not been significant water level declines in this aquifer, partly due to its shallow nature and interaction with the Red River.

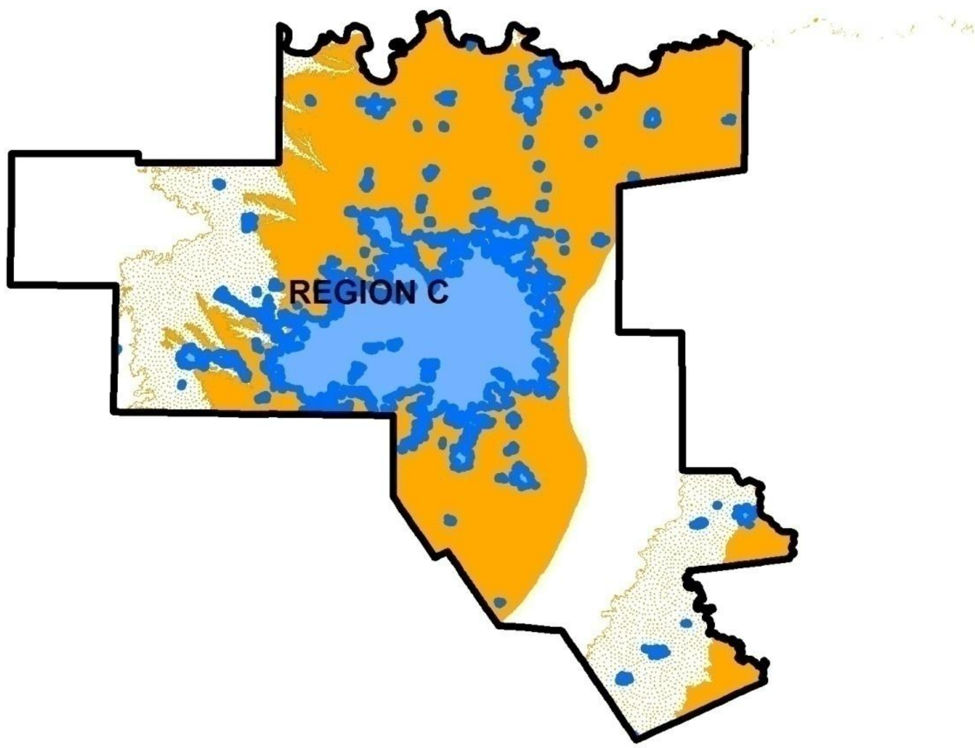
The Blaine Aquifer has reasonable potential and is used for some irrigation within the region. However, there are very few urban centers close to this unit to provide the stormwater, and the water quality is relatively poor. Therefore, there is little current demand for additional resource in this area.

C. Region C

Region C is situated in north central Texas, bordering Oklahoma. The area includes the counties of Collin, Cooke, Dallas, Denton, Ellis, Fannin, Freestone, Grayson, Jack, Kaufman, Navarro, Parker, Rockwall, Tarrant, Wise, and a portion of Henderson County.

Region C has moderate-to-good potential for aquifer storage of stormwater (Figure C-1). There is significant potential in the Trinity, Woodbine, and Carrizo-Wilcox Aquifers.

Figure C-1: ASR Potential in Region C



While infiltration beds are the most common forms of stormwater infiltration for aquifer storage, they are not possible over the whole area of Region C. The two areas where infiltration is possible are the outcrop areas of the Trinity and Carrizo-Wilcox formations (Figure C-1). In other areas, injection of stormwater into an appropriate aquifer is possible.

The Trinity formation within Region C has mainly potable or near-potable water quality within the vicinity of most of the urban areas. The aquifer dips generally towards the south and east so that the potential storage units would also deepen in this direction, becoming more expensive for well development. Also, with increasing depth, the ambient water quality includes increasing temperature and generally increasing total dissolved solids (TDS) content. There are some counties within Region C that have evidenced significant groundwater level declines including parts of Collin, Dallas, Parker and Tarrant. While this is problematic for continued groundwater production, it also means that there is significant available aquifer space for storage of stormwater.

The Woodbine formation has characteristics similar to the other Trinity units. The Woodbine formation has a lower potential for ASR due to the smaller size and greater variability of this aquifer within Region C. Water quality trends in this unit are similar to the Trinity formation, although with greater variability. The Woodbine formation has elevated concentrations of iron and manganese in a number of locations. Significant groundwater level declines were noted in the Sherman-Denison area and in southeast Fannin County.

The Carrizo-Wilcox has a relatively large infiltration potential. Existing use of this aquifer is not as great as the others within this region, so there is not as much availability for storage. Most of the urban centers, which would be the main sources of stormwater, are a significant distance from this unit. Carrizo-Wilcox water quality is good in most areas.

The overall potential is moderate-to-good due to the large areal extent of the aquifers within the Region. Injection ASR has more potential due to the relative locations of urban water sources and the aquifer outcrops. There are only small areas where the urban centers are located above the unconfined portions of the aquifers where the aquifer crops out.

D. Region D (North East Texas)

Region D is situated in northeast Texas, bordering Oklahoma, Arkansas, and Louisiana. The area includes the counties of Bowie, Camp, Cass, Delta, Franklin, Gregg, Harrison, Hopkins, Hunt, Lamar, Marion, Morris, Rains, Red River, Upshur, Titus, Van Zandt, Wood, and part of Smith.

The Carrizo-Wilcox Aquifer has a relatively large infiltration potential in this region (Figure D-1). Approximately 20 percent of the land area includes outcrop (suitable for infiltration) of the Carrizo-Wilcox and Nacatoch Aquifers. Most of the rest of the region has potential for storage by injection, including downdip areas of the Woodbine, Nacatoch, and Carrizo-Wilcox Aquifers. However, over most of the region, the Woodbine is relatively deep (more than 2,000 feet), so the Nacatoch and Carrizo-Wilcox will have the greatest potential.

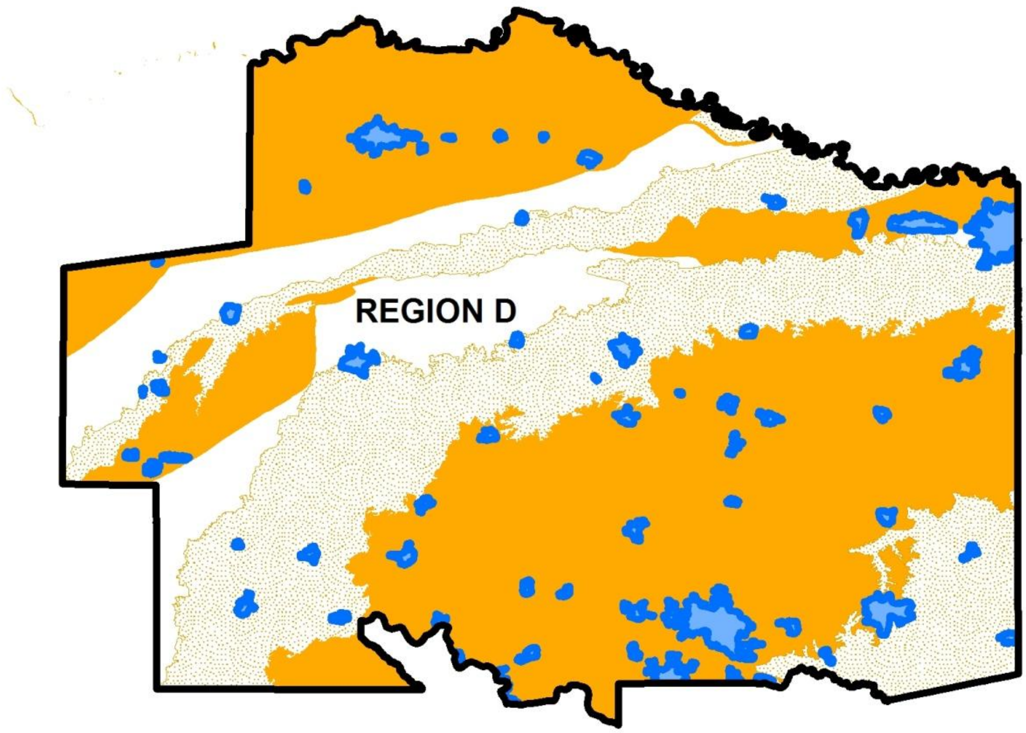
There are a number of small-to-medium sized urban centers in Region D. Therefore, there is good potential within this region for storage. Some local areas have had water level drawdowns, meaning there is room for storage. The rainfall in this area is relatively high, meaning increased stormwater availability but also decreased water demand.

The Carrizo-Wilcox Aquifer is significant in the Region D area. It is not over-utilized due to the level of rainfall (greater than 40 inches per year over the whole region). However, there are localized groundwater declines due to municipal, irrigation, and industrial pumping. These areas have potential for storage of stormwater.

E. Region E (Far West Texas)

Region E is situated in far west Texas, bordering Mexico and New Mexico. The area includes the counties of Brewster, Culberson, El Paso, Hudspeth, Jeff Davis, Presidio, and Terrell.

Figure D-1: ASR Potential in Region D (North East Texas)

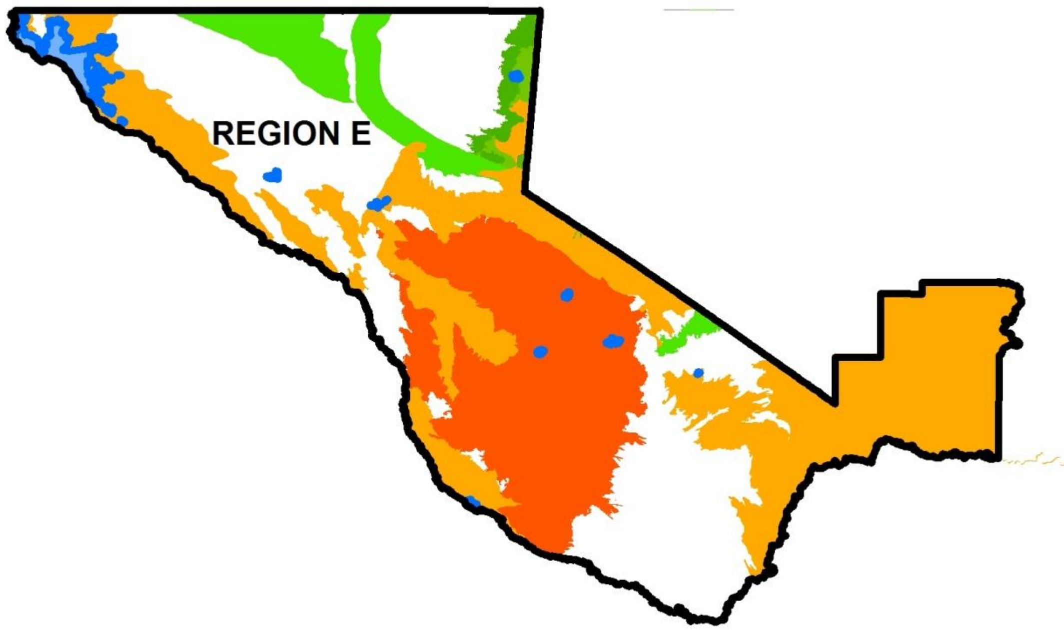


Region E has moderate-to-good potential for aquifer storage of stormwater in and around to El Paso; however, outside of this area, the potential is poor (Figure E-1). The most obvious aquifer unit for storage is the Hueco Bolson, which is already recharged by treated wastewater effluent from El Paso Water Utility.

The other aquifers in the region include the other West Texas Bolsons, Igneous, Bone Spring/Victorio Peak, Capitan Reef, Marathon and western Edwards/Trinity.

Generally the Bolsons have potential for storage, as they have been over-pumped in the last 50 years. However, they are relatively small in extent, and there will only be minimal stormwater available for storage from the rural communities that are within these aquifers. Most of this region is rural, with only the El Paso area having significant population. Therefore, all the other aquifers have the same issue of availability of stormwater. The recharge potential is highly variable within the Igneous Aquifer, where the groundwater characteristics change significantly over small distances. The other aquifers have poor-to-moderate potential.

Figure E-1: ASR Potential in Region E (Far West Texas)



F. Region F

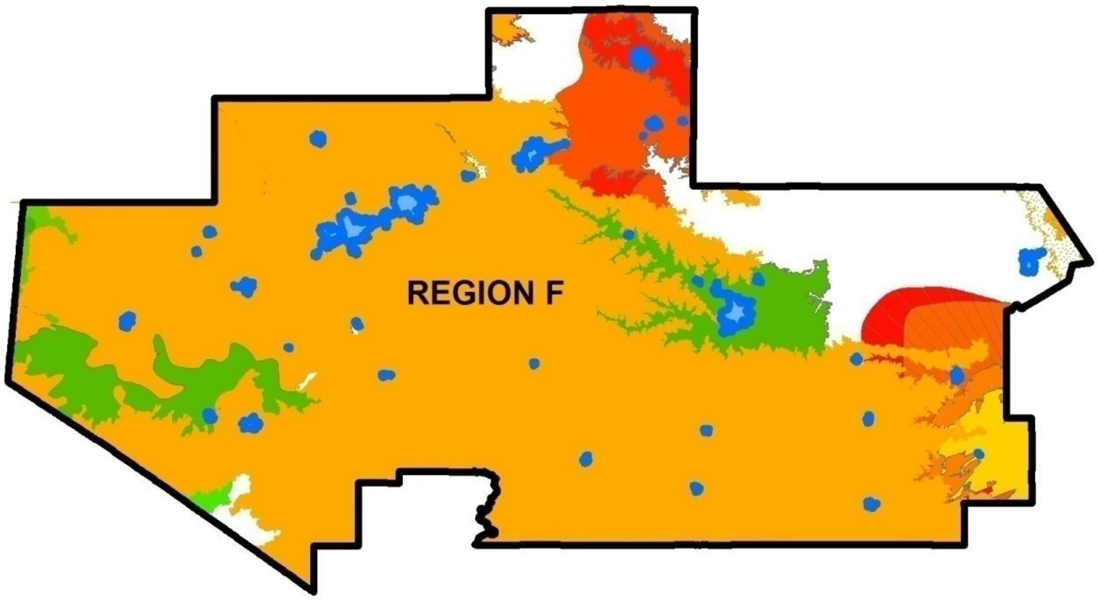
Region F is situated in central Texas. The area includes the counties of Andrews, Borden, Brown, Coke, Coleman, Concho, Crockett, Crane, Ector, Glasscock, Howard, Irion, Kimble, Loving, Martin, Mason, McCulloch, Menard, Midland Mitchell, Pecos, Reagan, Reeves, Runnels, Schleicher, Scurry, Sterling, Sutton, Tom Green, Upton, Ward, and Winkler.

Region F includes part of the Edwards/Trinity Plateau Aquifer, although this aquifer is generally relatively shallow and has with low permeability (Figure F-1). There are also a number of minor aquifers with moderate potential such as the Hickory and the Ellenburger. The overall potential in this region is poor-to-moderate due to the lack of a consistently high-yielding aquifer. However, there is localized potential for stormwater storage.

The Edwards/Trinity Plateau Aquifer covers most of the area within this region. The groundwater is generally available within this unit, but well yields are usually low-to-moderate. Injection rates would also be low-to-moderate, and the amount of water that could be stored would be lower than optimum and would increase the number of wells needed.

The Ellenberger/San Saba and the Hickory are also located within Region F. In some localized areas, they provide moderate-to-good yields. However, these units are highly faulted due to their age and the Llano Uplift. Therefore, large-scale projects may be difficult, as the aquifer characteristics change significantly over relatively small distances.

Figure F-1: ASR Potential in Region F



G. Region G (Brazos G)

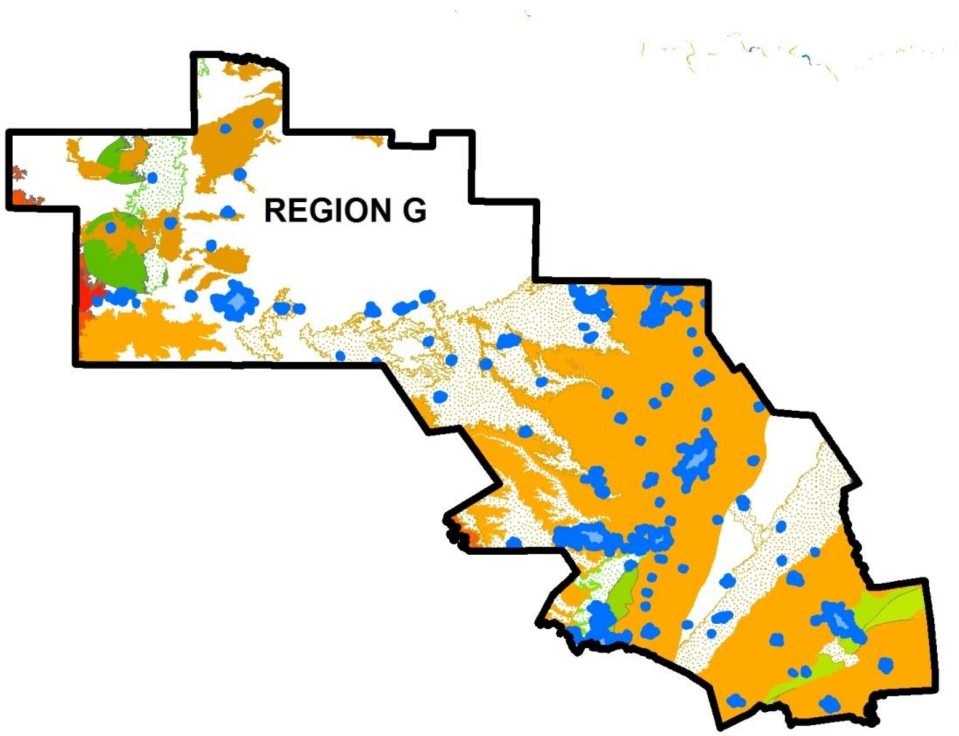
Region G is situated in central Texas and is mainly located within the Brazos River basin. The area includes the counties of Bell, Bosque, Brazos, Burleson, Callahan, Comanche, Coryell, Eastland, Erath, Falls, Fisher, Grimes, Hamilton, Haskell, Hill, Hood, Johnson, Jones, Kent, Knox, Lampasas, Lee, Limestone, McLennan, Milam, Nolan, Palo Pinto, Robertson, Shackelford, Somervell, Stephens, Stonewall, Taylor, Throckmorton, Washington, Williamson, and Young.

Region G has numerous aquifers, including the Seymour in the northwest (a very shallow porous sandstone formation), the Edwards/Trinity in the central area, and the Carrizo-Wilcox and Queen City/Sparta in the south (Figure G-1). The north central portion of the region has no recognized aquifer unit. While this area also has sparse population, the ASR potential within the whole region is moderate-to-good. However, portions of the region have poor potential, especially in the north.

The Edwards/Trinity, Carrizo-Wilcox, and Queen City/Sparta Aquifers, which make up the formations in the center and south of the Region, have moderate-to-good potential due to the fact that the aquifers themselves have relatively good properties. In addition, there are a number of medium-sized urban centers, so stormwater harvesting is available.

In the northern part of the region, there are fewer possibilities. The Seymour (mainly in Haskell and Knox Counties) is reasonably prolific, but the urban centers are sparse, and the aquifer is generally stable without significant available free storage due to its shallow unconfined situation and fast recharge rates.

Figure G-1: ASR Potential in Region G (Brazos G)



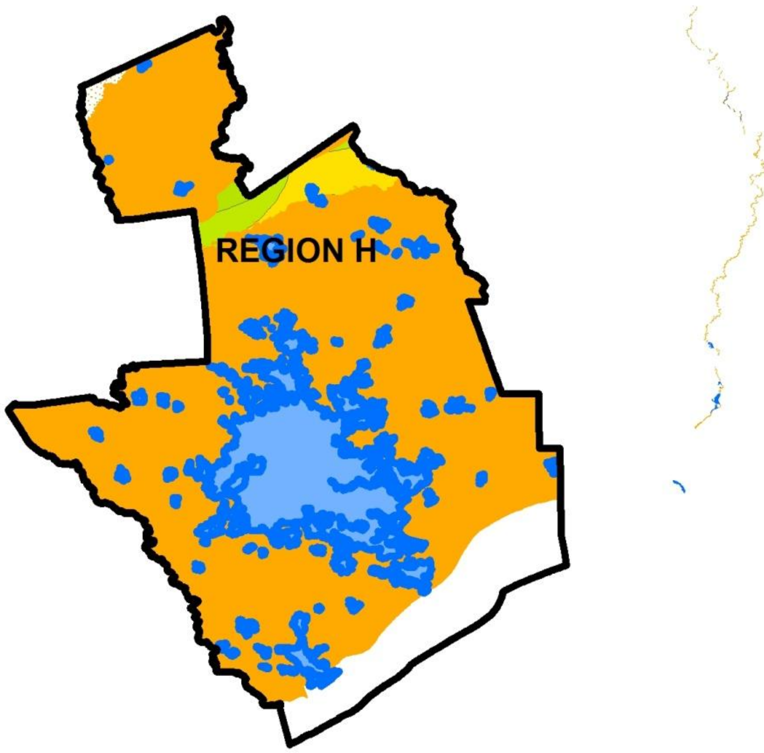
Small portions of the Blaine and the Ogallala are evident in the far northwest part of the region, but these are not significant enough to warrant serious consideration. The Blaine is relatively saline in this region, and the flow characteristics of this limestone make it difficult to stabilize any injected or infiltrated water.

H. Region H

Region H is situated in southeast Texas, bordering the Gulf of Mexico. The area includes the counties of Austin, Brazoria, Chambers, Fort Bend, Galveston, Harris, Leon, Liberty, Madison, Montgomery, San Jacinto, Walker, Waller, and parts of Polk and Trinity.

The potential for aquifer storage of stormwater in Region H is good (Figure H-1). There has been a history of over-use and mining of the groundwater resource in this region. Many of the larger water suppliers have converted to surface water in the recent past to reduce the effect of the groundwater withdrawals and the associated ground subsidence. There are still a large number of water suppliers using groundwater, and the levels are still low, so there is storage availability. The aquifers within this region include the Gulf Coast (the majority of the region is underlain by the Gulf Coast Aquifers), the Queen City/Sparta, and a small portion of the Carrizo-Wilcox in the far north of the region.

Figure H-1: ASR Potential in Region H



The Gulf Coast Aquifer has good transmission capacity and will allow reasonable injection rates. The Evangeline and Chicot formations within this aquifer are the most prolific in this region, with the oldest Catahoula formation an additional possibility. Due to the heavy rainfall in this area, there is often significant flooding. If large projects were put into place, some of this water could be stored in the aquifer.

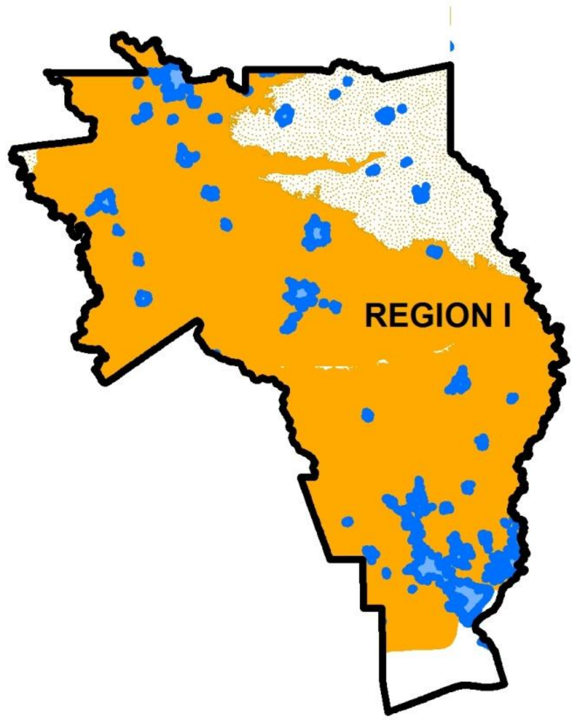
The Queen City/Sparta and Carrizo-Wilcox Aquifers are located at the northern end of the region and are further away from the urban stormwater availability. The characteristics of these units are good, but they are not as transmissive as many of the Gulf Coast units. These aquifers could potentially be considered for storage of stormwater from another region, but with the potential of the Gulf Coast Aquifer and its proximity to the possible supply, it is unlikely that these aquifer units would be considered for storage in this region.

I. Region I (East Texas)

Region I is situated in east Texas, bordering Louisiana. The area includes the counties of Anderson, Angelina, Cherokee, Hardin, Houston, Jasper, Jefferson, Nacogdoches, Newton, Panola, Orange, Rusk, Sabine, San Augustine, Shelby, Tyler, and parts of Henderson, Polk, Smith and Trinity.

Region I has good potential for aquifer storage of stormwater (Figure I-1). There is significant potential in the Carrizo-Wilcox, Queen City/Sparta, and Gulf Coast Aquifers, which cover most of the region.

Figure I-1: ASR Potential in Region I (East Texas)



The Carrizo-Wilcox Aquifer is prolific in Region I. It is not over-utilized due to the level of rainfall (greater than 40-inches per year over the whole region). However, there are localized groundwater declines due to municipal, irrigation, and industrial pumping. There is potential for aquifer storage in these areas.

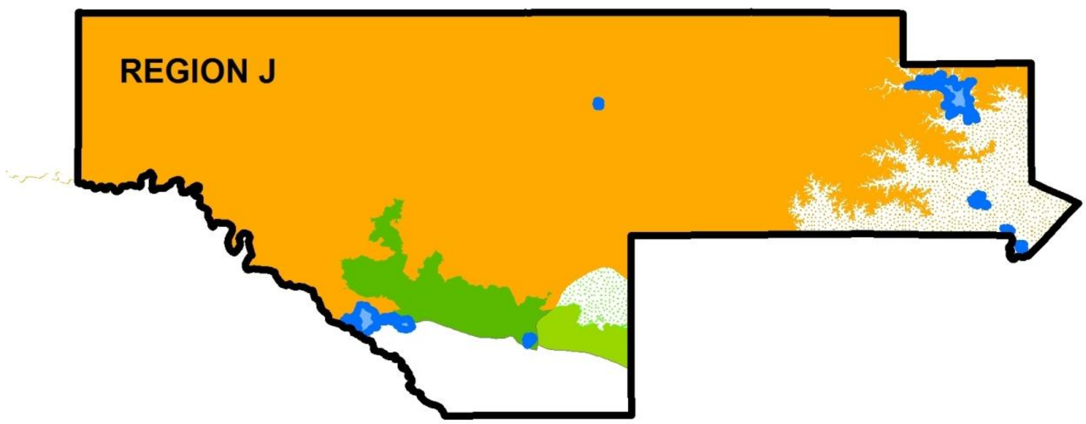
The Queen City/Sparta and Gulf Coast Aquifers have possibilities similar to the Carrizo-Wilcox. There is a large urban population (Beaumont and Orange) and stormwater availability in Orange County. The most important aquifers at this location are probably the Chicot and the Evangeline units of the Gulf Coast Aquifer, and the depths are not prohibitive.

J. Region J (Plateau)

Region J is situated in central Texas, in the plateau region. The area includes the counties of Bandera, Edwards, Kerr, Kinney, Real, and Val Verde.

Region J has moderate potential for aquifer storage of stormwater (Figure J-1). There is reasonable potential in the Edwards/Trinity plateau, although well yields are generally moderate.

Figure J-1: ASR Potential in Region J (Plateau)



The Edwards/Trinity Plateau Aquifer covers most of the area within this region. The groundwater is generally available within this unit, but well yields are usually low-to-moderate. Injection rates would also be low-to-moderate, and the amount of water that could be stored would be lower than optimum and would increase the number of wells needed.

In the southern part of the region, there is a small portion of the Edwards Aquifer (Balcones Fault Zone). This is more prolific and could sustain more storage. Natural processes already supply significant amounts of stormwater flow to this limestone formation. Additional stormwater storage may be possible, and this is the reason the region has a moderate designation rather than poor. The urban centers are also located around this formation, adding the possibility for available stormwater.

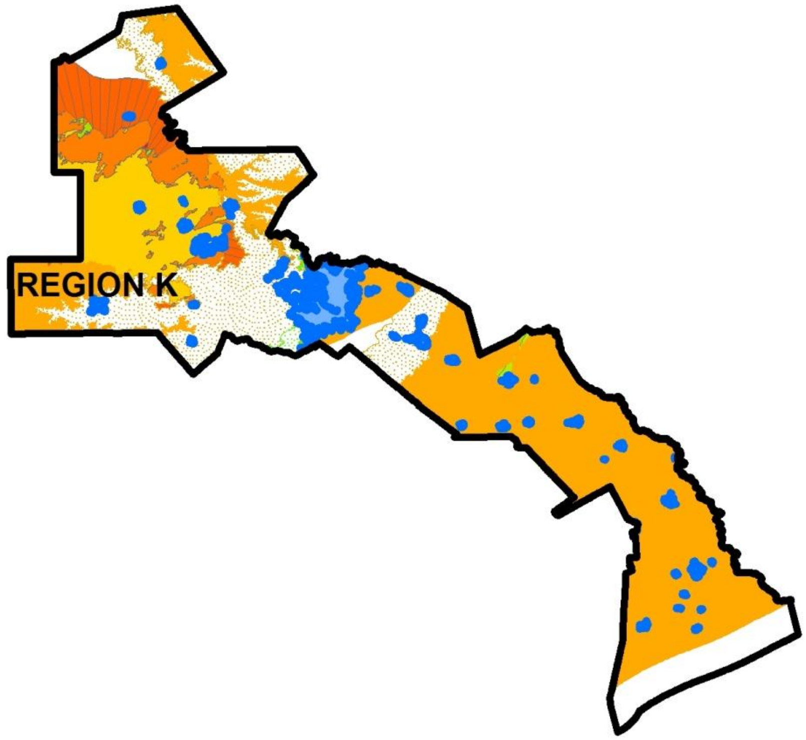
K. Region K (Lower Colorado)

Region K is situated in central Texas, around the Austin area and the lower Colorado River. The area includes the counties of Bastrop, Blanco, Burnet, Colorado, Fayette, Gillespie, Llano, Matagorda, Mills, San Saba, Travis, and parts of Hays and Wharton.

Region K has good potential for aquifer storage of stormwater (Figure K-1). There is significant potential in the Edwards/Trinity, Hickory, Ellenburger/San Saba, Carrizo-Wilcox, and Gulf Coast Aquifers.

The Edwards/Trinity is a major aquifer located within the main urban areas, with Barton Springs in the center of Austin being an example of the groundwater potential of this region. While the Edwards/Trinity is certainly not as prolific here as in Region L, there are still significant possibilities for storage in this unit.

Figure K-1: ASR Potential in Region K (Lower Colorado)



The San Antonio Water System (SAWS) has already used the Carrizo-Wilcox Aquifer in the adjoining Region L for a large-scale potable water ASR project. The aquifer is used heavily by the energy industry, so there are potential water quality issues, but yields are favorable if space can be found.

The Gulf Coast Aquifer is further away from most of the urban centers; therefore, the availability of stormwater is lower. However, it still has reasonable potential for stormwater storage.

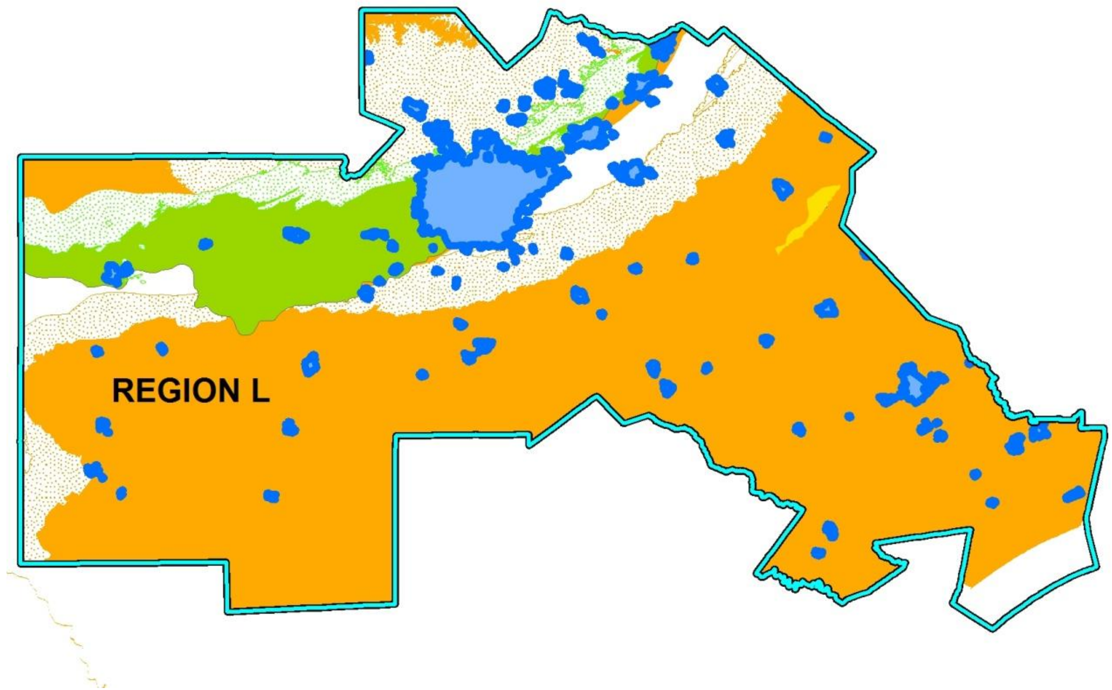
There is also minor localized potential in the Ellenburger/San Saba and the Hickory Aquifers. Locally they provide moderate-to-good yields. However, these units are highly faulted due to their age and the Llano Uplift. Therefore large-scale projects may be difficult, as the aquifer characteristics change significantly over relatively small distances.

L. Region L (South Central Texas)

Region L is situated in south central Texas, including San Antonio. The area includes the counties of Atascosa, Bexar, Caldwell, Calhoun, Comal, Dewitt, Dimmit, Frio, Goliad, Gonzales, Guadalupe, Karnes, Kendall, LaSalle, Medina, Refugio, Uvalde, Victoria, Wilson, Zavala, and part of Hays.

Region L has good potential for aquifer storage of stormwater (Figure L-1). There is significant potential in the Edwards, Carrizo-Wilcox, and Gulf Coast Aquifers.

Figure L-1: ASR Potential in Region L (South Central Texas)



The Edwards Aquifer is the primary resource for most of the urban centers, including San Antonio. This limestone formation has excellent flow characteristics and injection or withdrawal is not an issue in terms of volumes possible. A significant amount of natural and man-induced stormwater runoff is already channeled into the aquifer. The recharge flows through very quickly to be consumed or to exit as spring flow. This has two effects on the efficiency of a stormwater harvesting/ASR program. Injection is easy, but the injected stormwater spreads quickly. Since the Edwards Aquifer is highly regulated and protected, water quality would be a major concern.

SAWS already uses the Carrizo-Wilcox Aquifer within the region for a large-scale potable water ASR project. The aquifer is not used as heavily as the Edwards, so there are storage issues. However, yields are favorable if space can be found. It may be possible to engineer a site where potable water is removed for municipal, irrigation, or industrial uses and stormwater is stored in its place.

The Gulf Coast Aquifer is further away from most of the urban centers; therefore, the availability of stormwater is lower. However, it still has reasonable potential for stormwater storage.

M. Region M (Rio Grande)

Region M is situated in south Texas, along the southern Rio Grande River. The area includes the counties of Cameron, Hidalgo, Jim Hogg, Maverick, Starr, Webb, Willacy, and Zapata.

Region M has moderate potential for aquifer storage of stormwater (Figure M-1). There is significant potential in the Queen City/Sparta and Gulf Coast Aquifers.

Figure M-1: ASR Potential in Region M (Rio Grande)

The Gulf Coast Aquifer is also not as prolific in this region as in some regions. However, one of the main reasons for low usage is the salinity of the aquifer, especially closer to the coast. Most of the urban centers (and available stormwater) are also closer to the coast. Therefore, with respect to stormwater harvesting, it is possible that stormwater could be stored in non-potable units depending upon the severity of the salinity of the stored/mixed water.

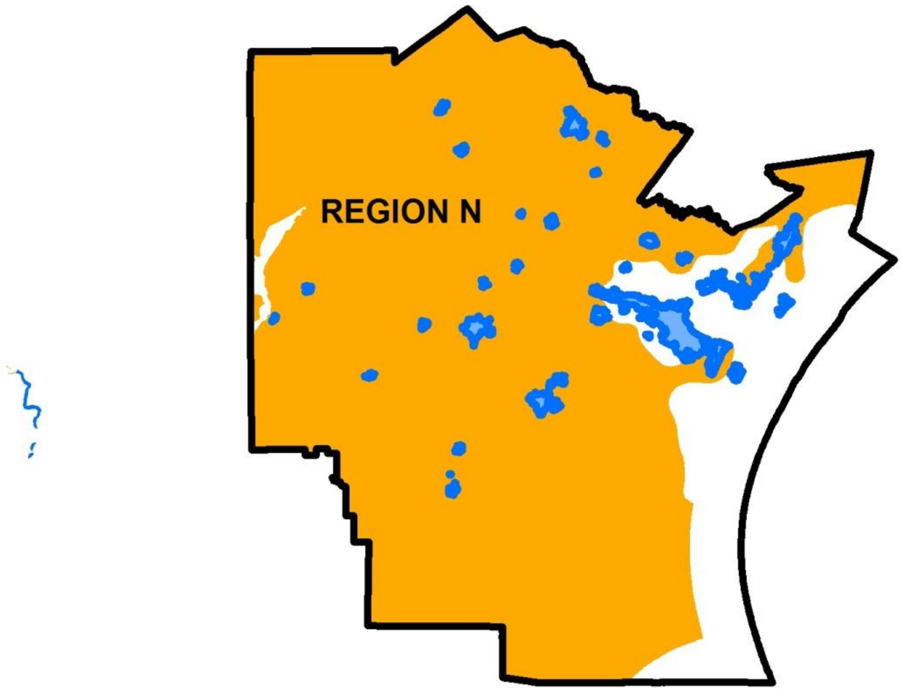
The Carrizo-Wilcox Aquifer has relatively low potential in this region. It has a smaller saturated thickness than in regions to the north, so the yields are not great.

N. Region N (Coastal Bend)

Region N is situated in south Texas, bordering the Gulf of Mexico. The area includes the counties of Aransas, Bee, Brooks, Duval, Jim Wells, Kenedy, Kleberg, Live Oak, McMullen, Nueces, and San Patricio.

Region N has moderate-to-good potential for aquifer storage of stormwater (Figure N-1). There is significant potential in the Carrizo-Wilcox and Gulf Coast Aquifers, which cover most of this region.

Figure N-1: ASR Potential in Region N (Coastal Bend)



The Gulf Coast Aquifer is not prolific in this region, although it is heavily used for irrigation and was used by Kingsville before the city was supplied with surface water by Corpus Christi. However, one of the main reasons for low usage is the salinity of the aquifer, especially closer to the coast. Most of the urban centers (and available stormwater) are also closer to the coast. Therefore, with respect to stormwater harvesting, it is possible that stormwater could be stored in non-potable units depending upon the severity of the salinity of the stored/mixed water.

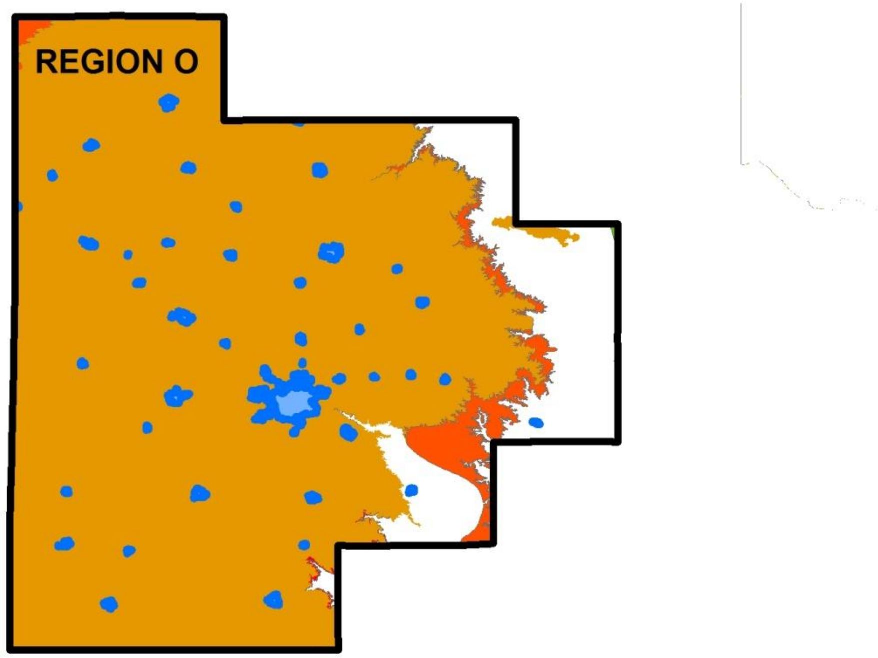
Aquifer storage testing research has been conducted in the Corpus Christi area. While the expected yields are not great, they are expected to be able to accept large volumes of water. Further inland, the salinity in the aquifer does decrease, so this may be a reasonable location for storage.

O. Region O (Llano Estacado)

Region O is situated in west central Texas, bordering New Mexico. The area includes the counties of Bailey, Briscoe, Castro, Cochran, Crosby, Dawson, Dickens, Deaf Smith, Floyd, Garza, Gains, Hale, Hockley, Lamb, Lynn, Lubbock, Motley, Parmer, Swisher, Terry, and Yoakum.

Region O has moderate-to-good potential for aquifer storage of stormwater (Figure O-1). There is significant potential in the Ogallala Aquifer and some potential in the underlying Dockum Aquifer.

Figure O-1: ASR Potential in Region O (Llano Estacado)



The Ogallala Aquifer is the most prolific porous sand and gravel aquifer in the state and is primarily used for irrigation. It is generally unconfined and as such allows use of infiltration or injection. The infiltration rates are generally good, however; due to the relatively low amounts of rainfall and the high net evaporation of this region (60 plus inches per year), very little acts as recharge. Infiltration beds would need to be designed to minimize residence time to reduce evaporative losses.

The aquifer itself has good characteristics with large yields and relatively shallow wells. There has been and continues to be significant mining of the resource in many areas. Therefore, there is a large availability for storage. While the urban centers are relatively small and spread out, there are possibilities for urban stormwater availability, especially near Lubbock. This stormwater will often make its way into the groundwater systems anyway, hence one of the reasons for a designation of moderate potential. However, due to the porous sand nature of this aquifer, there would be much more hydraulic control of any stored water. Within these units, the groundwater generally does not move at significant rates – usually only a few feet per day. This is relatively slow movement compared with karstic limestone aquifers, which often allow water movement in the hundreds of feet per day. This makes it more advantageous for the utilities storing the water as they can keep control of the resource.

The Dockum Aquifer is often found underneath the Ogallala in this region. This unit is generally confined, provides lower yields, and has water quality issues (elevated salinity). However, the Dockum Aquifer could also be used as a storage site if necessary.

P. Region P (Lavaca)

Region P is situated in south central Texas. The area includes the counties of Jackson, Lavaca, and part of Wharton.

Region P is the smallest Regional Planning area. The Gulf Coast Aquifer units are found below the entire region (Figure P-1). Aquifer depths vary (there are multiple units within the same formation), but the shallowest aquifers are generally at depths of less than 500 feet. There is some groundwater pumping for agricultural purposes, but the urban populations are generally small, and rainfall is relatively high. Therefore, this region has moderate potential for aquifer storage of stormwater.

Figure P-1: ASR Potential in Region P (Lavaca)

Q. Regional Potential of ASR Storage for Stormwater Harvesting

Table 1 below summarizes the overall potential for ASR for stormwater harvesting. Reasons for the regional designations have been presented in the regional descriptions.

Table Q-1: Regional Potential of ASR Storage for Stormwater Harvesting

Region		Stormwater ASR Potential				
		Poor	Poor-to-Moderate	Moderate	Moderate-to-Good	Good
A	Panhandle					X
B			X			
C					X	
D	North East Texas					X
E	Far West Texas	Other			El Paso	
F			X			
G	Brazos G				X	
H						X
I	East Texas					X
J	Plateau			X		
K	Lower Colorado					X
L	South Central Texas					X
M	Rio Grande			X		
N	Coastal Bend				X	
O	Llano Estacado				X	
P	Lavaca			X		

Appendix D: Sources of Stormwater Best Management Practice Treatment Performance Data

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Sources of Stormwater BMP Treatment Performance Data

The International Stormwater BMP Database project is an ongoing effort that has been collecting performance data on different stormwater best management practices (BMPs) since 1999. The project was initially funded by the U.S. EPA in association with the Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers (ASCE). The primary goal of the project was to gather scientifically valid technical information relating to the selection and performance of best management practices, helping communities to better address their stormwater problems. As of June 2009, performance analyses results (by treatment technique for various contaminants) of over 300 BMPs throughout the U.S., were available from the data base maintained at the project web site (http://www.bmpdatabase.org). Some of the best management practices considered in the project include:[143]

- Biofilters
- Detention Ponds
- Hydrodynamic Devices
- Infiltration Basins
- Media Filters
- Percolation Trenches/Wells
- Porous Pavements
- Retention Ponds
- Wetland Basins
- Wetland Channels

United States Environmental Protection Agency presented stormwater BMP pollutant removal efficiencies for total suspended solids, nutrients, and some metals for the following best management practices:[109]

- Detention Ponds
- Retention Ponds
- Wetlands
- Infiltration Practices
- Water Quality Swales
- Sand Filters
- Filter Strips
- Bioretention Areas

Sayre, Devinny, and Wilson compiled stormwater BMP pollutant removal efficiencies from numerous sources for total suspended solids, nutrients, metals, and fecal coliform for the following best management practices:[147]

- Porous Pavements
- Detention Basins
- Retention Ponds
- Wetlands
- Water Quality Inlets

- Filtration Basins
- Underground Sand Filters
- Sand Filters
- Grassed Swales
- Vegetated Strips
- Infiltration Basins
- Infiltration Trenches
- Bioretention Areas

Puget Sound Action Team and Washington State University Pierce County Extension presented stormwater treatment performance data for metals, nutrients, hydrocarbons, and bacteria for the following best management practices:[98]

- Bioretention areas
- Detention ponds
- Wetlands
- Water quality swales
- Ditches
- Permeable paving

National Resource Management Ministerial Council and others presented pathogen exposure reduction information for on-site preventive measures (e.g., drip irrigation, spray drift control, restricted public access, buffer zones, etc.) and discussed effectiveness of different treatment facilities (including dual-media filtration with coagulation, membrane filtration, reverse osmosis, chlorination, ozonation, and ultraviolet light).[13]

Fletcher and others reviewed the treatment performance of porous pavements and biofiltration.[21]

Department of Environment and Conservation NSW presented ranges of contaminant removals for conventional stormwater treatment measures, including gross pollutant traps, swales, sand filters, bioretention systems, ponds, and wetlands.[14] They also presented ranges of effectiveness for disinfection measures, including ultraviolet light, chlorination, and ozonation.

Urban Drainage and Flood Control District presented treatment performance data for suspended solids, nutrients, and some metals for the following best management practices:[7]

- Extended Detention Basins
- Wet Ponds
- Wetland Basins
- Biofilters
- Media Filters

Olivieri and others presented pathogen removal efficiency data for stormwater treatment best management practices including detention basins, retention ponds, infiltration basins and trenches, vegetated swales, stormwater wetlands, sand filters, and advanced treatment and disinfection.(26)

Mitchell and others presented:(15)

- Pathogen removal efficiency of filtration systems, ponds, wetlands, and wastewater systems
- Advantages and disadvantages of the following disinfection technologies: chlorination, ultraviolet radiation, ozonation, and membrane filtration.
- Biofilter design issues, such as release of nutrients from soil-based filter media, hydraulic conductivity, bed depth, and vegetation root depth and the impact of design choices on removal of sediment, metals, and nutrients.

Fletcher and others reviewed the treatment performance of various stormwater treatment best management practices, including gross pollutant traps; vegetated swales and filter strips; infiltration and bioretention systems; rainwater tanks; ponds, wetlands, and sediment basins; and porous pavements.(55) Modeling results from the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) were used to predict pollutant removal percentages over a range of annual rainfall, area ratio, and detention times for various best management practices.[hhh] Finally, for each best management practice, information on maintenance activities, necessary equipment, and design attributes that facilitate maintenance activities was provided.

The U. S. Environmental Protection Agency has published 31 stormwater technology fact sheets on topics such as treatment technologies and operation and maintenance of treatment systems.(108) The fact sheets include a description of each technology and discussion of applicability, advantages and disadvantages, design criteria, performance, and operation and maintenance. Fact sheets are available for the following stormwater treatment technologies:

- Airplane deicing fluid recovery systems
- Baffle boxes
- Bioretention
- Hydrodynamic separators
- Infiltration drainfields
- Infiltration trench
- Modular treatment systems
- On-site underground retention/detention
- Sand filters
- Sorbent materials
- Stormwater wetlands
- Turf reinforcement mats
- Vegetative covers
- Vegetative swales
- Water quality inlets (*a.k.a.*, oil/grit separators)

[hhh] Wong and others discussed the MUSIC model.(103)

- Wet detention ponds

NSW Environment Protection Authority reviewed primary, secondary, and tertiary stormwater treatment processes.[110] For each measure, a description and discussion of selection criteria/advantages, pollutant trapping efficiency, limitations/disadvantages, key performance factors, design considerations, inspection/monitoring, and maintenance is presented. The review included the following treatment measures:

- Primary measures
    - Litter baskets
    - Litter pits
    - Litter racks
    - Sediment traps
    - Gross pollutant traps
    - Litter booms
    - Catch basins
    - Oil/grit separators
- Secondary measures
    - Filter strips
    - Grass swales
    - Extended detention basins
    - Sand filters
    - Infiltration trenches
    - Infiltration basins
    - Porous pavements
- Tertiary measures
    - Constructed wetland systems

Prince George's County presented general ranges of pollutant removal for total suspended solids, total phosphorus, total nitrogen, zinc, lead, BOD, and bacteria for the following best management practices:[6]

- Bioretention
- Dry Wells
- Infiltration Trenches
- Filter/Buffer Strips
- Vegetated Swale
- Infiltration Swale
- Wet Swale

U.S. Environmental Protection Agency provided qualitative performance data for removal of suspended solids, nitrogen, phosphorus, pathogens, and metals by the following best management practices:[106]

- Extended Detention Dry Ponds
- Wet Ponds
- Constructed Wetlands

- Infiltration Basins
- Infiltration Trenches/Dry Wells
- Porous Pavements
- Grassed Swales
- Filter Strips
- Filtration Basins
- Sand Filters
- Water Quality Inlets

U.S. Environmental Protection Agency concluded the following about the effectiveness of urban runoff control measures:[145]

- Detention basins can be very effective in pollutant removal.
- Recharge devices can provide very effective control of urban runoff discharges.
- Street sweeping does not significantly improve urban runoff quality.
- Grass swales can moderately improve urban runoff quality.
- Wetlands have promise for control of urban runoff quality.

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Appendix E: TWDB Comments on the Draft Report and *Responses to Comments*

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Storm Water Reuse Guidance Document

Draft Report

TWDB Contract # 0804830853

In this section, plain text represents Texas Water Development Board comments on the draft report, and italicized text represents responses to these comments. Page numbers in the TWDB comments have been updated to match the final document.

The draft report is a well written and documents legal, regulatory, and technical issues for implementing storm water reuse in Texas. Reviewers of the Draft report made the following comments; please consider incorporating responses of these comments into the Final version of the report.

General Comments:

1. The report used the terms ‘storm water harvesting’ and ‘storm water reuse” interchangeably. Please clearly define these two terms in the report.

   Explanatory text was added as Footnote c on Page 1-1.

2. Please spell out the words WSUD, FD, WP, NRCS, ARI, BMP in the report.

   “WSUD” stands for water-sensitive urban design, which is a phrase commonly used in Australia. The phrase “low-impact development” is used more commonly in the United States. Therefore, the abbreviation “WSUD” was changed to “water-sensitive urban design (low impact development).”

   “FD” was changed to “flow distribution.”

   “WP” was changed to “watershed parameter.”

   Where there was no other context, “NRCS” was changed to Natural Resources Conservation Service. In other instances, where the context had already been established, “NRCS” was deleted.

   “ARI” was changed to “average recurrence interval.”

   “BMP” was changed to “best management practice” or other, more descriptive phrases.

Finally, a List of Abbreviations was added to the front matter, beginning on Page viii.

3. It seems that Task 6 of the "Scope of Work" has received minimal attention in the Draft report. Please consider defining issues related to the potential impacts of reusing storm water on downstream ecology in the Final report.

   Task 6 of the contract Scope of Work states, "Define issues related to the potential impacts of reusing stormwater on downstream ecology." A survey of the references in Appendix A identified the following impacts of stormwater harvesting that may affect downstream ecology: [eee]

   - *Changes in flows, including total volumes and peak flowrates*
   - *Changes in pollutant loadings/water quality*
   - *Changes in erosion*

   In this document, these impacts and their effects on downstream ecology are discussed in general language, primarily in Section 2.5 (other references to these impacts are located on pages 1-1, 2-3, 2-28, and 6-5 in the lists of advantages of various treatment technologies in Section 6.3). This document is intended to provide guidance for planning, design, and operation of stormwater harvesting projects in Texas. The discussion of potential impacts is admittedly brief and general in nature, because downstream ecology is highly site-dependent. Project planning, design, and operation that would enhance downstream ecology at one site might degrade downstream ecology at another site. Therefore, document users are encouraged to conduct site-specific investigations to assess ecosystem sensitivity, existing and projected flows, existing and projected water quality, and project objectives as necessary for management of environmental impacts from individual stormwater harvesting projects. Minor edits were made to the text of Section 2.5 to clarify the intent of the section.

4. Water supply reservoirs are designed to capture storm water runoff for use in times when streamflow is low. If another entity "captures" this water before it enters a watercourse, this could result in a reduction in yield for downstream water users. Therefore, any "gains" in water supply for the reusing entity would be offset by the yield reduction somewhere else.

   Stormwater that is intercepted and used prior to entering a natural watercourse (and is not subject to appropriation and permitting under the Water Code as state water) may result in reduced water availability/reliability for downstream water

[eee] *This document focuses on stormwater harvesting projects that do not require a water rights permit. On-channel stormwater harvesting projects may have additional impacts on aquatic ecology, such as barring fish passage, etc.*

rights. There is not necessarily a one-to-one relationship between intercepted stormwater and reduced downstream availability: Some of the stormwater would have been lost to evaporation or infiltration as it moved downstream. Impacts on downstream water availability should be evaluated on a case-by-case basis. Footnotes cc, ee, ii, and jj, and on Pages 4-5, 5-1, 5-11, and 5-21 were added or modified to reflect this issue.

5. If an entity which has historically discharged storm water directly into a watercourse reroutes their storm water system to direct the previously discharged storm water into an off-channel reservoir, and then subsequently discharges this storm water back into a watercourse, the entity may not be able to claim the re-routed storm water as their "private water". If the rerouted water is put back into the river, TCEQ would treat an application to divert this water just like any other request for unappropriated state water.

   This comment appears to be directed at the last sentence in the Section "Stormwater as State Water" on Page 3-4 and the third sentence in Section "Stormwater Stored in an Aquifer" on Page 3-4. These sentences state that stormwater is privately owned (belongs to the surface owner as diffused surface water) before entering a natural watercourse. These sentences are consistent with the above comment. Therefore, no changes were made in response to this comment.

   It is agreed that, should this privately-owned stormwater be subsequently discharged to a natural watercourse, then it would become "state water" subject to appropriation and permitting under the Water Code.

6. Over time, man-made ditches can essentially become watercourses. For example, TCEQ has issued numerous water rights with diversion points on canals and ditches. For example: *Watts v. The State of Texas*, 140 S.W.3d 860, 866 (Tex. App - Houston [14th Dist.] 2004, pet. dism'd), the court found that diffuse surface water in a drainage ditch was a watercourse and therefore was "water in the state" for the purposes of Chapter 26 of the Texas Water Code. The court stated that "diffused surface water (belonging to the landowner) becomes a natural watercourse (belonging to the state) at the point where it begins to form a reasonable well-defined channel, with bed and banks, or sides and current, although the stream itself may be very small and the water may not flow continuously." 140 S.W.3d at 866, citing *International-Great N. R.R. Co. v. Reagan*, 121 Tex. 233, 49 S.W.2d 414, 418-19 (1932).

   No case law exists that addresses when an artificial watercourse becomes a natural watercourse. Footnote w was added to Page 3-4 to apprise the reader of this potential issue.

   Regarding the example presented, "water in the state" is not synonymous with "state water." See 30 TAC 297.1(50) and 30 TAC 297.1(58). The court did not *conclude that the drainage ditch was a "natural watercourse" as required for "state water" but that it was a "watercourse" as required for "water in the state."*

7. The document relies heavily on the Australian experience, however the references cited define storm water as "water collected from drains and creeks" which seems to conflict with Texas' regulatory framework. The document needs some text explaining why guidelines developed for small projects that collect storm water from waterways would be appropriate for projects that are completely off-channel. Please explain if additional factors should be considered for the cases in Texas. Additionally, please consider describing relevant similarities and differences of storm water reuse between Texas and Australia in the 'Introduction' section of the report.

   The principal Australian references say that stormwater harvesting involves collecting runoff from "drains or creeks."[13,14] *"Drains" refers to a* stormwater *collection system. The Australian guidance documents are intended for use with stormwater harvesting projects that collect stormwater from either stormwater collection systems or natural watercourses. The principal steps involved in planning, designing, and operating a stormwater harvesting project are general in nature and are similar (with the exception of the water right permitting process) for projects that capture stormwater from any source.*

   Likewise, the principal steps involved in planning, designing, and operating a stormwater harvesting project are similar regardless of the project location (with the exception of differences in local regulations). Texas regulations that apply to stormwater harvesting were discussed in Chapter 3. Relevant topics included ownership of stormwater in Texas, the water right permitting process, Chapter 402 and 404 permits, and permits necessary for projects involving aquifer storage and retrieval.

   Other Texas-specific topics are also discussed in this guidance document, including methods for estimating stormwater availability in Texas (Chapter 4), the regional potential for stormwater harvesting in Texas (Chapter 5), and the regional potential for aquifer storage and retrieval of stormwater (Appendix C).

   Additional text was added to the discussion of the Australian guidance documents in the Introduction section to point out that there are differences between the Australian and Texas regulations that apply to stormwater harvesting.

8. In Section 2 of the report, please include the following sub-sections

   a. A sub-section on major challenges for implementing storm water reuse projects in Texas.

This document is very broad and addresses many topics that are important to planning, design, and operation of a stormwater harvesting project in Texas. These topics are addressed throughout the document. It is difficult to say that one topic is more important than another – it depends on the reader's interests.

Certain topics are unique to Texas, however. Texas-specific guidance is provided for the following topics: determining whether a water right permit is required for a stormwater harvesting project (Chapter 3), how to estimate stormwater availability for a project (Chapter 4), and which of the 16 water planning regions in Texas have the greatest potential for stormwater harvesting in Texas (Chapter 5).

Finally, Australian research on barriers to implementation of stormwater harvesting projects is presented in the section "Implementation Issues" beginning on Page 2-21. Although this research took place in Australia, it is likely that the same barriers represent "major challenges" to implementation in Texas.

b. A sub-section describing factors that influence pollutant concentrations in storm water runoff.

Additional information describing factors that influence pollutant concentrations in stormwater runoff was added to Section 2.2 (Site and Watershed Characteristics)

c. A sub-section for the 'Risks of storm water reuse'.

Risks and potential impacts of stormwater harvesting are addressed in Sections 2.5 (Environmental Impacts) and 2.6 (Public Health Issues) of Chapter 2. Management of these risks is discussed in Section 2.7.

9. In Section 7 of the report, please include a sub-section for 'Occupational health and safety' for workers in storm water harvesting and reuse schemes.

Section 7.3 (Occupational Health and Safety) was added to Chapter 7 to address this comment.

10. Citations in Appendix A are confusing. Second part of Appendix A contains 'Other Sources of Information'. Please clarify the difference between 'References' and 'Other Sources of Information'

The 'References' section contains bibliographic records for sources that were referenced in the text of the guidance document. 'Other Sources of Information' have been removed from Appendix A.

11. Numbering for the references is confusing. They are neither alphabetical nor in the order in which they appear in the text. For example, see pages 1-1 and 1-2. Additionally, please insert the footnotes and references at the end of the sentence instead of at arbitrary points in the sentence.

    References have been numbered in the order in which they first appear in the report. In general, footnotes and references were placed at the end of sentences. The exception is that, at the beginning of bulleted lists, footnotes and references were placed after the colon.

Specific Comments:

Page ES-1 – The Executive Summary was not included in this DRAFT document and assumed to be included in the final document. The Executive Summary should have a clearly stated purpose and scope section.

An Executive Summary has been included in the final document.

Page 2-1 "Planning of Storm Water Reuse Projects" – The customized flow chart should also include a task to determine whether a water rights permit would be required.

The bulleted list of items that should be included in a customized flowchart of planning actions for a specific stormwater harvesting project in Texas was expanded to include "determination of whether a water right permit would be required for the project."

Page 2-2 Step 2 – The item "Storm water quality and quantity" is assumed to be a determination of how much water could be harvested by the watershed and made available for other uses. It would be useful if this determination was made early in the planning process to know if it is worthwhile to pursue a project. Please clarify how this differs from Step 5; "Yield Analysis". Is this a different determination/calculation than made earlier in the planning process?

Explanatory text was added as a bulleted item under the first paragraph in Chapter 2.

Page 2-2 Step 3 – Downstream impacts are not clearly addressed in this process. Is "Flood and stream health protection" meant to address potential fishery/downstream ecology concerns? Is "Diversion water extraction license" meant to address other water right (downstream) concerns? This statement implies some type of permit/license is required, but the section on Legal and Regulatory issues seems to imply that "diffused waters" are not under the jurisdiction as "state waters" and no water right would be needed?

Explanatory text regarding "flood and stream health protection" was added as bulleted items under the first paragraph in Chapter 2. The "diversion/water extraction license" item in Figure 2-1 was changed to "water right permit." In addition, Footnote e was *added to Page 2-1 to guide the reader to the discussion of ownership of state water in Section 3.1.*

Page 2-6 "Storm Water Availability" – From a permitting perspective, there is a problem of using storm water as a supplement to water from another source. If storm water is the supplement, it will not be available during drought when the base supply needs supplementation. It would be difficult for TCEQ to consider this as a supplemental source in the context of a water rights application.

If the stormwater is not "state water" that is subject to appropriation, then this is a moot issue.

If the stormwater is determined to be "state water" that is subject to appropriation, then the project owner would apply for a water right permit. The application process includes an evaluation of water availability/reliability given the applicant's priority date. Depending on the degree to which water has been appropriated in the river basin in question, the evaluation may show that water is only available at certain times of the year (if at all). Subject to meeting other permit conditions, such as showing a beneficial water use, there is no apparent reason why the applicant could not obtain a water right permit to divert available water, even if the availability/reliability is limited. Depending on the anticipated water use, water available from other sources, and site-specific circumstances, this water may have significant value to the applicant, even if it is unavailable for portions of the year.

No changes were made based on this comment.

Page 2-6 "Environmental Impacts" – Please explain if the system is off-channel, how would there be upstream flooding?

The potential for upstream flooding is discussed under the heading "Flooding Hazards" on Page 2-7.

Page 2-7 "Environmental Flows" – Please verify if there is a conflict between the first sentence and the second sentence regarding peak flows.

There is not a conflict. Development (i.e., urbanization) leads to less pervious area in a watershed, increasing runoff frequency and peak flows in natural watercourses that drain the watershed from pre-development levels. Diversion of stormwater before it enters a natural watercourse reduces the runoff frequency and peak flows in the natural watercourse toward their pre-development levels.

Page 2-7 "Flooding Hazards" – On-line storage systems would require a water rights permit and availability analysis. The introduction states that the document discusses storm water that is collected and used before it enters a watercourse.

The text was edited to clarify that the discussion applies to a stormwater collection system. It is established in Section 3.1 that stormwater in a collection system is not "state water" and is not subject to appropriation under the Texas Water Code.

Page 2-8 "Water Quality Risks to Public Health", fourth paragraph – Please explain why a low-flow bypass is needed if the system is off-channel.

This section discusses design elements that should be incorporated into stormwater collection and storage facilities to decrease water quality risks to public health. During wet periods, use of a low-flow bypass in capturing water from the stormwater collection system to a storage facility would allow the "first flush" of stormwater (that may contain pollutants that have accumulated between storms) to flow past the diversion point. Similarly, should a chemical spill occur during dry periods, use of a low-flow bypass would allow the chemical to flow past the diversion point. In these ways, a low-flow bypass helps to protect the quality of the produced water. The text was modified to clarify the purpose of such facilities.

Page 2-9 "Risk Management through Storm Water Reuse Quality Goals" ,– Please provide some examples of the proposed storm water reuse quality goals to manage risks associated with public health, to reduce algal blooms in storm water storage, and to provide appropriate irrigation water quality.

Examples are provided in Tables 2-4 through 2-8.

Page 2-10 "Risk Management through Screening Investigations", third paragraph – Please mention that National Resource Management Ministerial Council is an Australian agency.

Footnote l on Page 2-11 was inserted to better define the National Resource Management Ministerial Council.

Page 2-19 "Aquifer Storage and Recovery" – The first sentence has a footnote 28 to 30 TAC 331. This chapter in the code is large, and there is a specific citation in the code that this sentence is supported by. Please correct footnote 28 to "Chapter 331.184(e)".

This reference has been corrected as suggested.

Page 2-19 "Aquifer Storage and Recovery", third paragraph – Please provide a more recent reference on the recharge of the Hueco Bolson Aquifer. The current value should be approximately half of the value that is used in the report.

The description of El Paso's recharge of the Hueco Bolson Aquifer with reclaimed water has been modified using 2008 data.

Page 2-21 "Implementation Issues" – Please revise the bulleted items for consistency.

The second list was placed in a bulleted format for consistency.

Page 3-1 "Storm Water on the Surface" – Please mention that the supply of the run-off and rainfall has not increased. Its time interval for reaching a stream has decreased due to impervious cover.

*The text on Page **3-1** has been modified to eliminate the implication that stormwater harvesting in and of itself leads to an increased water supply. However, between 2010 and 2060, the Texas population is projected to grow from almost 25 million people to more than 45 million people, creating water supply and stormwater management challenges, particularly in urbanizing areas of the state.[(1)] This large increase in population will be accompanied by a significant increase in impervious area that will substantially increase the amount of stormwater runoff and the quantity of surface water available for water supply.*

Page 3-2 "Current Legal Framework"

- Second paragraph – Definition of state water included the expected runoff, storm water and rainfall that fell upon the land. So in effect please consider the impact of removing historic rainfall from gage records to view what is appropriable under this theory. This will have a massive impact on existing water rights.

  This guidance document does not say that rainfall runoff (stormwater) never becomes appropriable – only that it is not appropriable until it enters a natural watercourse. This concept is summarized in the first paragraph of section "Stormwater as State Water" on Page 3-4. The impact on existing water rights of capturing stormwater before it enters a natural watercourse depends on the magnitude of the stormwater harvesting project.

  A stormwater harvesting project may reduce the water demand associated with an existing water right. In such cases:

  - *The cost of transporting water to meet the demand may be reduced, because stormwater harvesting projects are typically located in close proximity to the end user, and*

  - *The quality of the water used to meet the demand can be tailored to the needs of the end user.*

  Such benefits may help offset impacts on existing water rights.

- The cite to Section 11.021 is incorrect. The author mistakenly left out "river," (that is, "river"-plus-comma) after the word "flowing."

  The quote has been corrected.

- Third paragraph – Please include, "diffused water is water on the surface before it enters a watercourse."

  The parenthetical text "in places other than watercourses" was added to this paragraph to better align the definition of diffused water with that found in Reference 64.

- The discussion of "Diffused water" vs. "State water" seems to lead to the conclusion that water rights would not be necessary for a storm water capture project if captured before entering a "natural water course"; however, Figure 3-1 showing the flow chart for a water right permit procedure is an illustration for referencing the process.

  Some readers may contemplate a project where stormwater is diverted from a natural watercourse (i.e., is "state water"), which would require a water right permit. Although this situation is not the main focus of this document, Figure 3-1 is provided as a guide for such readers. No changes were made based on this comment.

Page 3-2 "State Water vs. Diffused Surface Water"

- Please explain if storm water drains will meet the criteria "flow from a definite and permanent source of supply."

  The legal analysis concluded that, "Only upon entering what is considered to be a natural watercourse that has (1) a well-defined bed and banks; (2) a current of water; and (3) flow from a definite and permanent source of supply will water become state water" (last sentence, first paragraph of the section "Stormwater as State Water" on Page 3-4). Regardless of whether storm drains receive flow from a definite and permanent source of supply, they are not <u>natural</u> watercourses. Therefore, stormwater intercepted from stormwater drains is not "state water" and is not subject to appropriation on Texas Water Code Chapter 11.

- The second of three elements established by the *Hoefs* court should be reworded to reflect the language of the court. The second element should be "a current of water," not "a regular flow of water".

  The correction has been made. A similar correction was made on Page 3-4.

- Footnote 50 left off a part of the citation. The citation should be: "Hoefs v. Short, 273 S.W. 785 (Tex. 1925)".

  The correction to the reference has been made.

- Footnote 51 is cited as "Turner vs. Big Lake," but this should be "Turner v. Big Lake." That is, it is "v." not "vs."

  The correction to the reference has been made.

- Footnote 54 should cite the actual legislation or the statute at issue, not the subsequent regulations promulgated in support.

  This reference was used correctly in another place, so a new reference (#69) was added to cite the actual legislation at issue.

Page 3-3 "Watercourse: Natural or Artificial"

- Third paragraph – The final quote in the paragraph is incorrect. The quote should add a comma after "gathers", and should delete the "and" before "prior". Additionally, there are currently two citations (#52 and #53), but all cases mentioned support the same proposition. This is an important legal point, and it is suggested to have only one citation with all the major supporting legal bases (including two cases not included by the author). Further, the citations have been corrected. The final combined footnote should be:

a. "City of San Marcos v. Texas Comm'n on Envtl. Quality, 128 S.W.3d 264, 272 (Tex.App.-Austin 2004, pet. Denied) (citing Turner v. Big Lake Oil Co., 96 S.W.2d 221, 228 (Tex. 1936) *and* Domel v. City of Georgetown, 6 S.W.3d 349, 353 (Tex.App.-Austin 1999, pet. denied); *See also*, Citizens Against Landfill Location v. Texas Com'n on Environmental Quality, 169 S.W.3d 258, 274 (Tex.App.-Austin, 2005); Dietrich v. Goodman, 123 S.W.3d 413, 417 (Tex.App.-Houston [14th Dist.] 2003, no pet.)."

   Corrections were made to the quote. A combined reference (#68) was used as described above.

- Second and third paragraph – Some historic man made channels, over time, become essentially natural watercourses. Additionally, the real question here is at what point does a watercourse become natural. There are many water rights with diversion points located on ditches or canals.

  No case law exists that addresses when an artificial watercourse becomes a natural watercourse. Footnote w was added to Page 3-4 to apprise the reader of this potential issue.

Page 3-4 "Storm Water as State Water" – Please explain how an interface exists between diffuse and state water.

The "interface" occurs at the location where diffused surface water enters a natural watercourse. No changes were made based on this comment.

Page 3-4 "Storm Water Stored in an Aquifer"

- First paragraph – "ASR" is mentioned without stating that it is an acronym for "Aquifer Storage and Recovery." Also, there is no need to include the cite (#64) to this sentence, since it is simply stating what ASR projects involve, not what the law says an ASR is. Also, citation #64 refers to a definition of storage of "appropriated" water, and storm water is not appropriated water, so the citation isn't accurate.

  The initials "ASR" have been defined in the text to represent "Aquifer Storage and Retrieval." Throughout the document, the phrase "aquifer storage and recovery" has been changed to "aquifer storage and retrieval" to match the language in the Texas Administrative Code. Finally, Reference #64 was removed from the paragraph in question.

- First paragraph, last sentence – There is no legal cite to this proposition, please include one. That is, what is the "existing law" that the report is referring to? Also, this paragraph states that GCDs are "regulated" under Chapter 36. It would be more accurate to say that they are "acting" under Chapter 36, since GCDs are not regulated by this Chapter. The same correction should be made to page 3-8, Section "Groundwater Conservation District Permits" (switch "regulated under Chapter 36" to "acting under Chapter 36").

  The section "Stormwater Stored in an Aquifer" has been rewritten to cite groundwater law and to better explain conclusions that were based on the law. In addition, "regulated" was changed to "acting" in the suggested places.

- Second paragraph – The final clause of the first sentence is not clear on the law. There are few limitations on the rule of capture, and they should be stated according to the most recent case law on the subject. Please leave off the reference to the *Beckendorff* case, which is not applicable. Please perform the following replacement first sentence and citations:

a. "The 'rule of capture,' the controlling law on groundwater in the State of Texas, provides that a person may pump as much groundwater as needed for his intended beneficial use as long as he is not negligent in causing subsidence of a neighbor's land, willfully wasteful, or malicious."
b. Citations: Friendswood Development Co. v. Smith-Southwest Industries, Inc., 576 S.W.2d 21, 30 (Tex.1978) (subsidence exception); City of Corpus Christi v. City of Pleasanton, 276 S.W.2d 798, 801 (Tex. 1955) (waste and malice exception); Fain v. Great Spring Waters of America, Inc., 973 S.W.2d 327, 329 (Tex.App.-Tyler, 1998); City of San Marcos v. Texas Com'n on Environmental Quality, 128 S.W.3d 264, 271 (Tex.App.-Austin, 2004).
c. For the second sentence, I suggest a reference to these exceptions tacked onto the end: "Without intervening regulation, the rule of capture would seemingly allow a landowner overlying the aquifer to withdraw not only the groundwater, but also the storm water contained therein, subject only to the subsidence, waste, and malice exceptions noted above."

Changes were made to the second paragraph as suggested.

- Third paragraph – Since many GCDs publish rules on their GCD websites, the following webpage (which includes links to GCD websites and contact information for each Texas GCD) may be helpful to include in the citation: http://www.tceq.state.tx.us/assets/public/permitting/watersupply/groundwater/gcd/gcdcontactlist.pdf.

Footnote z containing the URL was added to the paragraph.

- Third paragraph – Please clarify how storm water constitutes privately-owned water before entering a natural watercourse with a defined bed and banks.

The legal analysis that supports this concept is explained in detail in Section 3.1. No changes were made based on this comment.

- [First] paragraph – Please describe if the following sentence is an extension that is not explicit in the law "privately-owned water that is injected or infiltrated into an aquifer would likely be regarded as groundwater and would likely be subject to the rule of capture."

The section "Stormwater Stored in an Aquifer" has been rewritten to cite groundwater law and to better explain conclusions that were based on the law.

Page 3-6 – Sections "Chapter 404 Permits" and "Storm Water Discharge Permits" should be reworded to reflect the law. It is unclear if these sections' reference to "construction" is meant as a facility (a fixed construction) or activity (construction of a project). The two permitting schemes referenced (Section 402 is the unmentioned permitting requirement in the Storm Water Discharge Permits paragraph) could be implicated by construction of the storm water projects, but would not by operation of the actual projects. The draft does not cite law, nor does it fully state the applicability of both permitting schemes to reuse projects. Please combine the two sections into one, as follows:

a. "Storm water collection projects generally gather storm water into storage for beneficial use. Conceivably, the construction phase of a storm water project could implicate the permitting requirements under Sections 402 and 404 of the Clean Water Act. The project's subsequent beneficial use of the storm water would not implicate the permitting requirements. [Citation: 40 C.F.R. § 122.26(a) (exempting storm water discharges). The 404 permitting requirement would not be implicated because the nature of storm water reuse would not involve dredged or fill material that would change the bottom elevation of a receiving water body. [Citation: Coeur Alaska v. Southeast Alaska Conservation Council, 557 U.S. ___, 129 S. Ct. ___ (2009)]. If construction of the project causes a discharge of any 'dredged or fill material' into jurisdictional waters, then a corresponding 'Section 404' permit must be acquired from the Army Corps of Engineers under the Clean Water Act. [Citation: 33 U.S.C. § 1344(a).] If construction of the project causes a discharge of any pollutant into jurisdictional waters (other than dredge or fill material), then a corresponding 'Section 402' (NPDES) permit must be acquired from the Environmental Protection Agency (EPA). [Citation: 33 U.S.C. § 1342(a); 40 C.F.R. § 122.26(a)(9); See also, EPA Region 6 Storm water program webpage: http://cfpub.epa.gov/npdes/home.cfm?program_id=6]. If construction activity implicates the Section 402 NPDES permitting scheme, a general permit may be secured to cover the 402 permitting requirement. [Citation: 40 C.F.R. § 122.21; *See also*, EPA Region 6 Storm water program webpage: http://cfpub.epa.gov/npdes/home.cfm?program_id=6]."

   Changes were made to the text as suggested.

Page 3-7 "Injection Well Permits" – The second and third sentences should have citations. The sentences should link the legal requirements to the definition, and the slight change of label ("ASR injection well" to "Aquifer storage well") makes it unclear whether these are two different things. The law is clearer under the following edit:

a. “An injection well permit from the Underground Injection Control (UIC) group within the Texas Commission on Environmental Quality (TCEQ) is required for all ASR injection wells. [Citation: 30 TAC § 331]. Since ASR injection wells are considered Class V injection wells under 30 TAC § 331, these wells are subject to Class V construction and closure standards. [30 TAC §§ 331.132-331.133]. ASR injection wells are also subject to construction, closure, operating, monitoring, and water quality requirements. [30 TAC § 331; 30 TAC § 290]. The Underground Injection Control regulations at 30 TAC § 331 include regulations governing construction details for pressurized wells, and monitoring requirements to assess the migration of injected fluids. [30 TAC § 331].”

Changes were made to the text as suggested.

Page 3-8 “Water Right Permits for ‘State Water”’

- First sentence – Please break this sentence into two sentences and change the words a bit to clarify the applicability of water rights permitting to ASR projects, as follows:

a. “TWC Chapter 11, and the corresponding TCEQ regulations under Chapters 295 and 297 of 30 TAC, set forth water right permitting and reporting requirements. These water right permitting requirements are probably not triggered for ASR storm water projects because these projects contain unappropriated storm water owned by the landowner. ASR projects, as defined under 30 TAC § 297.1(5), do not involve unappropriated storm water, and instead involve aquifer storage and retrieval of ‘*appropriated* surface water.’ Similarly, the ASR project permitting procedure and requirements under Sections 11.153 and 11.154 of the Texas Water Code apply only for ‘*appropriated* water.’”

The text was amended as suggested.

- Last Paragraph – Please include that there is little to no water available for appropriation in most basins in Texas, which would certainly be a confounding factor for any applicant seeking to divert storm water which is determined [to be state water].

A second paragraph was added under the section “Water Right Permits” (Page 3-6) to convey this concept.

Page 4-1 "Storm Water Availability for Water Supply"

- First line of the second paragraph – Please delete the word 'historical'.

  The text was amended as suggested.

- Second paragraph – Creation of the naturalized flows was part of WAM development. In some basins naturalized flows were developed for ungaged control points or for points representing a hydrologic feature, such as a basin outlet. The only climate data in the WAMs currently is evaporation. Estimates for missing data more typically applies to naturalized flows

  The text was modified to acknowledge that creation of the naturalized flows occurred during WAM development, that the naturalized flows were estimated at primary control points, that evaporation is the only climate data in the existing WAMs, and that the naturalized flows and evaporation contain estimates to fill in missing data.

- Fifth line of the second paragraph, please delete the word 'gaged'

  The text was amended as suggested.

- Third paragraph – TCEQ discovered issues with the underlying datasets and no longer uses curve numbers in availability determinations. In addition, there were issues related to aggregation of curve numbers. Also, please clearly refer the modifications of DAR.

  The text was modified to clarify the reasons that TCEQ no longer uses the modified curve number method for water availability. The reference to modifications of the DAR was deleted.

- Fourth paragraph – There are a number of CPs which do not have drainage areas.

  The text was edited to say that WAMs include drainage areas for the large majority of CPs.

Page 4-2 "Storm Water Availability for Water Supply"

- Item #2 – GIS shapefiles are available for all river basins. Those that are not currently posted can be obtained by requesting them from TCEQ.

  This information was added to the text.

- Item #4 and 5 – This is confusing because the fields were not identified.

  In the Water Rights Analysis Package (WRAP) Modeling System Users Manual,(88) the fields do not have names more descriptive than Field 1, Field 2, etc. Example flow distribution (FD) and watershed parameter (WP) records are presented in Items #4 and #5, and example values associated with each field are identified. Minor changes were added to the text to clarify this identification.

- Item #4 and 5 – Please define different terms (e.g., FD, WP) to estimate monthly storm water availability using the DAR method.

  The "FD" (flow distribution) and "WP" (watershed parameter) abbreviations were defined in the text.

Figure 4-2 Note 5 – Note 5 should refer to the naturalized flow not the gaged flow

Note 5 has been corrected.

Page 4-4 – Figure 4-2 – The following issues are not clear in the Figure, please consider explaining the issues:

- Title of column 3 shows Naturalized Flow; however, the unit of the column is shown in volume (acre-ft)
- Please explain the factor 53.333

The column titles were changed to read "naturalized flow volume" instead of "naturalized flow." Note 4 was edited to include the number 53.333.

Page 4-5 "Storm Water Availability for Water Supply"

- First paragraph, second line – Acre-feet per acre or gallons??

  As shown in Figure 4-3, the monthly stormwater availability for the example is presented in gallons per acre.

- First paragraph – Please make it clear that this analysis assumes the withdrawal of all rainfall generated streamflow within a watershed, which could have huge impacts on existed permitted water rights.

  The example analysis provides a unit estimate (gallons per acre) of the "diffuse surface rainfall runoff" (see Footnote aa on Page 4-1) generated in a watershed on a monthly basis for the period of record. The potential impact on existing water rights would depend on the drainage area that contributes to the stormwater harvesting project and the percentage of the *available stormwater that is collected for use. The example analysis does not presume the size of the project drainage area or how much of the available stormwater would be collected for use. Footnote cc on Page 4-5 was added to remind the reader that intercepting and reusing stormwater may impact downstream water rights.*

- Second paragraph – Please consider using HECRAS or one of the other flood design models designing for storage.

  Should a project planner identify more appropriate models, data, and/or hydrographs for a specific site, use of such information in project planning and design is encouraged. A new paragraph to this effect was inserted into the discussion of stormwater hydrograph estimation on Page 4-8.

- Third paragraph – Please explain why would anyone use a WAM based flow to estimate storm water runoff since the WAM uses adjusted gaged flows. Please note that all this runoff appears in the gage record.

  The discussion in this section focuses on using the WAM data to estimate the amount of "diffuse surface rainfall runoff" (see Footnote aa on Page 4-1) that is available to a stormwater harvesting project. This can be difficult to separate from the gaged flow data, particularly for small watersheds located far upstream of a gage.

  The primary advantages of the WAM-based method are that the data are available for virtually any location in the State of Texas and that the resulting estimate of stormwater availability can be scaled to a wide range of project sizes. However, should a project planner identify more appropriate models, data, and/or stormwater availability estimates for a specific site, use of such information in project planning and design is encouraged. A new paragraph to this effect was inserted into the discussion on Page 4-5.

- Fourth paragraph – Naturalized flows are part of the WAMs….

  The text was amended accordingly.

Page 4-6 Figure 4-4 – WAM does not identify storm water, just water, so what criteria will be applied to determine the flood portion out of the hydrologic variability. Also, please indicate the point in the graph, where 1,000 gal/acre/month of storm water runoff is available for 60% of the time. This will help the readers to interpret the graph easily.

The example analysis provides a unit estimate (gallons per acre) of the "diffuse surface rainfall runoff" (see Footnote aa on Page 4-1) generated in a watershed on a monthly basis for the period of record. Presuming that this water does not enter natural watercourse (and does require a water right permit), then all of this water is available to its owner(s) for use.

The suggested point was added to Figure 4-4.

Page 4-7 "Storm Water Runoff for Flood Control" – Please define the term 'area-weighted curve number'. Also, please explain why 2-year 24-hour storm should be used for the design purpose.

Footnote dd was added to define "area-weighted curve number." As stated in the bulleted items on Page 4-7, the 2-year frequency, 24-hour duration design storm is an "assumed characteristic of the example project" and this design storm was used for demonstration purposes. Project planners should identify and use the design storm that is appropriate for their project objectives.

Table 5-1 – The category "Other" should list downstream water rights impacts as a "Factor". Downstream interests could certainly become a factor if they perceive an impact on their water rights.

Table 5-1 was modified as suggested.

Pages 5-3 and 5-4 – Please provide sources of figures 5-2, 5-3, 5-4, and 5-5.

Data sources and calculation methods for Figures 5-2 through 5-5 are discussed in the text beginning on Page 5-2. Additional explanatory text has been added.

Page 5-6 – Please define one-year 24-hour storm event. Also, please discuss how design volumes are determined. Please provide examples of areas that require larger storage volumes and have a decreased potential for storm water reuse.

Footnote gg was inserted on Page 5-6 to define the meaning of a one-year frequency, 24-hour duration storm event.

In this section, the ratio of the design storm rainfall amount to the average annual rainfall is used as an indication of rainfall timing. As discussed on Page 5-4, areas where a given design storm represents a larger percentage of the annual rainfall volume tend to experience more of their annual rainfall during fewer events, and such areas may require *larger storage volumes and may have a decreased potential for stormwater harvesting. Therefore, based solely on this factor, the East Texas and North East Texas regions would have the greatest potential for stormwater harvesting, and, by comparison, the Rio Grande region would have the least potential for stormwater harvesting (Figure 5-7).*

Design storm rainfall volumes were obtained from nomographs in National Weather Service Technical Publication 40.[(94)] Sizing of stormwater storage is one of the subjects discussed in Section 6.2.

Page 5-15 "Aquifer Storage and Recovery", first six paragraphs – Please make the paragraphs bulleted items.

This section was modified as suggested, with a summary sentence and five bulleted items.

Table 5-4 Column 'C' (fourth column), 8th Row ('water needs') – Much of the current water use in Region C comes from reservoirs, which were designed to impound the water being suggested to be diverted.

It appears that this comment is similar in nature to General Comment 4 on Page E-2. Please refer to the response to that comment.

Table 5-4 - Should there be a category for the degree of appropriation in a watershed basin? For example, if an individual watershed produces 100 ac-ft of runoff, and there are 99 ac-ft of water rights already in existence, then the potential to build a storm water capture project will require more education/negotiation/awareness than if only 50 ac-ft is already appropriated. Please explain if this data is available as a part of the WRAP discussed in Chapter 4 (Page 4-1).

As discussed in Chapter 1, this document focuses on stormwater that can be harvested from overland flow or from stormwater collection systems prior to entering a natural watercourse. As discussed in Section 3.1, such water is "diffused surface water" belonging to the surface owner and is not "state water" subject to appropriation and permitting under the Texas Water Code. For this type of stormwater harvesting project, the degree of appropriation of available water in the river basin is not directly relevant to the potential for stormwater harvesting. No changes were made to the document in response to this comment.

The degree of appropriation of available water in the river basin would be relevant if a stormwater harvesting project contemplated a diversion of water from a natural watercourse.

Page 6-5, Fourth paragraph – Please explain if this diversion is from a stream. This seems inconsistent with other sections of the report which discuss applications that do not require diverting state water.

This section refers to capture of stormwater that is not state water. Quantification of the impacts of a stormwater harvesting project on downstream flows may involve estimates of flows in natural watercourses.

Page 6-4, Figure 6-3 – The results of the graph cannot be interpreted easily, please provide some examples in the Text, so that the graph can be read easily.

Additional text was added to explain the use of Figure 6-3.

Page 6-5, First paragraph – Please note that making use of available storage in existing ponds and lakes rather than sizing storage to meet demand would require a water rights permit or an amendment in Texas.

An additional sentence was added to the paragraph to reflect that, if stormwater is introduced into a natural watercourse, a water right permit (or permit amendment) would be necessary to divert this water from the natural watercourse.

Pages 6-7 to 6-21 – Please consider incorporating the removal efficiencies of different treatment technologies in a separate Table.

The removal efficiencies of different treatment technologies are summarized in Table 6-3 near the end of the stormwater treatment discussion (Section 6.3).

Page 6-14 "Retention Ponds" – If the retention pond is on-channel, a water rights permit would be required

Footnote ss on Page 6-14 was inserted to reflect this comment.

Page 6-15 "Constructed Wetlands" – Depending on the project specifics, diversion of storm water into a constructed wetlands could require a water rights permit.

Footnote tt on Page 6-15 was inserted to reflect this comment.

Page 6-16 "Disadvantages to Constructed Wetlands" – Please add that treatment wetlands are complex and require a thorough understanding of the contaminants of concern and the removal thereof. There is a risk of actually impairing the water quality if the treatment wetland is not properly designed.

As suggested, Item 7, which discusses the complexity of treatment wetlands and the risk of water quality impairment, was added to the list of disadvantages of constructed wetlands on Page 6-16.

Page 6-18 "Disadvantages to Infiltration Trenches/Wells" – Please add that infiltration trenches/wells are prone to clogging; maintenance is required for infiltration trenches/wells.

As suggested, Item 6, which discusses the potential for clogging of infiltration trenches/wells and related maintenance, was added to the list of disadvantages of infiltration trenches/wells on Page 6-18.

Page 6-20 "Sand Filters", Third sentence – Please clarify that sand filters may only remove metals if they are oxidized and in solid form. Dissolved metals and other dissolved contaminants are not typically removed by a sand filter.

Text and Footnote uu were added to page 6-20 to reflect this comment.

Page 6-21 "Disadvantages of Sand Filters" – Please add that sand filters may require an air and water backwash equipment.

As suggested, Item 6, which discusses the need for air and water backwash equipment, was added to the list of disadvantages of sand filters on Page 6-21.

Page 6-23 "Advantages of Advanced Water Treatment" – Please add:

1. Produces better water quality than storm water BMP's;
2. Greater opportunity for a customized water quality product (i.e. contaminant-specific treatment);

As suggested, Items 3 and 4 were added to the list of advantages of advanced water treatment on Page 6-23.

Page 6-24 "Disadvantages of Chlorination" – Please mention

1. Chlorine may react with natural organic matters present in the storm water and form total trihalomethanes, which are carcinogens.
2. It may require an examination of the raw water quality (possibly a pilot test) to determine process selection.
3. Because of its toxicity to flora and fauna, dechlorination may be needed for storm water that is discharged to a natural watercourse

As suggested, Item 5, discussing the potential for trihalomethane formation, was added to the list of disadvantages of chlorination on Page 6-24. Additional text discussing examination of the stormwater quality prior to selection of a disinfection treatment technology was added to the general discussion on Page 6-23, since this comment applies to all disinfection methods. Finally, the possible need for dechlorination is already listed as a disadvantage of chlorination (Item 1 on Page 6-24).

Page 8-3, second paragraph – In some places the costs are reported as $/1000 gallons; in some other places the costs are reported as $ only. Please use $/1000 gallons of cost throughout the report for consistency.

In general, costs have been reported as they were found in the literature sources, and the cost units including dollars, dollars per thousand gallons, and other units. The literature sources do not always provide sufficient data for conversion between units. For example, to convert a capital cost in dollars to a unit cost in dollars per thousand gallons, the capital cost must be annualized (usually with the interest rate and term of the project financing) and divided by the annual water supply provided by the project. Not all of this information was available in every case. Therefore, no changes have been made in response to this comment.

Page 8-14, Figure 8-9 – Please use the extended form of the acronym GPT.

Footnote ddd on Page 8-14 was inserted to define gross pollutant trap (GPT).

Page 8-13, [Last] five paragraphs – Please consolidate the contents into one or two paragraphs, or turn the paragraphs into bullets.

The relevant paragraphs were turned into bulleted items, as suggested.

Suggestions:

- "TWC" is used as an acronym for "Texas Water Code" in the document. "TWC" often refers to the old Texas Water Commission. In order to reduce confusion, it is suggested to use "Water Code" instead of "TWC". This isn't a legal issue, but it would clarify the legal section of the document.

  "Water Code" was substituted for "TWC" as suggested.

- The document provided does not include a section on Municipal Setting Designations. MSDs do not necessarily apply to aquifer storage of storm water. But if the property above the aquifer is designated an MSD, then certain standards can be avoided, and extraction may be restricted by TCEQ. Please add the following brief paragraph and citations.

  "Municipal Setting Designations"

  Aquifer storage and retrieval projects pump collected storm water into aquifers for later extraction and beneficial use. Under the law of Municipal Setting Designation, a person or local government may apply to TCEQ to designate a property as a "municipal setting" if the groundwater beneath that property is an actual or potential threat to human health. [Citation: Tex. Health & Safety Code § 361.802 and §

361.8015]. Approval of the municipality is required for designation. [Citation: § 361.8065]. Upon designation, TCEQ would prohibit the potable use of groundwater from that property. [Citation: § 361.8065(a)(2)]. Potable water includes water used "for irrigating crops intended for human consumption, drinking, showering, bathing, or cooking purposes."[Citation: § 361.801(2)]. Industrial and other non-potable uses would not be prohibited. Furthermore, some investigation and remediation of the stored water and soil would not be required, because the water would be destined for non-potable use. [Citation: § 361.802 and §361.808]."

The key point that follows from this comment is that municipalities can regulate pumping, extraction, and use of groundwater within the city or its extraterritorial jurisdiction by persons other than retail public utilities for the purpose of preventing the use or contact with groundwater that presents an actual or potential threat to human health. (75) *Such a regulation is often implemented as part of the process for obtaining a Municipal Setting Designation (MSD) from the TCEQ. If a stormwater aquifer storage and retrieval project is located in an area that is subject to municipal limitations on groundwater use, these limitations could help restrict access to the stored water. The section "Municipal Regulations" on Page 3-5 was added to communicate this information.*

- In Appendix C, please include a general location map at the beginning showing all regions.

  A map of all of the regional water planning areas in Texas was included in Appendix C as Figure 1.