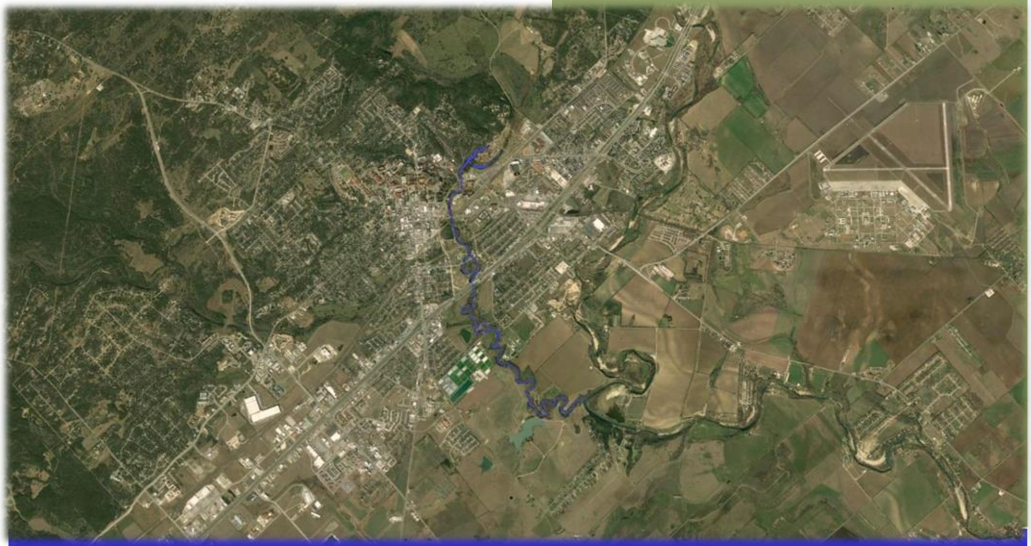

Water Quality Protection Plan

for the City of San Marcos and Texas State University

2016

Meets obligations of the
Edwards Aquifer Habitat
Conservation Plan

Prepared for the City of San Marcos
and Texas State University

Prepared by John Gleason LLC

1/18/2016

Water Quality Protection Plan

for the City of San Marcos and Texas State University

(Draft)

January 18, 2016

Prepared for:

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This Water Quality Protection Plan was prepared for the City of San Marcos and Texas State University. Melani Howard, City of San Marcos Habitat Conservation Plan Manager, served as Project Manager on behalf of the City of San Marcos and Texas State University. This planning effort and the preparation of this document were funded by the Edwards Aquifer Authority by way of a contract with the City of San Marcos.

Prepared by:

The Water Quality Protection Plan was prepared by a team of consultants, listed below, with input from representatives of the City and the University, citizens and other stakeholders.

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Engineering oversight of specific elements of the San Marcos Water Quality Protection Plan was provided by the following engineers, as required by the Texas Board of Professional Engineers (TBPE).

For the monitoring and evaluation of engineered water quality measures for assessment or adjustment of functional processes (Chapter 11 and Appendices G, H, I, J & L).

Patrick Hartigan, P.E.

Seal of Pat Hartigan

For the feasibility studies of engineered water quality measures and treatment technologies, and for siting of engineered water quality management measures (Chapters 8 & 9 and Appendix N).

Lee Sherman, P.E.

Seal of Lee Sherman

Table of Contents

Executive Summary: Texas State University

Executive Summary: City of San Marcos

List of Figures

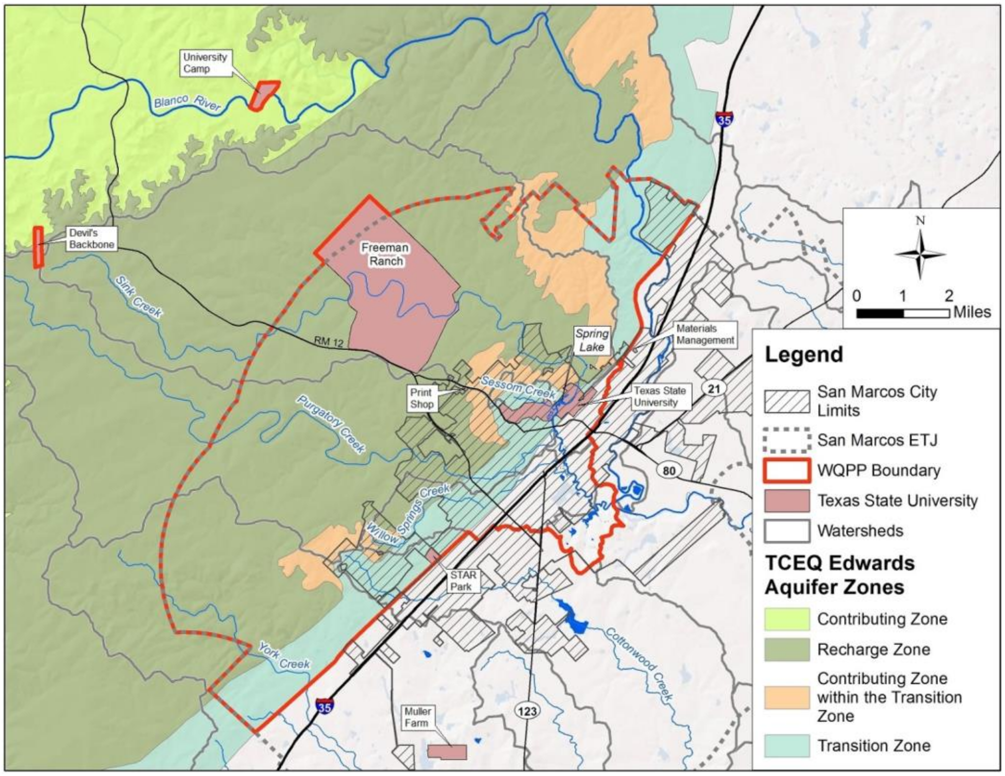
List of Tables

Commonly-Used Abbreviations

BASINS - Better Assessment Science Integrating point and Nonpoint Sources
BMPs – Best Management Practices
CoSM – City of San Marcos
EAA – Edwards Aquifer Authority
EAHCP – Edwards Aquifer Habitat Conservation Plan
EARIP – Edwards Aquifer Recovery Implementation Program
EARZ – Edwards Aquifer Recharge Zone
ESA – Endangered Species Act
ETJ – Extra Territorial Jurisdiction
HCP – Habitat Conservation Plan
HSPF – Hydrologic Simulation Program FORTRAN
IC – Impervious Cover
IPM – Integrated Pest Management
LDC – Land Development Code
LEED – Leadership in Energy and Environmental Design
LID – Low Impact Development
MCWE – Meadows Center for Water and the Environment
ROW – Right of Way
RWH – Rain Water Harvesting
SMR – San Marcos River
SMWI – San Marcos Watershed Initiative
SPV – Stream Protection Volume
SWMP – Storm Water Management Plan
TCEQ - Texas Commission on Environmental Quality
TDS – Total Dissolved Solids
TSS – Total Suspended Solids
TXST – Texas State University
USFWS - United States Fish and Wildlife Service
WQ – Water Quality
WQPP – Water Quality Protection Plan

Executive Summary – Texas State University

The Water Quality Protection Plan (WQPP or Plan) is being developed for the San Marcos area under the authority of the Edwards Aquifer Habitat Conservation Plan (EAHCP, 2012). The EAHCP requires that Texas State University, as well as the City of San Marcos, take actions that increase the likelihood of survival and recovery of threatened and endangered species found in the Edwards Aquifer and Upper San Marcos River ecosystems. The area addressed by the WQPP includes the jurisdictional areas of each entity that drain to critical habitat from surface or ground water sources, as shown in the figure below.



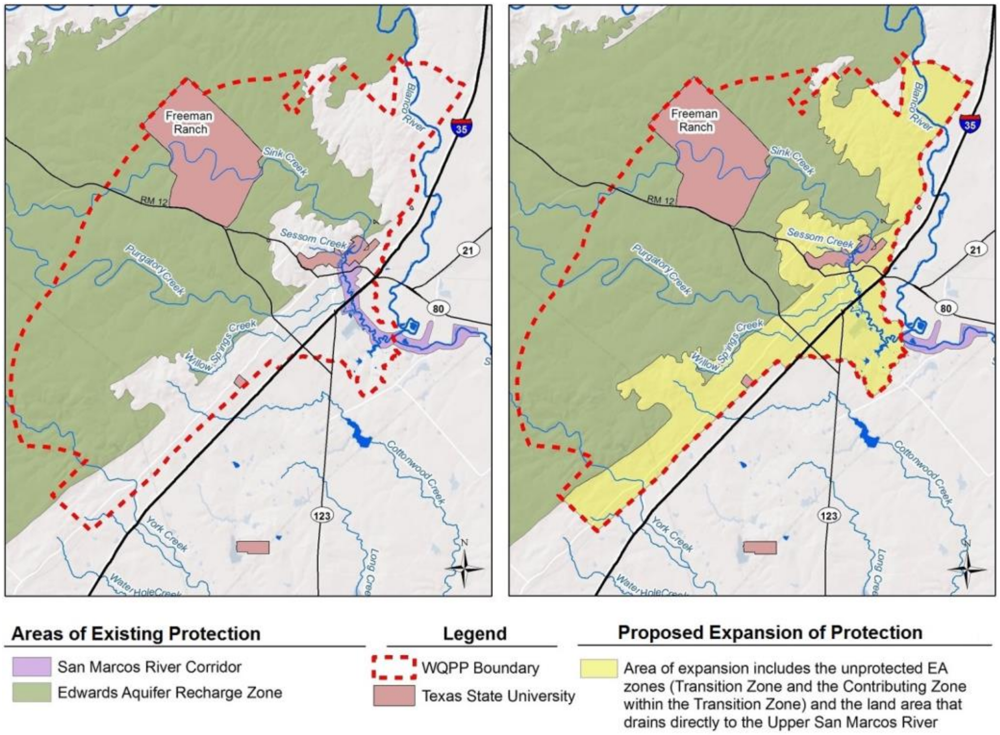
Map: RPS and John Gleason

The primary charge for the Plan, per the EAHCP, is to reduce the impacts of impervious cover (IC) and associated nonpoint source pollution. The WQPP team is coordinating its planning efforts with several related watershed protection initiatives. These related initiatives are described in the table below. The drivers for each are noted. Texas State University is the author of the other plans: the Watershed Protection Plan, the Texas State University MS4 Stormwater Management Program (SWMP) Plan, and the Texas State University Construction Standards.

	Concurrent Watershed Protection Initiatives			
Elements	**Watershed Protection Plan (WPP)**	**Water Quality Protection Plan (WQPP)**	**MS4 SWMP**	**TX ST Construction Standards**
Author	Meadows Ctr. for Water & the Environment	Consultants: John Gleason LLC, et al	Texas State University	Texas State University
Oversight Agency	TCEQ	US Fish & Wildlife Service* (FWS)	TCEQ	Texas State University
Plan Funding	TCEQ 319 Grant	EAA Aquifer pumping fees	Texas State University	Texas State University
Driver	TCEQ 303d List for TDS	EAHCP Incidental Take Permit	TPDES Permit	Chapter 3 Guidelines
WQ Threats/ Concerns	Total Dissolved Solids (TDS)	All pollutants; also stream erosion, infiltration/ recharge, water efficiency	All pollutants	TSS, nutrients, runoff rate and volume, infiltration, water efficiency
Required or Voluntary?	Voluntary	Required (specific solutions are chosen by the permittee*	Required (specific solutions are chosen by the permittee)	Required with LEED “silver” rating goal
Deliverables	WPP Report	Annual WQPP Report	Annual SWMP Report	Individual project design, construction, maintenance
Implementation Funding	Grant-funded	Texas State University (potential grant funding)	Texas State University	Texas State University

An assessment of Spring Lake and the Upper San Marcos River determined that these aquatic resources have been impacted by urban stormwater runoff from existing development in the San Marcos area (Nowlin and Schwartz, 2012). These impacts are related to both the quality and quantity of runoff. Pollutants in urban stormwater runoff include total suspended solids (TSS), nutrients (including nitrogen and phosphorus), bacteria, metals, and many other constituents. Spring Lake and the San Marcos River system are known to be highly susceptible to increases in total phosphorus (TP) which can cause excessive algae growth, deplete oxygen levels and adversely impacts aquatic species and habitat. Sources of TP include soil erosion, atmospheric deposition, automobile exhaust, animal waste, detergents, and fertilizers. In addition to the relatively poor water quality in urban stormwater runoff, land development and related activities can cause excessive volumes of stormwater that accelerate downstream erosion, limit infiltration and recharge, and reduce spring flow by pumping water from the Edwards Aquifer for human use. The WQPP recommends that Texas State University implement stormwater management measures that reduce pollutant loads, minimize downstream creek erosion, maintain or increase rates of infiltration for projects in the recharge zone, and reduce water use (potable, groundwater, river diversion) for landscape irrigation (by a percentage based on SITES guidelines). http://www.sustainablesites.org/

Currently the geographic area where all development must include water quality protection is limited to the Edwards Aquifer Recharge Zone (per TCEQ requirements). The WQPP recommends expansion of the protected area to include all areas within the Plan boundary, as shown below.



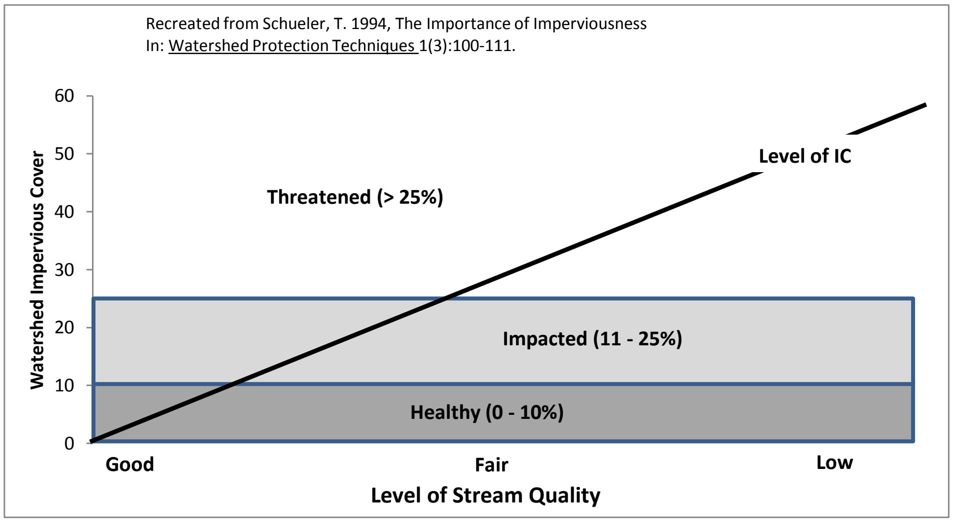
Map: RPS

Description of Water Quality Protection Measures

The Plan implements the concept of sustainability by integrating stormwater management with water conservation practices and water supply protection. The following information highlights essential elements and recommendations of the Plan as they apply to Texas State University – San Marcos. Many of them are broadly addressed in the recommendations of the 2012 – 2017 Campus Master Plan (Broaddus Planning, 2012). The WQPP advances these recommendations to a more specific level.

Gray-to-Green Transformation

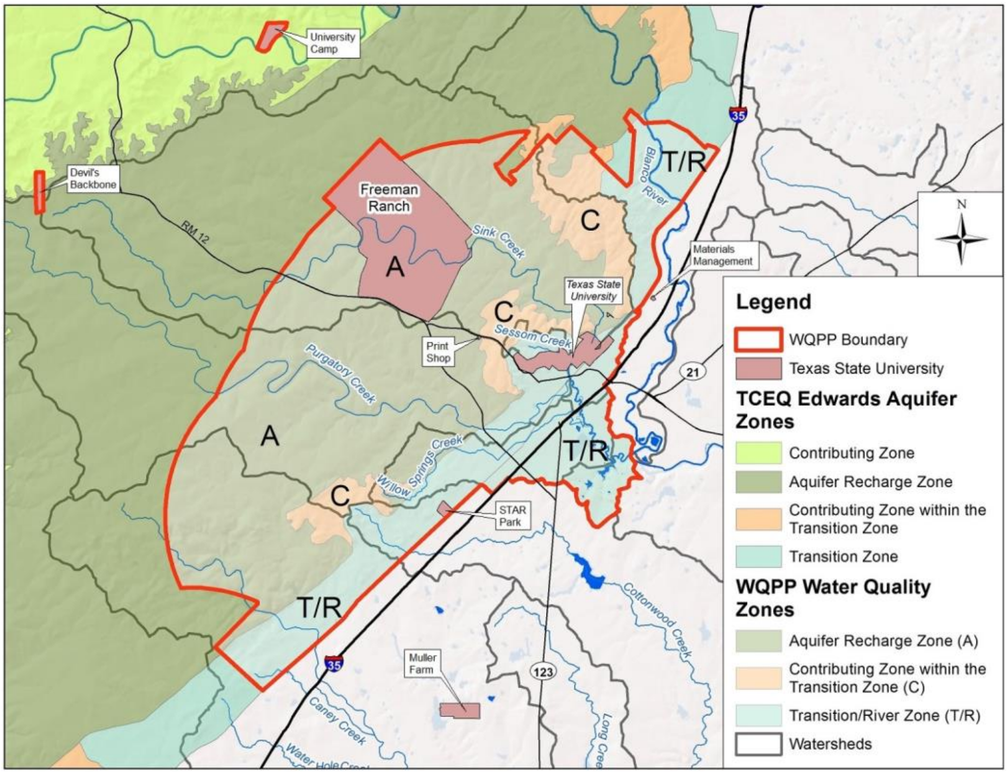
The current level of impervious cover (IC) on campus is 38.8%, per the Land Use Analysis in the 2012 – 2017 Campus Master Plan. Per the Campus Master Plan, Texas State University intends to reduce the overall level of impervious cover, which is commendable. Taking this idea further, the WQPP proposes that the campus implement stormwater management measures for new development and redevelopment in the main campus area, such that the post development runoff quality is equivalent to the water quality from a site with 10% impervious cover (though actual IC % will be higher). This is important because 10% imperviousness is the level at which streams degrade due to the negative impacts of stormwater runoff, as shown in the chart below (Schueler, 1994).


Recreated from Schueler, T. 1994, The Importance of Imperviousness
In: Watershed Protection Techniques 1(3):100-111.

The phrase ‘stormwater management measures’ includes structural stormwater facilities, such as ponds and rain gardens, as well as non-structural measures, such as design standards, design criteria, education and programs. These are also called best management practices (BMPs) and, when utilizing attractive landscaping rather than concrete, are often collectively referred to as green infrastructure.

Campus Standards

The WQPP proposes that Texas State University adopt standards requiring enhanced construction sediment controls and permanent, structural BMPs that manage stormwater runoff quality and quantity for all future campus projects that exceed a threshold of 5000 square feet of soil disturbance (whether new construction or redevelopment). Projects that meet this standard will also allow Texas State University to take credit towards meeting the requirements of Minimum Control Measure 4 of the Campus Storm Water Management Program (SWMP). Surface facilities (e.g. biofiltration, rain gardens, constructed wetlands) are recommended, and shall be designed based on their location within proposed Water Quality Zones (see map) and the performance standards described below.



Map: RPS and John Gleason

1. Zone A – Aquifer Recharge Zone: Achieve a pollutant load target condition equivalent to a site with 0% IC (non-degradation) and an actual impervious cover limit of 20%. University property that lies within this zone includes Freeman Ranch, Backbone property, University Camp, the Print Shop, and a very small area of campus near the Meadows Center parking lot. This is not intended to be retroactive for existing impervious cover.
2. Zone C – Contributing Zone (within the Transition Zone): Achieve a pollutant load target condition equivalent to a site with 0% IC (non-degradation). University property that lies within this zone includes portions of the Devil's Backbone Property, University Camp, and a very small area of campus near the Meadows Center.
3. Zone T/R – Transition/River Zone: Achieve a pollutant load target condition equivalent to a site with ≤10% IC. University property that lies within this zone includes 99% of the main campus and all of the STAR Park.
4. Capture and manage runoff to minimize downstream erosion and promote infiltration.
5. If the stormwater management target conditions (i.e. pollutant load, erosion and infiltration) cannot be met onsite, they shall be met in a downstream retrofit facility (further described below).
6. Reduce the use of potable water, river water diversion, and/or groundwater through coordination with the existing State regulations requiring rainwater harvesting, directing runoff from impervious cover onto

landscape areas, the use of drought tolerant plants, and the use of efficient irrigation systems that, in some situations, are capable of reusing captured stormwater.

The basis for the proposed higher standards described above is provided in the table below.

Recommendation	Basis
Require practices (BMPs) that manage stormwater runoff quality and quantity for all future campus projects that exceed a threshold of 5000 square feet	The proposed threshold of 5000 sf has been selected as reasonable compared to reference ranges, which extend from all IC (TCEQ EA Rules, CoSM Recharge Zone, CoA BSZ, and Lake Tahoe), the State of Maryland (250 sf when near Chesapeake Bay), CoA non-Barton Springs Zone (8,000 sf), and the MS4 SWMP (1 acre)
Zone A: For new development and redevelopment, manage stormwater runoff pollution from developed sites to mimic undeveloped conditions (non-degradation) and limit IC to 20% of site.	The Edwards Aquifer is highly susceptible to pollutants and the listed species are vulnerable to, and threatened by, pollution due to land development. Current impacts exist and are attributed to land development activities thus a high level of protection is necessary. Non-degradation and 20% IC limits are used regionally where endangered aquatic species exist (in the CoA BSZ Rules).
Zone C: For new development and redevelopment, manage stormwater runoff pollution to mimic undeveloped conditions (non-degradation) and no IC limits	This area drains into Zone A thus the pollutant load goals are the same ('Non-degradation', see Zone A, above). WQPP chapters 5 and 6 provide more detailed information on pollutants, threats and impacts. No IC limits are recommended since no direct recharge occurs.
Zone T/R: For new development and redevelopment, achieve a pollutant load target condition of 10%	No IC limits are proposed. 10% IC is a threshold at which stream systems are likely to become impacted, thus the proposed requirement should be reasonably protective.
Retain and manage frequent stormwater events to minimize downstream erosion and promote infiltration	Not required in TCEQ Rules or the MS4 SWMP. Yet the cause for the majority of sediment load in streams and rivers is due to downstream bank erosion caused by excessive runoff volumes from upstream IC.
Reduce the use of potable water, river water diversion, and/or groundwater (use the baseline for irrigation reduction described in SITES v2)	Experts estimate that as much as 50% of water used for irrigation is wasted on average nationwide. Alternative water sources include harvested rainwater and redirected stormwater runoff. Reduce demand with drought tolerant plants and efficient irrigation systems.
Reduce the impacts of existing development by implementing regional stormwater retrofits	Current impacts to Critical Habitat are attributed to existing IC thus stormwater retrofits are recommended to be included in new and redevelopment projects as the Campus Master Plan is implemented

Stormwater Retrofit Opportunities

The Plan recommends the implementation of stormwater retrofit projects to counteract impacts of existing development on Critical Habitat. Retrofit opportunities consist of new installations or upgrades to existing Best

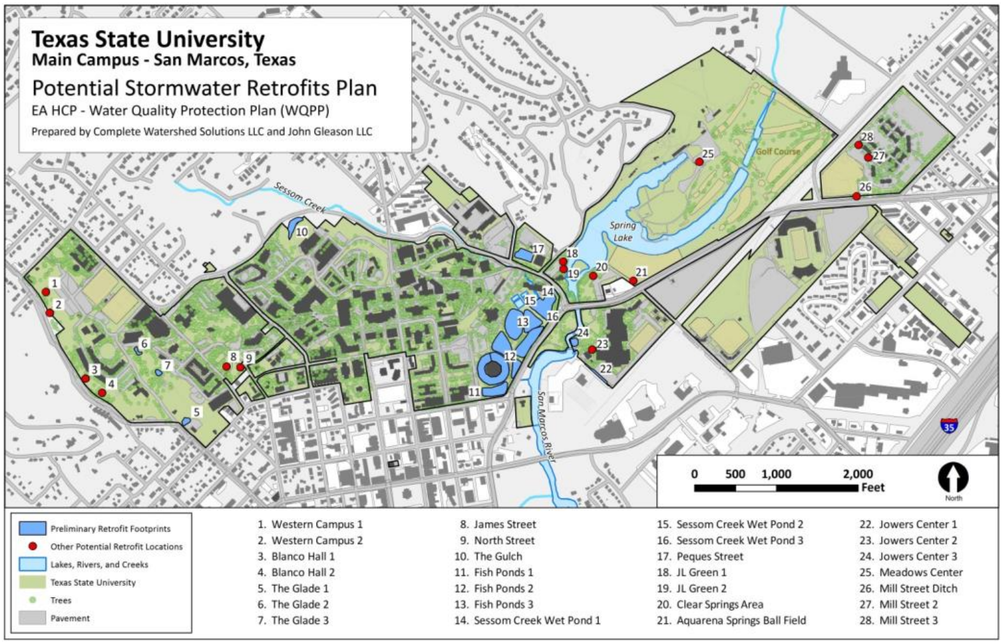
Management Practices (BMPs) in developed areas lacking adequate stormwater treatment. These projects can be challenging due to existing site constraints that reduce flexibility in selecting and sizing BMPs.

This WQPP Project Team undertook a rigorous selection process to identify and prioritize stormwater retrofit project opportunities for consideration by Texas State University. The process identified a number of feasible, cost-effective stormwater retrofit opportunities that might serve as valuable university investments. The work products developed also provide a solid starting point for an ongoing Water Quality Retrofit Program. These facilities shall be designed to serve as campus amenities and be integrated into projects resulting from the Ten Year Building Plan, the Ten Year Renovation Plan, and the Landscape System Plan. A prioritized ranking of selected potential projects is shown below.

Prioritized University Retrofit Opportunities

1. Fish Ponds (Option 3): The existing fish ponds are to be retrofitted as constructed wetlands. They will treat 413 acres and remove 184 lbs of phosphorus annually.
2. Sessom Creek Wet Pond (Option 3): The existing wet pond is under-sized and needs maintenance. Improvements allow it to treat 476 acres, removing 253 lbs TP annually.
3. The Gulch: Biofiltration is proposed at the existing facility, which drains 57 campus acres. 27 lbs. of phosphorus will be removed annually.
4. Jowers Center: Rainwater harvesting and rain gardens are proposed to treat 10 acres with 67% impervious cover yielding 15 lbs. of phosphorus annually.
5. The Glade: A series of rain gardens and biofiltration will treat 26 acres at 40% IC. Improvements will also address problematic storm flows at the adjacent recycling center.

The potential water quality retrofit opportunities noted above, as well as additional opportunities, are shown in the map below. In addition to those shown, the WQPP team believes that there are many additional small-scale potential retrofit opportunities throughout the 486 acre site. In addition to treating urban runoff, these small-scale BMPs can serve as landscape amenities that, if properly designed, may reduce the required levels of irrigation and maintenance in comparison to the landscapes they replace.



Map: Complete Watershed Solutions LLC

Additional Recommendations

Additional elements and recommendations of the Plan are noted below.

1) Design Criteria: Create and adopt design criteria that provide detailed design guidelines for stormwater BMPs intended to meet the Campus Standards noted above.
2) Turf Management: As required in section 5.4.9 of the HCP and addressed in section 6.2.3 of the Campus SWMP, update campus standards for turf management BMPs. This includes developing a Turfgrass Management System Plan for the campus golf course and athletic fields. This document should include proposals for, and descriptions of, improvements to current and future practices.
3) Adaptive Management Process (AMP): periodically review and revise the campus stormwater standards, criteria, and retrofit plans, as necessary, in order to be both protective and cost-effective. These periodic reviews could align with the Campus Master Plan updates, the Ten Year Building Plan, the Ten Year Renovation Plan, and the Landscape System Plan.

Stormwater Runoff Quality Programs - Requirements

The recommended stormwater management measures in the WQPP are designed to be compatible with, and build on, the State of Texas stormwater programs, activities and requirements noted in the table below. The requirements of each are provided as a comparison to WQPP recommendations. The Plan recommends that the measures are adopted within time frames that are congruent with the review periods for each of the documents referenced.

Program or Activity	TPDES MS4 Permit TXR 040000	TPDES Construction General Permit TXR 150000	TCEQ Edwards Aquifer Rule Water Pollution Abatement Plan (WPAP) §213	WQPP Recommendations
Public Education and Outreach	Required	-	-	Proposed
Public Participation/Involvement	Required	-	-	Proposed
Illicit Discharge Detection and Elimination	Required	-	-	Proposed
Construction Site Runoff Control aka Temporary Stormwater Controls	Required for all sites. SWPP and coverage under TXR 150000 required for ≥ 1 acre *	Required for sites ≥ 1 acre*	Required but no area threshold defined	Required for any land disturbing activity
Post-Construction Runoff Control aka Permanent Stormwater Controls	Required for sites ≥ 1 acre*	-	Required for sites adding > 20% impervious cover	Required for sites disturbing ≥ 5,000 ft^2
Pollution Prevention/Good Housekeeping	Required	Required	Optional	Required
Stormwater Retrofit Projects	-	-	-	Recommended
Geologic Assessment	-	-	Required	Required in EAZ
Stream Buffers	-	-	Optional	Required
Buffers around recharge features	-	-	Required	Required in EAZ
Buffers around wetlands and other critical ecological area	-	-	-	Required

* Superseded in the Edwards Aquifer Zone (EAZ) by 30 TAC 213 (Edwards Aquifer Rules)

Implementation

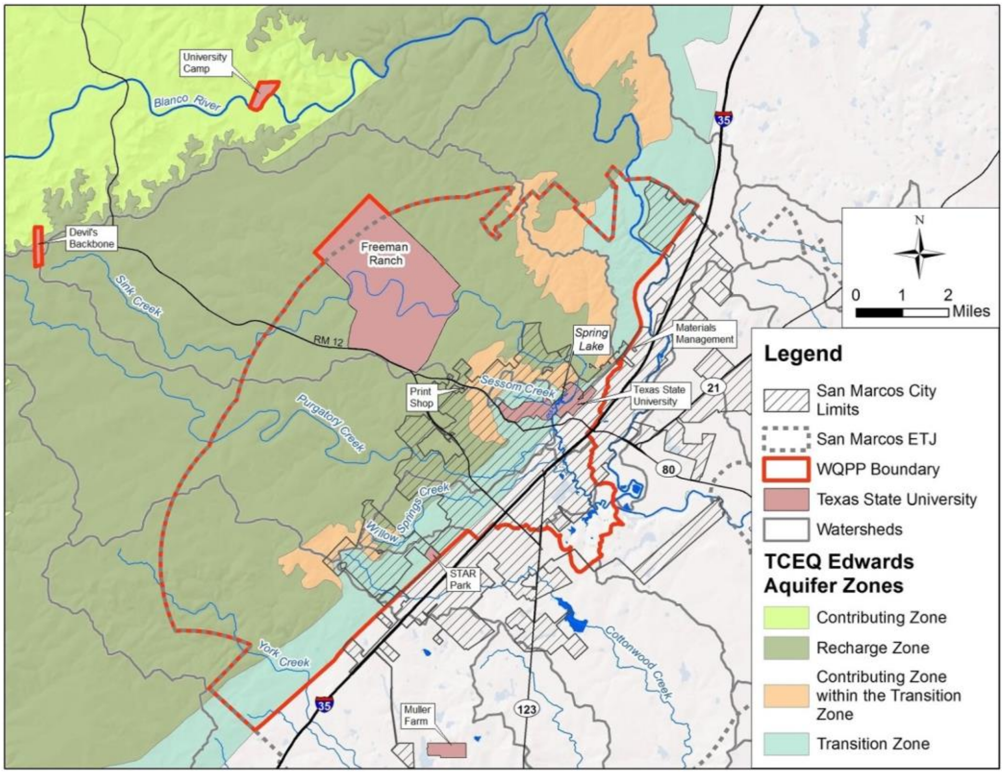
The WQPP recommends that generally, water quality requirements apply equally to the City and the University. With equal compliance by the City and University, the recommended approach:

- Brings uniformity to protection measures provided by each entity
- Advances the sustainability goals of each entity
- Appeals to an overall sense of fairness

The application of these water quality requirements to Texas State University will require that they be interpreted for the campus environment. In the municipal environment, the water quality requirements are designed to apply to land parcels of varied ownership and oversight. Individual lot lines and subdivided land parcels do not apply to the campus as they do in the municipal setting. The University is a single owner responsible for the infrastructure of a large, contiguous area within the Plan boundary. This is an advantage in that it allows a more holistic approach that may be customized for the needs of the receiving waters. A logical approach would be to apply water quality requirements for new development on the basis of the potential impact of the facility to campus subwatersheds (drainage areas). As a starting point, the WQPP proposes that the requirements be applied on a trial basis to selected campus improvement projects as identified in the 2012 – 2017 Campus Master Plan.

Executive Summary – City of San Marcos

The Water Quality Protection Plan (WQPP or Plan) is being developed for the San Marcos area under the authority of the Edwards Aquifer Habitat Conservation Plan (HCP, 2012). The Habitat Conservation Plan requires that the City of San Marcos, as well as Texas State University, take actions that increase the likelihood of survival and recovery of threatened and endangered species found in the Edwards Aquifer and Upper San Marcos River ecosystems. The area addressed by the WQPP includes the jurisdictional areas of each entity that drain to critical habitat from surface or ground water sources, as shown in the figure below.



Map: RPS and John Gleason

The primary charge for the Plan, per the EAHCP, is to reduce the impacts of impervious cover (IC) and associated nonpoint source pollution. The WQPP team is coordinating its planning efforts with several related watershed protection initiatives. These related initiatives are described in the table below. The drivers for each are noted. The City of San Marcos is the author of one of the plans: the City of San Marcos Stormwater Management Program (SWMP) Plan. Ongoing efforts of the WQPP will be synchronized with those of the other plans and processes noted below.

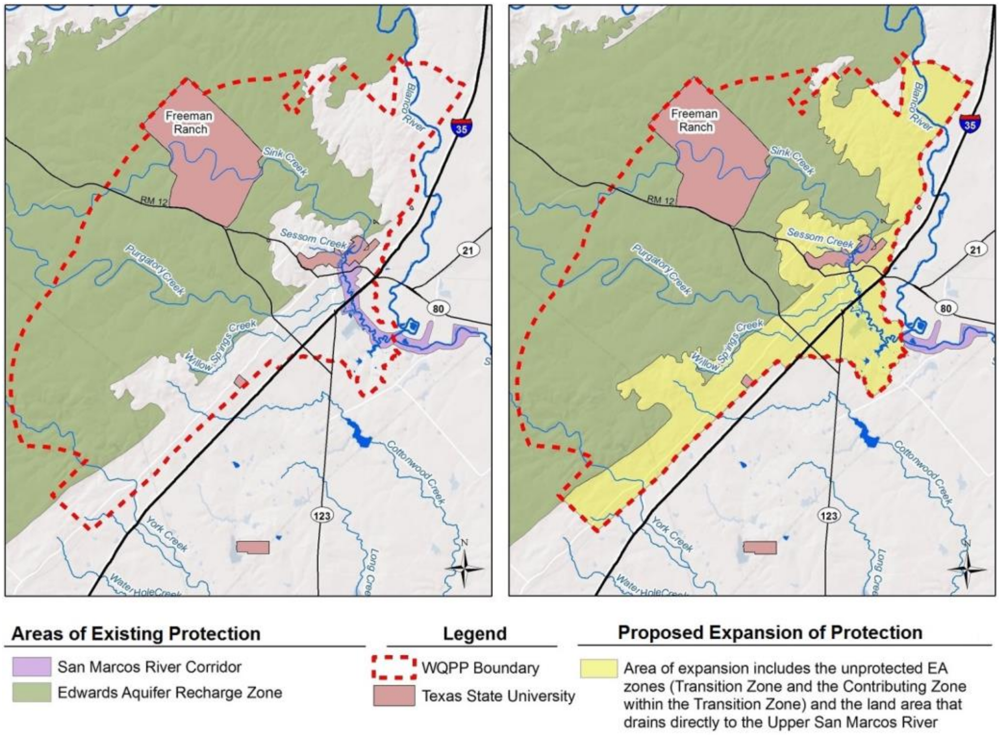
	Concurrent Watershed Protection Initiatives			
Elements	**Watershed Protection Plan (WPP)**	**Water Quality Protection Plan (WQPP)**	**MS4 SWMP**	**CoSM Land Development Code**
Author	Meadows Ctr. for Water & the Environment	Consultants: John Gleason LLC, et al	City of San Marcos	City of San Marcos (and consultants)
Oversight Agency	TCEQ	US Fish & Wildlife Service* (FWS)	TCEQ	City of San Marcos
Plan Funding	TCEQ 319 Grant	EAA Aquifer pumping fees	City of San Marcos	City of San Marcos
Driver	TCEQ 303d List for TDS	EAHCP Incidental Take Permit	TPDES Permit	City of San Marcos
WQ Threats/ Concerns	Total Dissolved Solids (TDS)	All pollutants; also stream erosion, infiltration/ recharge, water efficiency	All pollutants	TSS, runoff rate and volume, water efficiency
Required or Voluntary?	Voluntary	Required (specific solutions are chosen by the permittee*	Required (specific solutions are chosen by the permittee)	Voluntary
Deliverables	WPP Report	Annual WQPP Report	Annual SWMP Report	Revised Code
Implementation Funding	Grant-funded	City of San Marcos	City of San Marcos	City of San Marcos

An assessment of Spring Lake and the Upper San Marcos River determined that these aquatic resources have been impacted by urban stormwater runoff from existing development in the San Marcos area (Nowlin and Schwartz, 2012). These impacts are related to both the quality and quantity of runoff. Pollutants in urban stormwater runoff include total suspended solids (TSS), nutrients (including nitrogen and phosphorus), bacteria, metals, and many other constituents. Spring Lake and the San Marcos River system are known to be highly susceptible to increases in total phosphorus (TP) which can cause excessive algae growth, deplete oxygen levels and adversely impacts aquatic species and habitat. Sources of TP include soil erosion, atmospheric deposition, automobile exhaust, animal waste, detergents, and fertilizers. In addition to the relatively poor water quality in urban stormwater runoff, land development and related activities can cause excessive volumes of stormwater that accelerate downstream erosion, limit infiltration and recharge, and reduce spring flow by pumping water from the Edwards Aquifer for human use. The WQPP recommends that the City of San Marcos implement stormwater management measures that reduce pollutant loads, minimize downstream creek erosion, maintain or increase rates of infiltration for projects in the recharge zone, and reduce potable water use for landscape irrigation (by a percentage based on SITES guidelines). http://www.sustainablesites.org/

Currently the geographic area where all development must include water quality protection is limited to two areas:

- the Edwards Aquifer Recharge Zone (per TCEQ requirements)
- the San Marcos River Corridor (per City of San Marcos LDC)

The WQPP recommends expansion of the protected area to include all areas within the Plan boundary, as shown below.

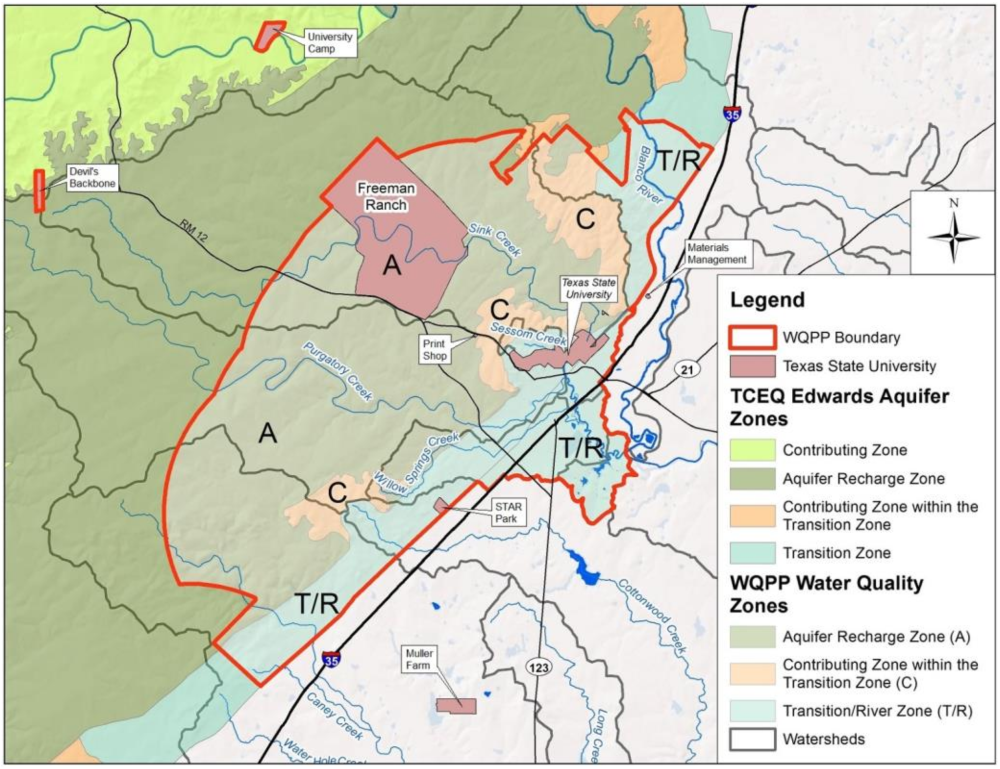


Map: RPS

Description of Water Quality Protection Measures

The Plan implements the concept of sustainability by integrating stormwater management measures with water conservation practices and water supply protection. Many of the Plan recommendations are broadly addressed in the City's Comprehensive Plan: Vision San Marcos (City of San Marcos, 2013). The phrase 'stormwater management measures' includes structural stormwater facilities, such as ponds and rain gardens, as well as non-structural measures, such as design standards, design criteria, education and programs. These are also called best management practices (BMPs) and, when utilizing attractive landscaping rather than concrete, are often collectively referred to as green infrastructure.

The WQPP proposes that the City of San Marcos adopt standards requiring enhanced construction sediment controls and permanent, structural BMPs that manage stormwater runoff quality and quantity for all future land development projects that exceed a threshold of 5000 square feet (whether new construction or redevelopment). Projects that meet this standard will also allow the City of San Marcos to take credit towards meeting the requirements of Minimum Control Measure 4 of the City's Storm Water Management Program (SWMP). Surface facilities (e.g. biofiltration and rain gardens) are recommended, and shall be designed based on their location within Water Quality Zones (see map) and the performance standards described below.

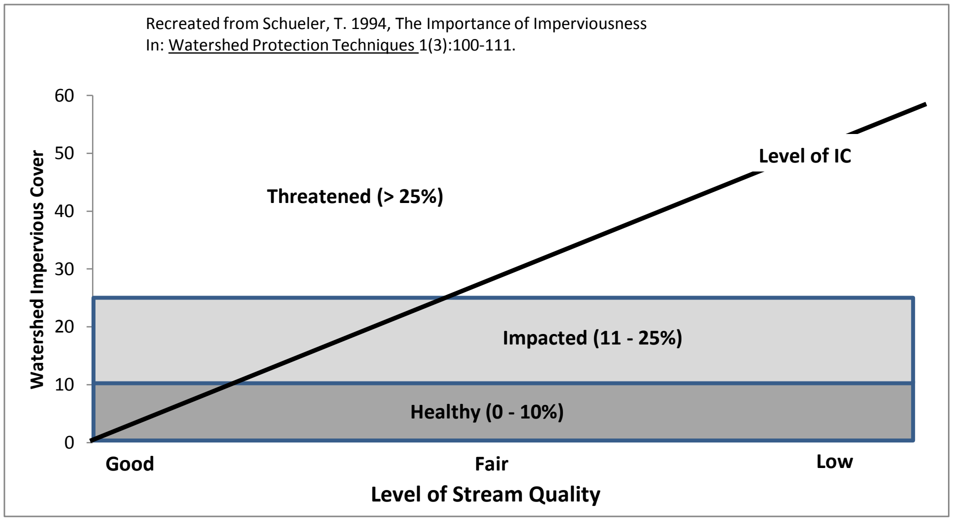


Map: RPS and John Gleason

The table below lists the recommended water quality zones and summarizes their requirements including pollutant load target conditions and impervious cover limits. Pollutant load targets refer to a target impervious cover percentage that a developed site will match in terms of pollution loading and hydrologic conditions. For example, a developed site has 50% impervious cover yet, through the use of LID and BMP's, generates the pollution load of 10% impervious cover. To minimize the potential for impervious cover to cause stream erosion, developed sites are to provide extended detention that will meet stream protection volume requirements. The table below shows proposed land development requirements, which are based on their location within each water quality zone.

Zone Symbol	Water Quality Zone	Pollutant Load Target	Impervious Cover Limit
A	Aquifer Recharge Zone	0% (Non-degradation)	20%
C	Contributing Zone	0% (Non-degradation)	None
T/R	Transition/River Zone	10%	None

Due to the sensitive nature of the Edwards Aquifer Recharge Zone, and because the Contributing Zone (within the Transition Zone) drains to the Recharge Zone, the WQPP proposes a non-degradation standard, such that the post development runoff quality is equivalent to the water quality from a site with 0% impervious cover (though actual IC % will be higher). In the Transition/River Zone, the WQPP proposes a pollutant load target of 10%. This is important because 10% imperviousness is the level at which streams degrade due to the negative impacts of stormwater runoff, as shown in the chart below (Schueler, 1994).


Recreated from Schueler, T. 1994, The Importance of Imperviousness
In: Watershed Protection Techniques 1(3):100-111.

The basis for each of the above recommendations is noted in the table below.

Recommendation	Basis
Require practices (BMPs) that manage stormwater runoff quality and quantity for all future land development projects that exceed a threshold of 5000 square feet.	The proposed threshold of 5000 sf has been selected as reasonable compared to reference ranges, which extend from all IC (TCEQ EA Rules, CoSM Recharge Zone, CoA BSZ, and Lake Tahoe), the State of Maryland (250 sf when near Chesapeake Bay), CoA non-Barton Springs Zone (8,000 sf), and the MS4 SWMP (1 acre)

Recommendation	Basis
Zone A: For new development and redevelopment, manage stormwater runoff pollution from developed sites to mimic undeveloped conditions (non-degradation) and limit IC to 20% of site.	The Edwards Aquifer is highly susceptible to pollutants and the listed species are vulnerable to, and threatened by, pollution due to land development. Current impacts exist and are attributed to land development activities thus a high level of protection is necessary. Non-degradation and 20% IC limits are used regionally where endangered aquatic species exist (in the CoA BSZ Rules).
Zone C: For new development and redevelopment, manage stormwater runoff pollution to mimic undeveloped conditions (non-degradation) and no IC limits	This area drains into Zone A thus the pollutant load goals are the same ('Non-degradation', see Zone A, above). WQPP chapters 5 and 6 provide more detailed information on pollutants, threats and impacts. No IC limits are recommended since no direct recharge occurs.
Zone T/R: For new development and redevelopment, achieve a pollutant load target condition of 10%	No IC limits are proposed. 10% IC is a threshold at which stream systems are likely to become impacted, thus the proposed requirement should be reasonably protective.
Retain and manage frequent stormwater events to minimize downstream erosion and promote infiltration	Not required in TCEQ Rules or the MS4 SWMP. Yet the cause for the majority of sediment load in streams and rivers is due to downstream bank erosion caused by excessive runoff volumes from upstream IC.
Reduce the use of potable water, river water diversion, and/or groundwater (use the baseline for irrigation reduction described in SITES v2)	Experts estimate that as much as 50% of water used for irrigation is wasted on average nationwide. Alternative water sources include harvested rainwater and redirected stormwater runoff. Reduce demand with drought tolerant plants and efficient irrigation systems.

Additional Recommendations

Additional elements and recommendations of the Plan are noted below.

1) Design Criteria: Create and adopt design criteria that provide detailed design guidelines for stormwater BMPs intended to meet the proposed Land Development Code standards noted above.
2) Comprehensive Site Planning and Pre-Development Review: Site plans of proposed new development and redevelopment should be include a technical demonstration that it meets the City's water quality standards.
3) Reuse Stormwater for Landscape Irrigation: Reduce landscape irrigation with potable water by ≥ 50% by implementing water conservation practices and stormwater capture and reuse.
4) Natural Area Conservation: Acquiring land and establishing conservation easements will provide benefits in perpetuity by preventing future development and associated pollutants.
5) Transferable Development Rights: Direct higher intensity development either outside the Planning Region or into preferred growth areas by allowing development rights to be transferred from one property to another.
6) Public Education and Outreach: As noted in section 3.1 of the City's SWMP, expand efforts to increase the public's understanding of their overall water quality impacts and what they can do to reduce them.
7) Turf Management: As required in section 5.4.9 of the HCP and in consideration of BMPs 5.01 and 5.06 of the City's SWMP, develop a Turfgrass Management System Plan to minimize the potential water quality impact of municipal athletic fields.

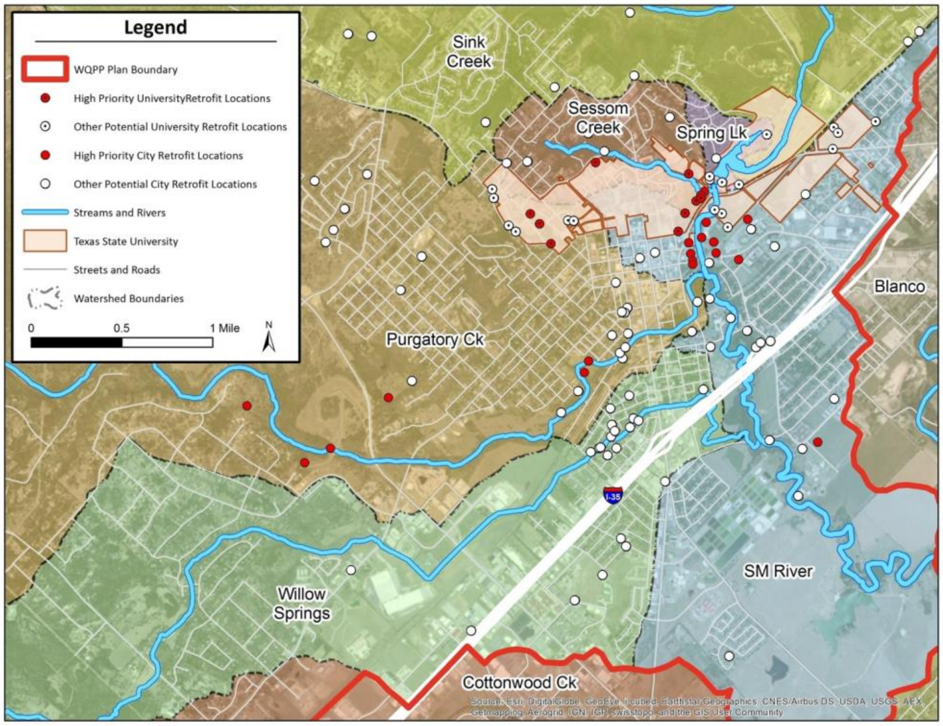
Stormwater Retrofit Opportunities

This WQPP Project Team undertook a rigorous selection process to identify and prioritize stormwater retrofit project opportunities for consideration by the City of San Marcos. The process identified a number of feasible, cost-effective stormwater retrofit opportunities that might serve as valuable community investments. The work products developed also provide a solid starting point for an ongoing Water Quality Retrofit Program. A prioritized ranking of selected potential projects is shown below.

Prioritized City Retrofit Opportunities

1. Wastewater Treatment Plant: The proposed infiltration and extended detention pond will treat 176 acres at 93% capture efficiency and remove 141 lbs of phosphorus annually.
2. Downtown Biofiltration: Construction of this facility near C.M. Allen Parkway was recently completed. It treats runoff from 32 acres that are 60% impervious.
3. The Big Ditch: This existing channel drains 320 acres in the mid-town area that are 43% impervious. Proposed improvements will remove 147 lbs of phosphorus annually.
4. Veterans Memorial Park: Proposed biofiltration will treat 86 acres that are 55% impervious and include most of Springtown Mall and many municipal facilities.
5. City Park: Biofiltration, rain gardens and rainwater harvesting are proposed in association with a new parking facility. This will also serve as a demonstration site.

The potential water quality retrofit opportunities noted above, as well as additional opportunities, are shown in the map below. In addition to those shown, the WQPP team believes that there are many additional small-scale potential retrofit opportunities available throughout all City-owned property, including the public ROW.



Map: Complete Watershed Solutions LLC

Stormwater Runoff Quality Programs - Requirements

The recommended stormwater management measures in the WQPP are designed to be compatible with, and build on, the State of Texas stormwater programs, activities and requirements noted in the table below. The requirements of each are provided as a comparison to WQPP recommendations. The Plan recommends that the measures are adopted within time frames that are congruent with the review periods for each of the documents referenced.

Program or Activity	TPDES MS4 Permit TXR 040000	TPDES Construction General Permit TXR 150000	TCEQ Edwards Aquifer Rule Water Pollution Abatement Plan (WPAP) §213	WQPP Recommendations
Public Education and Outreach	Required	-	-	Proposed
Public Participation/Involvement	Required	-	-	Proposed

Illicit Discharge Detection and Elimination	Required	-	-	Proposed
Construction Site Runoff Control aka Temporary Stormwater Controls	Required for all sites. SWPP and coverage under TXR 150000 required for ≥ 1 acre *	Required for sites ≥ 1 acre*	Required but no area threshold defined	Required for any land disturbing activity
Post-Construction Runoff Control aka Permanent Stormwater Controls	Required for sites ≥ 1 acre*	-	Required for sites adding > 20% impervious cover	Required for sites disturbing ≥ 5,000 ft^{2}
Pollution Prevention/Good Housekeeping	Required	Required	Optional	Required
Stormwater Retrofit Projects	-	-	-	Recommended
Geologic Assessment	-	-	Required	Required in EAZ
Stream Buffers	-	-	Optional	Required
Buffers around recharge features	-	-	Required	Required in EAZ
Buffers around wetlands and other critical ecological area	-	-	-	Required

* Superseded in the Edwards Aquifer Zone (EAZ) by 30 TAC 213 (Edwards Aquifer Rules)

Implementation

The WQPP recommends that generally, water quality requirements apply equally to the City and the University. With equal compliance by the City and University, the recommended approach:

- Brings uniformity to protection measures provided by each entity
- Advances the sustainability goals of each entity
- Appeals to an overall sense of fairness

The City of San Marcos is revising their Land Development Code in 2015 and 2016 by way of the CodeSMTX process. This is an ideal time to adopt the proposed land development regulations that are recommended in this Plan, which would primarily affect Chapter 6: Environmental Regulations. The proposed regulations are intended to provide an appropriate level of protection and to follow the guiding principle: those who benefit from an activity must bear the responsibility for the costs and impacts of that activity. In addition to new regulations, the WQPP recommends that the City adopt new and revised environmental protection programs. Doing so will help fund future efforts by the City to include WQPP-proposed high priority stormwater retrofits in their CIP program.

Photo: Meadows Center for Water and the Environment

1. PLAN CONTEXT

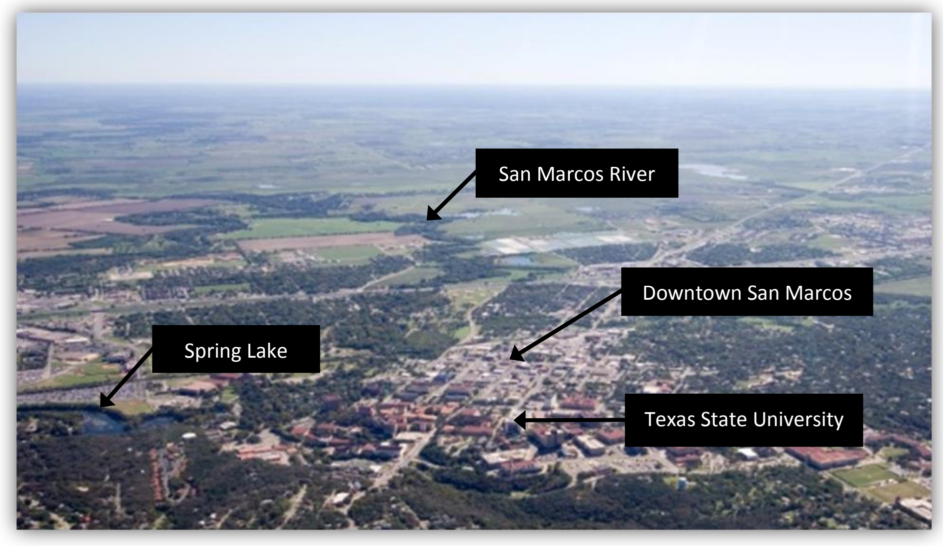
1.1 OVERVIEW AND BACKGROUND

Rapid growth, concerns over water pollution associated with this growth, and the need to protect threatened or endangered species provide impetus for the San Marcos Water Quality Protection Plan (WQPP, or simply, the Plan). Specifically, the WQPP is charged with developing an implementable plan for the City of San Marcos and Texas State University to protect water quality and reduce the impacts of impervious cover, with the following objective (Task 5.7.6 from the HCP Workplan, 2013):

> *Implement a program that minimizes the impacts associated with impervious cover associated with urbanization and changes in land use/cover in the Upper San Marcos watershed; manage stormwater as close to its source as possible, treat stormwater as a resource rather than a waste product; emphasize conservation and the use of on-site features to protect water quality; and increase infiltration to groundwater and aquifer recharge for the protection of riverine integrity.*

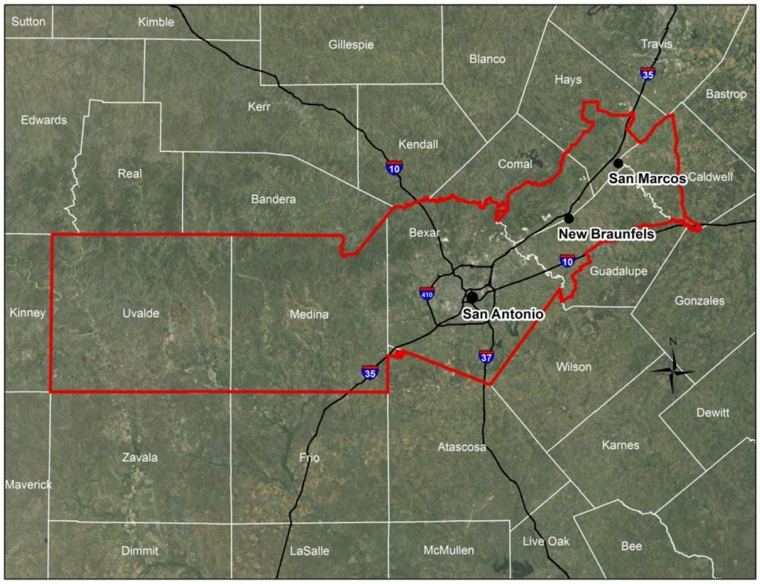
Essentially, the WQPP is a locally developed approach for compliance with the federal Endangered Species Act (ESA) in San Marcos, Texas. The City of San Marcos and Texas State University, in association with several other entities in south-central Texas, collectively hold an Incidental Take Permit (ITP) under Section 10(a)(1)(B) of the (ESA). The U.S. Fish and Wildlife Service issued the ITP in February 2013, allowing the “incidental take” of threatened or endangered species resulting from the otherwise lawful activities involving regulating and pumping of groundwater from the Edwards Aquifer for beneficial uses. Beneficial uses include irrigation, industrial, municipal, and domestic uses, as well as the use of the San Marcos spring and river systems for recreational and other activities. Issuance of the Incidental Take Permit enables all permittees: the Edwards Aquifer Authority; San Antonio Water Systems; the City of New Braunfels, Texas; the City of San Marcos, Texas; and Texas State University to continue their projects and operations while preserving protected species and their habitat. See Figure 1-1 showing some of the major landmarks in the San Marcos area.

Figure 1-1 Aerial Photo Showing Major Landmarks – Looking from North to South



The Plan was prepared in support of Section 5.7.6 Impervious Cover/Water Quality Protection in the Edwards Aquifer Habitat Conservation Plan (EAHCP). The EAHCP Permit Area is shown in Figure 1-2.

Figure 1-2 Edwards Aquifer Habitat Conservation Plan Area



Map: RPS

The EAHCP describes measures designed to ensure that incidental take resulting from the covered activities will be minimized and mitigated to the maximum extent practicable. The measures are also intended to ensure that the incidental take will not appreciably reduce the likelihood of the survival and recovery of covered species associated with the springs and river ecosystems. The EAHCP was published in December 2011. The EAHCP can be found online at: www.fws.gov/southwest/es/AustinTexas/ The Edwards Aquifer Habitat Conservation Plan:

- Describes the regulatory framework of the ITP
- Identifies and provides analyses of covered species
- Describes activities covered by the permit
- Describes the environmental setting and baseline conditions
- Identifies required measures intended to minimize and mitigate the impact of impervious cover
- Describes costs and funding for environmental protection measures

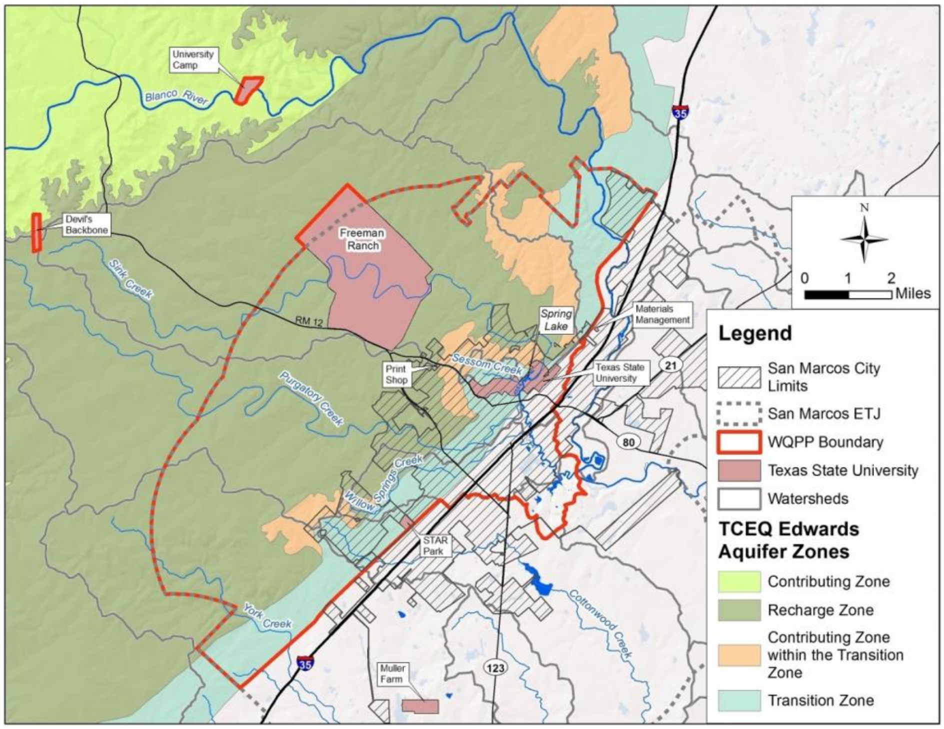
1.2 DESCRIPTION OF THE PLAN AREA

Located on the edge of the beautiful Texas Hill Country and within a population growth corridor, San Marcos is uniquely situated. The following information defines the Plan area and describes its ecoregions, demographics and climate.

1.2.1 PLAN AREA DEFINITION

The Plan includes all areas that drain to critical habitat for listed species, either by surface water runoff or by groundwater flow or both. This includes the Upper San Marcos River watershed and the Edwards Aquifer Zone, extending to the limits of the City's Extra-Territorial Jurisdiction (ETJ), as shown below in Figure 1-3, WQPP Plan Area. There are no endangered species that exist in the San Marcos River south of the point where it meets the Blanco River. Thus the Plan does not apply to the land areas that drain to the river below this confluence. Note that portions of the Blanco River and Caney Creek lie within the Edwards Aquifer Zone and are therefore included within the Plan area. The Plan area lies primarily in the southern tip of Hays County however it also dips into Comal County to the southwest.

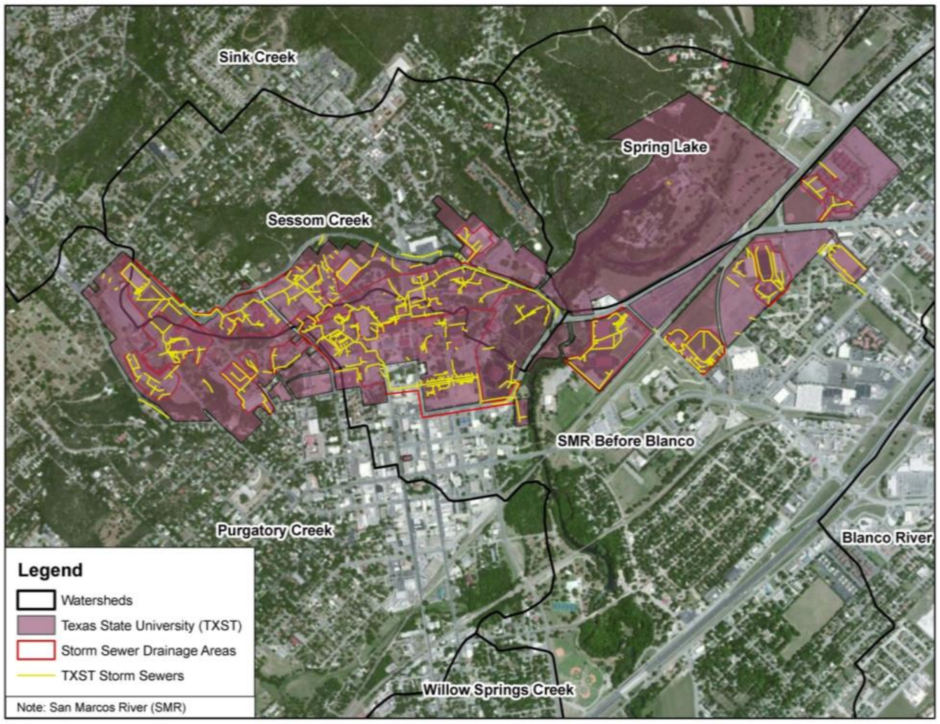
Figure 1-3 WQPP Plan Area



Map: RPS and John Gleason

Four major subwatersheds comprise the Upper San Marcos River watershed: Purgatory Creek, Sessom Creek, Willow Springs Creek, and Sink Creek. The Plan Area encompasses these contributing tributaries and watersheds of the San Marcos River as well as portions of the adjacent Blanco River, Caney Creek and Cottonwood Creek watersheds that extend over the recharge zone of the Edwards Aquifer. These areas were included because portions of the Edwards Aquifer recharge zone are direct conduits to the springs at the headwaters of the river. Therefore potential loadings from these watersheds could affect the water quality discharged at the headwaters. The University campus is within the Purgatory Creek, Sessom Creek, Spring Lake, and San Marcos River watersheds, as shown in Figure 1-4.

Figure 1-4 University Campus Major Watersheds



Map: RPS

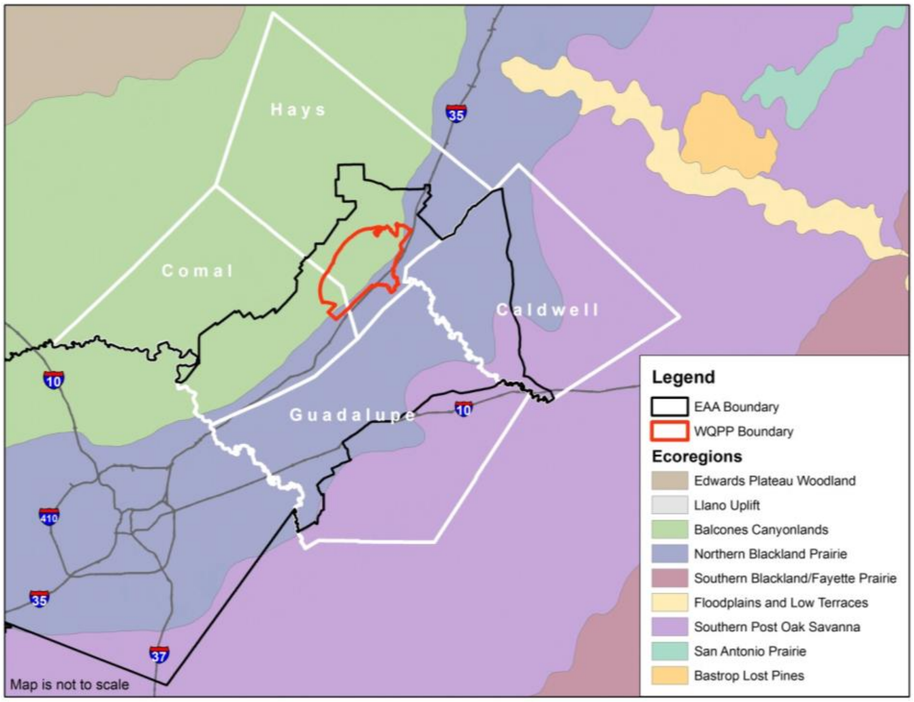
1.2.2 ECOREGIONS OF THE SAN MARCOS AREA

San Marcos is located on the Balcones Escarpment, which forms the boundary between the Hill Country and the Texas Coastal Plains. The Escarpment is a surface expression of the Balcones Fault and separates distinct ecological systems and species distributions. These ecosystems include the Edwards Plateau and Texas Blackland Prairie ecoregions, as described by the U.S. Environmental Protection Agency (Griffith et. al. 2004).

The area west of the city (areas shaded brown and green in Figure 1-5) is within the Balcones Canyonlands portion of the Edwards Plateau ecoregion and forms its southeastern boundary. The topography of this region is characterized by rolling hills composed of limestone rock. This portion of San Marcos has generally shallow, rocky soils over limestone bedrock formations. Some of the limestone formations are highly porous, with numerous caves and other underground cavities that provide channels for surface water to recharge the underlying Edwards Aquifer. The region is crossed by spring-fed streams and eroded canyons in the limestone bedrock.

The soil of the Edwards Plateau is characteristically shallow to moderately deep and undulates between steep to hilly soils over indurated limestone. Due to the predominantly karst limestone composition, there are many permeable recharge features within creek beds and breaks between hills and steep ravines. Common soils in this area include loams, clay loams, combined with limestone parent material. These soils are highly erodible overtime and leach calcium carbonate into overland surface water runoff.

Figure 1-5 Ecoregions of the Area



Map: RPS

The area east of San Marcos (shaded blue in Figure 1-5) is within the Northern Blackland Prairie ecoregion. Land east of the city has been converted to cropland, non-native pasture, and expanding urban uses. The Blackland prairie soil of this region is ideal for farming and agriculture and is primarily used for cropland and livestock grazing. The rolling to nearly level plains of this ecoregion are underlain by interbedded chalks, marls, limestone and shale. Soils in this part of the region are mostly fine-textured, dark, calcareous, and productive. (Griffith et al. 2004, McMahan et al. 1984)

Many springs emerge along the Balcones fault, including the San Marcos Springs. These artesian springs rise from the Edwards Aquifer and are the source of Spring Lake and the San Marcos River. More than 200 springs flow from fissures in the limestone and have never stopped flowing in recorded history. The stability of spring flow helps support rare flora and fauna found in Spring Lake and the upper San Marcos

River. The Edwards Plateau is predominantly covered with woodland vegetation comprised of clusters of Live Oak and Juniper.

1.2.3 GEOLOGY OF THE PLAN AREA

The Edwards Aquifer is one of the most prolific artesian aquifers in the world. It is also the source of the two largest springs in Texas: the Comal and the San Marcos. The Edwards Aquifer serves the domestic, agricultural, industrial and recreational needs of the area. It is also the primary source of drinking water for more than 2 million people including the seventh largest city in the nation, San Antonio.

The Edwards Aquifer in the Balcones fault zone is located in an area of karst terrain, which is landscape underlain by limestone that has been eroded by dissolution, producing ridges, towers, fissures, sinkholes, underground streams, and caverns. The water in the Edwards Aquifer circulates freely along fractures and faults and through honeycombed zones, channels, and caverns. The subterranean aquatic ecosystem of the aquifer is one of the most diverse groundwater ecosystems known in the world. See Figure 1-6 for a cross-section through the Edwards Aquifer.

Figure 1-6 Cross-Section through the Edwards Aquifer

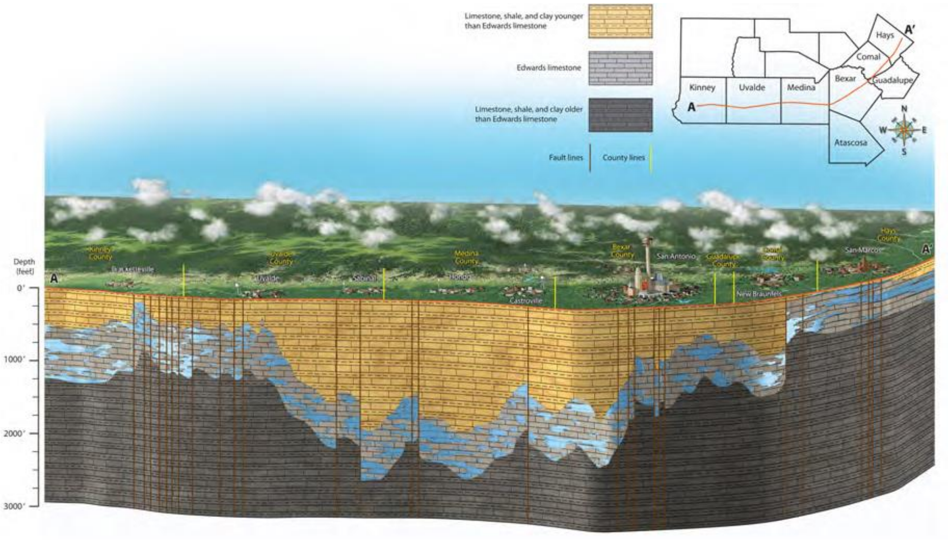


Illustration: Courtesy of the Edwards Aquifer Authority

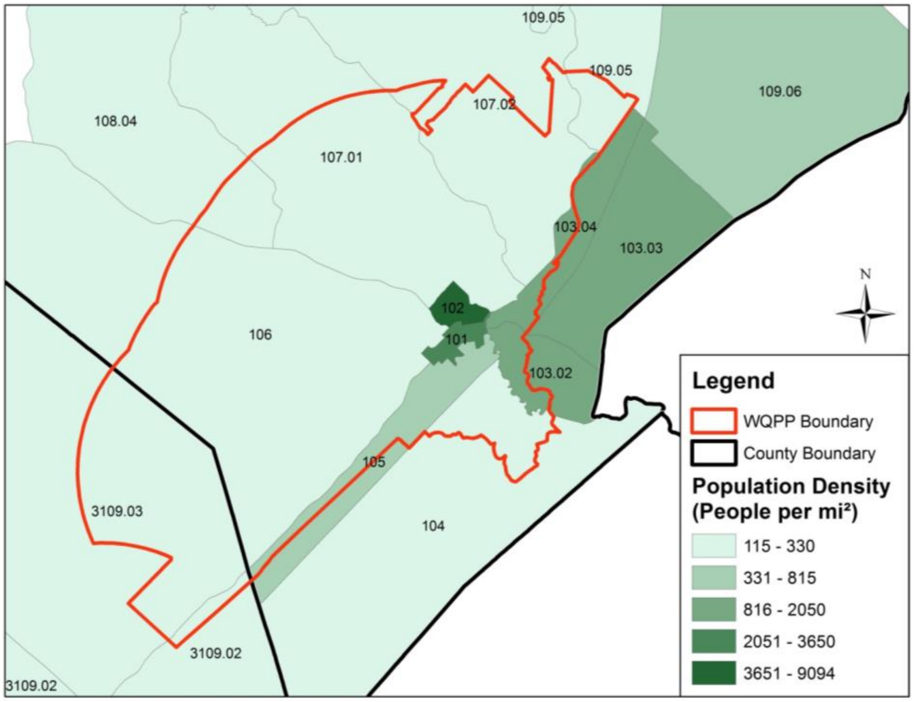
1.2.4 AREA DEMOGRAPHICS

Hays County and the City of San Marcos: Population growth rates in San Marcos and Hays County are among the highest in the country, with a 29.3% increase from 2000 to 2010 in the City, while the county population increased by a remarkable 61% (Nowlin and Schwartz, 2012). These growth rates are greater than the entire state of Texas over this time interval (20.6%) and are far greater than the United States growth rates (9.7%). It is projected that the population of Hays County will increase ~200% in the next

50 years, to a population of 493,320 (TWDB 2010). Indeed, the population of the entire Edwards Aquifer region will increase by 63% to nearly 1.3 million people. Given these population growth projections, the land use demands within the Spring Lake and upper San Marcos River will be much higher and the demand for Edwards Aquifer water resources will be exceptionally high.

To help forecast possible changes within Hays County during the next 30 years, population projections were developed (TXP and CMR 2008). The projections were based on an analysis of historic and recent demographic and economic data (such as population, income, employment, and economic activity). Figure 1-7 shows the boundaries of 8 census tracts in the southern tip of Hays County, as delineated by the U.S. Census Bureau.

Figure 1-7 San Marcos Area Population Growth



Map: RPS

The WQPP Plan area lies primarily within census tracts 10100, 10200, 10302, 10600 and 10700. The population of these census tracts is projected to increase 121 percent between the year 2000 and the year 2040 (TXP and CMR 2008). Table 1-1 shows the projected population growth per census tract.

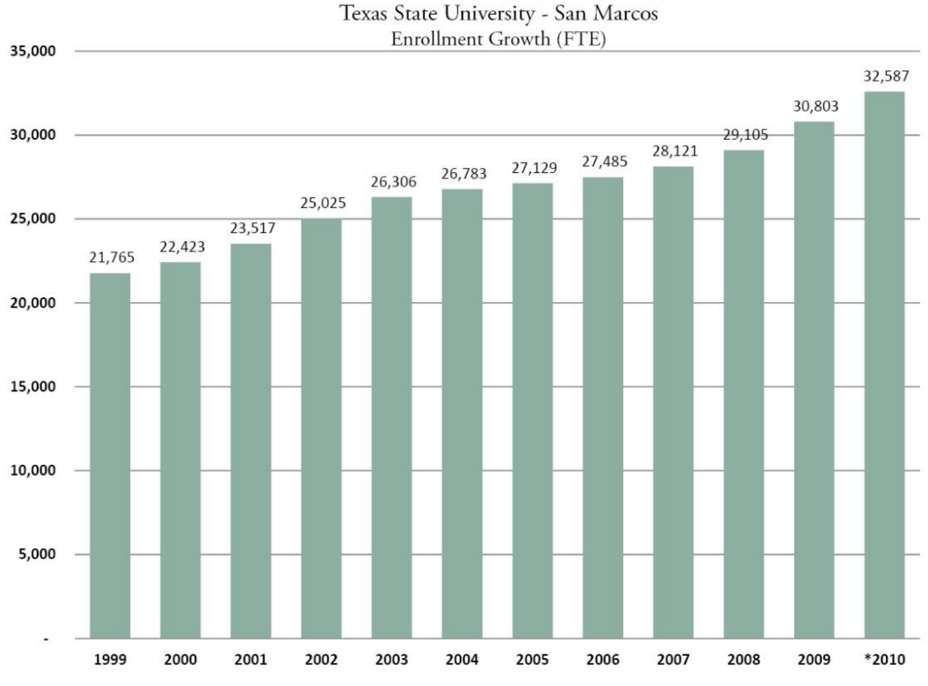
Table 1-1 Southern Hays County Populations

Community	Census 2000 Population	Projected 2040 Population	Estimated Percent Change (2000 – 2040)
CT 010100	1,908	3,799	99%
CT 010200	5,656	10,513	86%
CT 010301	10,176	22,600	122%
CT 010302	4,326	7,646	77%
CT 010400	4,343	18,691	330%
CT 010500	2,783	7,162	157%
CT 010600	7,904	18,689	136%
CT 010700	8,113	21,050	159%

Texas State University

Student enrollment at the Texas State University has been growing continuously for more than a decade, as shown in Figure 1-8. Student enrollment at Texas State University was 38,006 for the 2015 fall semester, marking the 18th consecutive year Texas State has set a new record for total enrollment (Texas State University, 2015).

Figure 1-8 Texas State University Enrollment Growth



Source: Texas Higher Education Coordinating Board

1.2.5 SOUTH CENTRAL TEXAS CLIMATE

The San Marcos region is located on the westernmost fringes of the humid subtropical climate type that covers the southeastern quarter of the United States. This climate type is strongly influenced by the maritime tropical air masses that emerge from the Gulf of Mexico to the southeast. Although this is the dominant air mass, south central Texas and the San Marcos area is frequented at different times of the year by other air masses that emerge from areas such as northern Mexico, Canada, the Pacific Ocean, and even occasionally from the arctic regions. It is an area of considerable weather variety. Average annual temperature in January is 40^{o}, while in July it is 96^{o}.

With the close proximity of the semiarid climate to our west, the south central Texas region experiences great variety as to precipitation amounts. Average annual rainfall is 33 inches however extremes in the form of drought and floods are regular occurrences. Drought, in combination with water pollution from urban stormwater runoff, poses a serious threat to the listed species (EAHCP, November 2012).

On a statewide basis, 2011 was the driest year in recorded history (National Weather Service, 2012), but the worst sustained drought, known as the Drought of Record, parched the state from the late 1940s to the late 1950s, with catastrophic consequences for land, livestock and people. Yet that drought was the longest only since rain gauges have been used to keep records — a practice that began in 1895. In fact, Texas has long been stalked by mega-droughts, events that can last 30, even 40 years. Using the science of dendrochronology (the study of tree rings), researchers present a record showing that in the 1700s and early 1800s, before American settlement and even extensive Spanish and Mexican settlement, several dry stretches were longer than the Drought of Record. The driest 10 years were 1716 through 1725, and the worst 20 years were 1697 through 1716. There have been numerous 30- and 40-year droughts. The worst gripped Texas and Mexico for nearly a half-century, from 1450 to 1489. Unfortunately, rainfall modeling shows that rising temperatures and more arid conditions over the last few decades are likely to increase in the 21st century (Parker, Richard, 2011).

1.3 REGULATORY PROGRAMS AND PERMITS AFFECTING THE PLAN

Regulatory programs and permits affecting the Plan include:

1.3.1 FEDERAL PROGRAMS.

The following Federal programs are applicable to the Plan.

United States Fish and Wildlife Service: The United States Fish and Wildlife Service (FWS) is a federal government agency within the Department of the Interior dedicated to the management of fish, wildlife, and natural habitats. The FWS administers and enforces the Endangered Species Act which seeks to stabilize populations of species at risk and conserve the habitats upon which they depend.

United States Environmental Protection Agency: The United States Environmental Protection Agency (EPA) administers and enforces the Clean Water Act and other Acts which address surface water and groundwater contamination. Section 301 of The Clean Water Act prohibits a direct discharge of pollutants into the waters of the United States without a permit from the EPA. This act requires that cities of a certain size have a National Pollutant Discharge Elimination System (NPDES) Stormwater Permit to operate its municipal storm sewer system. These stormwater permits are now managed by state agencies and in Texas are administered by the Texas Commission on Environmental Quality (TCEQ). The Texas Pollutant Discharge Elimination System (TPDES) permit is often referred to as an MS4 permit (MS4 abbreviates the phrase Municipal Separate Storm Sewer System).

1.3.2 STATE PROGRAMS

The following State programs are applicable to the Plan.

TCEQ: Land development activities in the Edwards Aquifer zone are subject to a baseline set of water quality protection measures (primarily the Edwards Aquifer Rules), administered by the TCEQ. Note that local water quality ordinances also apply to land development over the Edwards Aquifer when those areas are within City of San Marcos jurisdictional boundaries.

TPDES/MS4 Permits: The TCEQ administers the TPDES Phase 2 MS4 permit. This stormwater-permitting program is intended to improve the quality of the state's rivers, lakes, and streams by reducing pollution from non-point sources. Based on the 2010 census, the City of San Marcos was identified as an urbanized area and both the City and Texas State University became regulated under the TPDES MS4 Permit. Texas State University and the City of San Marcos each prepared individual Storm Water Management Plans (SWMPs) and received separate permits for their jurisdictions. Note that the TPDES/MS4 permit area (within City limits) is different than the WQPP Study Area.

1.3.3 CITY AND UNIVERSITY PROGRAMS

The following City and University programs are applicable to the Plan.

1.3.3.1 City of San Marcos

City of San Marcos Land Development Code: Following up on the recently completed Comprehensive Plan for the City of San Marcos, the Planning and Development Review Department has initiated a total re-write of their Land Development Code (LDC). The WQPP is providing recommendations that relate to water quality and land development for future inclusion in the City LDC. The WQPP team will also assist in the preparation of design criteria for the City's Stormwater Technical Manual (STM). It is important that the revisions to the Code and Criteria are seamlessly integrated.

City of San Marcos Stormwater Technical Manual: Following up on the completion of LDC revisions, the WQPP team will work with City staff to prepare design criteria for the City's STM. The STM will contain design criteria that define the technical requirements that will allow land development projects to comply with the City LDC. The STM will incorporate guidance and recommendations from the San Marcos Green Infrastructure – LID Practices Manual (San Marcos LID Manual).

1.3.3.2 Texas State University

Texas State University Construction Standards: The Texas State University System issues a Policies and Procedures Manual for Planning and Construction for use by each educational institution within the system. It is required that all capital projects sponsored by the Texas State University System are in compliance with this Manual. The Manual communicates laws, rules, regulations, policies and procedures to the University on how to engage with the System for the effective approval, contract administration and reporting of capital projects. The Manual does not describe how to plan, design, construct or operate a facility; that function is provided by the Texas State University Construction Standards.

Chapter 3, Section 3.02 Sustainable Design Principles, of the Texas State University Construction Standards describes the University's commitment to creating a "High Performance Campus", stating:

"Texas State University is committed to building a campus of architectural, engineering and environmental excellence. The University will strive to demonstrate good environmental stewardship by achieving Green Building Council objectives and following other nationally recognized sustainability principles and practices to achieve a high performance campus." (Texas State University, 2013)

The following information is from the Texas State University Construction Standards document, Chapter V. Working on City of San Marcos property, Section 5.01 Interface with the City of San Marcos.

> "Texas State University is obligated to pay Impact Fees for additional sewage discharge to the City system. A/E shall provide calculation, which establishes net increase/decrease of sewage to the City system, which will be used to determine Impact Fee Charges, which Texas State University will pay to the City."

This document contains the following text per Section 5.02 City Project Interface. Item D says:

> "Provide on-site architectural and civil drawings including total impervious cover for review by Public Works, San Marcos Electric Utility, and Utilities for determination of drainage utility impact, grading issues, and utility impact fees. As related to waste water and storm water discharge, A/E Team shall work with the City to comply with city ordinances. A/E shall comply with City of San Marcos storm water detention ordinance. Interface with SMEU is only applicable if we are connecting to SMEU or removing/relocating SMEU lines. Work totally within Texas State University property will require City interface only to the extent that waster and storm water are adjusted." (Texas State University, 2013)

1.4 RELATED PLANNING EFFORTS

It was during the creation of the EAHCP that the need for a water quality protection plan for San Marcos was recognized by staff at the City and Texas State University (i.e. Melani Howard and Dr. Thom Hardy). Various documents related to the HCP provided guidance for this Plan. A primary requirement is that the Plan meets the needs of the City of San Marcos and Texas State University so that the entities may comply with the requirements of the Incidental Take Permit. So that the plan can be more effective, the WQPP is intended to complement ongoing stormwater-related planning efforts sponsored by each of these entities. These plans are described below and organized according to the sponsoring entity. Also described are regional water quality protection plans that provide context for the San Marcos WQPP.

1.4.1 EDWARDS AQUIFER HABITAT CONSERVATION PLAN (EAHCP)

Section 5.7.6 of the EAHCP (and related documents) establishes specific requirements for the WQPP regarding the use of water quality protection measures in San Marcos. The related documents include:

- Work Plans associated with EAHCP Section 5.7.6
- EAHCP Appendix Q

Appendix Q of the EAHCP recommends the use of LID, or low impact development, defining it as "an integrated approach to development that seeks to maintain the natural hydrologic character and functioning of a site or region. Put simply, LID techniques address water at its source, capturing rainwater and treating it or reusing it on a site before discharging it into streams and aquifers. LID measures have been shown to be adequate to treat stormwater to regulatory standards, reducing the need for offsite treatment and conveyance. LID projects are typically planted with water-loving vegetation, increasing the beauty of the property while treating water quality."

Appendix Q also states that "the most effective way to protect water quality is to limit impervious cover (i.e., urbanization) of the vulnerable portions of the Aquifer. The available data show that there is a strong relationship between the urbanization of these vulnerable areas and the degradation of surface water and groundwater."

Section 5.7.6 of the EAHCP states "The City of San Marcos will establish a program to protect water quality and reduce the impacts of impervious cover (such as through LID). The City of San Marcos will develop criteria and incentives for the program based upon the LID/Water Quality Work Group Final Report (Appendix Q) recommendations for Implementation Strategies and BMPs."

The EAHCP Workplan that relates to Section 5.7.6 states the following regarding impervious cover and water quality protection: "The City of San Marcos and Texas State University will establish a program to protect water quality and reduce the impacts … based upon the LID/BMP practices."

Table 1-2 summarizes the requirements of the WQPP per the documents mentioned above.

Table 1-2 Requirements of the WQPP per the EAHCP

Requirements	EAHCP Section 5.7.6	EAHCP Appendix Q	5.7.6 Work Plans
Establish Water Quality Programs	x		x
Prepare a Water Quality Protection Plan (WQPP) including			x
▪ Integrated Stormwater Planning			x
▪ Land Use Recommendations			x
▪ Ordinance Modifications			x
▪ Low Impact Development (LID) Design Criteria	x	x	x
Assess Existing Watershed Impacts (incl. sedimentation)	x	x	
Mitigate Hazards (incl. spills & leaks)	x	x	
Implement Responsible Limits on Impervious Cover		x	
Implement Stormwater BMPs	x	x	x
Assemble Stakeholder Groups & Gather Public Input			x
Reduce the Impacts of Impervious Cover (Retrofit Facilities)	x		x
Reduce the Impacts of Impervious Cover (Redeveloped and New Infrastructure)	x		x
Protect Recharge Features		x	

1.4.2 TEXAS STATE UNIVERSITY

Development activities on land owned by Texas State University are subject to TCEQ water quality protection measures as well as University regulations and policies. University guidance documents that apply to facilities planning and implementation include the Campus Master Plan and Construction Standards.

Texas State University 2012 – 2017 Master Plan: The recently adopted Texas State Campus Master Plan looks out to the year 2015 and is built upon the guiding principles of identity, community, natural environment, architecture, and mobility. The quality of the physical and natural environment has a tremendous influence on the image and function of the institution. The Master Plan acknowledges this and places an emphasis on incorporating quality features into the plan. The plan conceives a systematic removal of surface parking lots that will create a comprehensive network of green open spaces and new building footprints. This recommended change to the physical character of the campus is beneficial on many levels: ecologically, it assists with stormwater management and water retention; it softens the look and feel of the campus; socially, it fosters spontaneous student interaction creating a sense of campus community; and physically, it supports a campus on which walking is preferable over driving. A holistic appearance is sought with the consistent use of native plants, paving materials, and site furnishings that will unify the campus and reinforce the unique character of the campus landscape and connect with the San Marcos River and Spring Lake. The complete campus master plan can be found at http://www.fss.txstate.edu/cmp/

Regarding stormwater management and water quality, the plan identifies the value in mapping and defining the ability of the storm drain system to safely convey design storms in coordination with the City of San Marcos to the receiving creek or river. This effort was recently completed and identified potential new projects in compliance with the City of San Marcos drainage criteria to accomplish the goals (see next item Texas State University Campus Stormwater Drainage Study and Plan).

Other initiatives included the start-up of a Watershed Protection Plan which began in early 2013, develop stormwater runoff management requirements for land within the San Marcos River Corridor and the Edwards Aquifer Recharge Zone, implement erosion control measures for land development activities that are both temporary and permanent in nature, and safely convey runoff from large storm events to limit the impact of increased runoff to downstream creeks, properties, and drainage systems.

The Plan recognizes the endangered and threatened species and has a ten year vision to perform the following:

- Work in an environmentally friendly manner in the transition zone to preserve the quality of water flowing into the Edwards Aquifer Recharge Zone even though not regulated by TCEQ;
- Prepare a Water Pollution Abatement Plan and Geologic Assessment before commencing construction in the Edwards Recharge Zone, and
- Obtain a Corps 404 before any construction commences in a wetland area.

In summary, the University is expected to coordinate with the City of San Marcos as the campus develops to provide appropriate drainage conveyance, add water quality treatment when possible, and build in a manner that respects and treats the natural environment as a campus resource, that not only provides water quality benefits but also improves the community and learning experience at Texas State.

The following sentence is a quote from the University website, in regards to the goals and objectives of the Office of Facilities, Planning, Design and Construction.
http://www.facilities.txstate.edu/pdc/mission.html

> "Provide and/or manage planning, design and construction services and standards for the University to comply with applicable codes, regulations, environmental requirements, and other standards for construction."

The following information is from the University Master Plan, Book 3, Final Plan, Stormwater Drainage System, page 45.

1. Storm drainage requirements for the proposed Texas State University-San Marcos Master Plan facilities were evaluated considering drainage criteria as outlined by the City of San Marcos.
2. For areas where proposed Master Plan facility modifications consist of replacing an existing paved parking area with a new structure, the quantity of stormwater runoff from this area could be considered to be the same as for current conditions, therefore may not require new drainage systems.
3. If the proposed facility includes replacing an unpaved area with a new structure, then stormwater runoff from the proposed facility would need to be collected in a drainage system considering the drainage criteria as required by the City of San Marcos.

Texas State University Campus Stormwater Drainage Study and Plan: Texas State University consulted with Bury & Partners – San Antonio to update the drainage plans for the campus. The focus of this effort was to identify drainage concerns related to storm drain infrastructure.

Meadows Center for Water and the Environment: Texas State University established The Meadows Center for Water and the Environment (MCWE), formerly the River Systems Institute, as a leadership initiative to coordinate and further university-wide efforts in the field of aquatic resource management. The MCWE led the San Marcos Watershed Initiative – Watershed Protection Plan process and prepared the plan (further described below).

In 2013, the MCWE served as a member of the WQPP consulting team, including Dr. Thomas Hardy and Kristina Tolman. They collected and compiled data, modeled possible pollution sources and loadings using HSPF-BASINS, and assisted in the selection of management practices to maintain and protect water quality.

San Marcos Watershed Initiative: The San Marcos Watershed Initiative (SMWI) is a three year Watershed Protection Planning process which began in 2013. This initiative is led by MCWE staff including Emily Warren, Mary Van Zant, Meredith Miller and Chris Clary. An overarching goal of the SMWI is to develop a comprehensive Watershed Protection Plan (WPP) that will incorporate and leverage various related environmental protection activities, including those of the City of San Marcos, Hays County, Texas State University and the Edward Aquifer Authority. A holistic and stakeholder driven approach will result in a protection and management plan that incorporates science, education and voluntary action. A community based stakeholder committee will determine specific goals of the WPP, including possible development scenarios, measures of success, management strategies and desired outcomes. The plan will include a watershed characterization of the entire Upper San Marcos River watershed, as well as potential management measures to protect water quality. Additionally, the plan will include implementation and funding strategies for management activities, and an education and outreach component.

Texas State University Construction Guidelines: The Construction Guidelines help guide infrastructure development on campus. There is the potential for WQPP recommendations to help the University adopt strong water quality protection measures as the Construction Guidelines are updated in the future.

Table 1-3 notes the various initiatives and programs that are currently being undertaken to protect and enhance water quality. Information on plan drivers and relationships are shown. While the focus of each is slightly different, their overall goal is to protect the water quality of San Marcos Springs and the San Marcos River. The authors of each are collaborating as necessary to ensure compatibility and integration of efforts. The MS4 Program represents the minimum regulatory requirements and is anticipated to become more stringent in the next 5 years.

Table 1-3 Concurrent Watershed Protection Initiatives

Elements	Watershed Protection Plan (WPP)	Water Quality Protection Plan (WQPP)	MS4 SWMP		TX ST Construction Standards
			TX ST	CoSM	
Author	Meadows Ctr. for Water & the Environment	Consultants: John Gleason LLC, et al	TX ST	CoSM	Texas State University
Oversight Agency	TCEQ	US Fish & Wildlife Service* (FWS)	TCEQ		Texas State University
Plan Funding	TCEQ 319 Grant	EAA Aquifer pumping fees	TX ST	CoSM	Texas State University
Driver	TCEQ 303d List for TDS	EAHCP Incidental Take Permit	TPDES Permit		Chapter 3 Guidelines
WQ Threats/ Concerns	Total Dissolved Solids (TDS)	All pollutants; also stream erosion, infiltration/ recharge, water efficiency	All pollutants		TSS, nutrients, runoff rate and volume, infiltration, water efficiency
Required or Voluntary?	Voluntary	Required (specific solutions are chosen by the permittee*	Required (specific solutions are chosen by the permittee)		Required with LEED “silver” rating goal
Deliverables	WPP Report	Annual WQPP Report	Annual SWMP Report		Individual project design, construction, maintenance

Implemen-tation Funding	Grant-funded	Texas State University (potential grant funding)	TX ST	CoSM	Texas State University

*The WQPP is an element of the EAHCP. The elements of the EAHCP are made binding through the Incidental Take Permit. Incidental Take Permittees (in this case, Texas State University) must avoid "taking" (defined below) listed species, usually through mitigation (defined below). Violation of the terms of an Incidental Take Permit would result in illegal take under Section 9 of the Endangered Species Act. The impacts addressed by the WQPP are those of stormwater runoff from impervious cover. Specific mitigation activities are not defined in the EAHCP. The WQPP provides recommendations regarding mitigation activities that may be undertaken by Texas State University. It is not required that Texas State University implement all (or even most) of the recommended mitigation activities. In consideration of these statements, specific terms and concepts are provided below, per the FWS (see link): http://www.fws.gov/midwest/endangered/glossary/index.html

***Take** – To harass, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct. Such acts may include significant habitat modification or degradation when it actually kills or injures wildlife by significantly impairing essential behavioral patterns including breeding, feeding, or sheltering.

***What is Mitigation?**

Mitigation is usually required of all landowners who participate in the incidental take permitting process. Under regulations outlined in the National Environmental Policy Act, mitigation is required to reduce or alleviate the impacts of a proposed activity. Mitigation may include avoiding an impact by not taking a certain action or parts of an action, minimizing impacts by limiting the magnitude of an action, repairing or rehabilitating the affected environment, reducing or eliminating the impact over time, and compensating for the impact by replacing or providing substitute resources or environment. How much mitigation is required and costs to the landowner will vary depending on the species, its habitat needs, and the magnitude of effect the proposed project has on the listed species and its habitat.

***What kinds of actions are considered mitigation?**

Mitigation measures are actions that reduce or address potential adverse effects of a proposed activity upon species covered by an HCP. They should address specific needs of the species involved and be manageable and enforceable. Mitigation measures may take many forms, such as: preservation (via acquisition or conservation easement) of existing habitat; enhancement or restoration of degraded or a former habitat; creation of new habitats; establishment of buffer areas around existing habitats; modifications of land use practices, and restrictions on access.

1.4.3 City of San Marcos

The City of San Marcos has full jurisdiction over land development within the City limits, excepting land owned by other jurisdictions including Texas State University and Hays County. The City also exercises extraterritorial jurisdiction (ETJ) over much of the surrounding unincorporated land, including planning major thoroughfares and enforcing rules for platting and subdivision. Land development activities in the ETJ are subject to water quality protection measures administered by the TCEQ.

City of San Marcos Comprehensive Plan (Vision San Marcos): The Comprehensive Plan creates a vision for the future of San Marcos. The Plan includes maps and a description of a preferred growth scenario that is intended to guide future growth. A framework of goals and objectives include replacing the Land Development Code with an updated document to support the preferred scenario.

The San Marcos Comprehensive Plan includes the following land use goals:

- Carefully manage and direct growth, ensuring compatibility with surrounding uses
- Encourage high-density mixed-use development and infrastructure in the activity nodes (including the downtown area); support walkability and integrated transit corridors
- Set appropriate density and impervious cover limitations in environmentally sensitive areas to avoid adverse impact

The Plan will seek to improve zoning ordinances and other land use planning tools to provide water quality protection. Other goals of the Comprehensive Plan include those related to economic development; environment and resource protection; neighborhoods and housing; parks, public places and facilities; and transportation.

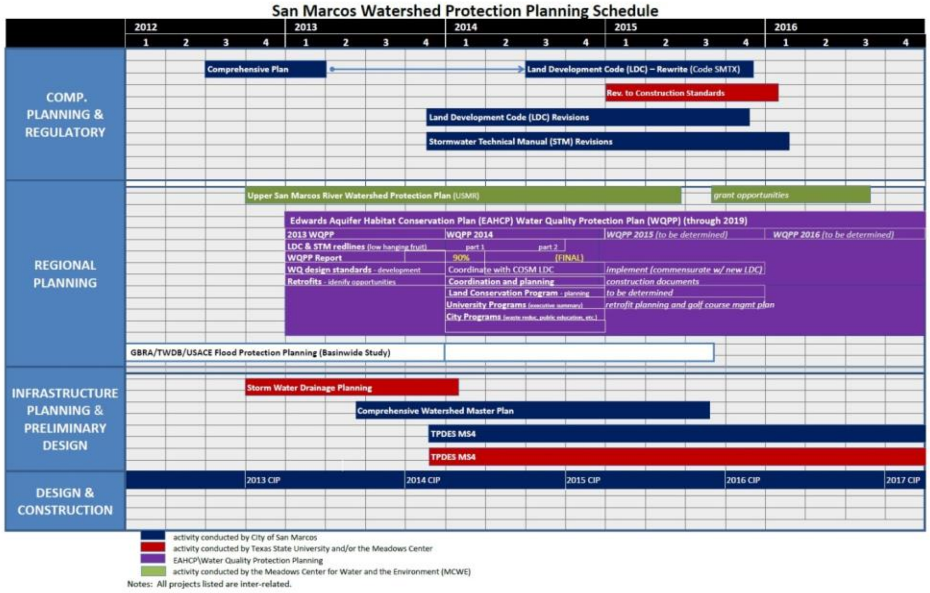
A detailed analysis that synthesizes the WQPP with the Comprehensive Plan has been identified as a task in the 2014 Work Plan. This process will proceed in step with the new Land Development Code.

City of San Marcos Comprehensive Watershed Master Plan: The City has initiated a Comprehensive Watershed Master Plan (CWMP) that will focus on drainage and flooding concerns within the City Limits. RPS Espey is the lead consultant on this project and is on the WQPP Project Team as well.

Sessom Creek Erosion Assessment: The Sessom Creek Erosion Assessment, prepared by RPS, identified approximately a dozen erosion sites on Sessom Creek for future repair.

Figure 1-9 diagrammatically represents the various planning efforts described above, their approximate time frame, and the manner in which each is related.

Figure 1-9 Local Planning Efforts and Community Involvement



Notes: All projects listed are inter-related.

RPS Espey in association with John Gleason LLC 9/29/2014 P:\Active\13030.00_San_Marcos_WQPP\2014 WQPP\WQPP 2014 Report\COSM_TxSt_WPP_schedule_092914

1.5 STAKEHOLDER INVOLVEMENT

The WQPP planning team seeks substantive and meaningful input on the Plan from a diverse group of stakeholders. Initial meetings and presentations in 2013 involved a variety of stakeholders and provided opportunities for the generation of ideas, input, comments and questions. Due to the many related planning efforts (see Section 1.4 of this Chapter) there have been considerable opportunities for the WQPP team to gain insight on planning and development concerns of many in the community. A list and description of meetings and presentations to date is provided in Appendix C.

Input on the Plan is especially needed from representatives of the City and University. The consulting team met with City and University staff at opportune occasions during preliminary development of the WQPP, often separately, out of respect for the time and convenience of entity representatives.

The San Marcos Watershed Initiative, described earlier in this chapter, provided an excellent forum for information exchange with a variety of stakeholders. To properly represent the interests of a community as large and diverse as San Marcos, the WQPP planning team seeks further input from representatives many organizations, a few of which are listed here:

- San Marcos River Foundation
- San Marcos Greenbelt Alliance
- The Greater San Marcos Partnership (GSMP)
- Home Builders Association (HBA) of Greater Austin

2. GUIDING PRINCIPLES

To provide direction and a steady reference point to the planning and stakeholder involvement process, the WQPP planning team adopted the following guiding principles.

1. The economy and environment of this unique part of Texas depend upon the preservation, conservation and management of dependable supplies of clean water. We recognize the unacceptable consequences that would result if we take no action to protect our water.
2. Both private individuals and the public have a responsibility to respect the legitimate interests of others and to do no harm in their activities.
3. Those who benefit from an activity must bear the responsibility for the costs and impacts of that activity.
4. We will favor measures which minimize the risk of failure or of damage to the watershed.
5. The recommended water quality protection measures will strive to balance government regulation with appropriate economic incentives.
6. The recommended regulatory measures shall be accompanied by strategies for administration and enforcement that provide clarity and as much certainty as possible while discouraging exemptions and exceptions.
7. Our decisions will be mindful of the economic impact of the measures recommended and strive to achieve a fair and reasonable balance among the various interests.
8. No party or group in this process will have undue or unfair control over the outcome.
9. We are willing to take action in the context of risk and uncertainty when further delay may prove costly to society and nature*.

*Precautionary Principle (Stallworth, et al., 1997)

3. PLAN GOALS AND OBJECTIVES

The primary goal of the WQPP is to recommend protective measures that minimize and mitigate the negative impacts of urbanization and impervious cover on the Edwards Aquifer and Upper San Marcos River. An overarching goal of the WQPP is to protect and restore the ecological integrity and resilience of the springs in the San Marcos Springs ecosystem. The healthier the aquatic environment of the springs, the better able they will be to withstand the significant threats imposed by water quality and quantity degradation that occurs outside the jurisdictions of the City and the University.

The impacts of new development should be prevented primarily through the adoption of new land development regulations (on behalf of the City), and new construction standards (on behalf of the University). The regulations and/or standards should include impervious cover limits and stormwater treatment requirements. However, it is unlikely that the impacts of future development can be fully prevented by stormwater treatment BMPs alone. For one reason, the "groundwatershed" extends outside the City's jurisdiction. Secondly, direct infiltration/recharge of contaminants into the aquifer from land development practices and landscapes is a significant concern. Effective water quality protection includes a wide range of programmatic and regulatory strategies, including site design, land conservation, buffers, public education and outreach, source control (e.g., Integrated Pest Management), stormwater retrofits for existing development, and other practices. Incentives to promote infill development and to direct growth to less sensitive areas are also recommended strategies.

While urban stormwater management has typically focused on flood control and, more recently, pollutants in runoff, the evolving state of the science has expanded concerns to include the hydrologic regime, stream erosion concerns, riparian zone integrity, and interactions with groundwater system. In Texas, an additional factor of significant concern is conservation of surface and ground water supplies.

The HCP recognized these concerns, as stated in the Workplan objectives:

> "… Treat stormwater as a resource rather than a waste product; emphasize conservation and the use of on-site features to protect water quality; and increase infiltration to groundwater and aquifer recharge …"

The 2012 State Water Plan has placed increased emphasis on reuse and conservation of water resources, recognizing that demand on Texas water supplies is increasing while supply is decreasing. The Texas Water Development Board projects that by 2060 water demand will increase by 18% while the water available will decrease by 10% (TWDB, 2012). If this scenario comes true, there could be significant economic and environmental impacts in the state. The 2012 State Water Plan has now put increased emphasis on reuse and conservation in promoting more sustainable water management in the future.

The concept of sustainability is gaining increasing attention, in Texas as elsewhere, and a logical application of this concept is to integrate stormwater management with protection and enhancement of water supplies. Efforts underway to promote sustainability include the LEED rating system and the

Sustainable Sites Initiative. The benefits of sustainability and "green infrastructure" go beyond just water and environmental considerations, as quality of life, economic factors, and energy and resource efficiency are equally important. Below are definitions of sustainable development and sustainable design applicable to the San Marcos WQPP:

- *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.* (World Commission on the Environment and Development Report, 1987)
- *Sustainable design is the ability to achieve continuing economic prosperity while protecting the natural systems of the planet and providing a high quality of life for its people.* (US EPA)

3.1 DEFINE AN ACCEPTABLE LEVEL OF WATER QUALITY

A distinction is necessary between acceptable water quality in receiving waters (rivers, streams, lakes, ground water) vs stormwater discharge quality. In terms of receiving waters, an acceptable level of water quality is to meet state water quality standards for surface and ground waters. Texas surface water quality standards are established by the TCEQ for Texas creeks, rivers, and lakes. Water quality monitoring occurs on a regular basis to document the water quality and if a water body is found not to meet the standards for identified pollutants then it can be placed on a 303(d) list that can cause the implementation of a Watershed Protection Plan or development of a Total Maximum Daily Load. Every two years, TCEQ compares water quality data to evaluate water bodies to define current water quality conditions and if potential management measures are necessary. TCEQ does not establish standards for stormwater runoff quality as the standards are based on normal or base-flow conditions.

If a receiving water body is violating water quality standards, dischargers may be required to comply with conditions adopted under a Total Maximum Daily Load (TMDL) program. As there is no TMDL in place for the Upper San Marcos River, stormwater discharges are not required to meet a specific standard under that program. The definition of acceptable stormwater quality is not always clear, but the following programs are applicable:

A. State Edwards Aquifer Rules (30 TAC 213) for the Recharge and Contributing Zones
B. U S Fish and Wildlife Service Incidental Take Permit TE63663A-0 and the associated Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan measures to protect threatened and endangered species in the Edwards Aquifer and Upper San Marcos River
C. MS4 General Permits TX04R4000 (issued by TCEQ, applicable to the City and Texas State University)
D. Construction Standards (Texas State University)

Each of these will be discussed further, below.

A. Edwards Aquifer Recharge and Contributing Zone

The minimum treatment standard, per the State Edwards Aquifer Rules 30 TAC 213.5, is to reduce the incremental increase in the annual mass loading of total suspended solids (TSS) by 80%, as calculated by the TCEQ technical manual RG-348. This "performance standard" applies to development in the recharge and contributing zones, but not in the transition zone (which includes the contributing zone within the transition zone).

Because runoff from both the University and the City is discharged to critical habitat, and in order to comply with the "no take" provision of the Federal Endangered Species Act, optional "enhanced measures" have been adopted by USFWS-TCEQ for the following species:

- Barton Springs salamander *(Eurycea sosorum)*,
- fountain darter *(Etheostoma fonticola)*,
- Georgetown salamander *(Eurycea naufragia)*
- San Marcos salamander *(Eurycea nana)*, and
- San Marcos gambusia *(Gambusia georgei)*

For discharges to the habitat for these species, the treatment standard for permanent BMPs is defined in the TCEQ technical manual RG-348A as "Reduction of 80% of the annual TSS load in storm water runoff from a site is required for all new development, without regard to the proposed level of impervious cover. On redevelopment projects that involve major changes to existing impervious cover and include modification of the drainage system, 80% TSS removal must be achieved for the entire project." Relevant points regarding this standard:

1. RG-348A does not list all of the species named in the Incidental Take Permit TE63663A-0, and no guidance has become available from the USFWS. Pending further guidance, it is presumed, for now, that meeting the enhanced measures standard will comply with the "no take" provision.
2. The primary difference between the RG-348 and RG-348A standards is that the latter applies to all development, not just the incremental increase over the existing condition due to development.

B. USFWS Incidental Take Permit and Habitat Conservation Plan measures for threatened and endangered species in the Edwards Aquifer and Upper San Marcos River

For all permittees, the stormwater treatment requirements in the Incidental Take Permit (ITP) and Habitat Conservation Plan (HCP) are provided under the "Minimization and Mitigation Measures", in particular measure 5.7.6 Impervious Cover/Water Quality Protection. Neither the ITP nor HCP require this measure of Texas State University, only applying it to the City of San Marcos:

> *The City of San Marcos will establish a program to protect water quality and reduce the impacts of impervious cover (such as through LID). The City of San Marcos will develop criteria and incentives for the program based upon the LID/Water Quality Work Group Final Report (Appendix Q) recommendations for Implementation Strategies and BMPs.*

However, the cited document, Appendix Q, includes the following provisions relevant to Texas State University:

> *B. RECOMMENDATIONS FOR ACTIONS TO BE INCLUDED IN THE HCP*
>
> *1. Pursue implementation, if adequate support is indicated by individual local governments, the EAA, Texas State University, and/or TCEQ, of a ban on use of coal tar sealants within (a) areas draining to Landa Lake or to the Comal River above the confluence of the old and new channels; (b) areas draining to Spring Lake or to the San Marcos River above the wastewater treatment plant outfall for the City of San Marcos; and (c) the recharge, contributing, and transition zones of the Edwards Aquifer that are subject to the pollution control authority of the EAA.*
>
> *2. Pursue implementation, if adequate support is indicated by individual local governments, the EAA, Texas State University, and/or TCEQ, of improved stormwater runoff controls, in the form of specific best management practices, applicable (a) in areas that contribute surface runoff to Landa Lake, to the old channel of the Comal River, or to the new channel of the Comal River above the confluence with Dry Comal Creek; (b) in areas that contribute surface runoff to Spring Lake or to the San Marcos River above the wastewater treatment plant outfall for the City of San*

> *Marcos; and (c) throughout the areas of the recharge zone, contributing zone, and transition zone that are subject to the pollution control authority of the EAA.*

It is not known why the Appendix Q recommendations applicable to Texas State University are absent from the ITP and HCP. The WQPP Team recognizes the uncertainty that this contradiction presents, but recommends that Texas State University voluntarily comply with measure 5.7.6 because:

- Clearly it is the intent of the ITP, HCP, and Appendix Q to reduce stormwater pollution from all areas that discharge to the aquifer, Spring Lake, and Upper San Marcos River where the listed species habitat occur. This is particularly relevant to Texas State University, as Spring Lake is located on the campus.
- Consistent with the WQPP Guiding Principles (Chapter 2), protection of the threatened and endangered species habitat is paramount, and uncertainty is not a valid reason for delaying necessary action.
- Spring Lake and the Upper San Marcos River ecosystem have already been impacted by existing development, which includes the Texas State University campus, and the WQPP recommends measures to prevent further degradation (Chapter 6 Water Quality Threats and Impacts).

Relevant points:

1. A key phrase in both recommendations is "if adequate support is indicated by individual local governments, the EAA, Texas State University, and/or TCEQ." In making its recommendation, the WQPP assumes that adequate support does exist, but the final determination is the responsibility of Texas State University and the City of San Marcos and, presumably, the Edwards Aquifer Recovery Implementation Program and/or the US Fish and Wildlife Service.
2. Measure 5.7.6 does not define a specific treatment standard. The WQPP does recommend specific "performance standards" for the design of stormwater and water management BMPs, e.g., a non-degradation standard such that, on an annual average basis, the pollutant load discharged from a site after development or redevelopment is no greater than the existing load (i.e. pre-developed conditions). Achievement of the performance standards is demonstrated through modeling procedures and/or compliance with design criteria, rather than monitoring of discharges.

WQPP Recommendations

So that the City and the University may meet acceptable levels of water quality for stormwater discharge, and in order to comply with the ITP/HCP measure 5.7.6, the WQPP has developed, and recommends adoption of, the following:

- Designate Water Quality Zones in the areas that drain to critical habitat (See Section 3.3 of this Chapter)
- Establish goals and performance standards for each Water Quality Zone (See Section 3.4 of this Chapter)
- Implement a stormwater retrofit plan specifically designed to reduce current pollutant loads, and which could also offset future loads (See Chapter 9 and Appendix N of this Report)

C. MS4 General Permit TX04R4000 (issued by TCEQ, applicable to the City and to the University)

The City of San Marcos MS4 Permit requires that the City conduct a review of the city's legal authority to require and inspect post construction storm water management of new development and redevelopment construction projects using structural and non-structural BMPs. This is being done in association with their efforts to revise the Land Development Code through the CodeSMTX process.

Permanent stormwater BMPs are required by the University's permit, under Chapter 5, Minimum Control Measure 4: Post-Construction Stormwater Management in New Development and Redevelopment.

- 5.1(a) All permittees shall develop, implement, and enforce a program to the extent allowable under state, federal and local law to control stormwater discharges from new development and redevelopment sites that discharge into the small MS4 that disturb one acre or more, including projects that disturb less than one acre that are part of a larger common plan of development or sale.
- 5.2.2 The University will modify the Construction Standards and/or other regulatory mechanisms to require installation of these permanent, structural BMPs

The actual BMPs, and any treatment standards required of them, are not specified in the permit, but the nationwide standard is "Maximum Extent Practicable" or MEP, which is not currently a numeric standard. The following, with WQPP emphasis, encapsulates the issue well (excerpted from "EPA Urged to Clarify CWA 'Maximum Extent' Mandate to Curb Discharges", Water Quality Policy Report 8/12/2013)**:**

> *The Clean Water Act (CWA) section 402(p) requires MS4s "to reduce the discharge of pollutants to the **"maximum extent practicable" but the law does not explicitly define the standard,** leaving EPA to determine how strict a discharge limit is "practicable" given the effectiveness of available technology. The agency has long defined MEP limits to be less stringent than the generally-applicable water quality standards that other dischargers must meet.*

Historically, the WQPP team could find no examples of case law in Texas that address this issue however there are cases on the US east coast that have bearing:

> *… Both the Boston consent decree and the D.C. permit create compliance schedules **based on the adoption of new best management practices (BMPs), rather than the achievement of discharge limits**…*

In summary, given the case law history, the MS4 permit does not require meeting discharge standards, or the adoption of specific design or performance standards, but does require implementation of BMPs. The Texas State University MS4 permit does cite the University's Construction Standards, which may define stormwater management performance standards and/or criteria, as described below separately.

D. Texas State University Construction Standards

Through its Construction Standards (revised January, 2015), Texas State University has adopted LEED-based sustainable design principles and goals for stormwater and water management, in order to achieve a "High Performance Campus." Chapter 3, Design Guidelines, has established a goal of achieving a LEED "silver" rating, and includes the following High Performance Project Plan goals:

- Sustainable Sites Credit 6.1 Stormwater Management, Rate and Quantity
- Sustainable Sites Credit 6.1 Stormwater Management, Treatment
- Water Efficiency Credit 1.1 Water Efficient Landscaping, Reduce by 50%
- Water Efficiency Credit 1.2 Water Efficient Landscaping, No Potable Use or No Irrigation

From LEED documentation and guidance material (note: LEED standards and guidance are constantly evolving, so the following may be supplanted):

- Credit 6.1 Stormwater Design, Quantity Control
    - Existing Impervious Cover ≤ 50%:
        - Rate and Quantity Calculations - Post-development peak runoff rate no more than pre-development (“keep it as good as you found it”)
        - Stream Protection Plan – Protect receiving stream channels from erosion (“make sure runoff doesn’t cause problems downstream”)
    - Existing Impervious Cover > 50% - Post-development quantity at least 25% less than pre-development (“make it better than you found it”)\
    - Encourage infiltration, rainwater harvesting, green roofs

- Credit 6.2 Stormwater Design, Quality Control
    - Capture and treat runoff from 90% average annual rainfall
    - Use BMPs to remove 80% of average TSS load
    - Promote infiltration, reduce impervious cover, use rainwater harvesting and/or green roofs, target nitrogen and phosphorus, practice pollution prevention

- Credits 1.1 and 1.2 Water Efficient Landscaping
    - 50% reduction of potable water use for irrigation (1.1)
    - No potable water use or no irrigation (1.2)
    - Eliminate turf grass, choice native and adapted plants, use efficient or no irrigation
    - The term “potable” water includes non-potable groundwater that can be used for irrigation

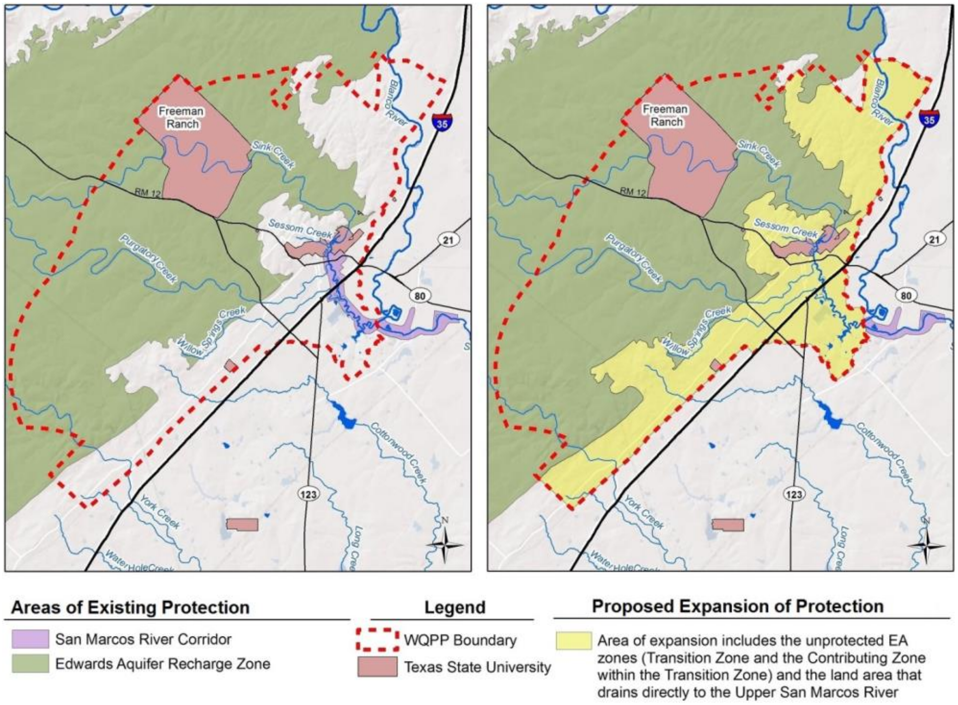
These goals are equivalent to “performance standards” for stormwater discharges and water management. Thus, in terms of stormwater discharges, “acceptable quality” would be to design and implement BMPs that meet Credit 6.1, but Credit 6.2 should also apply, as it includes a stream erosion prevention element (stream erosion is a large source of TSS loadings). Credits 1.1 and 1.2 are also applicable, as they offer the opportunity to utilize stormwater as a resource, i.e. rainwater harvesting for irrigation.

It is worth noting the similarity between the Construction Standards goals and the WQPP performance standards. While the exact mechanism for demonstrating compliance is different between the two, the goals overlap significantly. The WQPP has also expanded the water efficiency measure to include not just potable and groundwater, but water diverted out of the San Marcos River that is used for landscape irrigation.

3.2 EXPAND AREAS OF WATER QUALITY PROTECTION

Currently there are substantial areas within each jurisdiction that drain to critical habitat that have no existing water quality protection standards. Existing protective measures include TCEQ requirements that apply to the Edwards Aquifer Recharge Zone. The City of San Marcos has established protection standards for an area called the San Marcos River Corridor. The applicable guidance document for the University is titled ‘Construction Standards’. Since all areas that drain to critical habitat represent a potential threat, the Plan recommends that the entities implement water quality protection standards throughout their applicable jurisdictional areas. See Figure 3-1.

Figure 3-1 Proposed Expansion of Water Quality Protection



Map: RPS

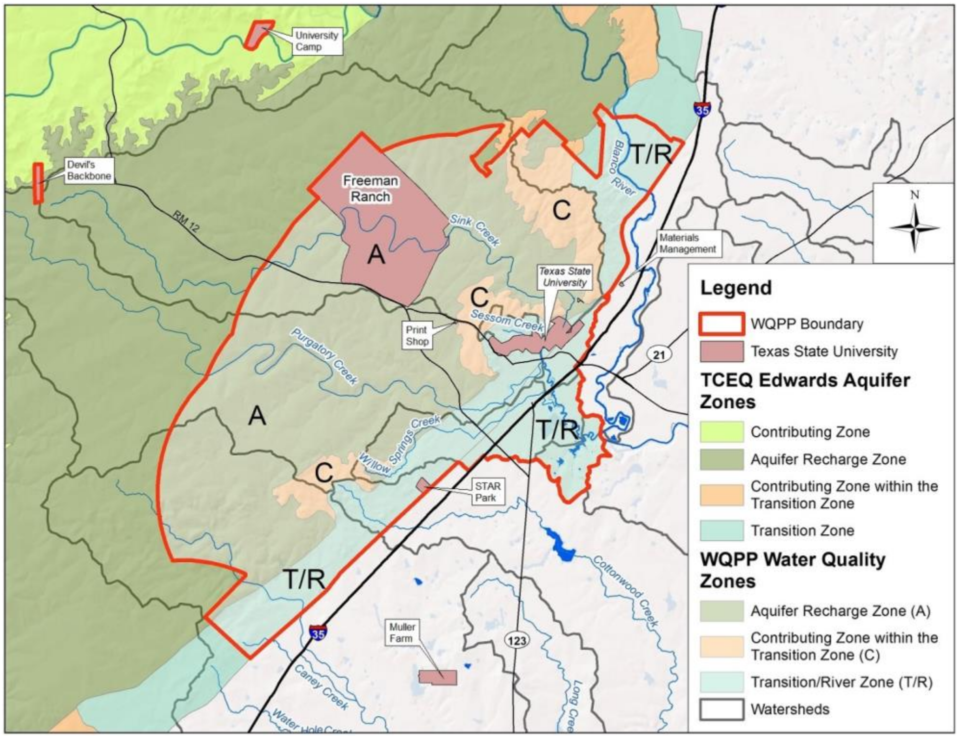
3.3 ESTABLISH WATER QUALITY ZONES

There are two distinct, but somewhat overlapping areas that contribute surface and/or subsurface flow to the Critical Habitat, the Edwards Aquifer Zones and the Upper San Marcos River. Because of the different geology, hydrology, and environmental sensitivity of these areas, different recommendations apply to each, thus it is recommended that "Water Quality Zones" be defined. The Water Quality Zone designations are intended to apply to both the City of San Marcos and Texas State University. See Table 3-1 and Figure 3-2 for a description and delineation of these zones

Table 3-1 Water Quality Zone Designations

Zone Symbol	Water Quality Zone	Description
A	Aquifer Recharge Zone	Based on the TCEQ Edwards Aquifer designation
C	Contributing Zone	Based on the TCEQ Edwards Aquifer designation (but not subject to Edwards Aquifer stormwater rules)
T/R	Transition/River Zone	A zone that combines the area designated as the Transition Zone by the TCEQ and the land area that drains to Critical Habitat of the San Marcos River

Figure 3-2 Water Quality Zones Map



Map: RPS and John Gleason

Zone A – Aquifer Recharge.

The recharge zone is highly vulnerable to being impacted by development, both in terms of hydrology and water quality. This zone is the most sensitive of the land development zones and in most need of protection. Some impacts to the system have already occurred, even in watersheds where the level of development is quite low. Further degradation of the system is unavoidable unless strong protective measures are adopted.

Zone C – Contributing Zone (within the Transition Zone)

Zone C has a significant thickness of relatively impermeable rock between the ground surface and the aquifer which limits the potential for direct recharge. Surface runoff from the Contributing Zone flows down gradient to the Aquifer Recharge Zone (A). The land areas of the Contributing Zone are small and they sit above major flow paths in the aquifer where water flows quickly. Because of potential impacts to the aquifer, this is a high priority zone. A geologic assessment is required to determine the potential for on-site features.

Zone T/R – Transition/River Zone

Two distinct land areas are combined into one in the Transition/River Zone. This zone combines the Edwards Aquifer Transition Zone and the River Zone. The surface runoff conditions are the primary determining factors for environmental protection requirements in the Transition Zone. Due to the relatively impermeable layer of rock above the aquifer there is a reduced opportunity for surface to groundwater interaction. However the term transition is referring to a geological change in the landscape that is dispersed throughout this zone, and the land in this area may or may not contain recharge features. A geologic assessment is required to determine the potential for on-site features. The River Zone includes the surface areas that drain to critical habitat for listed species in the San Marcos River. It excludes areas in the Edwards Aquifer zone, but does include the upper portion of the existing San Marcos River Corridor, expanded to include the surface drainage areas to the corridor.

Only a very small portion of the Texas State University campus is in either Water Quality Zones A and/or C. The majority of the campus is in Water Quality Zone T/R.

3.4 GOALS FOR WATER QUALITY ZONES

As the HCP specifically identifies the need to protect both the quantity and quality of water resources, the WQPP emphasizes the integration of stormwater management, water conservation, and sustainable development. The proposed receiving water goals are:

- Water Quality Zones A and C: Reduce the existing level of pollution, prevent excess stream erosion due to watershed hydromodification, maintain or enhance existing infiltration and recharge, and reduce demand on the aquifer water supply.
- Water Quality Zone T/R: Prevent further degradation by controlling current and future pollution in the entire contributing watershed, and prevent excess stream erosion (high sediment loads) due to watershed hydromodification, and reduce demand on water supply.

In regards to structural BMPs, the WQPP recommends the following performance standards, in order to comply with the ITP/HCP measure 5.7.6.

Water Quality Zones A (Recharge Zone) and C (Contributing Zone within the Transition Zone):

- Pollutant Load – no increase in the existing total phosphorus (TP) load
- Stream Protection – Provide Stream Protection Volume or equivalent
- Infiltration/Recharge – Maintain or increase existing rate of infiltration
- Water demand/reuse– Reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50%

Water Quality Zone T/R (Transition/River Zone)

- Pollutant Load – new development total phosphorus (TP) load to be no greater than that of a site with 10% impervious cover ("10% threshold")
- Stream Protection – Provide Stream Protection Volume or equivalent
- Water demand/reuse – Reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50%
- Infiltration/Recharge (optional) – Maintain or increase existing rate of infiltration

Demonstration of compliance with the performance standards would be achieved via modeling and criteria (design, operation, maintenance); monitoring of discharges would not be required. The following is a brief description of current BMP performance standards (for comparison to those noted above):

- State water quality standards – BMPs are not required to meet receiving water quality standards
- Edwards Aquifer Rules – BMPs must be designed to reduce average annual TSS load by 80%
- USFW Incidental Take Permit and EARIP Habitat Conservation Plan Measure 5.7.6 – no specific BMPs, discharge or performance standards are defined, and Texas State University is not clearly required to implement this measure
- MS4 General Permit TX04R4000 (issued by TCEQ) – no BMP standards or performance measures are defined
- Texas State University Construction Standards, Chapter 3: Design Standards
    - Maintain or reduce existing peak runoff rates and/or provide stream protection
    - Capture and treat runoff from 90% of the average annual rainfall
    - Remove 80% of the average TSS load (which matches the TCEQ Edwards Rules performance standard)
    - Reduce potable water for landscape irrigation by 50% or more
- City of San Marcos Land Development Code (LDC) – The existing code is being revised through the CodeSMTX process (underway at the time of this writing). Current code requires the following:
    - Development in the Edwards Aquifer Recharge Zone must implement BMPs that limit the increase in the total suspended solids load in drainage (from the developed areas of the site) to no more than 20 percent above that which would occur from natural drainage from the site
    - Development in the San Marcos River Corridor must implement a Sedimentation-Filtration BMP or equivalent, with ½” WQV for the entire contributing area, with a 48 hour drawdown time (though code states 24 hours, all sizing equations in TCEQ and City of Austin manuals are based on 40-48 hour drawdown times)

It appears that the primary program for defining stormwater management goals and standards should be the Texas State University Construction Standards document. In the future, the WQPP recommendations could be incorporated into the Construction Standards. While the WQPP Team recommends its performance standards, the LEED-based ones in the Construction Standards are a step in the right direction. Because of similarities between the two, it is readily achievable for revisions to the Construction Standards to match the WQPP recommendations. If Texas State University wishes to retain its LEED-based standards, the WQPP Team can provide technical assistance, if desired.

Technical Notes: In comparing the performance standards defined by the (1) Edwards Aquifer Rules, (2) WQPP recommendations, and (3) Texas State University LEED-based Construction Standards:

- The Edwards Aquifer Rules and Texas State University Construction Standards (LEED-based) use the “percent removal” procedure, which is an outdated procedure strongly discouraged by the ASCE (Water Environment Research Foundation), International Stormwater BMP Database Project, and others. The recommended “effluent concentration” method has been adopted in the WQPP. Several entities, including the Denver regional area and the City of Austin, have switched to the effluent concentration method. One implication of using this method is that BMP removal efficiency may be a variable, rather than a constant.
- For Water Quality Zone T/R, which applies to most of the Texas State University campus, the WQPP has adopted an impervious cover “threshold” as the basis for correlating pollutant loads to receiving water impacts, consistent with findings by EPA and others (see Chapter 6 of the WQPP). Specifically, impacts may be expected once a watershed exceeds 10% impervious cover,

and it is straightforward to interpret stormwater pollutant loads discharged from BMPs in terms of “equivalent” impervious cover, which is what the WQPP has done.

3.5 INTEGRATED STORMWATER MANAGEMENT PLANNING (ISMP)

The WQPP implements an integrated stormwater management planning approach. This comprehensive, interdisciplinary process coordinates the efforts of urban planners, ecologists, engineers, architects, and landscape architects. The goals are to optimize rainfall capture, manage the risk of flooding, improve water quality, and protect aquatic ecosystems on all scales (local, neighborhood, regional and watershed). ISMP should accommodate and inform all other land use development processes. ISMP uses a multi-faceted blend of regulatory, programmatic and on-site strategies intended to protect future watershed conditions. The following represent some of the latest scientific knowledge and successful water quality based planning practices that have been adapted it to the unique conditions of San Marcos.

- Handbook for Developing Watershed Plans to Restore and Protect Our Waters: This EPA publication is also known as the Watershed Handbook (US EPA Office of Water, March 2008, www.epa.gov/owow/nps/pubs.html) Watershed Academy (US EPA www.epa.gov/watertrain).
- International Stormwater BMP Database Project: The International Stormwater BMP Database Project (www.bmpdatabase.org) and associated Water Environment Research Foundation (www.werf.org) supporting documents and guidance are on the leading edge of stormwater technology.
- Denver Urban Drainage and Flood Control District: The Denver area is a national leader in stormwater management. Of note in their programs is that advanced modeling techniques have been used to develop guidance and criteria, and numerous design tools have been made available to the design and planning community. (www.udfcd.org)

4. What Does the Plan Protect?

The Plan is intended to protect the water resources that provide Critical Habitat for the Listed Species. These water resources include the Edwards Aquifer, Spring Lake and the Upper San Marcos River. The species and their habitat are described below.

4.1 Listed Species

The species covered by the Incidental Take Permit with the potential to occur within the WQPP Plan Boundary are shown in Table 4-1. These five endemic species are listed by the U.S. Fish & Wildlife Department and the Texas Parks & Wildlife Department as threatened or endangered. Shown in Figure 4-1 are two of species: the San Marcos Salamander and Texas Wild Rice.

Table 4-1 Listed Species with the Potential to Occur within the WQPP Boundary

Common Name	Scientific Name	ESA Status
Fountain Darter	Etheostoma fonticola	Endangered, Critical Habitat
Texas blind salamander	Typhlomolge rathbuni*	Endangered, Critical Habitat
San Marcos Gambusia	Gambusia georgei	Endangered, Critical Habitat
Texas Wild Rice	Zizania texana	Endangered, Critical Habitat
San Marcos Salamander	Eurycea nana	Threatened, Critical Habitat

*Formerly called Eurycea rathbuni

Figure 4-1 Photos of San Marcos Salamander and Texas Wild Rice

Salamander Photo: Seth Patterson

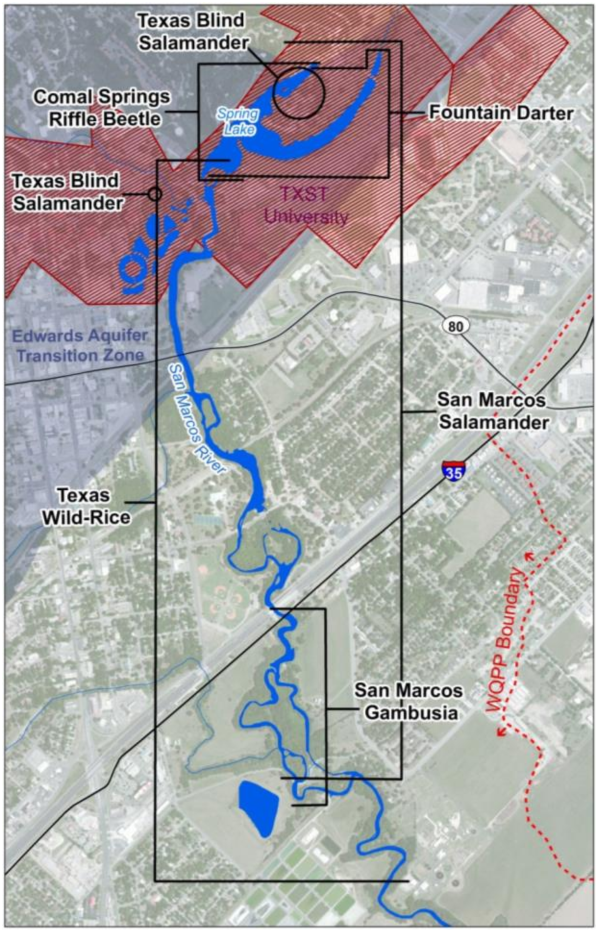
Wild Rice Photo: Ricardo B. Brazziell

Additional species covered by the Incidental Take Permit are not shown in the table because they do not have the potential to occur in the Plan area. These include the Comal Springs Riffle Beetle, Comal Springs Dryopid Beetle, and the Peck’s Cave Amphipod (USACE, May 2013). The habitat of the listed species is protected only to the extent that the surrounding ecosystem, both terrestrial and aquatic, is protected.

4.2 CRITICAL HABITAT

Critical habitat is a term defined and used in the Endangered Species Act. It is a specific geographic area that contains the physical, chemical and biological attributes needed for the continued success of an endangered or threatened species and that may require special management and protection. The constant water quality, temperature and consistent flow of San Marcos Springs allow these unique species to survive. The springs discharge a median flow of 164 cubic feet per second. Critical habitat may include an area that is not currently occupied by the species but that will be needed for its recovery (USFWS. 2013). See Figure 4-2 showing a map of critical habitat for listed species within the Plan Area.

Figure 4-2 Critical Habitat of Listed Species



Map: RPS

To determine what areas to designate as critical habitat, biologists consider physical and biological features needed for life processes and successful reproduction of the (U.S. Fish & Wildlife Service, 2013). These include:

- space for individual and population growth and for normal behavior
- cover or shelter
- food, water, air, light, minerals, or other nutritional or physiological requirements
- sites for breeding and rearing offspring, and habitats that are protected from disturbances or are representative of the historic geographical and ecological distributions of a species

The Fountain Darter and San Marcos Salamander, for example, are dependent on proper streambed vegetation and bottom substrates (e.g. sand, gravel, or soil) to provide food and protection from predators. Excess sediment and other pollutants found in urban stormwater runoff threaten the integrity of critical habitat.

Table 4-2 Description of Critical Habitat for Listed Species

Listed Species	Description of Critical Habitat
Fountain Darter	Upper San Marcos River
Texas blind salamander	Water-filled caves of the Edwards Aquifer near San Marcos. It is subterranean but individuals may reach the surface via springs.*
San Marcos Gambusia	Upper San Marcos River
Texas Wild Rice	Upper San Marcos River
San Marcos Salamander	Spring Lake and its outflow, the San Marcos River, downstream approximately 50 meters from the Spring Lake Dam.

*Texas blind salamanders were first discovered in a flowing artesian well at the San Marcos National Fish Hatchery (now Texas State University - San Marcos)

Figure 4-3 Texas Blind Salamander

Photo: Gary Nafis

4.3 Water Resources

This Plan addresses three types of water resources: surface water, groundwater, and groundwater under the influence of surface water. Each is described in more detail in the following sections.

4.3.1 Surface Waters

Although the hydrologic cycle deals with both surface and groundwater, the term "hydrology" classically refers to surface water. There are several surface water features that influence the hydrology of the Plan Area.

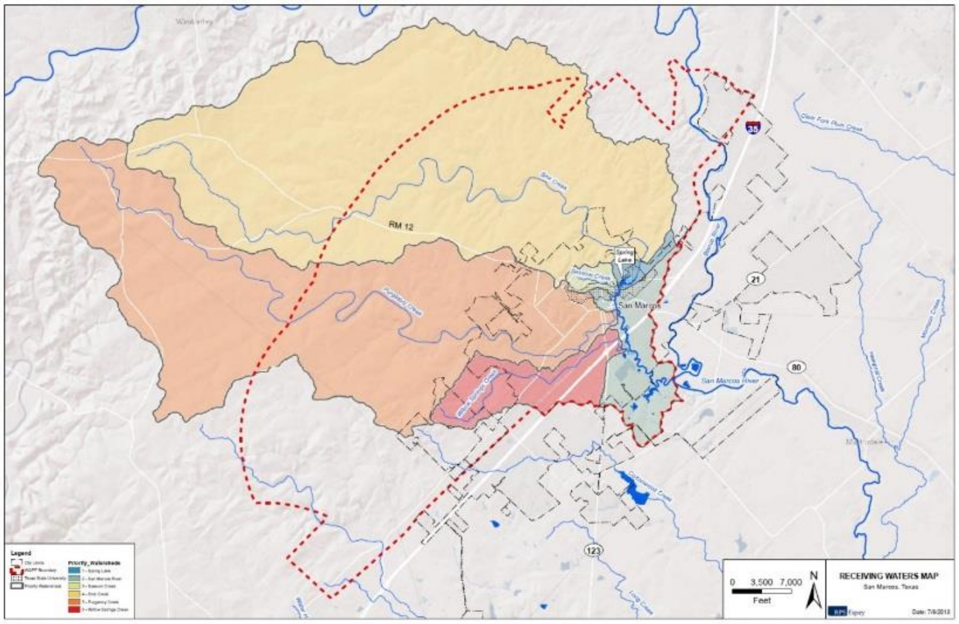
> *"Surface water" includes all forms of water on the surfaces of the earth, including that flowing or stored in above or below ground watercourses or storage features. (Chow, V.T., et al., 1964, p.27)*

Watercourses can be natural, man-made or somewhere in between. Gullies, creeks, streams and rivers are examples of natural watercourses. Culverts, storm sewers, and gutters are examples of man-made watercourses. There are also many types of natural watercourses that have been modified by man, and are neither entirely natural nor entirely man-made. Storage features for surface water can also take many forms. These storage features can include lakes, depressions, ponds, impoundments and tanks. Water in these types of watercourses or storage features would be considered surface water (Naismith Engineering, Inc., 2005).

Sink Creek flows eastward from the Hill Country before turning south into Spring Lake. The lagoon formed where the creek joins Spring Lake is known as the Slough Arm of the lake. San Marcos Springs is the source of water for the San Marcos River, which meets the Blanco River 30 miles downstream. The Upper San Marcos River is the reach that flows approximately 4 miles from its source to the confluence with the Blanco River. The Upper San Marcos River watershed includes the San Marcos River and the major tributaries Sink Creek, Sessom Creek, Purgatory Creek, and Willow Springs Creek.

The location of these streams and watersheds is portrayed in Figure 4-4, below. Two (2) of these streams (Sink, Purgatory) are large and within the Recharge Zone. Thus they are likely to be responsible for a significant portion of the recharge to San Marcos Springs.

Figure 4-4 Watershed Map



Map: RPS

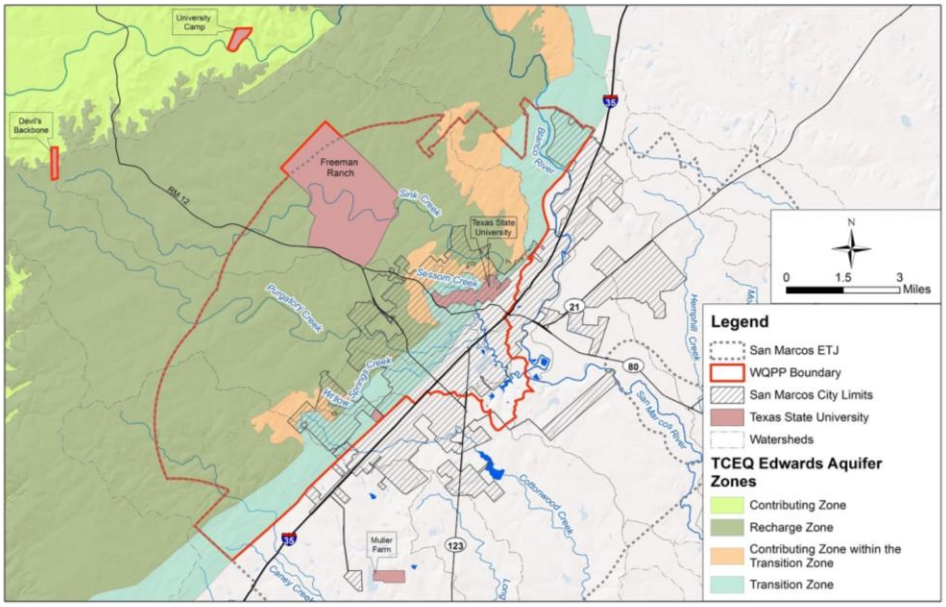
4.3.2 GROUNDWATER

> *"Groundwater" is water flowing or stored in the voids of natural earthen material below ground level. (Chow, V.T., et al., 1964 p.13)*

Groundwater is found in the voids of many natural earthen materials, often called media. While groundwater is found in all types of earthen media, it is most frequently encountered in useable quantities in sand, gravel and porous rock. Surface water becomes groundwater when it infiltrates into the earthen media through a process called "recharge". The location where this recharge occurs is referred to as the "recharge zone". The earthen media containing groundwater is often referred to as an "aquifer". When groundwater discharges to the land surface, for example at a "spring", the groundwater once again becomes surface water (Naismith Engineering, Inc., 2005).

The Edwards Aquifer Zone is one of the most permeable and productive carbonate aquifers in the United States. Edwards Aquifer Zones within the Plan Area are shown in Figure 4-5, and are further described below:

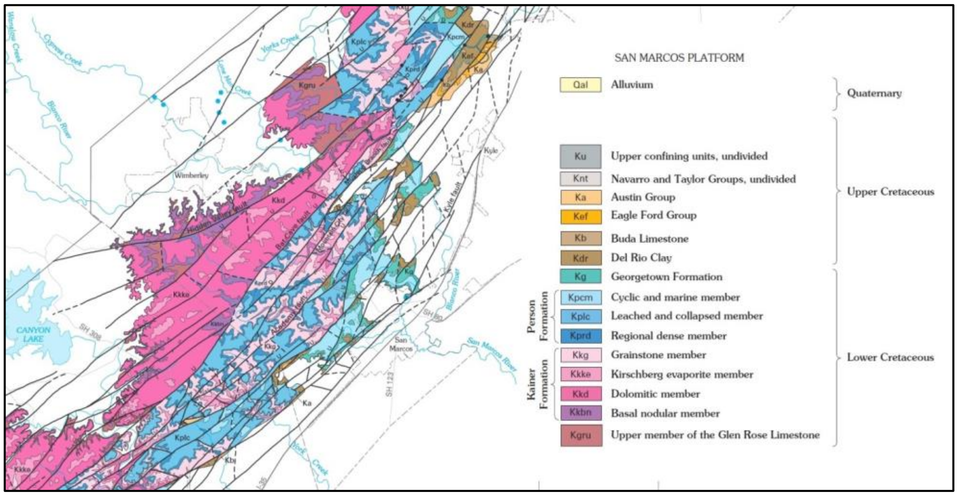
Figure 4-5 Edwards Aquifer Zones in the San Marcos Area



Map: RPS

The Edwards Aquifer Recharge Zone is the outcrop of the geologic unit known as the Edwards Group. The Lower Cretaceous age Edwards Group overlies the Lower Cretaceous Age Glen Rose Formation. The Edwards Group includes the Edwards and Georgetown limestone layers which are characterized by light to dark beds of highly fractured limestone. This Group consists of complex carbonate formations with characteristic karst features. A significant number of faults are found in these formations in the San Marcos area as shown in Figure 4.6.

Figure 4-6 Geology of the Balcones Fault Zone in the San Marcos Area



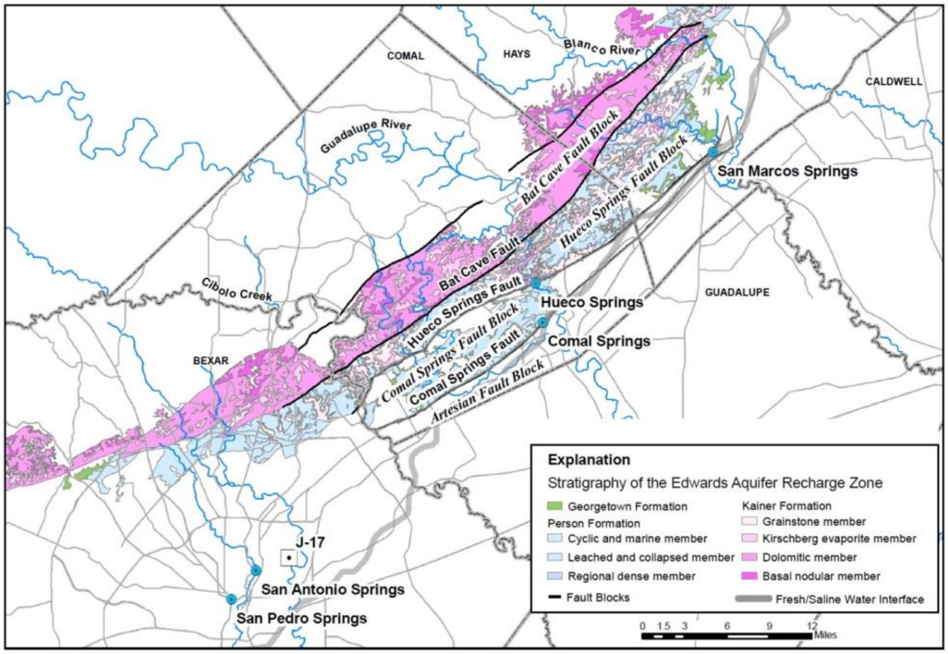
(This figure is a selected portion of the USGS Scientific Investigations Map 2873)

The Edwards Aquifer is comprised of groundwater bearing geologic formations within the Edwards Group. There are three (3) recognized zones within the Edwards Aquifer: 1) the Southern (or San Antonio) Zone, the 2) Barton Springs Zone, and 3) the Northern Zone.

The Southern Zone of the Edwards Aquifer in the Vicinity of San Marcos

The hydrogeology of the Edwards in the area of San Marcos is complex. It was studied in EAA Report No. 08-01 titled Evaluation of the Option to Designate a Separate San Marcos Pool for Critical Period Management. See Figure 4-7 Stratigraphy of EARZ in central Texas.

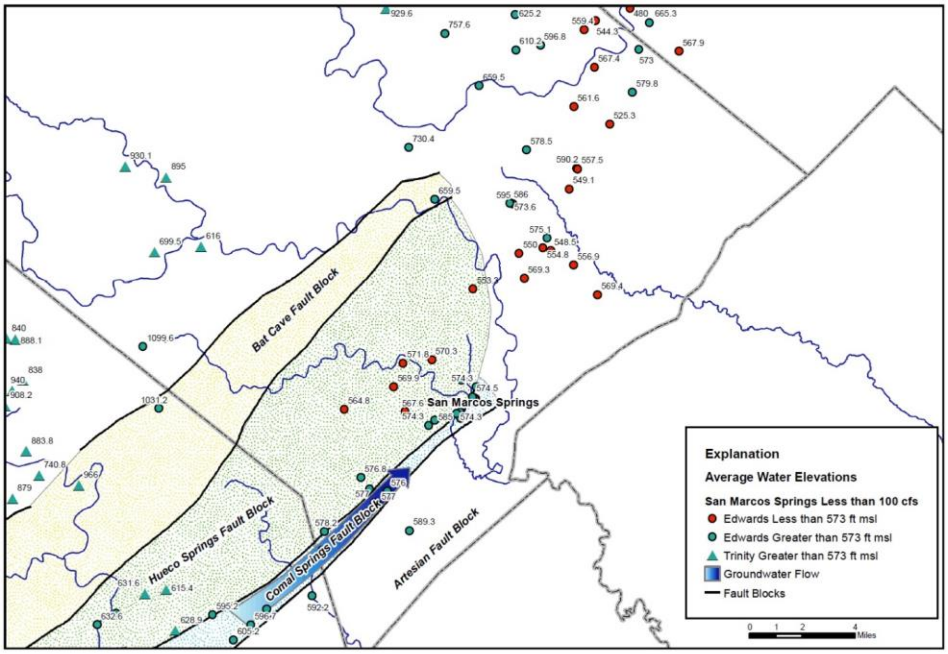
Figure 4-7 Stratigraphy of the EARZ in Central Texas



Edwards Aquifer Authority

The sources of water for San Marcos Springs were described in the study. San Marcos Springs is part of a multicomponent surface water and groundwater hydrologic system that has developed in the Balcones Fault Zone Edwards Aquifer. Groundwater generally flows (southwest to northeast) from Bexar County toward Comal and San Marcos Springs through Bat Cave, Hueco Springs, Comal Springs, and Artesian fault blocks (See Figure 4-8 Groundwater Flow at 100 CFS). Additional water recharges the fault blocks from principal perennial streams: Cibolo Creek, the Guadalupe River, and the Blanco River. Ephemeral streams (e.g. Dry Comal Creek, Blieders Creek, and Sink Creek) also recharge water, but little information exists regarding the volume that recharges the aquifer from the streams (Johnson, Steven B, Schindel, Geary M, EAA Evaluation of the Option to Designate a Separate San Marcos Pool for Critical Period Management).

Figure 4-8 Groundwater Flow at 100 CFS



4.3.3 GROUNDWATER UNDER THE DIRECT INFLUENCE OF SURFACE WATER

> ***"Groundwater under the Direct Influence of Surface Water" is groundwater that is in continuous, open communication with surface water, such that the characteristics of the groundwater are determined almost entirely by the characteristics of the surface water.*** *(Texas Administrative Code, 1997, Ch.290)*

"Groundwater under the direct influence of surface water" is a special category of groundwater that is treated differently under certain state and federal regulatory programs. In most instances, groundwater under the direct influence of surface water is located very near the recharge point, where it changes from surface water to groundwater. This proximity to the recharge zone does not allow an adequate time or distance buffer to offset changes in groundwater quality resulting from changes in surface water quality. There are two basic differences between normal groundwater and groundwater under the influence of surface water that form the basis for distinguishing between the two. The first difference is the presence of larger microorganisms (e.g. algae, bacteria, etc.). As groundwater flows through most earthen media, larger microorganisms are filtered out fairly rapidly. Normal groundwater will not have these larger microorganisms. The second difference is rapid, unpredictable changes in water chemistry due to fluctuations in the chemistry of the surface water influencing the groundwater. Normal groundwater has typically been buffered by the earthen media in the aquifer and will not typically experience rapid, unexpected changes in quality (Naismith Engineering, Inc., 2005).

There are a number of common elements for the recharge occurring to all of the aquifers in the Plan

Area. In the recharge zones for these aquifers, direct recharge occurs from infiltration through the soil column. However, for both the Trinity and the Edwards, significant portions of the recharge also occur along streams that cross the recharge zone. This recharge from streams includes both percolation/ infiltration of surface water through the stream beds, and entry through "point" recharge features, including caves, sinkholes, solution cavities, fractures, and other similar features (Naismith Engineering, Inc., 2005).

4.4 CRITICAL ENVIRONMENTAL FEATURES IN THE PLAN AREA

Critical Environmental Features (CEFs) are defined as geological, topographical, physiographical, or hydrological components of the landscape within the Edwards Aquifer that, if protected, would serve to remediate the quality of surface and ground water for consumptive and non-consumptive human use as well as protect biological components of the human environment such as terrestrial and aquatic biological resources including listed species (Naismith Engineering, Inc., 2005). Critical Environmental Features, as used in this Plan, are described as follows:

4.4.1 CATEGORY 1: LIMESTONE RECHARGE FEATURES

- Caves – natural underground open spaces formed by dissolution of limestone that are large enough for an average-sized person to enter.
- Solution Cavities – a natural cavity or depression formed as a result of dissolution of limestone.
- Solution-enlarged Fractures – fractures that show evidence of being locally enlarged by dissolution of limestone, may be part of interconnected voids connecting surface with subsurface strata.
- Faults – a fracture along which there has been displacement of one side of the fracture relative to the other.
- Manmade features affecting bedrock – unplugged abandoned water wells, quarries, or cultural features that would permit infiltration of surface water to subsurface strata.
- Swallet or swallow holes – a recharge feature in a streambed or drainage where surface flow is diverted to subsurface strata.
- Sinkholes – a broad topographic depression greater than 6 feet in diameter with more than 6 inches of topographic relief that provides a pathway to subsurface strata.

4.4.2 CATEGORY 2: STREAMS AND ASSOCIATED STREAMBEDS

Streams and associated streambeds that transport water to recharge features or contain aquatic communities are adversely affected by degraded water quality. This category includes all creeks and associated tributaries lying over the recharge zone of the Edwards Aquifer.

4.4.3 CATEGORY 3: FLOODPLAINS AND WETLANDS

Floodplains, wetlands, associated soils, and vegetation attenuate rainfall runoff, decrease the volume and velocity of flood flows, filter suspended solids and contaminants, and contribute to groundwater recharge. Construction and development activities in the vicinity of floodplains and wetlands are governed by several existing federal regulatory programs.

4.4.4 CATEGORY 4: EDWARDS AQUIFER DISCHARGE AREAS

These areas support biological communities including rare or endangered species that depend on spring discharge entirely or partially for survival. Because these features function as a result of the combined effects of pumping and recharge, they are directly affected by effects to the previous Categories 1-3.

As discussed in more detail below, all projects under the jurisdiction of the TCEQ's Edwards Aquifer Protection Program require a geologic assessment. These features should be identified and categorized as a part of this assessment. Categories 1-3 are geographically located with generally finite boundaries, and can function to substantially affect water quality. Therefore, protection of these features is the first line of defense in protecting Category 4 features. A number of structural and non-structural measures are identified in this Plan to protect Critical Environmental Features. Category 1, 2 and 4 features should be protected using dedicated offsets, as described in Chapter 7, Section 7.5, and shown in Figure 7-5. Procedures for protecting Category 3 features (floodplains wetlands) have been incorporated into the protections for streams. Any development occurring in the vicinity of these features should incorporate the water quality protection measures prescribed in this Plan (Naismith Engineering, Inc., 2005).

5. WATER QUALITY PARAMETERS, MONITORING AND MODELING

The information in this chapter describes water quality parameters as well as local monitoring and modeling efforts.

5.1 DEFINITION OF WATER QUALITY PARAMETER

Water quality parameters are specific chemical, physical, or biological aspects of surface or ground water that are used to assess, monitor and control water quality. They serve as a measure of the conditions of water relative to the requirements of one or more biotic species or to human needs or purposes. Water quality parameters are also referred to as constituents and the two words have the same meaning. A constituent is only considered a pollutant when it causes an impact, but the terms are used somewhat interchangeably here.

The level of suitability for human use or maintenance of aquatic life would be determined by the quantity of water available, the type of water quality constituents present, and whether the minimum or maximum acceptable threshold concentration levels of the constituents have been exceeded. Many different public and private scientific studies of water quality have identified numerous water quality parameters used for different purposes. The further discussion of water quality parameters in this Plan will be subdivided by the water medium (surface water, groundwater or both) to which these parameters apply. In addition to their subdivision by medium, the Plan discusses the use of water quality parameters in four (4) general contexts (Naismith Engineering, Inc. 2005):

- General Categories of Water Quality Parameters
- Historical monitoring
- Planning and design
- Monitoring and evaluation

5.2 GENERAL CATEGORIES OF WATER QUALITY PARAMETERS

There are numerous ways to assign water quality parameters to general categories. Since regulatory programs are a significant factor in determining which water quality parameters are widely used, the general categories used by these regulatory programs serve as a good starting point for distinguishing between various parameters. Although numerous water quality parameters have been identified, a smaller (although still extensive) set of water quality parameters is used in these regulatory programs for the purposes of assessing water quality and evaluating compliance with regulatory standards. Also, since most regulatory programs require some type of monitoring, there is generally a much larger universe of available data for the monitored parameters through these regulatory programs. This is certainly true for the Plan Area. While the scope of this Plan prevents a complete listing of all the parameters utilized by all the current water quality regulatory programs, several general categories of water quality parameters have been identified that span most water quality regulatory programs (U.S. Environmental Protection Agency, August, 1999). These general categories will provide some background information on water quality parameters. The descriptions are based largely on those of the Regional Water Quality Protection Plan by Naismith Engineering, Inc. prepared in 2005.

5.2.1 SOLIDS (TSS AND TDS)

Solids in water originate from many sources and can vary widely in size and physical form. They are introduced into the water column in a variety of ways, including human activity and natural process. Solids can float on the surface, be suspended, or settle out of the water column. Floating solids are an anecdotal water quality parameter, since they are generally observed visually and do not require a specific measurement method. Suspended solids are most frequently measured in water as Total Suspended Solids (TSS). A secondary parameter for solids in water is turbidity. However, turbidity can also at times be affected by dissolved constituents.

Floating or suspended solids increase turbidity, reduce light penetration, and limit the growth of desirable aquatic plants. Solids that settle out as bottom deposits contribute to sedimentation and can alter and eventually destroy habitat for fish and bottom-dwelling organisms. Solids can also facilitate the transport, storage and accumulation of other pollutants. Pollutants bound up in settled solids remain in contact with the water column and are subject to re-suspension, and redeposition.

In most locations, solids are primarily a surface water issue, since they are often filtered out of groundwater by the earthen media. However, aquifers in karst environments, such as the Edwards Aquifer, can experience very pronounced solids impacts to groundwater due to the ‘short-circuiting’ of groundwater flow through faults, fractures and secondary features. This short-circuiting prevents the natural filtering process which normally removes these solids. For this reason, TSS is a water quality parameter that applies to both surface water and groundwater in the Plan Area.

Total dissolved solids (TDS) are a measure of the combined content of all inorganic and organic substances contained in water in molecular, ionized or micro-granular form. TDS is not generally considered a primary pollutant since it is not deemed to be associated with health effects. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium and chloride. The San Marcos River was listed for impaired total dissolved solids (TDS) concentrations in the 2012 *Texas Integrated Report* with an average concentration of 402.64 mg/L, which was just 2.64 mg/L over the state standard of 400 mg/L. Since that time additional data was collected and new analyses found that the TDS mean concentration is less than 400/mg/L. Thus, this river segment is no longer listed for general use impairment due to TDS (GBRA, 2015). For more information on state standards see section 6.12.1 of Chapter 6 in this document.

5.2.2 DISSOLVED OXYGEN/OXYGEN-DEMANDING SUBSTANCES

Adequate levels of dissolved oxygen in water are necessary for the survival of aquatic plants and animals. However, many pollutants sequester or extract oxygen when introduced into the water column. These pollutants are generally described as oxygen-demanding substances. While these substances vary in origin and composition, they all can adversely impact water quality by removing sufficient oxygen from the water column to reduce dissolved oxygen levels below those necessary to sustain aquatic life.

Several different water quality parameters are used to quantify this condition. The first is the direct measurement of dissolved oxygen (DO) in the water column, most frequently using a hand-held probe. Oxygen-demand potential for substances in the water is typically measured by Biochemical Oxygen

Demand (BOD), Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC), utilizing laboratory tests.

Although oxygen demanding substances are most frequently encountered in surface water, insufficient DO levels can also occur in groundwater. If DO levels are reduced prior to surface water being recharged to groundwater, there is typically no mechanism available in the earthen media to reintroduce oxygen to the water. For this reason, DO, BOD, COD and TOC are parameters that apply to both surface water and groundwater in the Plan Area.

5.2.3 NUTRIENTS

Nutrients are necessary to support aquatic life. The principal nutrients impacting water quality are nitrogen and phosphorus. Major sources of these nutrients include urban landscape runoff (fertilizers, detergents, & plant debris), atmospheric deposition, soil erosion (phosphorus) improperly functioning domestic waste management systems, animal wastes, and in some instances treated domestic wastewater.

A number of water quality parameters are used to measure the various forms of nitrogen and phosphorus in water. Ammonia (NH3) nitrogen is the nitrogen form that is usually the most readily toxic to aquatic life. Nitrate (NO3) and nitrite (NO2) are the inorganic fractions of nitrogen. Total Kjeldahl nitrogen (TKN) measures the organic and ammonia nitrogen forms. By subtraction, the organic fraction can be determined. Total phosphorus measures the total amount of phosphorus in both the organic and inorganic forms. Orthophosphate measures phosphorus that is immediately biologically available.

Excessive quantities of nutrients in the water column can result in significant increases in primary biological productivity, with the major impact being excessive algal growth (see Figure 5-1). In surface waters, this can lead to nuisance algal blooms and eutrophication. A secondary impact is increased oxygen-demand resulting from the decomposition of dead algae.

As discussed above in the section on solids, the karst characteristics of the Edwards Aquifer often circumvent the natural filtering process which might normally remove these nutrients from groundwater. For this reason, the nutrient parameters identified above apply to both surface water and groundwater in the Plan Area.

Figure 5-1 Algae in Spring Lake and in the Slough Arm

Photo: John Gleason

Photo: John Gleason

5.2.4 PATHOGENS

Pathogens are disease-producing organisms that present a potential health threat when present in water. The principle pathogens from a water quality standpoint are bacteria, viruses, protozoans and toxigenic fungi. These pathogens are typically introduced to water through contact with human or animal waste products, or decomposing organic matter. Some types of pathogenic bacteria are also naturally present in soil and can be introduced where surface water or groundwater come in contact with that soil. Since they are living organisms, pathogens require favorable environmental conditions (e.g. suitable temperatures, etc.) for their continued existence. Pathogens pose potential health threats to humans, animals and aquatic life.

Due to the large number of species and significant variations within each species, the monitoring and identification of pathogens is difficult. However, a number of indicator organisms have been used historically to assess the presence of harmful pathogens in water. While not necessarily pathogenic themselves, these indicator organisms can provide a useful marker when attempting to assess and quantify the presence of pathogenic organisms. Fecal coliform has been widely used as a parameter indicating the presence of harmful pathogens in wastewaters and storm water runoff. Other bacterial indicator parameters that have been used to evaluate the presence of harmful pathogens in water include Escherichia coli, streptococci and enterococci. In more specialized situations, the presence of enteric viruses and/or protozoans such as Giardia lamblia and cryptosporidium are also monitored. Specific laboratory testing and evaluation is typically required to measure the presence of these pathogens and surrogate indicator parameters.

As discussed above in the section on solids, the karst characteristics of the Edwards Aquifer often circumvent the natural filtering process which might normally remove most pathogenic organisms from groundwater. For this reason, pathogens are water quality parameters that apply to both surface water and groundwater in the Plan Area.

5.2.5 PETROLEUM HYDROCARBONS

Petroleum hydrocarbons include oil and grease; volatile and semi-volatile organic compounds (VOCs and SVOCs), and a variety of polynuclear aromatic hydrocarbons (PAHs). Sources of petroleum hydrocarbons include parking lots and roadways, leaking storage tanks, auto emissions, and improper disposal of waste oils and other petroleum products. Higher concentrations are typically found in soils and sediments along transportation corridors. PAHs, while naturally occurring in crude oil and coal, are usually at undetectable levels in runoff from natural, undeveloped sites.

Numerous scientific studies have evaluated and identified various toxic effects of petroleum hydrocarbons, sometimes at very low concentrations. These toxic effects pose potential health threats to humans, animals and aquatic life. Numerous regulatory agencies have established water quality criteria for petroleum hydrocarbons, principally VOCs, SVOCs, and PAH compounds. Most petroleum hydrocarbons have low solubility in water and will generally remain phase-separated when in contact with water. In a phase separated state, petroleum hydrocarbons are still mobile in both surface water and groundwater. However, a few petroleum hydrocarbons have higher solubility and will partition readily into water when they are in contact. Once dissolved in water, petroleum hydrocarbons are very mobile in both surface water and groundwater. Specific laboratory testing and evaluation is typically required to measure the presence of petroleum hydrocarbon parameters.

Due to their mobility in both surface water and groundwater, petroleum hydrocarbon parameters apply to both surface water and groundwater in the Plan Area.

5.2.6 METALS

Metals are naturally occurring compounds that are frequently encountered in water. The principal sources of metals in water are industrial activity and mechanized equipment, including automobiles. Metals are introduced to water through a variety of processes, including storm water runoff, atmospheric deposition, leaching of earthen materials.

Various regulatory programs categorize “heavy metals” as priority pollutants. While the definition of this term varies some across regulatory programs, heavy metals generally include arsenic, barium, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver and zinc (Title 40, Code of Federal Regulations, Chapter 261, 2003). In water, metals are most frequently encountered in dissolved form. Metals may also be adhered to suspended solids. In dissolved form, metals are very mobile in both surface water and groundwater. Metals in water have the potential to impact human uses and cause acute or chronic toxic impacts to aquatic life. Specific laboratory testing and evaluation is typically required to measure the presence of metals parameters.

Due to their mobility in both surface water and groundwater, metals parameters apply to both surface water and groundwater in the Plan Area.

5.2.7 SYNTHETIC ORGANIC COMPOUNDS

The term synthetic organic compound (SOC) is used to describe a variety of manufactured or refined organic compounds, including pesticides, solvents and household and industrial chemicals. The principle sources of SOCs are the residuals of these chemicals. SOCs are introduced to water through a variety of processes, including storm water runoff, discharge through point sources and atmospheric deposition.

Various regulatory programs categorize SOCs as priority pollutants. Most SOCs are soluble in water and are therefore very mobile in both surface water and groundwater. Numerous scientific studies have identified SOCs as posing serious health risks to humans and aquatic life, often at very low concentrations. One aspect generally unique to SOCs is their tendency for bioaccumulation in the food chain. Specific laboratory testing and evaluation is typically required to measure the presence of SOCs.

Due to their mobility in both surface water and groundwater, SOC parameters apply to both surface water and groundwater in the Plan Area.

5.2.8 PHYSICAL PARAMETERS

Several physical parameters of water also play a key role in evaluating and assessing water quality.

Temperature: Water temperature is an important measure of water quality, since the temperature affects other physical properties of water, including conductance and the solubility of both chemical compounds and gases (Malina, J. F. 1996). Other previously identified parameters, such as dissolved oxygen (DO), are directly linked to temperature. The principal determinants of water temperature are natural. However, increased temperature can be imparted to water through the discharge or runoff of water whose temperature has artificially been raised due to human activity. Temperature is measured directly using a variety of different instruments.

Elevated temperatures are typically a water quality issue for surface water since the significant geothermal capacity of earthen media tends to moderate groundwater temperatures rapidly. In surface water, elevated temperatures can significantly increase the metabolism, respiration, and oxygen demand of fish and other aquatic life. This poses a potential threat to aquatic life. While excessive temperature can sometimes cause direct mortality, it is more often the secondary conditions associated with elevated temperature (e.g. low DO) which result in mortality. Even if significant aquatic life mortality does not result from elevated temperatures, it can result in a change of character in the aquatic life in surface water bodies (California State Water Resources Control Board, 1963). Sudden changes in temperature can also directly stress aquatic ecosystems. Due to its unique impacts to surface water, temperature is a water quality parameter which generally only applies to surface water in the Plan Area.

pH: The pH value is a measure of intensity of alkali or acid contained in the water. Absolutely pure water has a pH value of 7.0. While pH levels fluctuate naturally based on changes in temperature, circulation, and DO content, significant changes in pH can result from the introduction of additional water with differing pH levels, or through the introduction of other compounds in the water. Most aquatic ecosystems experience natural fluctuations of pH, but can be significantly harmed if human activity or natural events cause significant changes in pH levels. Rainwater typically has much lower pH levels than surface waters (e.g. acid precipitation), while storm runoff from alkaline environments can have much higher pH levels. Groundwater flowing through earthen media can also experience significant changes in pH based on the characteristics of the media. pH is measured directly using a variety of different instruments. pH is a water quality parameter that applies equally to surface water and groundwater.

5.2.9 APPLICABILITY OF PARAMETERS TO SURFACE WATER AND GROUNDWATER

Table 5-1 provides a summary of water quality parameter categories, the potential threat they pose as pollutants and their applicability to surface water and groundwater analysis.

Table 5-1 Applicability of Parameter to Surface Water and Groundwater

Parameter	Pollutant Threat	Applicability	
		Surface Water	Ground Water
Total Suspended Solids (TSS)	Excess TSS can destroy critical habitat and kill aquatic life	x	x
Dissolved Oxygen, Oxygen-demanding Substances: DO, BOD, COD, & TOC	Excessive levels can eventually kill aquatic plants and animals	x	x
Nitrogen: NH3, NO3, NO2 & TKN	Excess causes algae and eventually may kill aquatic plants and animals	x	x
Total Phosphorus (TP) and Orthophosphate	Excess causes algae and eventually may kill aquatic plants and animals	x	x
Pathogens: many including e. coli, fecal coliform, streptococci and enterococci	Health threats to humans, animals and aquatic life	x	x
Petroleum Hydrocarbons: PAHs, oil and grease, VOCs and SVOCs	Health threats to humans, animals and aquatic life	x	x
Heavy Metals: many including copper, lead, mercury, nickel, zinc and arsenic	Threats to humans, animals, critical habitat and aquatic life	x	x
Synthetic Organic Compounds: chemicals (landscape, household & industrial)	Health threats to humans, animals and aquatic life	x	x
Temperature	Causes indirect mortality to aquatic life	x	
pH	Indicator of aquatic health	x	x

5.3 MONITORING IN THE PLAN AREA

There are numerous efforts to monitor the hydrologic and water quality characteristics of the Edwards Aquifer, Spring Lake and the upper San Marcos River. This monitoring is being conducted by the Meadows Center for Water and the Environment, Texas State University, the City of San Marcos, Guadalupe Blanco River Authority, the U.S. Geological Survey, the Edwards Aquifer Authority, and others. Monitoring programs are also in effect at the AE Wood Fish Hatchery and at the City of San Marcos Wastewater Treatment Plant. Some notable monitoring programs are described below.

5.3.1 SAN MARCOS OBSERVING SYSTEM (SMOS)

The SMOS is a broad environmental data collection and analysis effort within the San Marcos River Watershed led by the MCWE. SMOS is studying the interactions of the system as a whole through continuous monitoring and computerized habitat modeling. SMOS provides this research to support sustainable management practices and policy decisions for Spring Lake and the upper San Marcos River watershed. Knowledge gained by SMOS and MCWE supports efforts in the understanding and management of the water resources and future sustainability of the San Marcos River basin.

SMOS researchers have mapped the aquatic vegetation along the entire river. They’ve used techniques to determine the shade of every tree onto the river so it could be correlated with plant distribution. They’re collecting monthly samples of macroinvertebrate by vegetation type. They’ve installed sampling equipment on the springs to continuously monitor water quality parameters to better understand how they respond to regional rainfall differences. At five locations in the river, they’ve deployed probes measuring temperature, pH, dissolved oxygen, turbidity, and other key parameters every 15 minutes.

SMOS is also monitoring recreational use, which is an important contributor to turbidity levels in the stream. Researchers have installed cameras along the river that were designed to capture pictures of wild game. Instead, they’re helping keep track of the number of kayakers, tubers and fisherman on the river. The data goes toward an effort to balance recreational uses with restoration of species like Texas Wild Rice.

5.3.2 WATER QUALITY MONITORING SITES

Water quality monitoring sites are located throughout the Spring Lake/Upper San Marcos River system. Figure 5-2 shows the location of water quality monitoring sites used regularly by the programs that sponsor them.

Figure 5-2 Water Quality Monitoring Sites

5.4 WATER QUALITY PARAMETERS FOR PLANNING AND DESIGN

Water quality data used for planning and design should be evaluated and treated differently than data used for monitoring and evaluation. One primary difference is the number of parameters to be used. While in monitoring and evaluation, all parameters of concern should be addressed. However, for planning and design, a more limited approach can be taken. This limited approach typically focuses on using representative parameters. In this situation, one or two representative parameters are used to represent the presence and movement of other similar parameters and can serve as surrogates for them during the design process. (Naismith Engineering, Inc., 2005).

There are two criteria for selecting a target constituent:

- The constituents should reflect the types of water bodies identified for protection, and be associated with specific impacts to the water bodies
- Sufficient monitoring data should be available in order to reasonably characterize BMP removal effectiveness.

In the San Marcos area, public water supply, recreation, aquatic life, and endangered species are supported uses in the aquifer, Spring Lake, and/or Upper San Marcos River. A report of recommended water quality for the local endangered species identified constituents of concern to include nutrients, bacteria, sediment, debris, turbidity, metals, temperature, pesticides, and petroleum hydrocarbons (White, et al., 2006). A study of the Spring Lake system identified a similar list (Nowlin and Schwartz, 2012). Given these studies and the type of receiving waters under consideration, the following constituent categories are candidates to use as target pollutants for BMP design:

1. Solids, included suspended, dissolved, turbidity, and gross solids
2. Nutrients, especially nitrogen and phosphorus species
3. Metals, including copper, lead, zinc, arsenic, nickel, cadmium, and silver.
4. Bacteria, including E. coli and/or fecal coliform.
5. Petroleum hydrocarbons
6. Pesticides and herbicides
7. Trash and debris

Extensive information exists for the first four categories, thus it is possible to reasonably characterize runoff quality and BMP effectiveness, but data is limited for the remaining categories. The list of constituents used for BMP design is limited to those that dictate design, e.g., are most difficult to effectively treat. A review of several target constituents has been conducted (see Appendix D). Based on the analysis described in Appendix D, the recommended target constituent is Total Phosphorus.

The San Marcos River and possibly the Comal River in central Texas may have phosphorus-limited systems of nutrient cycling. In a water quality study on the San Marcos River, Groeger et al. (1997) suggested that the spring-driven river is a phosphorus-limited system due to high nitrogen-to phosphorus ratios and the response of algae to added phosphorus in a bioassay experiment. Relatively small additions of phosphorus to this type of water system by effluent discharge from wastewater treatment plants or by surface runoff can greatly increase the potential for plant growth such as algae and thereby affect habitat of aquatic listed species endemic to these rivers.

Phosphorus is considered a greater concern because it is typically the limiting nutrient in most freshwater systems, and Spring Lake is known to be extremely phosphorus limited (Nowlin and Schwartz, 2012). ‘Limiting nutrient’ means the nutrient that controls the growth of plants, such as algae. High nutrient levels can result in excessive plant growth, with impacts to water quality, aquatic habitat, and recreational uses of water bodies. Phosphorus is typically the limiting nutrient in freshwater systems. Stormwater discharges of phosphorus, especially soluble reactive phosphorus (SRP), can cause significant water quality impairment to receiving waters (Geosyntec, et al., 2010). Particulate phosphorus is also a concern because organic particulate phosphorus can be broken down and eventually converted to orthophosphates by bacteria (Geosyntec, et al., 2010). Thus, Total Phosphorus

(TP), which includes both soluble and particulate phases, is recommended as the indicator of nutrient impacts.

5.5 Evaluation and Modeling

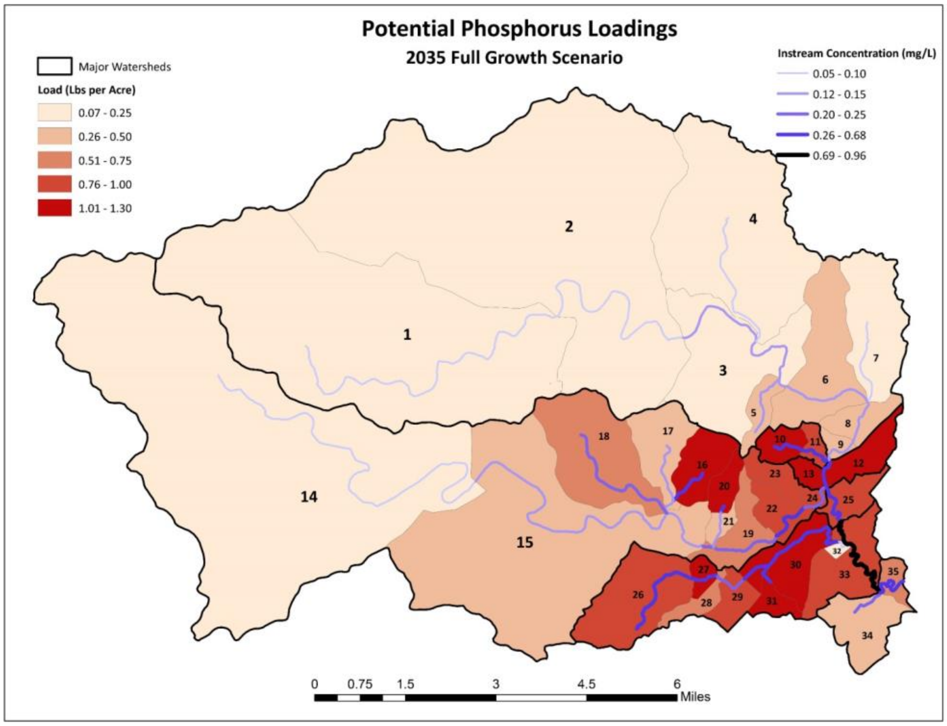
Water quality evaluation and modeling can provide a greater understanding of existing, and potentially, future water quality conditions.

5.5.1 HSPF/BASINS Water Quality Modeling Analysis

The Meadows Center for Water and the Environment performed water quality modeling to assess existing land use conditions as well as identify areas and potential sources of nonpoint source pollutants. The Hydrological Simulation Program –Fortran (HSPF) was utilized through BASINS 4 to perform the analysis. The results of this investigation characterize effects of land use and impervious cover relative to existing development patterns. The simulated output for each drainage basin characterizes discharge and pollutant loadings for nitrate, phosphorous, dissolve oxygen, bio-oxygen demand, ammonia, E. coli bacteria, and total suspended sediments. Best management practices can be incorporated into the model, based on the pollutant, location, topography, and vegetation coverage. The model can simulate the potential reduction of loadings based on the implemented best management practices. The results of the modeling effort are described in the Watershed Protection Plan (WPP) created through the efforts of the San Marcos Watershed Initiative (as noted in Section 1.4.2 of this Plan). Refer to Appendix F – Water Quality Modeling Analysis for more information on the software and the process.

Modeling results of the WPP predict an increase in potential phosphorus loadings to Spring Lake and the upper San Marcos River as the areas that drain to these resources continue to urbanize (see Figure 5-3). Correspondingly, other pollutants associated with urban runoff are expected to increase as well including those described in this chapter: Total Suspended Solids, Oxygen-demanding Substances, Nitrogen, Pathogens, Petroleum Hydrocarbons, Metals and Synthetic Organic Compounds.

Figure 5-3 Potential Phosphorus Loadings in Upper San Marcos Watersheds



5.5.2 LIMITATIONS OF PREDICTIVE WATER QUALITY MODELING

The science of predictive water quality modeling is complex and multi-faceted. There is still some uncertainty in many models surrounding the formulation of sedimentation and nutrient regeneration, as well as other complicating factors that are not yet fully understood. This, in conjunction with the sensitivity of models to assumptions regarding dynamic balance between receiving water concentrations and nutrient loadings, undermines the predictive capability of dynamic water quality models. In order to be truly effective, it’s likely that the necessary investment in water quality modeling for the San Marcos aquatic system would have to be immense and conducted over a long period of time. For this reason, future efforts using more simplified methods are concluded to provide the best focus for the limited resources of the City of San Marcos and Texas State University.

6. WATER QUALITY THREATS AND IMPACTS

The greatly restricted distribution of the listed species and apparent intolerance of habitat conditions outside the immediate vicinity of this springs system gives evidence of their vulnerability. Increased groundwater utilization in the near future and the probability of contaminants increasing in almost direct ratio to expanding real estate development activity over aquifer recharge zones constitute serious potential threats to the continued existence of the species (Federal Register, 1980).

Water resources in San Marcos include ground and surface water, the latter including lakes, rivers, and streams. It is important to recognize the interaction and interdependency between surface and groundwater, which should be viewed as "integrated resources."

Because lakes tend to be pollutant sinks, the accumulation of sediment and nutrients can result in loss of storage, a change in trophic status, and contamination of bottom sediments, all which can affect uses such as water supply, recreation, and aquatic life support. Streams tend to retain pollutants in the water column for shorter periods of time, but are also more susceptible to erosional processes, thus control of erosive flows and establishment of buffer zones can be important. Perennial streams typically support more uses than intermittent and ephemeral streams, and may require a higher level of protection. Aquifers are also often "sinks" and, in karst areas, easily contaminated. All these receiving water types are vulnerable to changes in water quantity and watershed hydrology, due to increased withdrawals, the loss of recharge and increase in runoff from impervious cover additions, and other factors.

The Texas Commission on Environmental Quality (TCEQ) has named the Edwards Aquifer the major aquifer in the state most vulnerable to pollution, due to its status as a sole drinking source and the growing urbanization of the region (Texas Groundwater Protection Committee, 2003).

The Edwards is one of the most permeable and productive carbonate aquifers in the United States. Due to the predominantly karst limestone composition, there are many permeable recharge features within creek beds and breaks between hills and steep ravines. Karstic aquifers are highly susceptible to pollutants due to relatively little filtration by shallow surface soils, direct runoff into aquifer recharge features, absence of granular textures within aquifers that ordinarily provide filtration or biological degradation, rapid flow velocities with aquifer conduits, and relatively short periods of degradation of groundwater pollutants by microorganisms and other time-dependent processes (White, et al., 2006).

6.1 URBANIZATION AND IMPERVIOUS COVER.

The negative impacts of unmanaged urban stormwater runoff are well-known, have been documented for the local area, and include the following (MDE, 2009):

- Diminishing groundwater recharge (along with an associated decrease in stream baseflow)
- Declining water quality
- Degradation of stream channels
- Increased overbank flooding
- Floodplain expansion

Increased urbanization and population growth place additional demands on limited sources of surface and groundwater. Known or suspected negative effects attributable to urban development are summarized in this chapter. More detail is provided in Appendix G: Urbanization Effects and Impervious Cover Thresholds. This information will be useful for defining goals, or target conditions, for the San Marcos watersheds, including setting of an impervious cover limits and “thresholds”, i.e., a levels of imperviousness that are likely to cause unacceptable impacts. The aerial photograph in Figure 6-1 shows existing impervious cover relative to the critical habitat of Spring Lake and the upper San Marcos River.

Figure 6-1 Aerial Photo: Impervious Cover and the Upper San Marcos River

Photo: Google Earth

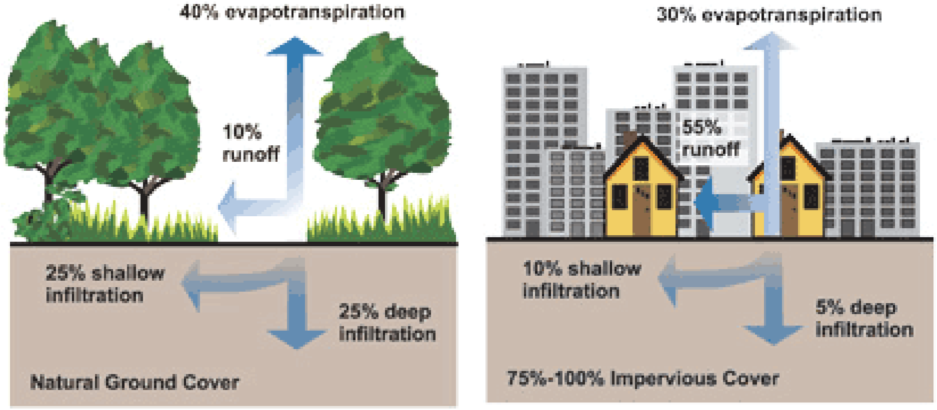
In developing water quality recommendations for endangered aquatic species in the Edwards Aquifer and San Marcos River systems, the US Fish and Wildlife Service (White, et al., 2006) identified threats attributable to urban development and impervious cover to include biological integrity, dissolved oxygen, debris, indicator bacteria, nutrients, sediment, turbidity, metals, pesticides, petroleum hydrocarbons, and polycyclic aromatic hydrocarbons.

6.1.1 IMPERVIOUS COVER EFFECTS ON SITE HYDROLOGY

Evidence of the impact of urbanization on national and regional environments is provided. Additional information is provided in Appendix G. The impervious cover associated with urbanization affects how stormwater acts on a site. One reason stormwater management is an important consideration is that storm events in urban areas tend to be more "flashy" than rural storm events. This term describes how quickly stormwater runoff appears in storm sewers or streams and how quickly it then recedes when compared to natural conditions.

Urban development can dramatically alter the local hydrologic cycle (see Figure 6.2). The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees, meadow grasses, and agricultural crops that had intercepted and absorbed rainfall are removed and natural depressions that had temporarily ponded water are graded to a uniform slope. Cleared and graded sites erode, are often severely compacted, and can no longer prevent rainfall from being rapidly converted into stormwater runoff.

Figure 6-2 The Hydrology of Pre-Developed Conditions vs. Urbanized Conditions



Relationship between impervious cover and surface runoff: Impervious cover in a watershed results in increased surface runoff. As little as 10 percent impervious cover in a watershed can result in stream degradation.

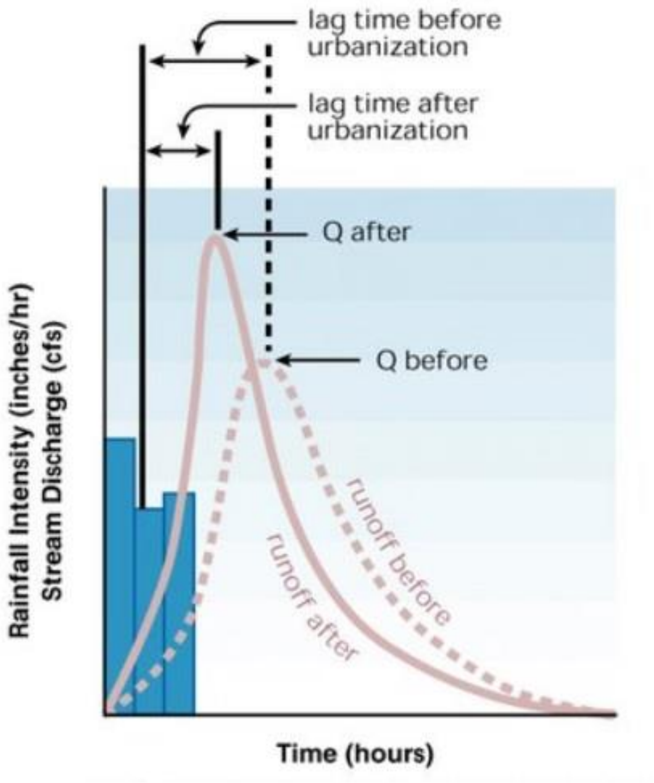
The situation worsens after construction. Roof tops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is converted directly to stormwater runoff. In Central Texas, a natural site (i.e., undeveloped with no impervious cover), will typically have 5% or less of the annual rainfall converted into runoff, the remaining infiltrated (est. 15-35%) or lost to evapotranspiration (est. 60-80%). Ideally, development should attempt to replicate the hydrology of a natural site, perhaps a theoretical possibility but difficult to achieve in reality.

Impervious cover can restrict decomposition or removal of contaminants during stormwater events, and increases in impervious cover may eventually impact the water quality of the Edwards Aquifer (White, et al., 2006).

6.1.2 IMPERVIOUS COVER THRESHOLDS

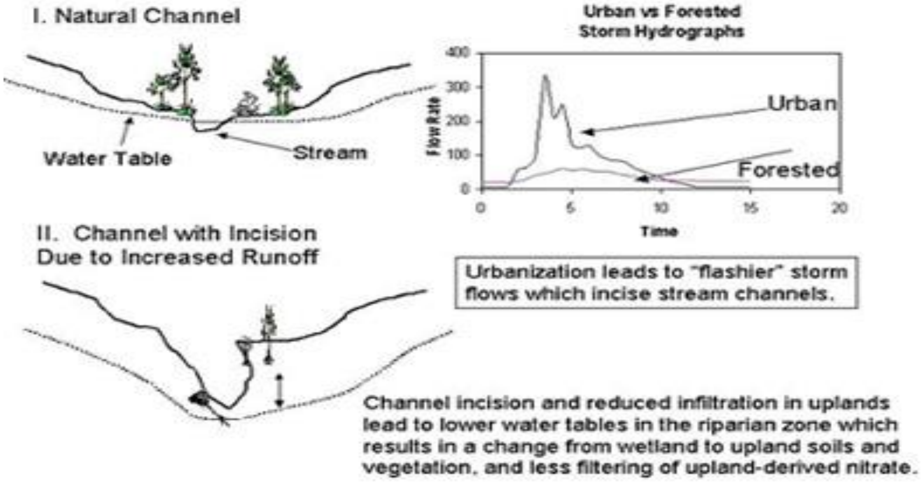
It is well documented that large increases in runoff volume occur when impervious cover replaces pervious areas. A totally impervious site can generate more than 20 times the amount of runoff that an undeveloped site can. For example, the TCEQ Edwards Rules Technical Manual (TCEQ, 2005) assumes a runoff coefficient of 0.90 for a 100% impervious cover site, and 0.03 for an undeveloped site, thus the developed site is predicted to generate 30 times more runoff, on an annual average basis.

Figure 6-3 Hydrographs Before and After Development



A hydrograph compares the runoff rate versus time. Figure 6-3 shows how a hydrograph after urbanization peaks sooner and recedes much faster than a natural conditions hydrograph. The water post development travels at a much faster rate because of the increase in impervious and smooth surfaces. Water will travel down a concrete driveway much faster than it will through the adjacent lawn. Flashiness tends to damage streams by causing increased erosion with moderately large storm events. Stormwater management is partly meant to control this increased flashiness and keep it from damaging property and the natural environment.

Figure 6-4 Impacts of Urbanization on Streams and Channels



Urbanization leads to "flashier" storm flows which incise stream channels.

Channel incision and reduced infiltration in uplands lead to lower water tables in the riparian zone which results in a change from wetland to upland soils and vegetation, and less filtering of upland-derived nitrate.

Illustration: Groffman et al. 2003

Impacts to stream ecology, morphology and water chemistry have been found to be correlated to multiple indicators of urbanization, and not just impervious cover (Tate, et al., 2005). Significant factors include land use, land cover, population density, road density, and socioeconomic factors. Thus, management measures that address these variables can be important. Distinguishing total vs. effective impervious cover can also be important.

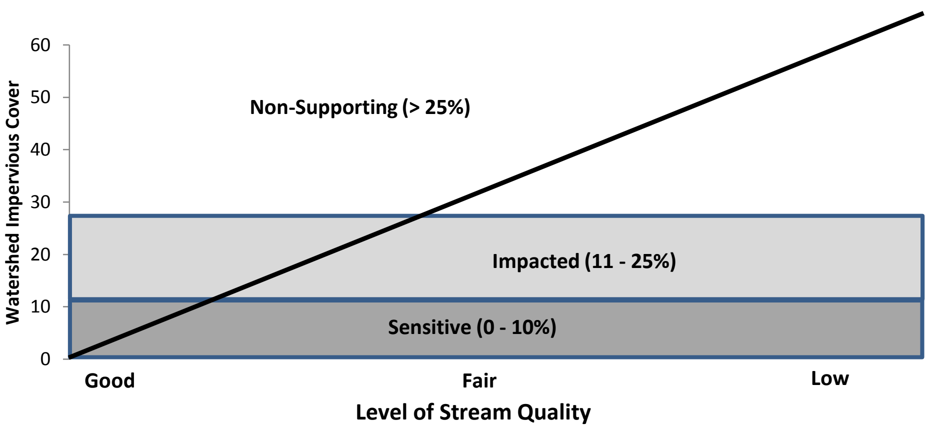
- Total impervious area (TIA) = all impervious area in catchment
- Effective impervious area (EIA) = impervious area in catchment that is directly connected to stream channels (i.e., precipitation falling on that area is effectively transported to the stream)

The EPA Watershed Academy (USEPA, 2013b) has adopted the following impervious cover classification scheme (note that in these cases impervious cover means TIA). See Figure 6-5.

- Impervious cover < 10% = Sensitive
- Impervious cover of 10-25% = degraded or impacted system
- Impervious cover > 25% = Non-supporting, with characteristics such as eroding banks, poor biological diversity, and high bacterial levels

Figure 6-5 Relationship between Impervious Cover and Stream Quality

Recreated from Schueler, T. 1994, The Importance of Imperviousness
In: Watershed Protection Techniques 1(3):100-111.



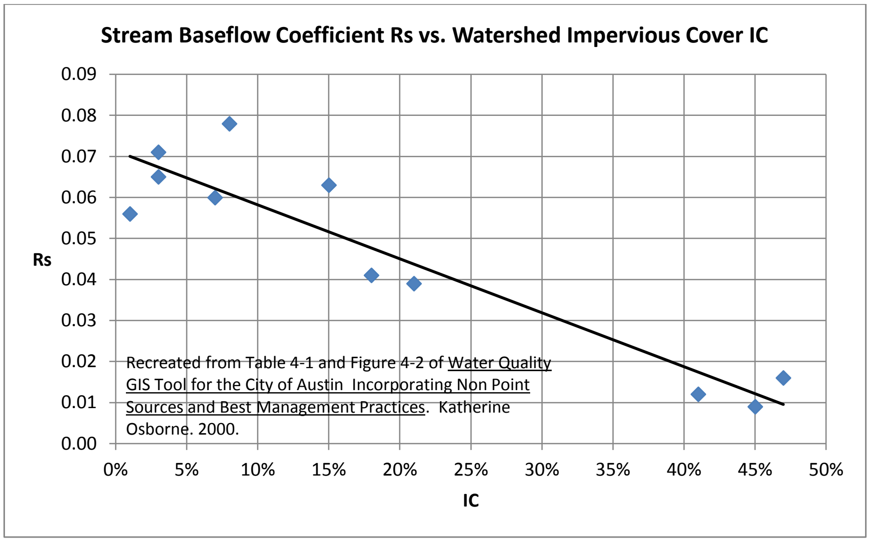
6.1.3 IMPERVIOUS COVER THRESHOLDS IN CENTRAL TEXAS

The Austin area has similar stream, spring, and aquifer systems to San Marcos and has urbanized to a far greater extent. Thus it's useful to critically assess the impacts of Austin's urbanization in consideration of potential future conditions in San Marcos.

From the data provided by the City of Austin stormwater quality monitoring program, stormwater pollutant loads are more sensitive to changes in stormwater quantity than concentration. Thus, land use changes that increase stormwater quantity (runoff) are especially significant in increasing constituent loads. (citation)

In a study of Austin streams (Glick, et al., 2010) found that stream water quality was strongly correlated to total impervious cover, i.e., as impervious cover increases the water quality degrades. A high aquatic life condition (e.g., AQP ≥ 85) was typically associated with impervious cover < 15%, but could be observed for some watersheds up to about 30% TIA. Reduction in baseflow was also strongly correlated to increasing impervious cover. An earlier, separate report (Osborne. 2000) quantified the negative effect of increasing impervious cover on baseflow, as shown in the following chart. As can be extrapolated from the chart, baseflow can be reduced by about 25% at just 15% impervious cover, and approaches zero at around 50% imperviousness.

Figure 6-6 Stream Baseflow Coefficient (Rs) vs. Watershed Impervious Cover (IC)


Stream Baseflow Coefficient Rs vs. Watershed Impervious Cover IC

Recreated from Table 4-1 and Figure 4-2 of Water Quality GIS Tool for the City of Austin Incorporating Non Point Sources and Best Management Practices. Katherine Osborne. 2000.

Loss of recharge and baseflow as impervious cover increases can exacerbate water quality problems, especially during drought periods. Not only can lack of flow directly impact aquatic life and water recreation uses, dissolved oxygen levels can drop to levels that impact aquatic life. Protection of headwater spring areas is especially important.

In-stream sediment loads can increase dramatically with increasing impervious cover. As much as 90% of the sediment and other pollutants carried in urban waterways are derived from the accelerated rate of channel erosion caused by the increase in rate and volume of stormwater runoff from impervious cover (Osborne, 2000). Total Suspended Solids (TSS) concentrations are higher in streams than in upland washoff (typically 10 times or more), and a study of Austin area creeks (COA, 1990a) reported average TSS concentrations in upland runoff of 37-173 mg/L while average in-stream concentrations were 700-1936 mg/L. In addition to increasing sediment loads, accelerated channel erosion can threaten property and infrastructure, damage riparian vegetation, and seriously degrade habitat for aquatic ecosystems. Reducing runoff volume and providing extended detention to control "channel forming" flows can be effective control measures, as well as establishing "erosion hazard zone" buffers around streams. This approach will minimize the impact of stream erosion on nearby buildings and infrastructure (see Figure 6-7).

Figure 6-7 Creek Erosion Threatening Home

In an update to a 2000 study of long-term temporal trends in Barton Springs (Herrington, et al., 2005), degrading trends were observed for 15 parameters, and only one parameter exhibited an improving trend. Several of the degrading parameters had shown no degrading trend in 2000. Increasing development was cited as one of the primary threats to water quality, but determining development or impervious cover thresholds was not within the study's scope. Nonetheless, the following statements in the report could be cautionary regarding the San Marcos system:

> *Observed changes in long-term Barton Springs water quality over time, though still potentially below environmental effect thresholds, are indicative of degradation from increasing development throughout the contributing watershed…it is certain that the continued influence of declining water quality may have a cumulative negative impact on both the endangered salamander and the swimmability of the pool as well as drinking water supplies.*

One potential concern related to urban development is the conversion of native landscapes to managed ones (e.g., lawns) that have chemicals applied (fertilizer, herbicides, pesticides), and are irrigated, increasing the possibility of both leaching of pollutants into groundwater and adding them to surface runoff. One reason this is an important issue is that the TCEQ Edwards Rules assume that all pervious landscapes behave the same, in terms of runoff quantity and quality. Thus, presumably, a well-manicured lawn or golf course is assumed to have the same runoff characteristics as a natural landscape. While the Edwards Rules uses only TSS as the targeted constituent, if others are included, such as nutrients and bacteria, the evidence strongly suggest that landscapes in developed areas may behave very differently than those in natural settings.

A key issue that is not well addressed in many studies is the mitigating effect of management measures, or BMPs. Monitoring of individual BMPs has clearly demonstrated that some BMPs, when properly designed, constructed, operated and maintained, can provide substantial control of runoff hydrology and pollution. The effect of BMPs at the watershed scale is much less well understood. In a study of Austin area creeks (Turner and Herrington, 2005), the implementation of BMPs appeared to have positive effects, with stream water chemistry, sediment quality, and aquatic life improving. In another Austin study of 5 creeks (Turner, 2007), concentrations of solids, nutrients, and bacteria decreased after enactment of ordinances that required implementation of stormwater BMPs. That study also found that stormwater peak flows decreased and storm flow duration increased after enactment of the ordinances, which could indicate the hydrologic benefits of BMPs. On the other hand, despite implementation of BMPs in the watershed since the late 1970s, degrading water quality at Barton Springs has been documented, in particular dissolved oxygen and total Kjeldahl nitrogen (Herrington, et al., 2005). A follow-up study (Herrington and Hiers, 2010) found that the degrading trends continued, and stated that "Trends in DO and nutrients are of particular concern due to the potential for impact on both the endangered salamander and aesthetic impairments in the swimming pool." The degrading trend in this karst aquifer system may indicate that stormwater BMPs may have limited ability to protect groundwater resources. The direct loss of recharge due to impervious surfaces and the leaching of landscape chemicals into aquifers are two examples of such limitations. In sensitive recharge areas, additional measures may be necessary, such as source controls and impervious cover limits.

6.1.4 IMPACT OF IMPERVIOUS COVER ON SURFACE WATER

The USFWS Report (White, et al., 2006) found that Texas wild-rice is threatened by sediment, turbidity, and debris. Sediment deposition has eliminated some stands at the confluence of the river and Sessom Creek, and sediment carried by surface runoff is a contributing factor. Increased turbidity is probably due to various land use activities, including construction and residential development. The report recommended that there should be no increase in turbidity beyond natural causes due to stormwater discharges.

It's likely that algal blooms in Spring Lake each summer are due in part to the impact of stormwater runoff. Algal growth at Spring Lake requires frequent management as described by Section 5.3.3/5.4.3 of the annual EAHCP Workplan. This Section, titled "Management of Floating Vegetation Mats and Litter", states that "Each week about five springs are cut, with divers returning to cut the same springs every two to three weeks. During summer algal blooms, the springs will be managed more frequently (up to four springs per day), but mostly to remove algae" (EAHCP Workplan).

6.1.5 IMPACTS OF IMPERVIOUS COVER ON GROUND WATER AND BASE FLOW

Karstic aquifers are highly susceptible to pollutants due to relatively little filtration by shallow surface soils, direct runoff into aquifer recharge features, absence of granular textures within aquifers that ordinarily provide filtration or biological degradation, rapid flow velocities with aquifer conduits, and relatively short periods of degradation of groundwater pollutants by microorganisms and other time-dependent processes (White, et al., 2006).

Groundwater flow in the San Marcos Springs region of the Edwards Aquifer is dependent on a number of factors. These factors include recharge, groundwater withdrawal, NE-SW trending faulting and jointing associated with the Balcones Fault Zone, and karst solution features. The karst features such as caves, sink holes and enlarged fractures of the Edwards Aquifer are the result of dissolution of the limestone aquifer along groundwater flow paths. In contrast to more homogeneous aquifers, these secondary solution features serve as preferred pathways for groundwater flow. Darcy's Law (Chow, V.T., et al, 1964), which normally is used to describe flow in porous media, typically does not properly represent flow in highly karstic formations such as the Edwards. Groundwater flow in the aquifer occurs primarily in these solution features with secondary transport through porous limestone. Unfortunately, these preferred pathways for water also serve as preferred pathways for pollutants. This feature makes the Edwards Aquifer extremely susceptible to contamination from pollutants (Naismith Engineering, Inc., 2005).

6.2 LACK OF ADEQUATE PROTECTION MEASURES ON EXISTING DEVELOPMENT

There is currently a lack of water quality protection measures on existing development and this poses a threat to critical habitat. Recommendations for stormwater retrofits that will mitigate the impacts of existing development are discussed in Chapter 8 for the City of San Marcos, and in Chapter 9 for Texas State University.

6.3 FAILURE TO IMPLEMENT/ENFORCE EXISTING REGULATIONS

The failure to fully implement and enforce existing water quality protection measures presents a threat to water quality in the Plan Area. The water quality protection measures currently in existence were implemented to address recognized threats. Failing to enforce existing regulations in effect neutralizes safeguards established to prevent adverse impacts from these recognized threats. Based on reviews of available literature, conversations with citizens, and in recognition of past media coverage, the following concerns have been identified:

- Inadequate implementation of construction site storm water controls (Earl, et al, 2002)
- Inadequate inspection and operation of structural BMP's and stormwater treatment systems

The WQPP recognizes that considerable progress has been made on behalf of the City and University regarding these issues.

6.4 POINT SOURCE DISCHARGES

Point source pollution is from a discrete, discernable source such as effluent from a water treatment plant or concentrated animal feeding operation (EPA 2013). Discharge from a point source is permitted by TCEQ and is subject to standards set by section 502 (14) of the federal Clean Water Act. Each permit varies depending on the source; however, the permit holder must routinely monitor the amount and quality of their outflow. There are two point sources along the Upper San Marcos River: A.E. Wood State Fish Hatchery and the San Marcos Waste Water Treatment Plant (WWTP). The WWTP and A. E. Wood Fish Hatchery are located downstream of Thompson's Island, between Interstate Highway 35 and the confluence with the Blanco River.

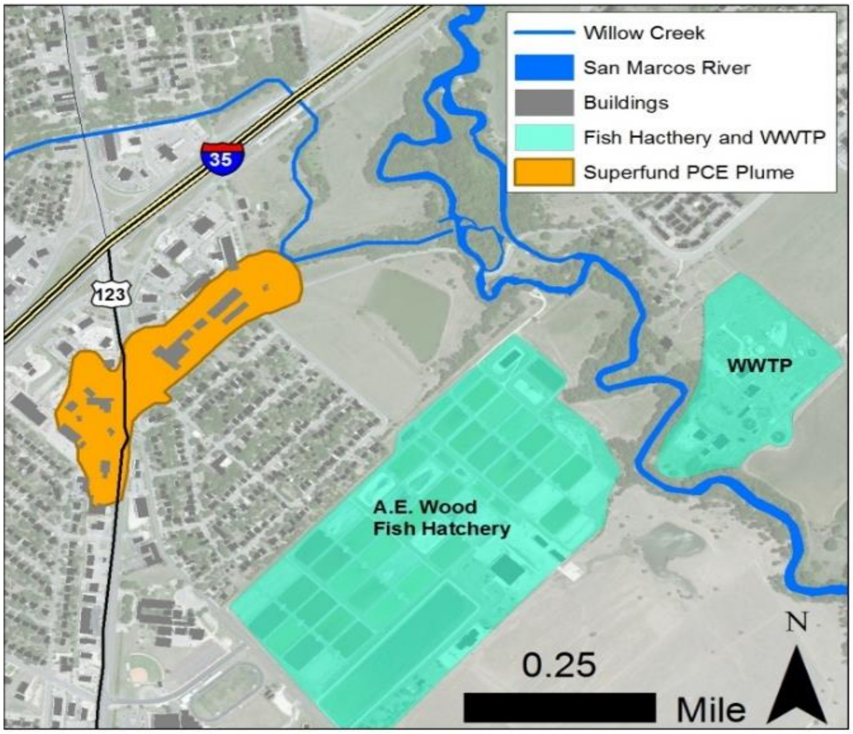
6.4.1 PERMITTED POINT SOURCES

Various studies have reported a longitudinal deterioration of water quality from the headwaters to the confluence with the Blanco River (Groeger et al., 1997; Saunders et al., 2001). Historical surveys have cited the inflows from the Fish Hatchery and the WWTP as potential sources of degradation of water quality due to the high concentration of nutrients.

The City of San Marcos operates a wastewater treatment plant that discharges to the upper San Marcos River. The facility is permitted to discharge 9.0 million gallons per day, with permit limitations of 5 milligram per liter (mg/L) carbonaceous biochemical oxygen demand, 5 mg/L total suspended solids, 2 mg/L ammonia nitrogen and 1 mg/L total phosphorus. The facility also has a permit limit for bacteria.

In addition to the City of San Marcos's Wastewater Treatment Plant, there is one other wastewater discharge to the segment. The Texas Parks and Wildlife Department's A.E. Wood Fish Hatchery is complying with a concentrated aquatic animal production general permit. The General Permit (TXG130005) requires measuring and reporting flow once daily; daily maximum total suspended solids of 90 mg/L monitored once per month; dissolved oxygen of 5.0 mg/L monitored once per week; carbonaceous oxygen demand of 250 pounds per day maximum reported once per month and an ammonia daily maximum of 2.0 mg/L (GBRA, 2013). See Figure 6-8.

Figure 6-8 Point Source Discharges to the San Marcos River



Map: Meadows Center for Water and the Environment

6.4.2 SUPERFUND PCE PLUME

A superfund site, listed on the Texas State Superfund Registry, is located between State Highway 123 and Interstate Highway 35. Superfund sites are sites that contain hazardous waste material that may constitute a risk to the environment, public health and safety. They are identified and registered by TCEQ (TCEQ, 2009). These sites are added to either a state or federal superfund registry and receive funding to remediate and clean the contaminated area. State Highway 123 PCE Plume is a contaminated groundwater plume that contains volatile organic compounds (VOCs), and solvents commonly used by dry cleaners and metal degreasing activities. It was first detected in 1986 during the removal of an underground petroleum storage tank (UST). Additional monitoring found that the UST was not the original source of contamination; however, the source is still unknown. Chemicals were detected in samples collected in 1989 in Willow Springs and small fish caught in Willow Springs Creek (TCEQ, 2004). Contamination levels within the fish never exceeded the national fish consumption standards. TCEQ has conducted various monitoring and remediation activities to remove the contaminants. In 2000, due its confined nature, lack of wells, and exposure to drinking water, the EPA concluded that no further remedial action was necessary (TCEQ, 2004).

6.5 NON-POINT SOURCE POLLUTION

Nonpoint source pollution (NPS) comes from many diffuse natural and artificial sources, often entrained and transported by water. In contrast to point source discharges, storm water non-point source (NPS) pollution occurs as a result of rainfall events. When human activities or natural processes result in pollutants being present at or near the land surface, these pollutants can be taken up by storm water runoff and can result in NPS pollution. The impacts of NPS pollutants vary widely and depend on the following general factors:

- Topography
- Land surface characteristics
- Human activities or natural processes taking place
- Types of pollutants present

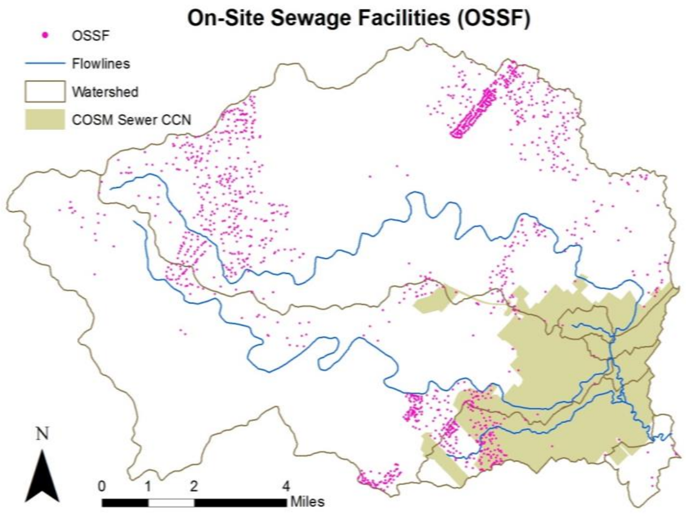
Until relatively recently, storm water NPS discharges in the U.S. have been largely unregulated. In the early 1990's, EPA adopted the Phase I Storm Water Regulations, which attempted to address NPS pollution from industrial activity, construction sites greater than five (5) acres in size and from large (greater than 100,000 population) cities. In 1999, the EPA adopted the Phase II Storm Water Regulations, which extended storm water NPS regulation to additional industrial/commercial activities, smaller construction sites (greater than one [1] acre in size) and smaller cities in defined urbanized areas. Many states, including Texas, have been delegated the authority to implement these federal regulatory programs. Certain aspects of the TCEQ's Edwards Aquifer Protection Program also govern storm water NPS pollution. As discussed in the section on Urbanization, above, there are also a number of existing regulatory programs at the local level with water quality protection aspects. Further discussion of storm water NPS pollution is subdivided by the general types of activities that contribute to storm water NPS pollution.

Organic sources of nonpoint source pollution include suspended sediments from denuding of topsoil, fecal matter from animals, and transport of nutrient rich vegetation debris. Urban areas are great contributors of NPS pollutants through various human activities, these activities include but are not limited to: fertilizer and pesticides from agricultural practices, sediment from improperly managed construction sites, oil from parking lots, and leaking septic tanks. The effects vary depending on the amount, rate of transport as well as the source, time, and location.

6.6 DOMESTIC WASTEWATER COLLECTION, TREATMENT AND DISCHARGE

On-site sewage facilities (OSSF), commonly referred to as septic tanks, can potentially degrade and leak over time if not properly cared for. Properties within the city limits receive water and wastewater utilities from the city of San Marcos. However, some properties that are within the ETJ but outside of the city limits still use OSSF and wells. There are an estimated 1545 OSSFs within the Upper San Marcos Watershed. Many of these are in the Recharge Zone and pose a threat to groundwater if not managed properly (see Figure 6-9). The City of San Marcos has a Certificate of Convenience and Necessity (CCN). A certificate of public convenience and necessity is a permit issued by a public body that is charged with the supervision of public facilities, e.g., carriers or public utilities. It authorizes the holder of the permit to operate such a public facility within a particular area. Refer to Appendix F for a more detailed description of OSSFs as a water quality threat in the Upper San Marcos Watershed.

Figure 6-9 On-Site Sewage Facilities in the Upper San Marcos Watershed



Map: Kristina Tolman

6.7 IMPROPER USE OF LANDSCAPE CHEMICALS

This broad category includes many water quality threats whose potential impact can be greatly reduced through proper management. Landscape chemicals include pesticides (in the broadest sense) and fertilizers. Improper use of landscape chemicals can occur on land uses of all types: public and private, golf courses, lawns, etc. Texas A & M University recommends the use of integrated pest management (IPM) to manage pests effectively and minimize the threat of improper landscape chemical use. The following factors represent areas of concern regarding the threat of landscape chemical use:

- **Areas (extent) of Use:** Turf is the vegetation type that typically receives greater use of landscape chemicals. Large areas of highly maintained turf include sports fields and golf courses.
- **Proximity:** Locations where highly maintained landscapes are in close proximity to critical habitat represent a greater potential threat than areas further away. Examples where this condition occurs include the Texas State University Golf Course (Spring Lake) and City recreational facilities (e.g. ball fields) near the river.
- **Frequency of Use:** Landscape areas where chemicals are used frequently provide a greater risk than areas where no chemicals are used.
- **Mobility:** Some landscape chemicals tend to ‘stay in place’ while others are more ‘mobile’ (e.g. fast-release nitrogen fertilizers and certain pesticides). For example, Atrazine, an active ingredient present in some “weed and feed” products, is known for being mobile in the environment. The WQPP recommends that highly mobile landscape chemicals be avoided whenever possible.

6.8 GROUNDWATER OVERUSE AND DEPLETION

Should rates of groundwater withdrawal exceed those of recharge over the long-term, the net decrease could deplete the aquifer. Under normal conditions, most rivers are gaining rivers: groundwater flows into the rivers because the local water table sits at a higher elevation than the river water. However, with excessive groundwater pumping, water tables slowly decline and natural discharge to the rivers is reduced, so river flow declines. Over the long term, groundwater extraction may greatly reduce river flows in many regions. This connection between water levels in aquifers and river flows complicates the process of estimating sustainable yield from aquifers. If users pump more water from an aquifer than the natural rate of recharge, the aquifer may draw water from adjoining rivers and increase its rate of recharge. However, by doing so it will reduce surface water flows.

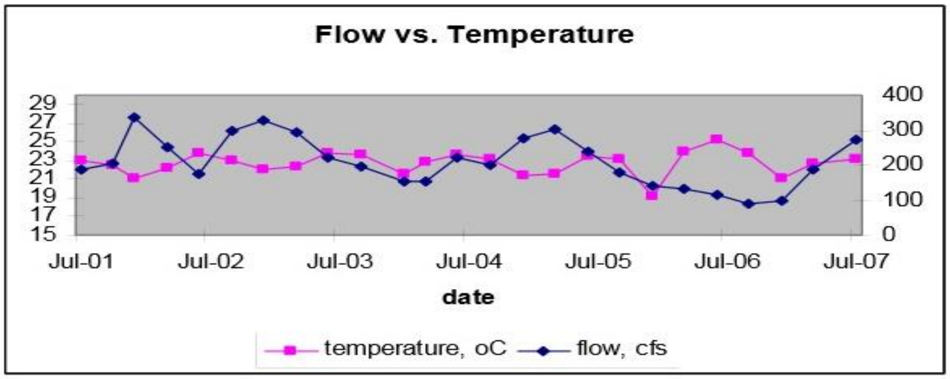
6.9 THREAT OF CLIMATE CHANGE

New challenges lie ahead in the conservation of threatened and endangered species as a result of climate change. Because many imperiled species are already surviving at the limits of their ecological tolerance, the additional stress of a rapidly changing climate adds to the urgency of recovery actions. Climate change not only has direct effects on at-risk species and ecosystems, it also exacerbates the impacts of other stressors, such as invasive species, limited water supplies, habitat loss, and environmental contaminants (USFWS 2013).

Climate change is expected to cause more frequent and severe drought in Central Texas. This aspect of climate change provides a threat of particular importance for the listed species, as the San Marcos Springs Complex and associated critical habitat are susceptible to drought conditions. During past times of extreme drought, water levels in the springs have dropped, resulting in exposure of habitat and a likely increase in species mortality rate. This may be in part due to differences in water temperature (citation needed). A series of drought years approaching 1956 drought conditions, when coupled with the effects of increasing human impact, could precipitate extirpation of these species from major segments if not all of their currently known range (Federal Register, 1980). The mean discharge from San Marcos Springs is 175 cfs (4,950 lps) while the lowest recorded discharge was 46 cfs (1,300 lps) on 8/16/1956 (Smith, Brian A. et. al. 2009)

The flow from San Marcos Springs keeps the temperature in the upper San Marcos stable at a median temperature of 22.8ºC (73ºF), ranging from 19.2C (66.5ºF) to 25.2C (77.3ºF). Figure 6-10 shows the inverse relationship between temperature of the upper San Marcos River and flow at the springs. Note the prolonged drought seen in 2006 when, in the data set collected by the Guadalupe Blanco River Authority, the site experienced its maximum temperature and minimum flow during its recorded history (GBRA, 2013).

Figure 6-10 Flow and Temperature on the Upper San Marcos River (GBRA, I-35 Site)



Source: GBRA

Conversion of natural, undeveloped land to urban land uses can significantly increase the demand for surface and groundwater sources, while also decreasing supply as impervious cover reduces recharge. Withdrawal of groundwater and the possibility of increased drought frequency are significant concerns regarding protection of the aquifer, springs, and endangered species associated with the system (HCP, 2011). On a statewide basis, the Texas Water Development Board (TWDB, 2012) projects that by 2060 water demand will increase by 18% while the water available will decrease by 10%. If this scenario comes true, there could be significant economic and environmental impacts in the state. A study of water supply and demand (Ward, 2009) in the central Texas region, which includes San Marcos, projects potential decreases in stream flow, with increases in municipal and industrial surface and groundwater demands of 93% and 78%, respectively, by the year 2050, with greater increases under drought and/or climate change scenarios. While acknowledging that additional water supplies will be necessary to support population growth, the report cautions that Texas is highly vulnerable to drought conditions, and that “the drought of the 1950’s is within living memory, and yet it is evident that population growth alone would make it extremely difficult to cope with a similar drought under the 2050 scenario, during which many water uses would have to be curtailed.”

Karst Systems

The impact of climate change on karst systems is a relatively new area of study. Simulations of climate change on the Edwards Balcones Fault Zone aquifer indicated that climate change could exacerbate water shortages in the aquifer zone, even if pumping of water by humans remains at present average levels (Loáiciga et al., 2000). Studies conducted in other karst systems have shown similar detrimental results. A simulation conducted in the United Kingdom indicated that climate change could influence three key aspects of karst geomorphology: hydrology, dissolution rates, and the operation of other geomorphological processes such as mass movements (Viles, 2004).

6.10 RECREATIONAL USE OF THE RIVER

The San Marcos Observing System (SMOS) is monitoring recreational use, which is an important contributor to turbidity levels in the stream. Researchers have installed cameras along the river that were designed to capture pictures of wild game. Instead, they're helping keep track of the number of kayakers, tubers and fisherman on the river. The data goes toward an effort to balance recreational uses with restoration of species like Texas Wild Rice. The Meadows Center for Water and the Environment will help interpret SMOS data to characterize the extents of the physical, chemical, and biological impacts of recreational uses on the listed species.

6.11 SENSITIVITY OF SPECIFIC RECEIVING WATERS

The following highlight the sensitivity of specific receiving waters in the Plan Area.

6.11.1 RECHARGE ZONE

The recharge zone is the most fragile areas of the Edwards Aquifer system due to the potential for pollutants to enter the aquifer where the karst geology is exposed at the surface of the ground. The area of the recharge zone near the city is particularly important to protect, because studies indicate that the aquifer in the San Marcos area is more significantly influenced by local recharge than other areas of the aquifer near springs, and because flow rates in the aquifer are higher in the San Marcos area than in other areas of the aquifer (San Marcos City Code, Chapter 94, Article 6, Sec 94.501, item 8).

The Edwards is one of the most permeable and productive carbonate aquifers in the United States. Due to the predominantly karst limestone composition, there are many permeable recharge features within creek beds and breaks between hills and steep ravines. Karstic aquifers are highly susceptible to pollutants due to relatively little filtration by shallow surface soils, direct runoff into aquifer recharge features, absence of granular textures within aquifers that ordinarily provide filtration or biological degradation, rapid flow velocities with aquifer conduits, and relatively short periods of degradation of groundwater pollutants by microorganisms and other time-dependent processes (White, et al., 2006).

6.11.2 CONTRIBUTING ZONE WITHIN THE TRANSITION ZONE

Due to an impermeable layer of rock between the land surface and the aquifer below, the land in this zone does not recharge directly into the aquifer. However, since the land in this zone slopes towards the recharge zone, untreated urban runoff has the potential to enter the Aquifer with little or no filtration.

6.11.3 SPRING LAKE

A characterization study of Spring Lake also provided management recommendations (Nowlin and Schwartz, 2012). While the primary surface water inflows are from Sink Creek and the immediate adjacent Spring Lake areas, the groundwatershed is much larger, and contributing flows likely enter from as far north as Travis County, as well as south of Hays County. The study provided the following information:

- Spring Lake and the Upper San Marcos River have recently experienced increased turbidity and declines in water quality after rainfall events, and Sink Creek appears to discharge substantial loads of sediment and nutrients in the lake and river.

- Low dissolved oxygen (DO) levels are generally recorded in the lake after storm events, with some levels approaching 0 mg/L DO in 2012. Nutrients flushed into the lake contribute to low DO levels by stimulating biological activity that consumes oxygen (Nowlin and Schwartz, 2012).
- High nutrient loads can also contribute to high total dissolved solids (TDS) levels, and the Upper San Marcos River segment is already exceeding State water quality standards for TDS.
- Changes in the intensity and composition of land cover/land use (LCLU) practices in the larger recharge area will increase the potential for water quality impairment and may place further strain on groundwater inputs to the lake by the lowering of aquifer levels through groundwater extraction.

The fact that there are current impacts to the Spring Lake and the Upper San Marcos River is significant because the impervious cover in Sink Creek, the only major tributary to Spring Lake, is estimated to only be 1.2% (Tolman, et al., 2013). As noted in the study, exports of nutrients such as nitrogen and phosphorus, sediments, and bacteria from surrounding landscapes can have substantial impacts on the water quality and subsequent suitability of waters as recreational resources, drinking water sources, and quality habitat for organisms.

6.11.4 SESSOM CREEK

Streams tend to retain pollutants in the water column for shorter periods of time, but are also more susceptible to erosional processes, thus control of erosive flows and establishment of buffer zones can be important. Perennial streams typically support more uses than intermittent and ephemeral streams, and may require a higher level of protection. Aquifers are also often “sinks” and, in karst areas, easily contaminated. All these receiving water types are vulnerable to changes in water quantity and watershed hydrology, due to increased withdrawals, the loss of recharge and increase in runoff from impervious cover additions, and other factors.

At 510 acres, Sessom Creek watershed is the smallest of the watersheds draining to the upper San Marcos River, yet it is one of the most important tributaries due to its proximity to the headwaters of the river. Relative to its size, the watershed contains the second highest amount of impervious cover per area at 48 percent. Sessom Creek is intermittent in the upper reaches. The creek in the lower portion of the watershed is relegated to a series of pipes, an unfortunate result of the placement of Sessom Drive directly on top of it. Small springs near Freeman Aquatic Biology supply minimal flow before joining the San Marcos River. Freeman Aquatic Biology has an artesian well that supplies flow for adjacent fish ponds and raceways used for aquatic research. Overflow from the fish ponds goes into a diversion pond that connects with Sessom channel before entering the San Marcos River. Sessom Creek, combined with outflow from the ponds, flow into the river just above the intersection of Aquarena and Sessom Road. This section of the river is home to populations of endangered Fountain Darter, Texas Wild Rice, and San Marcos Salamander. Therefore, ensuring exceptional water quality for this area is essential to protecting the vulnerable endangered species.

Sessom Creek is exhibiting a high rate of stream erosion, resulting in excessive sedimentation in the San Marcos River. Much of the stream erosion can be attributed to changes in watershed hydrology due to development and impervious cover. To bring this watershed closer to a state of equilibrium, the WQPP recommends that the City and the University implement projects both within the channel and throughout the watershed. The that will stabilize the banks, restore the riparian landscape, and .

stream stabilization projects

riparian restoration projects

retrofit projects that incorporate extended detention, in order to reduce he impacts of existing development.

extended detention (“stream protection”) requirements for new development and redevelopment

6.11.5 PURGATORY CREEK

Both Purgatory Creek and Sessom Creek provide nutrient and ionic particles into the Upper San Marcos River during rainfall events. However, in an analysis of urban runoff monitoring data, it was determined that the water discharged by Purgatory Creek was significantly higher in Total Phosphorus (TP) and Phosphate (PO4) than water discharged from Sessom Creek. This issue shows that Purgatory Creek may be of greater concern than Sessom Creek when assessing the integrity of water quality in the San Marcos River. (Schwartz and Nowlin, 2011).

6.11.6 DIRECT TO THE SM RIVER (I.E. DOWNTOWN & SEWELL PARK)

This stretch of river is home to the endangered Fountain Darter and large stands of Texas Wild Rice therefore ensuring exceptional water quality for this area is essential. This drainage area has a relatively high amount of existing impervious cover (approximately 50 percent of the total area). This drainage area accepts runoff from both City and University jurisdictional areas. The City’s Land Development Code requires that new development in the areas immediately adjacent to the San Marcos River provide a minimal level of treatment for urban runoff in this area per the San Marcos River Corridor regulations. However the vast majority of development in this drainage area occurred prior to the adoption of these regulations. Currently Texas State University has no specific standards for urban runoff control in this area, or elsewhere on campus. See Figure 6-11 for a photo of this reach of the River.

Figure 6-11 Upper San Marcos River at Sewell Park

Photo: SMWI Watershed Protection Planning Fact Sheet, March 2013

6.12 SUMMARY OF THREATS

Overall, the antecedent conditions within the San Marcos watershed meet or are superior to the TCEQ water quality criteria standards. It was found that the San Marcos River currently exhibits exceptional water quality, but that the water quality progressively deteriorates downstream. Inflows from intervening urban areas are contributing to the deterioration. The model (HSPF) predicted an increase in bacteria and Total Suspended Solids (TSS) loads, and associated automotive oil, pet waste, fertilizer, and other pollutants. The increases are attributed to predicted increases in impervious cover and loss of undeveloped open land. Bacteria loadings, in particular, were associated with residential development.

The evidence indicates that impacts to water resources can occur at impervious cover less than 5%, and are generally apparent in the 10-25% impervious cover range, but other factors can be important, including connectivity of imperviousness, population density, road density, land use type, soil and stream erodibility, and riparian integrity and vegetation. Studies have shown that stormwater BMPs may have limited ability to protect groundwater resources. The direct loss of recharge due to impervious surfaces and the leaching of landscape chemicals into aquifers are two examples of such limitations. In sensitive recharge areas, additional measures may be necessary, such as source controls and impervious cover limits.

While water quality at San Marcos Springs is excellent, it deteriorates longitudinally within the river due to natural and anthropogenic causes. Soil composition, disturbance from recreation, inflows from urban tributaries, and stormflow runoff can degrade the quality of water with various inflows. The variation between the upper and lower reaches is more pronounced during storm events (Groeger et al., 1997, Schwartz and Nowlin, 2012).

7. STRATEGIES FOR SELECTING WATERSHED PROTECTION MEASURES

7.1 STRATEGIES FOR PLAN AREA

The term *strategy* refers to coordinated actions taken to achieve plan goals and objectives, taking into account the unique programmatic and regulatory characteristics of the City of San Marcos and Texas State University. The following findings form the basis of such strategies:

- Critical Habitat has already been impacted, thus existing development is contributing to impacts.
- Future urban development can significantly increase impacts to Critical Habitat, unless appropriate control measures are implemented.
- The San Marcos area is one of the fastest growing regions in the United States. Rapid population growth and urban development are currently occurring, and are expected to continue for the foreseeable future
- Current programs and regulations are deemed inadequate for protecting Critical Habitat.
- Impacts can be attributed to both water quality and quantity issues, including:
  - Pollutants in urban runoff, with higher concentrations and loads than those found under natural, undisturbed conditions
  - Excess stream erosion caused by the increase in the frequency and magnitude of erosive flows (hydromodification)
  - Loss of infiltration and groundwater recharge, which affect aquifer levels and stream flow during dry weather periods (baseflow)
  - Water demand and groundwater withdrawal, which affect aquifer levels and stream flow
  - Loss of riparian buffers and buffer zones around recharge features, which provide essential ecological services and protection of critical environmental features
  - Many of these impacts are associated with increases in impervious cover

Recall from Chapter 3 that the following goals have been proposed:

- Water Quality Zones A and C: Reduce the existing level of pollution, prevent excess stream erosion due to watershed hydromodification, maintain or enhance existing infiltration and recharge, and reduce demand on the aquifer water supply.
- Water Quality Zone T/R: Prevent further degradation by controlling current and future pollution in the entire contributing watershed, prevent excess stream erosion (high sediment loads) due to watershed hydromodification, and reduce demand on water supply.

7.2 STRATEGY FOR THE CITY OF SAN MARCOS

Based on the goals and the objectives presented in Chapter 3, and the findings presented in Chapter 6 (Water Quality Threats and Impacts) and in 7.1 above, the following strategies are proposed for the City of San Marcos.

1. Implement protection measures in all areas that affect Critical Habitat (see 8.4 below)
2. Implement a stormwater retrofit program to reduce the impacts of existing development

3. Amend the current Land Development Code to prevent impacts from new development and redevelopment, and amend the Stormwater Technical Manual accordingly:
    a. Reduce impervious cover limits in the Edwards Aquifer Zone
    b. Improve BMP treatment requirements for all areas that drain to Critical Habitat:
        i. Establish appropriate pollutant load performance standards:
            1. Non-degradation in WQ Zones A and C, to protect the most sensitive receiving waters
            2. 10% IC equivalency in WQ Zone T/R, to protect San Marcos River system
        ii. Prevent excess stream erosion due to hydromodification
        iii. Maintain or increase existing infiltration rates, especially in WQ Zones A and C
        iv. Reduce potable and groundwater use for landscape irrigation by (1) installing more water efficient landscapes and (2) using stormwater as an irrigation source (all WQ Zones)
    c. Require water quality protection measures for both new development and redevelopment, i.e., implement on-site BMPs and, under certain circumstances, partially or fully waive on-site BMP requirements and allow for fiscal contributions to the stormwater retrofit program (“Fee-in-Lieu”).
    d. Incentivize redevelopment in high-intensity redevelopment, e.g. SmartCode Zones T4 and T5, by providing reimbursement for BMP costs (Cost Recovery)
    e. Improve buffer zone requirements for streams, recharge features, and critical environmental features
4. Promote compact development and the use of Low Impact Development/Green Infrastructure principles and techniques for development in the areas that drain to Critical Habitat
5. Implement a land conservation program, especially in the recharge zone
6. Implement programs that promote watershed stewardship

7.2.1 STRATEGY NOTES FOR BMP TREATMENT REQUIREMENTS: ZONES A & C

The BMP strategy for Water Quality Zones A and C are designed to simultaneously address water quantity and quality concerns. Pollutant removal is a concern addressed in some manner by current TCEQ and City of San Marcos regulations, except in Water Quality Zone C. Neither TCEQ nor the City require control of erosive flows due to hydromodification, but this can usually be accomplished with careful design using the same water quality volume as is needed for pollutant removal. Neither TCEQ nor the City promote maintenance or enhancement of recharge, and TCEQ may actually discourage this (a significant problem). The WQPP has proposed an innovative approach that would (1) require maintenance or increase in infiltration/recharge and (2) reduce groundwater withdrawals by using stormwater as an alternate water source, in conjunction with more water-efficient landscaping. This can be a cost-effective strategy that closely adheres to the HCP mandates to not only control pollution, but to “treat stormwater as a resource” and to “increase infiltration to groundwater and aquifer recharge”.

7.2.2 STRATEGY NOTES FOR BMP TREATMENT REQUIREMENTS: ZONE T/R

The BMP requirements for Water Quality Zone T/R are less stringent, primarily because protection of the aquifer is not a factor. However, control of pollutant loads, especially phosphorus as the river is a phosphorus-limited system, is very important. Control of erosive flows (hydromodification) is also very important, not only to reduce stream erosion sediment loads, but also sediment-derived phosphorus loads (which also reduces threats to streamside property and infrastructure). Reduced water use is also a recommended requirement, in order to preserve stream baseflow, in particular. Infiltration is encouraged in Water Quality Zone T/R, but not required, as is the case in Water Quality Zones A and C.

For areas with high-intensity redevelopment planned in Water Quality Zone T/R (e.g., SmartCode Zones T4 and T5), meeting the BMP treatment goals can be imminently feasible with good site planning, but an option is offered whereby a payment to the retrofit program can be allowed, in lieu of full implementation of on-site BMPs. Furthermore, to further encourage infill development, which is desirable, a cost recovery option is proposed, i.e., the cost of BMPs would be partially offset by a City reimbursement program.

7.3 STRATEGY FOR TEXAS STATE UNIVERSITY

Based on the goals and the objectives presented in Chapter 3, and the findings presented in Chapter 6 (Water Quality Threats and Impacts) and in 7.1 above, the following strategies are proposed for Texas State University:

1. Implement protection measures in all areas that affect Critical Habitat (see 8.4 below)
2. Develop and implement a stormwater retrofit program to reduce the impacts of existing campus development, using a combination of small scale Low Impact Development projects (e.g., disconnect rooftops, rainwater harvesting, rain gardens) and larger scale retrofits (e.g., ponds)
3. Amend the Constructions Standards document to clearly define stormwater BMP treatment standards for new development and redevelopment projects on University property, and develop a Stormwater Technical Manual for providing guidance and design criteria:
    i. Reduce pollutant loads
    ii. Prevent excess stream erosion due to hydromodification
    iii. Maintain or increase existing infiltration/recharge rates (especially WQ Zones A and C)
    iv. Reduce river diversion, and potable and groundwater use for landscape irrigation by (1) installing more water efficient landscapes and/or (2) using stormwater as an irrigation source
4. Develop and adopt a master plan that identifies water quality projects designed to treat both existing and future planned projects; this can be a more efficient mechanism than implementing projects solely on a case-by-case basis.
5. Implement an education and outreach program

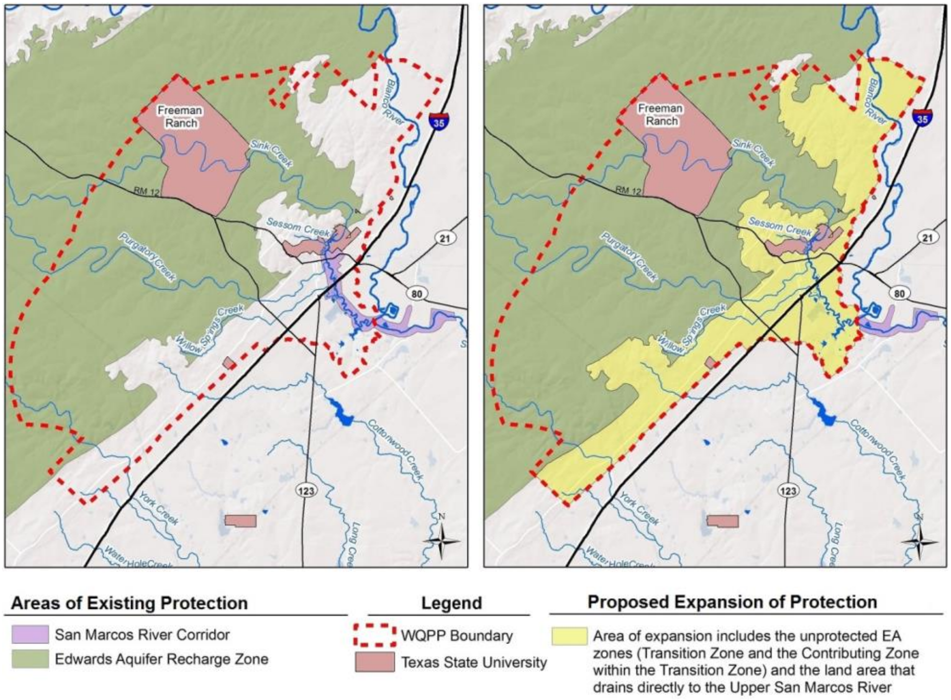
The Texas State University campus is fundamentally different than the City of San Marcos, in that the University owns the property. Thus, individual construction projects, while having “limits of construction”, are not necessarily constrained by those limits when investigating BMP treatment opportunities. The concept of “on-site” BMPs that applies readily to the City’s regulatory programs, do not apply well, if at all to the University, since the campus lacks “lot lines”, thus the entire campus is a “site.”

7.4 STRATEGY ISSUES APPLICABLE THROUGHOUT THE PLAN AREA

7.4.1 IMPLEMENT PROTECTION MEASURES IN ALL AREAS THAT AFFECT CRITICAL HABITAT

Currently there are substantial areas within each jurisdiction that drain to critical habitat that have no existing water quality protection standards. Existing protective measures include TCEQ requirements that apply to the Edwards Aquifer Recharge Zone. The City of San Marcos has established protection standards for an area called the San Marcos River Corridor. The applicable guidance document for the University is titled 'Construction Standards'. This document refers to water quality requirements described by the TCEQ and the City. See Figure 7-1. Since all areas that drain to critical habitat represent a potential threat the Plan recommends that the entities implement water quality protection standards throughout their applicable jurisdictional areas.

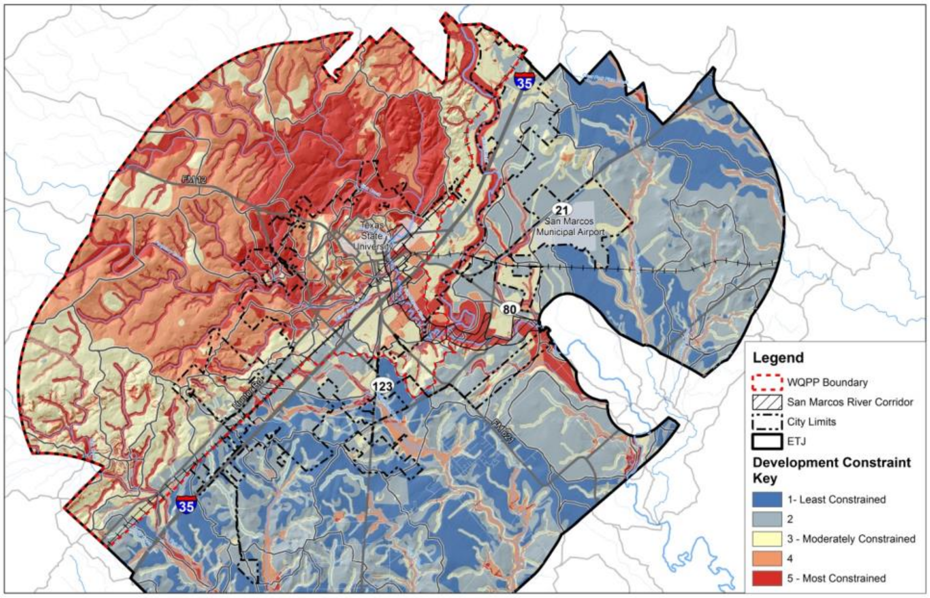
Figure 7-1 Existing Protected Areas and Proposed Expansion of Protection



7.4.2 Fit Development Characteristics to the Receiving Waters

The Plan recommends that the characteristics of future development within each jurisdiction conform to the needs of the receiving waters. Primary characteristics of concern include development location and intensity. Limiting these characteristics for new development in the most sensitive receiving waters allows for a better fit and maximizes protection of critical habitat. The Land Use Suitability map shown below (Figure 7-2) is a graphic analysis combining the sensitivity of receiving waters with constraints on land areas in regards to water quality, and historical, cultural and natural resources.

Figure 7-2 Land Use Suitability Map



Map: RPS

8. RECOMMENDED MEASURES FOR THE CITY OF SAN MARCOS

The following sections provide regulatory and programmatic recommendations, based on the WQPP goal, objectives, and strategies described earlier.

8.1 PLANNING AND DEVELOPMENT REGULATIONS AND PROGRAMS

This chapter presents water quality protection measures that reflect the goals, objectives, and strategies described in earlier chapters.

The City is challenged with balancing water quality protection with the desire to accommodate infrastructure, growth and development. To successfully meet this challenge it will be necessary to integrate better stormwater management and watershed protection into planning and development standards. Building, landscape and parking requirements should complement strong stormwater standards and make it easier for those involved in development to meet multiple requirements simultaneously.

Growth and development bring in new residents, students, businesses, and investments. Growth can give a community the resources to revitalize a downtown, refurbish a main street, build new schools, and develop vibrant places to live, work, learn, shop, and play. The water quality protection measures described herein are intended to guide the planning and development that are necessary components of this growth.

8.1.1 IMPLEMENT A STORMWATER RETROFIT PROGRAM

A retrofit program is necessary because Critical Habitat has been impacted by existing development, thus reducing the effects of existing development is a necessary component of the protection plan. A complete description of the proposed retrofit program for the City is provided later in this chapter.

8.1.2 ESTABLISH APPROPRIATE IMPERVIOUS COVER LIMITS IN THE RECHARGE ZONE

The HCP (Appendix Q) recommends that appropriate impervious cover (IC) limits be adopted in the recharge and contributing zones. The TCEQ Edwards Aquifer Rules have no impervious cover limits, but the City of San Marcos has established limits in the recharge zone, and in water quality and buffer zones. The WQPP recommends the adoption of more protective IC limits in the recharge (WQPP Water Quality Zones A), but proposes no changes in the contributing zone, nor in the City's water quality and buffer zones.

8.1.2.1 Water Quality Zone A (Aquifer Recharge Zone)

In the recharge zone, primary reasons for limiting impervious cover are (1) the aquifer is easily contaminated and BMPs have limited ability to protect groundwater from such contamination, and (2) impervious cover and land disturbance reduce infiltration and recharge, which are significant concerns. A 20% impervious cover limit is felt to be protective as it preserves much of the natural recharge, and allows for sufficient room to implement BMPs to meet the non-degradation treatment standards, including the "maintain or increase existing infiltration rates" performance standard. Theoretically, the pollutant load, stream protection, and infiltration performance standards could be met for sites with higher impervious cover, but this would require greater soil disturbance, and put greater reliance on engineered solutions that require proper operation and maintenance. Resources available to ensure proper operation and maintenance are limited, and it is recommended to place more reliance on preserving the natural system and limiting disturbance. The current impervious cover limits (LDC 5.2.3.1) are deemed to be too high, and the reasoning behind the setting of limits based on site size is unknown (i.e., impacts are strongly correlated to site impervious cover, not site size). Table 8-1 shows the current and proposed impervious cover limits in the City of San Marcos Land Development Code.

Table 8-1 Current and Proposed Impervious Cover Limits in Edwards Aquifer Recharge Zone

Current City of San Marcos Impervious Cover Limits	40% IC for site size ≤ 3 acres 30% IC for site size 3 – 5 acres 20% IC for site size > 5 acres
Recommended City of San Marcos Impervious Cover Limits	20% IC for all sites

8.1.2.2Water Quality Zone C (Contributing Zone within the Transition Zone)

The geology of this zone is such that direct recharge into the easily-contaminated aquifer is unlikely, and that surface runoff is the primary concern. Therefore, there is less need to establish specific impervious cover limits, and impervious cover will be self-limiting because of the area required to meet the non-degradation performance standards, given the typical clayey and/or rocky soils present in the zone.

8.1.3 ADOPT IMPROVED BMP PERFORMANCE STANDARDS

8.1.3.1Water Quality Zones A & C

These zones are the recharge zone (A) and contributing zone within the transition zone (C). The following performance standards are recommended in the recharge and contributing zones:

- Pollutant Load – no increase in existing TP load
- Stream Protection – Provide Stream Protection Volume or equivalent
- Infiltration/Recharge – Maintain or increase existing rate of infiltration
- Water demand/reuse– Reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50%

The integration of water quality and quantity protection is a key difference between the WQPP recommendations and existing regulations, and is much more in line with the HCP recommendations.

The following table presents BMP performance requirements for Water Quality Zones A & C.

Table 8-2 BMP Performance Requirements in Aquifer Recharge and Contributing Zones

Zone	Entity	Pollutant Load	Stream Protection	Infiltration	Water Demand/Reuse
Zone A (Recharge)	City of San Marcos	Limit TSS load to 20% above	None	None	None

		natural conditions			
	TCEQ (TxSt*)	80% reduction in TSS load	Optional	None	None
	WQPP	No increase in existing TP load	Provide SPV or equivalent	Maintain or increase existing infiltration	Reduce water use for landscape irrigation by at least 50%
Zone C (Contributing)	City of San Marcos	None	None	None	None
	TCEQ (TxSt*)	None	None	None	None
	WQPP	No increase in existing TP load	Provide SPV or equivalent	Maintain or increase existing infiltration	Reduce water use for landscape irrigation by at least 50%

*Texas State University is required to comply with TCEQ water quality rules

After meeting the water demand/reuse standard, a BMP system would have to be designed to simultaneously meet or exceed each of the three other performance standards (pollutant load, stream protection, and infiltration), with the most stringent standard dictating the design (and which will vary with site impervious cover and BMP selection). It is proposed to meet the infiltration standard, in compliance with TCEQ's impermeable liner requirements for ponds, by using a treatment train system where the 2nd BMP infiltrates "post-TCEQ" runoff (alternately, discharging runoff to vegetation could be a viable option for lower impervious cover drainage areas). Compliance with the water demand/reuse performance standard is achieved through landscape design and rainwater harvesting (RWH), using a separate procedure, and RWH performance is expressed in terms of "Effective Impervious Cover" rather than pollutant removal and hydrologic control parameters.

Pollutant Load: Based on findings of Water Quality Threats and Impacts (Chapter 6) and an analysis of water parameters for BMP design (Appendix D), Total Phosphorus (TP) is recommended as the representative pollutant of concern. TP incorporates both particulate and dissolved phases, both which can impact receiving waters. Based on analysis conducted by CRWR (Barrett, et al., 1998), TP concentrations in urban runoff increase with impervious cover (see Figure 11-13). Sources including soil erosion (Central Texas soils are typically high in phosphorus), grass clippings and leaf litter, lawn fertilizers, animal wastes, detergents, flame retardants, corrosion inhibitors, and plasticizers.

The proposed performance standard is to allow for *no increase in the existing TP load*, a "non-degradation" standard. The procedures for estimating TP load and BMP removal are described in chapter 11 (Stormwater Treatment BMPs). The technology of available, widely-used BMPs is sufficient to meet the load reduction standard, with proper sizing and design, individually or as a "treatment train" system of multiple BMPs. A design recommended by the WQPP is a treatment train, with the first BMP being a Rain Garden or Biofiltration system, and the second an Infiltration Basin.

The current City of San Marcos requirement (LDC 5.3.4.1(b)) to "*limit the increase in the total suspended solids load … to no more than 20 percent above that which would occur from natural drainage…"* is problematic in several ways:

- A Retention/Irrigation BMP may be required in many instances, a result of having to use the TCEQ Edwards Aquifer technical manual-based equations and procedures, which are now incorporated into the San Marcos Stormwater Technical Manual. This BMP is not recommended by the WQPP, for operation and maintenance reasons, and because it will not be able to meet the infiltration performance standard (see below).
- The resulting BMP system will be large, larger than either the TCEQ or WQPP systems.
- Theoretically, the BMP will "over treat" the runoff, i.e., the resulting TP load discharged will be much less than a site with no impervious cover.

The WQPP performance standard will provide much better protection than the TCEQ Edwards Aquifer Rules, achieving a TP load discharge quality equivalent to a site with 0% IC (non-degradation). In contrast, the Edwards Aquifer Rules can be met with relatively low-performing BMPs such as sand filters, with the resulting TP load discharge equivalent to sites with significant development, e.g., a sand filter treating a 100% IC drainage area is predicted to discharge a TP load equivalent to a site with about 47% IC. As an alternative, Total Suspended Solids (TSS) can be used, primarily because it has been used historically by the Edwards Aquifer Rules.

Commented [D1]: Added.

Stream Protection: To protect streams from excess stream erosion due to hydromodification (the increase in the frequency and magnitude of erosive flows), and to reduce sediment and sediment-derived phosphorus loads, providing extended detention of a minimum specified *"Stream Protection Volume"* (SPV) is recommended. The minimum SPV is a function of site impervious cover, as shown in the following table (further explained in Chapter 11):

Table 8-3 Stream Protection Volume (SPV)

IC	Minimum SPV (in.)
0%	0.00
5%	0.00
10%	0.08
15%	0.15
20%	0.22
25%	0.29
30%	0.37
35%	0.44
40%	0.51
45%	0.58
50%	0.65
55%	0.72
60%	0.80
65%	0.87
70%	0.94
75%	1.01
80%	1.08
85%	1.15

90%	1.23
95%	1.30
100%	1.37

Many widely-used BMPs can meet this performance standard, with proper sizing and design, with the exception of numerous proprietary BMPs that do not provide the recommended 48 hour extended detention (drawdown) time; however, these BMPs could be combined with other BMPs in a “treatment train” system. Filtration BMPs can provide effective protection *if* an underdrain orifice is used, but this is seldom required, with the exception of the City of Austin. BMPs that provide volume reduction via infiltration, reuse, or evapotranspiration, can be very effective, and will reduce the SPV requirements.

A stream protection metric has been developed so that the flow rates and volumes discharged from a site can be compared against the SPV extended detention standard. Such a metric is necessary as sites can incorporate multiple BMPs, including volume reduction BMPs, and may treat runoff from off-site areas, thus outflow hydrographs can be highly variable, making direct comparison with the SPV-based hydrograph difficult. The metric is described in Appendix G (Water Quality Spreadsheet BMP Model), and is based on a flow energy procedure (energy ~ flowrate^2).

While the City of San Marcos does not require stream protection volume or equivalent, it would be provided by a Retention/Irrigation (R/I) BMP designed to meet the City TSS load standard. However, as discussed above, the use of R/I systems is considered problematic, and this BMP is not recommended by the WQPP.

The TCEQ also does not require stream protection volume, but it is an optional measure in technical manual (*Erosion Prevention* in the structural BMPs chapter). Some of the TCEQ BMPs can provide some stream protection, especially Retention/Irrigation and Sedimentation (extended detention).

Infiltration and Recharge: The proposed performance standard is to *maintain or increase the existing rate of infiltration*. Maintaining infiltration in the recharge zone is an important goal that is acknowledged by the HCP, but is not incorporated into state and local stormwater regulations. Maintaining recharge in the contributing zone is also recommended, due to its close proximity to the recharge zone, and also because infiltration is crucial for sustaining streamflow during dry periods (“baseflow”).

Procedures for estimating infiltration are presented in Chapter 9 (Stormwater Treatment BMPs). The existing infiltration rate is estimated as a function of site impervious cover, with infiltration decreasing rapidly as impervious cover increases (and assumed to be 0 at 100% IC).

As should be apparent, to meet this performance standard will require the use of infiltration BMPs, which limits the use of several BMPs, including some volume reduction ones that rely on evapotranspiration (e.g., retention/irrigation, green roofs). The TCEQ requires impermeable liners for pond-type BMPs in the recharge zone, which can be a deterrent for providing infiltration. The proposed solution is as follows:

1. For low impervious cover drainage areas, disconnect runoff by routing it as overland flow to vegetation, i.e., a Vegetative Filter Strip, which can be done in conjunction with Rainwater Harvesting (which reduces “Effective Impervious Cover”)
2. For high impervious cover drainage areas, use a BMP “treatment train”, with the 1st BMP designed to achieve or exceed the TCEQ 80% TSS reduction standard (Biofiltration or Rain Garden BMP recommended because of high TP removal), and the 2nd BMP designed for infiltration (e.g., Infiltration Basin). A RWH system can also be incorporated into the design, to reduce “Effective Impervious Cover” (see 8.3.1.4 below).

The 2nd option presumes that once the TCEQ 80% TSS reduction standard is met, the Edwards Aquifer Rules no longer apply to subsequent BMPs. This is also consistent with how the City of Austin permits BMPs in its recharge zones. The design should be feasible in the San Marcos Recharge Zone, even for the clayey soils that present there, a primary reason being that the 1st BMP discharges treated runoff at a slow rate to the 2nd, infiltration BMP.

It should also be noted that if the site impervious cover increases by less than 20%, the TCEQ Edwards Aquifer Rules may not apply. Single-family residential developments would be exempt, and other types of development are reviewed on a case-by-case basis when less than 20% impervious cover.

There are no impermeable liner restrictions in Water Quality Zone C, and the TCEQ Edwards Aquifer Rules are not applied there, thus the BMP sizing and design options are more flexible than in Water Quality Zone A.

Water Demand, Conservation, and Stormwater Reuse: Because the HCP identified groundwater withdrawal as a significant concern, and also recommended that stormwater be treated as a resource rather than a waste product, this measure is designed to reduce water use (whether potable water, groundwater, or river diversion water) and to reuse stormwater beneficially.

The performance standard proposed is to *reduce potable water, groundwater and/or river diversion water use for landscape irrigation by at least 50%*, and reflects a goal from the Sustainable Sites Initiative (SSI, 2014). The standard can be achieved by a combination of water-efficient landscaping, which reduces water demand, and rainwater harvesting (RWH), which replaces potable, groundwater, and/or river diversion supplies by reusing stormwater. It may be possible to meet this standard without using RWH, i.e., water efficient landscaping may be sufficient. The landscaping and RWH practices available to achieve this standard are widely used in Central Texas. Appendix J describes procedures developed for this performance standard, as well as a spreadsheet tool that can be used for design of the landscape-irrigation-rainwater harvesting system. The stormwater performance of this system when RWH is used is quantified in terms of “Effective Impervious Cover” (EIC) rather than direct calculations of pollutant loads and hydrologic variables. This is because there is significant uncertainty as to how these systems will be operated, e.g., there is no “design” drawdown time, as it is highly variable depending on irrigation demand and/or harvested rainwater supply. The EIC is based on the volume reduction potentially achievable by this BMP (i.e., captured runoff lost to evapotranspiration as a result of landscape irrigation). For example, if a 100% IC roof that generates 26.28 inches/year of runoff has 5 inches/year captured and reused by the landscape-irrigation-RWH system, the resulting 21.28 inches/year of runoff is equivalent to a site with ≈ 90% IC, thus the site is assumed to have 90% EIC.

Comparison of BMP Sizes and Performance: The following table was derived using the BMP spreadsheet model described in Appendix G, using TP as the pollutant constituent, and provides estimates of BMP sizes and performance for hypothetical sites with varying impervious cover, and under different regulatory requirements. Retention/Irrigation systems are specified for San Marcos, and sized using the TCEQ Technical Manual procedures but using the City's "20% above natural drainage" TSS load standard; R/I is the only standalone BMP that can meet this standard. A Sand Filtration BMP is selected for TCEQ, as it is often the BMP of choice. The City of Austin SOS ordinance typically requires Retention/Irrigation, and the sizing is based on Austin's Environmental Criteria Manual. The WQPP system is a biofiltration-infiltration "treatment train" whereby the 1st BMP has an impermeable liner, and complies with the TCEQ 80% TSS load reduction standard, while the 2nd BMP meets the WQPP infiltration performance standard, along with providing the additional treatment required for the more protective WQPP standards. All filtration systems in the table are assumed to *not* have an extended detention/sedimentation basin providing pretreatment.

Commented [D2]: Added note re TP, as TSS is now an option (Dec 2014)

Table 8-4 Comparison of BMP Designs in the Edwards Aquifer Zone

Drainage Area IC*	Parameter	City of San Marcos	TCEQ	City of Austin SOS	WQPP
		Biofilt/VFS (25% IC) Ret/Irrig (other)	Sand Filtration	Ret/Irrig	Biofiltration/ Infiltration
25%	WQV (in)**	1.01	0.35	1.05	0.55
	BMP Footprint as % of Drainage Area***	22%	2%	67%	6%
	TP Load as Equiv. IC	<0% IC	10% IC	<0% IC	0% IC
50%	WQV (in)	1.21	0.62	1.50	1.40
	BMP Footprint as % of Drainage Area***	61%	3%	96%	12%
	TP Load as Equiv. IC	<0% IC	21% IC	<0% IC	0% IC
75%	WQV (in)**	2.24	1.01	1.95	2.38
	BMP Footprint as % of Drainage Area***	112%	5%	125%	22%
	TP Load as Equiv. IC	<0% IC	35% IC	<0% IC	0% IC
100%	WQV (in)**	4.00	1.80	2.40	4.11
	BMP Footprint as % of Drainage Area***	199%	7%	133%	42%
	TP Load as Equiv. IC	<0% IC	52% IC	3% IC	0% IC

Commented [D3]: Biofilt = .39/.47; Infil = 0.08

Commented [D4]: Biofilt = 1.01/1.22; Infilt = 0.18

Commented [D5]: Biofilt 1.64/1.97; Infilt 0.41

Commented [D6]: Biofilt 2.71/3.26; Infilt 0.85

*In the recharge zone, recall that the site impervious cover is limited to 20%, thus, for example, a 50% IC drainage area could only occupy 40% of a site to meet the IC limit, i.e., 60% of the site would have to be left undeveloped (0% IC).

**The WQV values for the City of San Marcos, TCEQ, and WQPP incorporate a 20% sediment accumulation factor for the 1st BMP, while the City of Austin WQV does not require this. This explains the apparent discrepancy for the 75% IC site, e.g., the footprint area is smaller for the San Marcos system than for the City of Austin's, even though the San Marcos WQV is larger. The San Marcos irrigation area is based on the WQV not including the sediment accumulation (TCEQ procedure), or 1.87 inches (2.24 ÷ 1.2), while the City of Austin's is based on 1.95 inches.

***Assumes all ponds have 3 ft ponding depth, 3:1 side slopes, and L:W ratio of 2, with exception of WQPP Infiltration Basin, where ponding depth is a function of soil hydraulic conductivity; 0.06 in/hr is assumed, thus ponding depth ≈ 3 inches to achieve 48 hour drawdown time.

Findings from the table:

- The City of San Marcos system is assumed to be Retention/Irrigation BMP, with its attendant operation and maintenance challenges, as this may be the only BMP that will meet the City's performance standard when using the TCEQ Technical Manual-derived procedures (now included in the San Marcos Stormwater Technical Manual, February, 2014)
- The City of San Marcos system will require a large land area, 4-5 times more than the WQPP BMP system; the primary reason is because a biofiltration/infiltration "treatment train" can require less area than a retention/irrigation system.
- The WQPP BMP system provides a non-degradation level of treatment, and is the only system that also meets both stream protection and infiltration performance standards
- The TCEQ system does not provide a high level of protection, as equivalent TP loads are much higher than background conditions, and no infiltration is provided (pond has an impermeable liner)

8.1.3.2Water Quality Zone T/R

The following performance standards are recommended for this zone:

- Pollutant Load – new development TP load to be no greater than that of a site with 10% impervious cover ("10% threshold")
- Stream Protection – Provide Stream Protection Volume or equivalent
- Water demand/reuse – Reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50%
- Infiltration/Recharge (optional) – Maintain or increase existing rate of infiltration

The following table presents current and proposed BMP performance requirements for these zones.

Table 8-5 BMP Performance Requirements in Water Quality Zone T/R

Requirement	Pollutant Load	Stream Protection	Water Demand/Reuse	Infiltration
City of San Marcos	Sedimentation BMP only in San Marcos River Corridor*	None	None	None
WQPP	New development load no greater than site with 10% IC	Provide SPV or equivalent	Reduce water use for landscape irrigation by at least 50%	Optional - Maintain or increase existing infiltration

*Per Land Development Code 5.3.2.2(e) and (f); the San Marcos Stormwater Technical Manual (February, 2014) has a different standard of sedimentation-filtration with larger water quality volume.

To meet the performance standards, a BMP system would have to be designed to simultaneously meet or exceed both the pollutant load and stream protection performance standards, with the most stringent standard dictating the design, and which will vary with site impervious cover and BMP selection. The water demand/reuse performance standard would also apply.

Pollutant Load: The Water Quality Threats and Impacts chapter (Chapter 6) found that 10% impervious cover is a threshold at which stream systems are likely to be impacted, thus requiring on-site controls that replicate the pollutant load of a 10% IC site should be reasonably protective of the Critical Habitat, in conjunction with the non-degradation standard proposed for the Edwards Aquifer Zone above WQ

Zone T/R. Chapter 6 also demonstrated that total phosphorus (TP) is a good representative pollutant to use for BMP design.

The technology of available, widely-used BMPs is sufficient to meet the load reduction standard, with proper sizing and design, individually or as a “treatment train” system of multiple BMPs. In particular, BMPs that can be incorporated into or augment landscaping are highly recommended, e.g., rain garden, biofiltration, rainwater harvesting.

The City’s current BMP requirements are insufficient to protect Critical Habitat because:

- BMPs are only required within the San Marcos River Corridor, thus the vast majority of the area that drains to Critical Habitat will have no water quality BMPs
- The BMP requirement for the San Marcos River Corridor (SMRC) is relatively weak

The current San Marcos Land Development Code (LDC) requirement in the SMRC is to use a sedimentation-filtration basin, with a water quality volume of ½” for the entire contributing area, and a 24 hour drawdown time. This replaces the previous and weaker criteria of a sedimentation basin with ½”volume based on impervious cover only (instead of the entire site).

Stream Protection: The WQPP would require implementation of BMPs providing the Stream Protection Volume or equivalent, as described above in 8.3.1.2. Because there are no infiltration restrictions, as there are in the recharge zone, the use of these types of BMPs is highly encouraged, e.g., porous pavement, rain gardens and biofiltration designed for infiltration (no impermeable liner, no underdrain system).

Infiltration and Water Demand/Reuse: The recommendations for Water Quality Zone T/R is the same as for Water Quality Zones A and C above (Section 8.1.3.1), but the infiltration performance standard is optional.

Comparison of BMP Sizes and Performance: The following table was derived using the BMP spreadsheet model described in Appendix I, and provides estimates of BMP sizes and performance for hypothetical drainage areas with varying impervious cover, and under different regulatory requirements. Two City of San Marcos designs are provided. One is per the previous Land Development Code 5.3.2.2(e) and (f), which specifies a sedimentation basin with ½”water quality volume for the impervious cover only, and a presumed 24 hour drawdown time. The second is per the revised LDC and Stormwater Technical Manual, which specify treatment equivalent to a sedimentation-filtration basin (Sand Filtration is assumed), with ½”water quality volume for the entire contributing area, and a presumed 48 hour drawdown time (the LDC specifies 24 hours, but all TCEQ and Austin sizing equations are based on 40-48 hours; the latter will be used). Unlike the TCEQ requirements in the EAZ, there is no requirement to account for sediment accumulation, and the City has a limited inspection and maintenance program. To be conservative, for modeling purposes the WQV is reduced to account for 20% sediment accumulation.

As a local comparison, the City of Austin BMP standard for outside the Barton Springs Zone is included, which is equivalency to a sedimentation-filtration basin with the water quality volume being a function of impervious cover (the ½”+ sizing rule), and a 48 hour drawdown time. A Sand Filtration BMP is assumed.

The WQPP system is a Biofiltration BMP with a 48 hour drawdown time, except for the sites with 75% and 100% impervious cover. At IC values >61%, the TP load reduction goal cannot be achieved unless volume reduction is provided (Note: if TSS is the pollutant constituent, no such constraints exist – see Appendix H). Volume reduction is always feasible with good site planning, and the choice of appropriate BMPs, such as porous pavement, rainwater harvesting (reduces Effective Impervious Cover, thus the volume of runoff), green roofs, and rain garden or biofiltration BMPs designed for infiltration (no underdrain system, no impermeable liner). For the table, a treatment train is assumed, with the 1st BMP being a biofiltration system with an underdrain, and the 2nd BMP a much smaller infiltration basin, using a conservative soil hydraulic conductivity value of 0.06 in/hr.

Table 8-6 Comparison of BMP Designs in Water Quality Zone T/R

Drainage Area IC	**Parameter**	**City of San Marcos Previous LDC**	**City of San Marcos Revised LDC**	**City of Austin**	**WQPP**
		Sedimentation Basin	**Sand Filtration**	**Sand Filtration**	**Biofiltration**
25%	WQV (in)*	0.125	0.50	0.55	0.36
	BMP Footprint as % of Drainage Area**	0.3%	3%	3%	2%
	TP Load as Equiv. IC	***18% IC***	***9% IC***	***8% IC***	***5% IC***
50%	WQV (in)*	0.25	0.50	0.80	0.82
	BMP Footprint as % of Drainage Area**	2%	3%	4%	4%
	TP Load as Equiv. IC	***38% IC***	***23% IC***	***18% IC***	***10% IC***
75%	WQV (in)*	0.375	0.50	1.05	1.61***
	BMP Footprint as % of Drainage Area**	2%	3%	5%	10%
	TP Load as Equiv. IC	***62% IC***	***47% IC***	***32% IC***	***10% IC***
100%	WQV (in)*	0.50	0.50	1.30	3.44****
	BMP Footprint as % of Drainage Area**	3%	3%	6%	23%
	TP Load as Equiv. IC	***88% IC***	***77% IC***	***55% IC***	***10% IC***

*The San Marcos WQV is that for construction purposes: for modeling purposes it is WQV/1.2 to account for sediment accumulation

**Assumes all ponds have 3 ft ponding depth, 3:1 side slopes, and L:W ratio of 2, with exception of WQPP Infiltration Basin for 75% IC site, where ponding depth is a function of soil hydraulic conductivity; 0.06 in/hr is assumed, thus ponding depth ≈ 3 inches to achieve 48 hour drawdown time.

***At IC >61%, volume reduction is required in order to meet the WQPP TP load standard, thus a treatment train is used, in this instance, a biofiltration BMP with 1.51"WQV followed by an infiltration basin with 0.10"WQV

**** Treatment train, a biofiltration BMP with 3.04"WQV followed by an infiltration basin with 0.40" WQV

Findings from the table:

- The previous City of San Marcos Land Development Code BMP requirement was very weak, with TP loads equivalent to highly developed sites, and with minimal stream protection provided.
- The revised City of San Marcos LDC is significantly more protective, but still weak compared to BMP practices elsewhere. In particular, the level of protection sharply decreases with increasing impervious cover.

- The WQPP BMP system is smaller than the City of Austin's at lower IC levels, and larger at higher IC levels, which can be interpreted as meaning that the Austin's requirements may be too stringent for low IC (equivalent TP load < 10% IC) and too lenient for high IC (equivalent TP load > 10% IC).
- Only the WQPP and City of Austin BMP systems consistently meet the WQPP Stream Protection standard (but the City's does not at 100% IC).

8.1.3.3 When are BMPs Required?

It is not always practical to require BMPs for every development situation, thus BMP "thresholds" are proposed for each of the Water Quality Zones.

Area of Disturbance Criteria: Though neither San Marcos nor TCEQ have area-based criteria for when BMPs are required, from a practical standpoint, such criteria must exist, informally if not formally. The WQPP recommends that this be clearly defined to eliminate uncertainty with both the development and regulatory communities. Across the country, it is not uncommon to see 5000 – 10000 ft^2 of disturbance or impervious cover used but, in sensitive receiving waters the criteria can be much lower (e.g., Lake Tahoe, Chesapeake Bay). Within 1000 feet of Chesapeake Bay, the State of Maryland requires BMPs whenever site disturbance equals or exceeds 250 ft^2. Lake Tahoe requires that *all* property owners implement infiltration BMPs, in order to prevent surface runoff from further degrading the lake's clarity. The WQPP recommends criteria that will require most development to implement BMPs, as allowing broad exemptions is not protective of Critical Habitat. As with low impervious cover sites, good site design may be all that's necessary to meet the performance standards.

The WQPP recommends that BMPs be required when the total of new and redeveloped area equals or exceeds 5,000 square feet. There are three possible outcomes for any new development or redevelopment project:

- There is a net increase in site impervious cover
- There is a net decrease in site impervious cover
- There is no net change in site impervious cover

The water quality requirements would be different for each of these scenarios, as described in the next section.

Water Quality Zones A & C (Edwards Aquifer Zone): The City and TCEQ both exempt BMP requirements under certain circumstances, as shown in Table 8-7.

Table 8-7 BMP Requirement Thresholds in Water Quality Zones A and C

Entity	IC at which BMPs are Required	Area of Disturbance at which BMPs are Required
City of San Marcos Recharge Zone	15%	No criteria
TCEQ Edwards Aquifer Rules	20%	No criteria
WQPP	>0%	5000 ft^2*

*after ensuring compliance with TCEQ, which does not have analogous criteria

The City of San Marcos 15% IC threshold is not consistent with its treatment standard, i.e., given that the City discharge goal is a TSS load 20% greater than the undeveloped condition, this equates to an impervious cover level of less than 1%, much less than the 15% "exemption" value.

The reasons the WQPP does not recommend an impervious cover exemption in the Edwards Aquifer Zone are:

- An increase in existing impervious cover will increase impacts to Critical Habitat, unless controls are implemented, and exempting a large number of sites is not protective.
- Sites with low impervious cover can meet the performance standards with good site design that "disconnect" roof tops and impervious cover, by routing runoff to vegetated areas.
- Redevelopment sites with existing high impervious cover should be able to meet the treatment standard, with good site design, as the sites only need to implement BMPs sufficient to offset the effects of additional impervious cover, i.e., the treatment requirements only apply to new development.

Water Quality Zones T/R

Table 8-8 BMP Requirement Thresholds in Water Quality Zone T/R

Entity	IC at which BMPs are Required	Area of New and Redeveloped Impervious Cover at which BMPs are Required
City of San Marcos River Corridor	15%	No criteria
WQPP	≥0%*	5000 ft^2

*Triggered by 5,000 ft^2 threshold, and the term "BMPs" may include payment of fee-in-lieu, in place of or in addition to implementation of treatment BMPs.

As with Water Quality Zones A and C, the 5000 ft^2 of new or redeveloped impervious cover criteria is recommended, in the interest of ensuring that most new development and redevelopment sites contribute to protection of Critical Habitat.

A simplified permitting program could be adopted for small sites, or those with low impervious cover, as has been done by some regulatory entities.

8.1.4 FEE-IN-LIEU AND COST RECOVERY

As the stormwater retrofit program is an important measure for offsetting the impacts of existing development, creative mechanisms for providing funds for that program are needed. One option is to require sites to contribute to the retrofit program when redevelopment activities occur, especially when implementation of on-site BMPs is not fully feasible. This approach has been successfully adopted by some municipalities (e.g., City of Austin), and is recommended by the WQPP. Under this plan, redevelopment sites would have the option of payment in lieu of fully implementing on-site BMPs, subject to certain criteria (see below). Because the BMP performance standards only apply to new development and not existing development, there should be sufficient space available for many redevelopment sites to meet the standards, with good site planning. Thus, partial implementation of BMPs would typically still be required, at a minimum, unless significant site constraints exist.

The WQPP also proposes to expand the fee-in-lieu approach to encompass redevelopment sites that do not reduce existing impervious cover, for the simple reason that impacts have already occurred to Critical Habitat from existing development, thus measures to offset those impacts are necessary. In these cases, where a site redevelops but maintains or slightly increases the existing impervious cover, a contribution to the stormwater retrofit program would be required, but with the option to implement on-site BMPs if desired.

Cost Recovery is a program that incentivizes implementation of on-site BMPs in areas where redevelopment is desired. The WQPP recommends adopting this strategy, specifically in Water Quality Zone T/R for SmartCode Zones T4 (General Urban) and T5 (Urban Center), where densification and redevelopment are City of San Marcos goals. A maximum 75% reimbursement is recommended.

In Water Quality Zones A and C, fee-in-lieu options would be very limited, as the need to implement on-site BMPs in these sensitive areas is a primary need. The Cost Recovery program would also not be an option in those zones.

Should the City decide to implement these programs, a proposed fee schedule for them will be a future action item for the WQPP.

The following section provides guidance on application of the Fee-in-Lieu and Cost Recovery programs.

8.1.5 BMP REQUIREMENTS WITH FEE-IN-LIEU AND COST RECOVERY OPTIONS

Under the WQPP water quality protection measures would be triggered when 5,000 ft^2 or more of site disturbance occurs either through new development or redevelopment. Measures required would be either implementation of on-site BMPs, contribution to the stormwater retrofit program, or a combination of both. Requirements for residential sites can be simplified, with presumptive compliance if impervious cover is disconnected, and no site plan submittal would be required.

The following presents a “decision making” hierarchy for making BMP, fee-in-lieu, and Cost Recovery decisions for each of the Water Quality Zones.

8.1.5.1 Water Quality Zone A

1. First determine if TCEQ Edwards Aquifer Rules require on-site BMPs; the rules have no “area of new or redevelopment impervious cover” threshold, but do exempt sites with < 20% impervious cover, among other possible exemptions.
2. A 20% impervious cover limit applies, e.g., if existing IC = 20%, the maximum allowable = 40%
3. If the total of new and redeveloped impervious cover is < 5000 ft^2 no BMP requirements apply
4. If the total of new and redeveloped impervious cover is ≥ 5000 square feet, see following table:

Table 8-9 Zone A: BMP Requirements per Net Change in Existing Site Impervious Cover

Net Change in EXISTING Site Impervious Cover	BMP Requirements
Decrease	None
No Change	Payment into fee-in-lieu required
Increase	BMPs required for New and Redeveloped IC*

* In WQ Zone A, the BMP requirements are to meet the 4 performance standard:

- TP Load – no increase from existing condition
- Stream Protection Volume or equivalent to be provided for the new and redeveloped IC
- Infiltration – maintain or enhance the existing infiltration rate
- Water demand and conservation – reduce water use (potable, groundwater, river diversion) by 50% for landscape irrigation

Note: Individual residential or duplex lots - presumptive compliance if all impervious cover is disconnected, and net increase

8.1.5.2 Water Quality Zone C

1. TCEQ Edwards Aquifer Rules do not apply
2. Impervious cover limits do not apply
3. BMP requirements – see following table

Table 8-10 Zone C: BMP Requirements per Net Change in Existing Site Impervious Cover

Net Change in EXISTING Site Impervious Cover	BMP Requirements
Decrease	None
No Change	Payment into fee-in-lieu required
Increase	BMPs required for New and Redeveloped IC*

* In WQ Zone C, the BMP requirements are to meet the 4 performance standard:

- TP Load – no increase from existing condition
- Stream Protection Volume or equivalent to be provided for the new and redeveloped IC
- Infiltration – maintain or enhance the existing infiltration rate
- Water demand and conservation – reduce water use (potable, groundwater, river diversion) by 50% for landscape irrigation

Note: Individual residential or duplex lots - presumptive compliance if all impervious cover is disconnected

8.1.5.3 Water Quality Zone T/R

1. TCEQ Edwards Aquifer Rules do not apply
2. Impervious cover limits do not apply
3. BMP requirements – see following table

Table 8-11 Zone T/R: BMP Requirements per Net Change in Existing Site Impervious Cover

Net Change in EXISTING Site Impervious Cover	BMP Requirements
Decrease	None
No Change	Payment into fee-in-lieu required
Increase	BMPs required for New and Redeveloped IC* to the extent possible**

* In WQ Zone C, the BMP requirements are to meet the 2 performance standards:

- TP Load – load for new and redeveloped IC to be no more than a site with 10% IC
- Stream Protection Volume or equivalent to be provided for the new and redeveloped IC
- Water demand and conservation – reduce water use (potable, groundwater, river diversion) by 50% for landscape irrigation
- Optional - Infiltration performance standard

** If the site cannot fully meet the 3 performance standards, than an option may be available to contribute funds to the stormwater retrofit program (fee-in-lieu). Proposed criteria: if the net increase in impervious cover is ≤ 50%, then full implementation of on-site BMPs is presumed feasible

Cost Recovery option In SmartCode Zones T4 and T5 – sites that implement on-site BMPs can be reimbursed up to 75% of the BMP costs (no reimbursement for fee-in-lieu), to the extent reimbursement funds are available.

Note: Individual residential or duplex lots - presumptive compliance if all impervious cover is disconnected.

Redevelopment BMP Requirement Examples with Fee-in-Lieu and Cost Recovery Options

1. *A 1 acre site in Water Quality Zone T/R with a 20,000 ft^2 parking lot and 15,000 ft^2 building (total of 35,000 ft^2 of impervious area) is redeveloped, reducing the parking lot size down to 15,000 ft^2, retaining the existing building but adding a 10,000 ft^2 expansion, for a total of 40,000 ft^2 of site impervious cover. The site impervious cover increased by more than 10% (from 80% to 92%) AND more than 1000 ft^2 of site disturbance has occurred (at least 10,000 ft^2, with 5,000 ft^2 of parking lot replaced, and 5,000 ft^2 of impervious cover added).*
Would WQ controls be required? *YES, including on-site BMPs. Because the site impervious cover increases by only 12%, and there is still 8% pervious area (about 3500 ft^2), there should be sufficient area available to meet the performance standards with on-site BMPs, e.g., a Rain Garden, possibly with Rainwater Harvesting and/or Porous Pavement. If site constraints are severe, a (partial) fee-in-lieu option is possible.*

If this site is in the recharge zone (WQ Zone A), any increase in impervious cover would trigger control requirements, and the redevelopment can only add up to 20% impervious cover; it added 12%, thus would comply with the impervious cover limits. There should still be sufficient room to meet the stricter performance standards, e.g., Rain Garden-Infiltration Basin treatment train, possibly with Rainwater Harvesting. Because the change in impervious cover is < 20%, the TCEQ rules would not apply, thus the Rain Garden alone could be used, if designed for infiltration (no impermeable liner, no underdrain system). No fee-in-lieu option is available for sites in Water Quality Zones A and C.

If this site is located in Water Quality Zone T/R AND SmartCode Zone T4 or T5, then it could be eligible for "Cost Recovery", i.e., up to 75% cost reimbursement for implementing on-site BMPs (but no reimbursement for fee-in-lieu).

2. *A 1 acre site in Water Quality Zone T/R with a 40,000 ft^2 parking lot is redeveloped, reducing the parking lot size down to 15,000 ft^2, adding a 20,000 ft^2 building, and converting 5,000 ft^2 of existing parking lot into a landscaped area, for a total of 35,000 ft^2 of impervious cover after redevelopment. The site impervious cover is reduced from 92% to 80%r, but more than 1,000 ft^2 of impervious cover has been disturbed (at least 20,000 ft^2).*
Would WQ controls be required? *NO, as the net reduction in site impervious cover reduces the impacts of existing development, meeting a goal of the WQPP.*

3. *A 1 acre site in Water Quality Zone T/R with a 40,000 ft^2 parking lot is redeveloped, converting 20,000 ft^2 of the parking lot into a building. Though there is no net increase in site impervious cover, more than 1,000 ft^2 of impervious cover has been "disturbed", as 20,000 ft^2 of impervious cover has been replaced.*
Would WQ controls be required? *YES, as the impacts of existing development would NOT be reduced (a goal of the WQPP). A payment into the stormwater retrofit program is required, with the option of implementing on-site BMPs.*

8.1.6 ADOPT BUFFER ZONE REQUIREMENTS TO PROTECT CRITICAL ECOLOGICAL AREAS

Critical ecological areas include steep slopes, floodplains, areas adjacent to streams, lakes and wetlands, and critical environmental features. The following recommendations apply to these areas.

8.1.6.1Slope Protection

Steep slopes are particularly susceptible to erosion and sediment loss. Placing restrictions on the development of these areas:

- minimizes erosion and slope destabilization
- may help minimize the extent of land disturbance and
- preserves natural character

The City's current Code requires that development "minimize the amount of cut and fill on slopes". The use of the word 'minimize' is non-specific and ambiguous. Adding specificity to this part of the Code will eliminate ambiguity and give development interests more clarity. The WQPP recommends that the City revised the Land Development Code according to Table 8-9. The University would be wise to adopt similar guidance criteria.

Table 8-12 Slope, Cut and Fill Standards

Entity	Current	Recommended
City	Open-ended requirement: Designs shall 'minimize' cut/fill on slopes	✓ Limit cut/ fill to maximum of 4' ✓ Administrative Variance 4' – 8' ✓ P & Z Variance > 8'
University	Minimum standards	Equal to City STM

8.1.6.2Floodplains, Setbacks and Buffers

A floodplain is an area of low-lying ground adjacent to a river or a stream, typically formed mainly of river sediments, that is subject to flooding. Setback requirements stipulate that land use near an environmental feature, such as a river, must be "set back" from the feature a defined distance based on site-specific criteria. Buffers provide vegetated zones between sensitive environments and land developments in order to protect water quality, filter runoff, reduce flooding, minimize bank erosion and benefit habitats.

Floodplain Protection: Regulating construction in the floodplain or buffer zone of streams and river saves the community money. Construction in the floodplain takes up space needed by floodwaters. As a result, during a flood, floodwaters rise higher than normal. This damages buildings and features originally constructed well outside the floodplain. Restricting construction in the floodplain or stream buffer area protects water quality and has the added benefit of flood control. The City of San Marcos currently allows development in the floodplain. The following recommendations apply to floodplains in San Marcos.

- Change from FEMA (Federal Emergency Management Agency) floodplain to fully-developed floodplain
- Strengthen regulations to positively impact the class rating given San Marcos by the FEMA NFIP Community Rating System to receive discounted flood insurance premium rates

The National Flood Insurance Program's (NFIP) Community Rating System (CRS) is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed the minimum NFIP requirements. http://www.fema.gov/national-flood-insurance-program-community-rating-system As a result, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community actions. In particular, the recommendations in this Plan are intended to positively influence stormwater management points (maximum = 670), including:

- Regulate new development throughout the watershed to ensure that post-development runoff is no worse than pre-development runoff.
- Regulate new construction to minimize soil erosion and protect or improve water quality

Other points that are of benefit to both critical habitat of listed species and the CRS Rating include those of Open Space Preservation (maximum = 900) and Higher Regulatory Standards (maximum = 2,740).

Stream Buffers and Setbacks: The following recommendations apply to stream buffers and setbacks in San Marcos.

- Base stream buffer on fully developed watershed conditions
- Require that water quality controls, wastewater lines and trails be in outer half of stream buffer
- Trails shall coexist with the intent of a stream buffer (water quality, bank stability, etc.)
- Support pervious, hard-surfaced trails (based on cost & maintenance considerations)
- The above recommendations do not apply to trail crossings

Table 8-13 Stream Buffer Requirements per Regional Jurisdictions

	Jurisdiction/Regulation/ Applicable Area	Starting Point (acres)	Buffer width (on each side of centerline)
Proposed Stream Buffer Rules	Proposed San Marcos Rules (Headwaters-first order)	5	25’[1]
	Proposed San Marcos Rules (Headwaters-second order)	32	50’
	Proposed San Marcos Rules (Minor Streams)	64	100’
	Proposed San Marcos Rules (Intermediate Streams)	320	200’
	Proposed San Marcos Rules (Major Streams)	640	300’
Other Jurisdictions	TCEQ Edwards Enhanced Water Quality Protection Rules	5	25’
	LCRA Highland Lakes Watershed Ordinance	5	25’
	Regional Water Quality Plan (2005)	32	100’
	City of San Marcos, Edwards Zone	50	50’
	City of Austin, SOS Ordinance	64	50’ – 100’ [2]
	City of Austin Erosion Hazard Zone	Site specific	Site specific

[1] Buffer width applies only if a centerline can be determined.

[2] SOS Ordinance: Use required buffer width or the 100 year floodplain (whichever is larger).

Figure 8-1 presents a diagrammatic representation of these recommendations.

Figure 8-1 Diagram of Recommended Stream Buffers

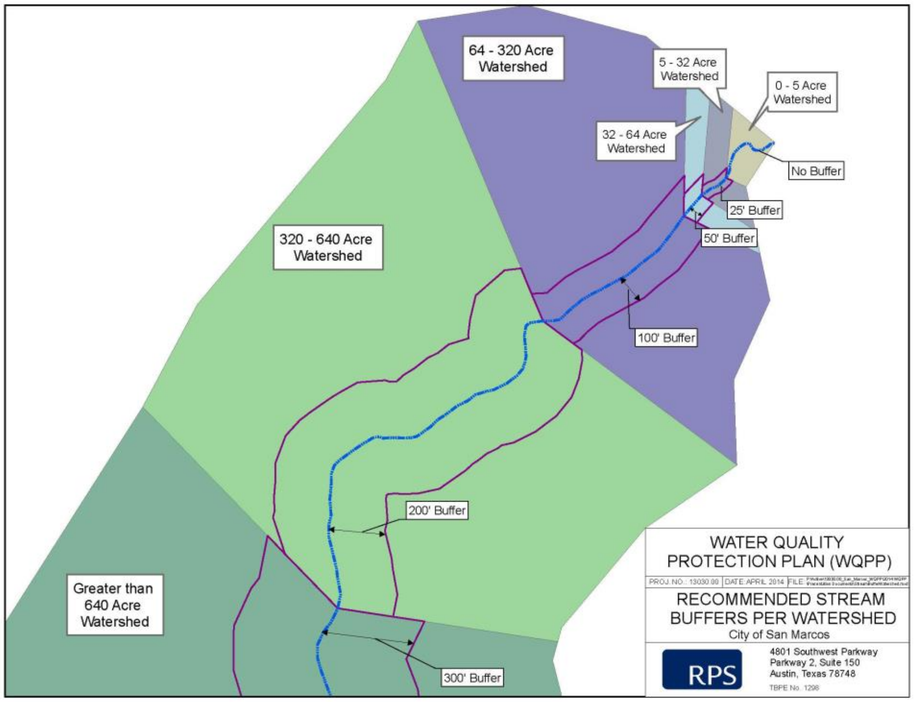
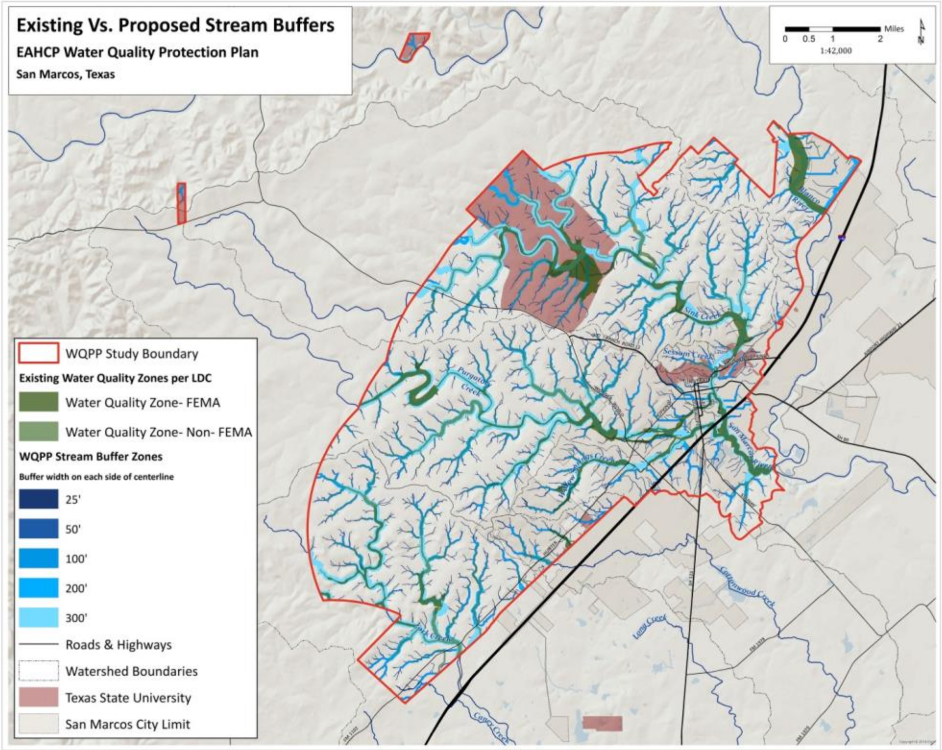


Figure 8-2 shows how these recommendations apply to the area within the Plan boundaries.

Figure 8-2 Recommended Stream Buffers Within the Plan Area



Map: Complete Watershed Solutions LLC

8.1.6.3Setbacks from Critical Environmental Features

Groundwater flow is rapid in the area of the Edwards Aquifer Recharge Zone that is within the City of San Marcos ETJ. Thus there is the potential for pollution introduced in this area to quickly cause adverse effects for listed species. Similarly, damage to such a recharge feature could result in reduced recharge and, ultimately, in reduced spring flows. Therefore recharge features shall be provided special protections. The following information defines the features and describes the minimum requirements for protection.

Definitions of Critical Environmental Features (CEF's):

1) Critical environmental features are features that are of critical importance to the protection of environmental resources, and include bluffs, canyon rimrocks, caves, sinkholes, springs, and wetlands.
2) Faults and fractures are limited to significant fissures or cracks in rock that may permit infiltration of surface water to underground cavities or channels.
3) Point recharge feature means a cave, sinkhole, fault, joint, or other natural feature that lies over the Edwards Aquifer recharge zone and that may transmit a significant amount of surface water into the subsurface strata.

Recommended Protection for Critical Environmental Features:

1) Drainage patterns for proposed development must be designed to protect critical environmental features from the effects of runoff from developed areas, and to maintain the catchment areas of recharge features in a natural state. Special controls must be used where necessary to avoid the effects of erosion, or sedimentation, or high rates of flow.
2) A residential lot may not include a critical environmental feature or be located within 50 feet of a critical environmental feature.
3) This subsection prescribes the requirements for critical environmental feature buffer zones.
    a) A buffer zone is established around each critical environmental feature described in this subchapter.
        i) Except as provided in the subsection below, the width of the buffer zone is 150 feet from the edge of the critical environmental feature.
        ii) For a point recharge feature, the buffer zone coincides with the topographically defined catchment basin, except that the width of the buffer zone from the edge of the critical environmental feature is:
            (1) not less than 150 feet; and
            (2) not more than 300 feet.
    b) Within a buffer zone described in this subsection:
        i) the natural vegetative cover must be retained to the maximum extent practicable;
        ii) construction is prohibited; and
        iii) wastewater disposal or irrigation is prohibited.
    c) If located at least 50 feet from the edge of the critical environmental feature, the prohibition of construction (item 3)(b)(ii) above) does not apply to:
        i) a yard or hiking trail; or
        ii) a recharge basin approved that discharges to a point recharge feature.
4) The director may grant an administrative variance to a requirement. An applicant for a variance must demonstrate that the proposed measures preserve all characteristics of the critical environmental feature.

8.1.6.4Lake and Wetland Buffers

Spring Lake is a critical resource that requires an adequate buffer for proper protection. The adjacent University golf course represents a potential threat to the water quality of the lake. A buffer of native vegetation was constructed around the perimeter of the lake in 2012. The WQPP will review site conditions and golf course management practices in 2014 to determine that Spring Lake is adequately protected. The buffers for critical environmental features previously described apply to lakes and wetlands that require protection from future land development.

8.2 PROMOTE COMPACT DEVELOPMENT AND THE USE OF LID

8.2.1 PROMOTE COMPACT DEVELOPMENT THAT MANAGES STORMWATER ONSITE

The City has initiated efforts to promote compact development, especially in the downtown area, and this concept is supported by the Comprehensive Plan. A general description of compact development follows and is based on information provided by the National Association of Home Builders (NAHB, www.nahb.org).

Important elements of water quality protection and “smart growth” include using land more efficiently and preserving those lands that are most environmentally sensitive. By building in a more compact way, these goals can be achieved. Compact development also reduces development costs through more efficient use of infrastructure, which in turn makes housing more affordable. It provides more transportation options, by providing opportunities for pedestrian access and to provide densities that can be efficiently served by transit.

The current prevalent pattern of lower density development in San Marcos is the result of local zoning codes that require low densities and separation of uses, combined with consumer preferences for single-family homes and larger lots, and low land prices that permit this larger consumption of land. Any movement toward more compact development will have to address barriers in zoning codes while conceding that most new development will continue to be single-family detached homes. Even when land is zoned for higher densities and there is market demand for it, citizen and neighborhood opposition often defeat proposed high density developments.

Several forms of compact development are described in the pages that follow. The actual planning tools and strategies selected will vary according to local politics and market conditions. In addition, interpretation of what compact development means in terms of lot sizes and allowable densities varies across the country. Compact development can encompass the following:

Cluster development: This type of development produces very attractive and marketable communities and makes it easier for developers to preserve environmentally sensitive lands such as wetlands and forests by allowing lots to be grouped on certain portions of a site, rather than spread uniformly across a site, so that other areas of the site may remain undisturbed as open space. Yet many localities make it difficult or impossible to develop in this manner.

Higher-density development: Higher-density development uses land more wisely by building more homes on the land. Higher density housing could include single-family homes on smaller lots, or it could include attached homes or apartment buildings. Many people enjoy the affordability and ease of maintenance of higher density housing. Higher densities also create cost-savings through greater efficiencies in infrastructure. Zoning codes that prohibit this type of development should be changed.

Mixed-use development: Mixed-use development can produce diverse and convenient communities that can have the added benefit of reducing traffic. By integrating different uses such as residences, offices, and shopping, many daily vehicle trips can be eliminated or reduced in length. Zoning was established to separate different uses that created nuisances, such as separating factories from residences. But today most workplaces are clean and quiet and can be built closer to homes without adverse effects. Many employers also find that locating workplaces near shops, banks, dry cleaners, and restaurants can save their employees time. Zoning needs to address our modern condition and make these kinds of developments possible. Any of the following components of mixed use development should be considered “amenities” and are typically seen as promoting the concepts of “smart growth” and sustainable communities:

- Civic Sites
- Walkability
- Connectivity

- Mix of Land Uses
- Diverse Housing Types
- High Quality Architecture and Urban Design
- Increased Density
- Environmental Sensitivity
- Public Transportation
- Stronger Neighborhood Character

Traditional Neighborhood Developments (TNDs): TNDs are a type of community that mixes uses and housing types to create a form more like the towns of the past than the automobile dominated suburbs we have come to know. These new communities are built for walking, and ideally allow residents to walk to shops, schools, and places of worship, parks, and eventually transit stops. There are now over 200 traditional neighborhood projects under way or in the planning stages. Examples include Celebration, near Orlando, Florida; Harbor Town in Memphis; and Kentlands, in Gaithersburg, Maryland. Again, zoning often prohibits this type of development, but some communities are adopting new zoning codes to permit it (NAHB, www.nahb.org).

Community Supported Agriculture and Development Supported Agriculture: In the planning process of a new neighborhood, a developer includes some form of food production – a farm, community garden, orchard, livestock operation, and/or edible park – that is meant to draw in new buyers, increase values and stitch neighbors together. http://wuis.org/post/forget-golf-course-subdivisions-build-around-farms

8.2.1.1 Infill

Infill development shall comply with the recommended water quality requirements in accordance with its locations within the zones. Infill development in its simplest form is the development or redevelopment of land that has been bypassed, remained vacant, and or is underutilized as a result of the continuing development process. Infill development can occur anywhere that a parcel of land is underutilized or misused compared to the surrounding land use activities, such as large urban areas, village settings, town centers, or areas with large lot development that the master plan designates for higher densities. It is often a component of mixed-use development and is a technique that is frequently used in housing strategies to provide affordable housing or to fulfill the need for various types of housing. In addition to its role in housing strategies, infill development plays a critical role in the conservation of land, the creation of community centers, and provides an alternative to sprawl.

8.2.1.2 TIF Districts

Tax Incremental Financing (TIF) districts are used to encourage redevelopment and are recommended for areas where this is desired. The City may want to consider:

- Providing capital or financing for infrastructure improvements (e.g. water, sewer, road, sidewalk, and/or ROW upgrades) provided by others, especially in identified growth areas
- Using reduced impact fees to spur infill development could
- Offering density bonuses or financial incentives to direct growth to already developed areas or to the Activity Nodes identified in the Preferred Scenario of the Comprehensive Plan
- Overlay zoning districts to permit increased density or development intensity in areas where this is appropriate, such as downtowns, along commercial corridors, or near transit stations.

- Using density bonuses to allow a developer to increase the number of housing units or square feet of commercial or office space if specific design criteria are met, such as including a green roof or developing an infill site.

8.2.1.3Protective Zoning

Up-zoning and down-zoning are practices that can be used individually or in tandem with TDR/PDR programs. These tools restrict development in areas that are more appropriately left undeveloped while encouraging more efficient use of land targeted for growth. Form-based zoning codes regulate building appearance rather than density and use. By stressing the appearance of the streetscape or the public realm, form-based codes allow greater development intensity while still promoting good design.

- Traditional Neighborhood Development (TND) codes, a subset of mixed-use codes, seek to replicate the look and feel of attractive, old-fashioned neighborhoods with a combination of street grid, short blocks, pedestrian orientation, and architectural interest.
- Large-lot/agricultural zoning (e.g., 1 unit/160 acres) might be used outside of a growth boundary or at the edge of San Marcos to restrict development and preserve rural character.

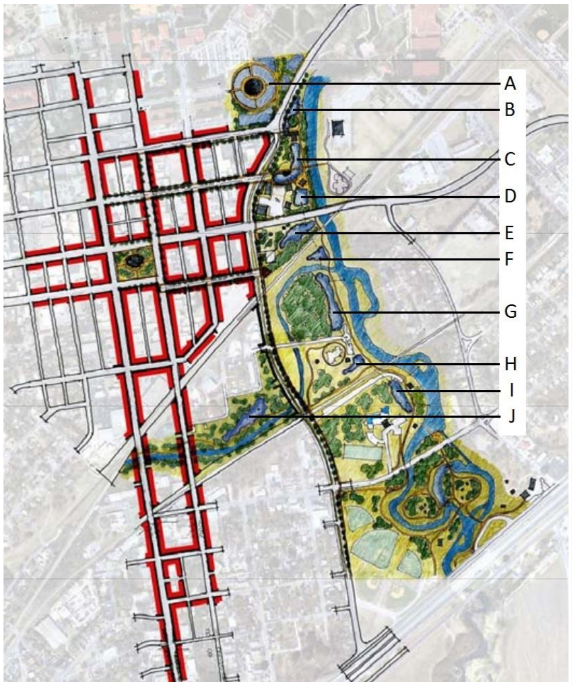
8.2.1.4Downtown Master Plan

The current City of San Marcos Downtown Master Plan was prepared by Broaddus & Associates in 2008. The plan recommends that a “chain of ponds” be placed on the land between the Central Business District (CBD) and the River. This idea for a chain of ponds is offered by the consultant as the primary mechanism to serve the necessary functions of flood detention and water quality treatment for downtown runoff. No engineering assessment as to the feasibility of each of the ponds can be found in the Downtown Master Plan.

Implementation Concerns: The “chain of ponds” is a high-level planning suggestion that offers a collection of potential solutions for treating downtown stormwater runoff. The WQPP has reviewed them to determine which of the ponds may be realistic project sites. The Downtown Master Plan doesn’t label specific pond sites however the blue shapes on the plan offered by the consultant give the viewer an indication of potential size and location. The WQPP Project Team has conducted an initial assessment of some of the sites indicated in the Master Plan and will continue to assess other potential opportunities. Figure 8-3 shows the Chain of Ponds Plan prepared by Broaddus & Associates and includes labels added by the WQPP consulting team identifying potential pond sites.

Figure 8-3 ”Chain of Ponds” Plan

A. Pond A: "Fish Ponds" on the Texas State University campus
B. Pond B: small pond east of University Dr. at C.M. Allen Parkway
C. Pond C: Water quality pond east of Hutchison and C.M. Allen Parkway
D. Pond D: at the storm sewer outlet between the Parks & Recreation Bldg. and the River
E. Pond E: at the storm sewer outlet in Veramendi Park
F. Pond F: small pond in Bicentennial Park
G. Pond G: large pond in Bicentennial Park
H. Pond H: small pond in Children's Park
I. Pond I: in Rio Vista Park north of the swimming pool
J. Pond J: large pond near Purgatory Creek between Porter St. and C.M. Allen Parkway



Map by Broaddus & Associates, Inc. (text by John Gleason LLC)

Initial indications are that a few sites indicated in the Master Plan provide valid opportunities for stormwater treatment while others may not be feasible. There are substantial obstacles to implementation of a chain of ponds concept that the Master Plan doesn't address. Some of the proposed ponds have very little drainage area and would require extensive tree removal and/or repurposing of park land. While the chain of ponds is an interesting concept the issues mentioned above would need to be resolved before implementing. Each of these sites was screened and notes on their potential viability are included below. Additional sites that have been assessed by the WQPP team are described in Sections 8.5 and 9.3.

- **Pond A.** This idea is recommended by the WQPP team as described in Section 9.3. The City might collaborate with Texas State University to assist in implementing this project to offset downtown pollution loading.
- **Pond B.** Note that this location contains an outfall from the Fish Ponds located across the street. Instead of creating a new facility in this location that would likely be undersized due to space constraints, it is instead recommended by the WQPP team to retrofit the Fish Ponds to provide stormwater treatment as discussed in Section 9.3.
- **Pond C.** This pond has recently been constructed. The original design was completed by HNTB, with some modifications recommended by the WQPP team.
- **Pond D.** The area where Pond D is shown is occupied by a newly constructed concrete stage and runoff that used to pass through the park has been connected directly to the river. It is

recommended that the stormsewer drop box in the parking lot between Ponds C and D be retrofitted with a manufactured treatment device such as a Filterra©, or a rain garden facility be placed in the park just behind the drop box where runoff would have a chance to infiltrate before being conveyed to the river. Slightly to the south is the Hopkins Channel Pond 1 (#10291), which is recommended by the HCP and WQPP team as discussed in Section 8.5.

- **Pond E.** This pond is the Hopkins Channel Pond 2 (#10292) that is recommended by the HCP and WQPP team as discussed in Section 8.5.
- **Pond F.** Very little natural drainage flows to this location due to topography and the presence of train tracks. The only way to route stormwater to this facility would be to bore through the railroad embankment, which would likely be challenging and cost prohibitive. The only other alternative would be to try and treat the main stem of Purgatory Creek, which is not advised because the drainage area is 23,700 acres (or 37 square miles) so any water quality facility would be grossly under-sized. Finally the facility is in a park and there might be conflict with recreational uses.
- **Pond G.** Very little natural drainage flows to this location due to topography and presence of Purgatory Creek. The only way to route stormwater to this facility would be to connect it to other drainage areas or ponds through underground boring, which would likely be cost prohibitive. The only other alternative would be to try and treat the main stem of Purgatory Creek, which is not advised because the drainage area is 23,700 acres (or 37 square miles) so any facility would be grossly undersized. Finally the facility is in a park and there might be conflict with recreational uses.
- **Pond H.** Very little natural drainage flows to this location due to topography and the presence of Purgatory Creek and train tracks. The only way to route stormwater to this facility would be to connect it to other drainage areas or ponds through underground boring, which would likely be cost prohibitive. Finally the facility is in a park and there might be conflict with recreational uses.
- **Pond I.** Very little natural drainage flows to this location due to topography and the presence of train tracks, CM Allen, and Purgatory Creek. The only way to route stormwater to this facility would be to connect it to other drainage areas or ponds through underground boring, which would likely be cost prohibitive. Finally the facility is in a park and there might be conflict with recreational uses.
- **Pond J.** A small drainage area bound by LBJ to the west, Comal Street to the north, CM Allen to the east, and Purgatory Creek to the south, might be routed to a facility in this location. However, this facility would be in the floodplain of Purgatory Creek, which would likely lead to frequent flooding and maintenance issues. The only other alternative would be to try and treat the main stem of Purgatory Creek, which is not advised because the drainage area is 23,700 acres (or 37 square miles) so any facility would be grossly undersized.

Considering the constraints discussed above, in combination with the stated intention to increase density and impervious cover downtown, important questions arise as to the effectiveness of relying solely on regional controls in the public realm. Should the pond sites that are shown in the Broaddus Master Plan be feasible, it’s unlikely that the treatment levels provided would even begin to approach those necessary to achieve the 10% pollutant load target for the Transition/River Zone as recommended in this WQPP. There are additional related concerns regarding implementation described in Chapter 10.

8.2.1.5Public Improvement Districts

The Downtown Master Plan recommends that the City of San Marcos establish a Regional Management Authority for the downtown area. This Regional Management Authority would be created to manage a Public Improvement District (PID) that would establish stormwater impact fees that would finance operation and maintenance costs of water quality ponds. The stormwater impact fee is proposed on particular properties that would benefit with increased economic value. While the improvements are intended to directly benefit those private properties financially, they also indirectly generate spillover non-financial public benefits. Chapter 372 of the Texas Local Government Code describes the legal requirements of a PID, which are being established in cities across the state. The following information explains some of the basic aspects of a PID and is from the website: http://subregional.h-gac.com/toolbox/Implementation_Resources/Public_Improvement_Districts_Final.html

Purpose of the Tool: A Public Improvement District is a special district that is created by a local government to fund services and improvements beyond those normally provided by the municipality. The district is funded by special property assessments paid by taxpayers. These funds are subsequently managed and distributed by the local government to the designated agency in charge of the PID, such as the Regional Management Authority. There are many eligible activities in a PID, including improvements to water, wastewater, parks, and drainage.

Benefits of Using the Tool: A PID is beneficial in providing dedicated funding towards specific improvements in communities. It is most beneficial when the property owners have the financial ability to pay the special assessments that will go toward the public improvements. A majority of taxpayers in the proposed PID area must petition the local government to form a PID.

Steps Involved in Using the Tool: Chapter 372 of the Texas Local Government Code specifies the procedures by which a PID must be established. A petition must be submitted to the local government stating:

- The general nature of the proposed improvement
- The estimated cost of the improvement
- The boundaries of the proposed district
- The proposed method of assessment
- The proposed apportionment of cost between the PID and the municipality
- The managing body of the district
- That the persons signing the petition request or concur with the proposed district
- That an advisory board will be formed to develop and recommend an improvement plan to the governing body of the municipality

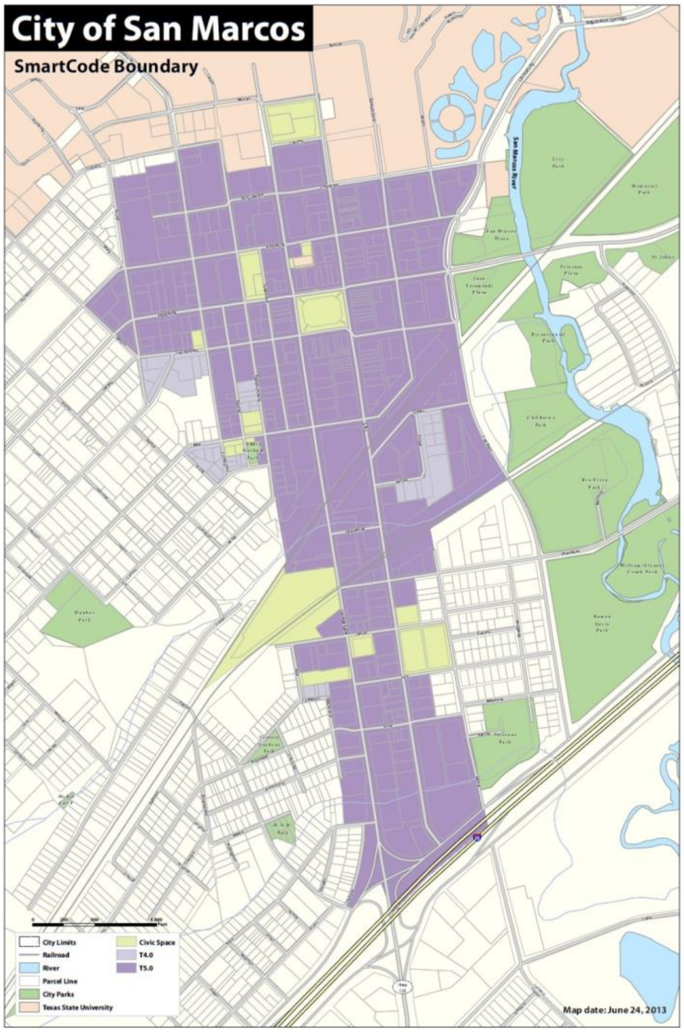
Furthermore, the petition must be signed by at least 50% of property owners in the proposed district, or owners of at least 50% of the land area. Before establishment of the district, a public hearing must be held to advise the community of the nature of the district.

Once the PID is established, the actual implementation of the improvements may occur after 20 days, to allow any public comment to be submitted to the municipality. If the community or municipality wishes to dissolve the PID at any time, a petition must be signed by at least 50% of property owners in the proposed district, or owners of at least 50% of the land area, and a public hearing must be held.

8.2.1.6City of San Marcos SmartCode

The City of San Marcos has an existing SmartCode in place. The SmartCode is a model transect-based planning and zoning document based on environmental analysis. It addresses all scales of planning, from the region to the community to the block and building. The template has been calibrated to the conditions in San Marcos. As a form-based code, the SmartCode is intended to keep urban development compact and rural lands open, thus reforming the sprawling patterns of separated-use zoning. Transects are noted as T1 through T5. Figure 8-4 shows transects T4 and T5 in the downtown area.

Figure 8-4 SmartCode Boundary in Downtown San Marcos



8.2.2 USE LOW IMPACT DEVELOPMENT, GREEN INFRASTRUCTURE AND BETTER SITE DESIGN

Green infrastructure is a relatively new term based on concepts that highlight the importance of the natural environment in decisions about land-use planning. Although the definition of the term is not narrowly defined, it is being used by many in the design, conservation and planning related disciplines to describe sustainable, multi-functional green spaces that mitigate impacts associated with urbanization and a changing climate.

The US EPA says green infrastructure "is an approach that communities can choose to maintain healthy waters, provide multiple environmental benefits and support sustainable communities. Unlike single-purpose gray stormwater infrastructure, which uses pipes to dispose of rainwater, green infrastructure uses vegetation and soil to manage rainwater where it falls. By weaving natural processes into the built environment, green infrastructure provides not only stormwater management, but also flood mitigation, air quality management, and much more." (www.epa.gov)

The WQPP recommends that new development within the City and on the University campus implement green infrastructure at all scales of (e.g. in neighborhoods and at the site level). Due to the multi-faceted nature of green infrastructure this recommendation is given more specificity in sections throughout this chapter.

8.2.2.1LID and Green Infrastructure

Site design measures seek to establish design and development standards based on the use of low impact development (LID) and green infrastructure. Green infrastructure manages stormwater runoff through the use of natural systems, or engineered systems that mimic natural systems, to treat polluted runoff and support long-term sustainability. Low impact development is a related design approach that implements engineered small-scale hydrologic controls to replicate the pre-development hydrologic regime of sites through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. In general, the concepts of green infrastructure and LID can also be applied at the land-use planning level. The following sections outline a general design approach to LID.

Runoff Reduction and Source Controls: The first step in the process is to consider opportunities for hydrologic source controls based on the project layout. These controls are designed to reduce or eliminate stormwater runoff at the source by promoting either or both direct infiltration to the subsurface or beneficial reuse. Hydrologic source controls promoting infiltration include Porous Pavement for Pedestrian Use and Non-Required Vegetation. Rainwater Harvesting can also function as a source control promoting beneficial reuse if drawdown of the water quality volume occurs within the required timeframe without discharge to landscape areas during precipitation events (e.g., water is pumped to a separate tank for subsequent beneficial reuse) (Note: infiltration or irrigation from Rainwater Harvesting is addressed below). Hydrologic source controls typically achieve partial water quality credit, consequently reducing the size of downstream controls.

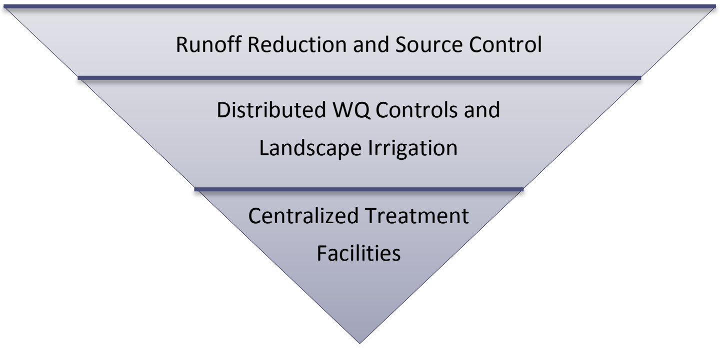
Small Scale Distributed Controls: After considering opportunities for reducing runoff at the source, the next step in the water quality control selection process is to consider opportunities for incorporating smaller-scale distributed controls in landscaped areas throughout the site. Distributed controls should be designed to maximize the natural infiltration and storage capacity of the site where feasible. Infiltration is typically not feasible if:

- soils are not conducive for infiltration (low permeability); in-situ soil testing is recommended
- subsurface water storage capacity is limited due to high groundwater levels or shallow bedrock or impermeable layers,
- infiltration would cause or contribute to soil or groundwater contamination, or
- infiltration would cause or contribute to geotechnical issues such as slope or foundation stability.

Distributed controls typically reduce the amount of directly connected impervious area on a site, which will reduce the peak discharge rate by increasing the time of concentration and allow runoff to be managed closer to the source. In addition, distributed controls can often be used to satisfy landscaping requirements. Therefore, both water quality credit and landscape credit can usually be achieved for the same area. Examples of distributed controls include Vegetated Filter Strips and Rain Gardens. Rainwater Harvesting can also function as a distributed control if the water quality volume is discharged to landscaped areas for infiltration or irrigation. All of these controls can be designed to achieve full or partial water quality credit.

Centralized Controls: If it is not feasible to fully capture and treat the required WQV using hydrologic source controls and distributed controls, then centralized treatment facilities should be selected and sized for the remaining WQV. Centralized facilities typically collect runoff from larger drainage areas and are therefore larger in size. Examples of centralized facilities include Retention/Irrigation Systems, Biofiltration Systems, Sedimentation/Filtration Systems, and Wet Ponds. Figure 8-5 outlines the recommended hierarchical approach for selecting on-site water quality controls (recreated from the City of Austin Environmental Criteria Manual).

Figure 8-5 Hierarchy for On-Site Stormwater Controls



8.2.2.2Use Preferred Neighborhood and Site-Scale Design

Preferred neighborhood and site-scale strategies reduce stormwater runoff and associated pollutants while creating more interesting and attractive neighborhoods. They include the use of narrow streets, parking reduction strategies, and integration of small-scale BMP’s such as rain gardens and pervious pavement.

8.2.2.3Complete Streets, Parking, and Place-Based Policies

Streets are a complex intersection of multiple users and functions; autos, bicycles, pedestrians, trees, water and wastewater, drainage, electrical, lighting, parking, and so on. Conventional street design practices focus primarily on moving the automobile and diverting runoff to the curb and gutter, contributing to increased runoff volume and poor water quality.

Complete streets is a transportation policy and design approach that requires streets to be planned, designed, operated, and maintained to enable safe, convenient and comfortable travel and access for users of all ages and abilities regardless of their mode of transportation. Complete streets allow for safe travel by those walking, bicycling, driving automobiles, riding public transportation, or delivering goods. To provide stormwater benefits, complete streets and parking lots are usually designed with a landscape element and/or pervious pavement system that captures, slows, filters, and potentially infiltrates stormwater runoff. By providing safe options for people to walk and bike, complete streets can lead to fewer people driving alone in their cars. This means fewer dangerous emissions from automobiles, which benefits all residents. Review the street-width standards and require the minimum travel-lane and right-of-way widths necessary to meet safety and traffic concerns.

Yet to be truly complete, streets need to be integrated into genuinely place-based and community-based transportation policies. Place-based plans, policies, and programs allow downtown and village streets to become destinations worth visiting, not just throughways to and from the workplace or the regional mall. Transit stops and stations can make commuting by rail or bus a pleasure. Neighborhood streets can be places where parents feel safe letting their children play, and commercial strips can be designed as grand boulevards, safe for walking and cycling, allowing for both through and local traffic. In other words, the desire to go 'through' a place must be balanced with the desire to go 'to' a place. The following guidelines are recommended (based on Toth, 2011):

- **Think of streets and parking lots as public spaces:** Roads can be shared spaces, with pedestrian refuges, bike lanes, and on-street parking. Parking lots can become public markets on weekends. Even major urban arterials can be designed to provide for dedicated bus lanes, well-designed bus stops that serve as gathering places, and multimodal facilities for bus rapid transit or other forms of travel.
- **Plan for community outcomes:** Integrate street networks around great places with an appropriate mix of people and activities. Livable places which can be comfortably reached by foot, bike, and transit put little strain on the transportation system.
- **Design for appropriate speeds:** Streets need to be designed in a way that induces traffic speeds appropriate for that particular context. Desired speeds can be attained by changes in roadway widths, intersection design, minimal building setbacks, trees and sidewalks with lots of activity.

There are exceptions to complete streets roadway projects such as freeways or other roads where non-motorized transportation is banned by law, roadways where the cost of accommodation would be too disproportionate to the need or expected use, and roadways where lack of present and future need is shown to make accommodation unnecessary.

Parking Ratios and Shared Spaces: Appropriate parking ratios are recommended for development projects that, because of their location, users, or project features, can be expected to have lower-than-average parking demand. Such land uses include compact, mixed-use, and transit-oriented developments; those in downtowns, near transit stations and along commercial corridors; and those catering to students, the elderly, and other demographic groups with lower-than-average car ownership rates.

Shared parking reduces the number of spaces that each development has to provide while still meeting the needs of drivers. For example, an office building parking lot might be full during the day but empty at nights and weekends. Sharing a parking lot with a movie theater, where demand is greatest at night and on weekends, would reduce the total parking required.

Permeable Pavement Systems and Green Infrastructure: Permeable paving is a range of sustainable materials and techniques for permeable pavements with a base and sub-base that allow the movement of stormwater through the surface. In addition to reducing runoff, this effectively traps suspended solids and may filter certain pollutants from the water. The goal is to control stormwater at the source, reduce runoff and improve water quality by filtering pollutants in the substrata layers.

Permeable pavement with a “structural-soil” pavement base, which combines structural aggregate with soil, admits vital air and water to the rooting zone. Green infrastructure appropriate to ROW’s and parking lots include rain gardens, landscaped medians, planted curb extensions, shade trees, swales, and filter strips. Combining green infrastructure with permeable pavements may give urban trees the rooting space they need to grow to full size. Together permeable pavement and vegetated BMP’s help integrate ecological functions into urban spaces by allowing the soil to treat runoff and offset the urban heat island effect with a thriving canopy above. These systems are only effective when proper design and construction practices are followed. Refer to Chapter 8 for a detailed description of these BMP’s.

8.2.2.3Erosion and Sediment Control

Temporary sediment control practices include those practices that intercept and slow or detain the flow of stormwater to allow sediment to settle and be trapped. It is recommended that the City and University enhance inspection, enforcement and ongoing monitoring of temporary erosion and sediment controls.

8.3 CONSERVE NATURAL AREAS & OPEN SPACE

Land that is allowed to stay in its natural state will not typically contribute significant pollutants that adversely impact water quality. The purpose of this measure is to restrict the land in that space from further development. All entities and individuals inside and outside the Plan Area should be encouraged to voluntarily conserve natural areas/open space. In addition to voluntary conservation, several elements of the Plan require the conservation of natural areas in exchange for certain flexibility in implementation. While it often involves either the purchase of the land or purchase of development rights for the land, natural area/open space preservation is considered a non-structural protection measure. Natural area conservation accomplishes the objective of no net increase in pollutant loadings by restricting development activities that would generate these additional pollutant loadings (Naismith Engineering, Inc., June 2005).

8.3.1 SUMMARY OF WQPP RECOMMENDATIONS FOR LAND CONSERVATION

The WQPP recommends that the City establish a Land Conservation Program in the WQPP Plan Area. Initial program objectives are to:

- Acquire land and establish conservation easements in environmentally sensitive areas to meet the goals of the Edwards Aquifer HCP and the WQPP
- Prioritize the most sensitive areas including the aquifer recharge zone and the contributing zone
- Establish the resources necessary (money, personnel, etc.) to acquire land and conservation easements by identifying potential funding, grants and collaborators
- Develop strategies to encourage private land easements for riparian buffers, floodplains, and recharge features (i.e. easement holding partner, funding, and promotion to landowners). Evaluate land along the river and consider land acquisition, building removal and site restoration when suitable properties become available. (City of San Marcos Parks and Open Space Master Plan)
- Explore mitigation options for developments in areas that are planned for higher density
- Integrate the program with a City payment-in-lieu for stormwater treatment by requiring that a minimum portion of the payments be dedicated to acquiring natural areas and open space

Potential Funding & Collaborators:

- General obligation bonds, which are repaid by property taxes
- Governmental entities: Hays County, Natural Resources Conservation Service, National Park Service (Rivers, Trails, and Conservation Assistance Program)
- Non-Governmental Organizations: the Trust for Public Land, the San Marcos River Foundation, the San Marcos Greenbelt Alliance, the Hill Country Conservancy, the Nature Conservancy of Texas, the Guadalupe-Blanco River Trust, the Hill Country Land Trust, and more
- Development Interests: Conservation of land in connection with development activities may take a number of forms, including:
    - Required dedication of land as a condition of development approvals
    - Fee-in-lieu payments by developers used to acquire conservation land
    - The use of Conservation Development and/or LID practices, with open space areas being maintained in accordance with conservation standards
    - Proactive acquisition by the City of land or easements for conservation purposes in a program that allows developers to make specified payments towards the acquisition costs in connection with development approvals

Related Information:

- Consider the proximity of potential land to other conservation property and the cost to buy and manage.
- Prioritize environmentally sensitive land with recharge features, such as caves, sinkholes and seeps, that are characteristic of the Edwards Aquifer
- Consider allowing public access with low-impact recreational and educational opportunities, provided such activities are compatible with the primary purpose of water quality protection. One such consideration is the Violet Crown Trail, a 30-plus-mile regional public trail system that will run from Hays County to Zilker Park in Austin.
- Since 1998, the City of Austin has spent 128.4 million to purchase land and conservation easements. They have set aside 26,577 acres and they spend about $40 an acre per year to maintain conservation property it owns outright. Other government entities and environmental have contributed an additional $14.9 million toward the acquisitions. (Asher Price, 10/15/2013)
- Proposition 13 in Austin (2012) has widespread support, as have previous water quality bonds. It is endorsed both by environmental groups, which generally are opposed to suburban development in the environmentally sensitive Hill Country, and by real estate interests, as the stymieing of development on some tracts typically makes neighboring land more valuable.

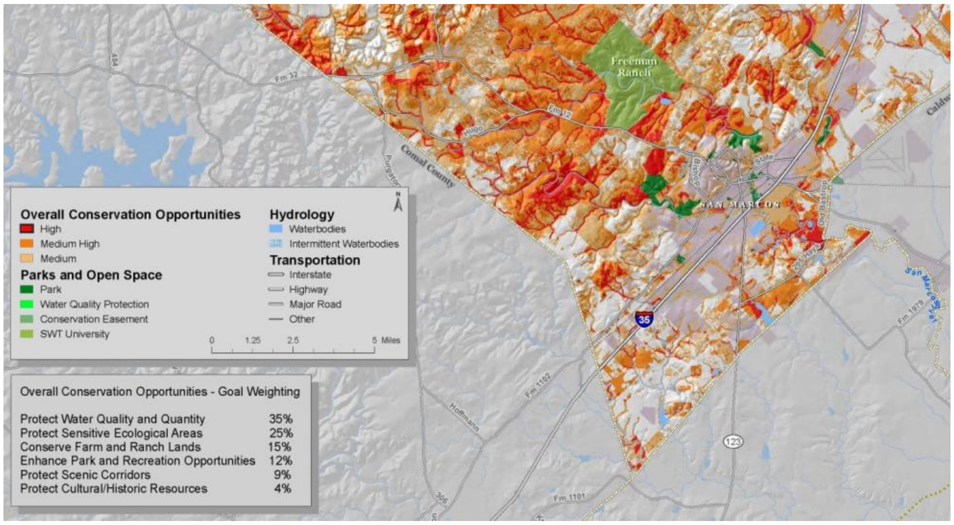
- While the proposed Land Conservation Program in San Marcos would be primarily intended to protect listed aquatic species, there are numerous other species, both listed and unlisted, that the Program may collaterally benefit including the golden-cheeked warbler and black-capped vireo (species included in the Hays County RHCP, see http://www.hayscountyhcp.com/)

8.3.2 LAND CONSERVATION AS GREEN INFRASTRUCTURE

An ideal application of green infrastructure at the regional scale would include an interconnected network of preserved or restored natural lands and waters. The protection of natural landscape features such as floodplains, forested areas, and wetland are critical components of green infrastructure at the regional and municipal levels. By choosing not to develop on ecologically sensitive areas, San Marcos can provide opportunities for outdoor recreation, provide for and protect wildlife habitat, and improve water quality. Interconnected open space provides the critical advantage of allowing a transportation network of hike and bike trails. An alternative transportation network will minimize the pollutants associated with cars, both in the air and water, and provide other benefits to personal health, property values and lifestyles.

Land conservation is probably the most effective means of protection against water quality impacts from increasing impervious cover. Land placed in conservation is usually in the form of parkland when held by a city, a conservation easement or full ownership when held by a land trust, or through contract when held by private entities including non-profits, homeowners associations and individuals. Each provides varying degrees of conservation depending on the terms of the agreements and the ordinances by which they were conserved. Figure 7-4 shows a portion of the Hays County area of the Central Texas Greenprint for Growth. Overall land conservation opportunities are shown color coding of weighted goals including Protection of Water Quality and Quantity.

Figure 8-6 Hays County Land Conservation Opportunities



Credit: www.capcog.org

8.3.3 NATURAL AREA CONSERVATION MECHANISMS

There are a number of mechanisms that can accomplish natural area conservation. Each of these mechanisms involves establishing or identifying a Conservator, implementing restrictions to prevent the future development of the land, and providing long-term funding for its conservation. Specific procedures for securing the conservation area are provided in the section on Implementation. While each mechanism has one specific purpose for natural area conservation, it may also accomplish other purposes. Mixed use natural area conservation may be beneficial, but for the purposes of this plan, separate descriptions are provided for each mechanism, based on its intended purpose. The following natural area conservation mechanisms are identified for use within the Plan Area (Naismith Engineering, Inc., June 2005).

8.3.3.1Conservation Easements

A conservation easement is a written agreement between a landowner and the "holder" of the conservation easement under which a landowner voluntarily restricts certain uses of the property to protect its natural, productive or cultural features. The holder of the conservation easement must be a governmental entity or a qualified conservation organization. With a conservation easement, the landowner retains legal title to the property and determines the types of land uses to continue and those to restrict. As part of the arrangement, the landowner grants the holder of the conservation easement the right to periodically assess the condition of the property to ensure that it is maintained according to the terms of the legal agreement.

While some improvement may be made to facilitate access for maintenance or public recreation, other uses of the land (other than conservation) should be restricted. To qualify as a conservation easement for the purposes of the Plan, the land should remain in a reasonably undeveloped state in perpetuity, and comply with the restrictions outlined in the Implementation section. In instances where the ownership remains privately held, the maximum amount of development of the property should be established at the time the conservation easement is set aside. These areas should be subject to proper vegetative management. Public and private entities should be encouraged to voluntarily secure conservation easements as a means of natural area conservation. Mandatory conservation easements may also be established under this Plan as a component of a Transferable Development Rights program (Naismith Engineering, Inc., June 2005).

The donation of a conservation easement can have potentially significant tax benefits. Conservation easements are recognized for legal and tax purposes by the state of Texas (chapter 183, Texas natural resources code) and the internal revenue service (internal revenue code, section 170(h)). These state and federal laws allow for tax benefits to landowners who protect natural or historic land with qualifying conservation easements. (Source: des.nh.gov)

8.3.3.2Land Acquisition

In addition to continuing to purchase large areas of open space for public parks and water quality purposes, it is recommended that San Marcos participate in the Hays County RHCP land acquisition program. This program conserves land in a variety of ways including fee simple acquisition and conservation easements. Fee simple is the most common type of land ownership, meaning that the owners have complete ownership of the land. Fee simple ownership does not generally have a time limit.

Natural areas/open space set aside for habitat protection has different objectives than natural areas set aside for other reasons. In most instances, areas of critical habitat for the species to be protected will be identified. Typically, no development is allowed on areas set aside for habitat protection except for that necessary for access. Land acquired for habitat protection may be on a voluntary basis or it may be required under some regulatory programs. (Naismith Engineering, Inc., June 2005).

8.3.3.3Transfer of Development Rights

Transfers of development rights (TDRs) allow a community to direct development to areas targeted for growth while preserving undeveloped land elsewhere. Purchases of development rights (PDRs) operate similarly to TDRs except that the developer is required to purchase those development rights.

Existing City of San Marcos Code – Transfer of Development Rights: The following is an excerpt from the City Land Development Code.

- Sec 94.530.2: Transfer of development rights. The transfer of development rights from a site located in the recharge zone to a receiving site located outside of the recharge zone is encouraged. The following provisions are intended to provide incentives for the transfer of development rights.

  (1) The allowance for impervious cover under the provisions of this article for a site located in the recharge zone may be transferred in the form of a residential unit bonus to a receiving site inside the city limits that is appropriately zoned and is not located on the recharge zone. The receiving site may be granted additional residential units to be added to the total number of units that would otherwise be allowed within the zoning district of the receiving site. For each 5,000 square feet of impervious cover that could be legally constructed in the sending site, but is instead transferred to the receiving site, the following additional number of residential units may be constructed on the receiving site:

  (A) Two single family homes, duplexes or townhouses, or

  (B) Three apartment units.

  (2) The commission and the city council must approve the transfer to the receiving site following the process described in Chapter 114 for a zoning change, including all notification and public hearing procedures.

  (3) The total increase in residential density allowed on the receiving site must not exceed 25% of the density otherwise allowed on the receiving site.

Proposed Code Revisions: Transfer of Development Rights: The WQPP recommends that the existing code establishing Transfer of Development Rights be assessed and revised as necessary in 2015 in conjunction with the upcoming efforts to prepare new City Land Development Code.

Mitigation Banking: The WQPP recommends that the proposed City Land Conservation program participate in the Hays County mitigation banking program. While the focus of the Hays County program is on the protection of Golden-Cheeked Warbler habitat, natural areas that are set aside will provide protection for the listed aquatic species as well. The programs shall also consider wetland and stream mitigation banking.

Wetland mitigation banks are permanently protected lands that contain natural resource values (wetlands and associated uplands). These lands have been restored and managed for wildlife habitat, water quality, flood amelioration, and ecological diversity. Stream mitigation banks are streams and/or stream riparian zones that are restored and enhanced to create stable stream corridors that result in improved, water quality, wildlife habitat, and watershed integrity.

Both wetland and stream mitigation banks are used to compensate for adverse impacts generally occurring within a specified service area, or designated watershed. The US Army Corps of Engineers (USACE), along with other state and federal agencies, approves a specified number of wetland/stream credits available to be sold by the bank sponsor. Permitted entities needing to compensate for project-related unavoidable adverse impacts to streams may purchase credits from bank sponsors, upon approval by the USACE, to compensate for those impacts. Each state and USACE District, however, continues to quantify wetland and stream credits uniquely; therefore, understanding the credit generation and impact assessment process for each individual District is critical.

Landscape Conservation Cooperatives (LCCs): LCCs are conservation-science partnerships established within geographically defined areas to support conservation planning and design, research, and monitoring programs (USFWS 2013). An LCC in San Marcos could serve as an invaluable new tool to help us meet the challenges of establishing a new land conservation program.

City of San Marcos: Conserving natural areas and open space will support the following vision statement of the San Marcos Comprehensive Plan.

> *We envision San Marcos with safe and attractive parks, public spaces and facilities which provide a range of amenities and experiences. We envision a connected system of parks and natural areas that focus on our unique cultural and environmental heritage.*

8.3.4 OPEN SPACE STANDARDS

Open space standards refer to the open space or parkland dedication required to serve new residential or non-residential areas.

Existing City of San Marcos Code: Open Space Standards:

- LDC Ch7, Article 6, Division 1, Section 7.6.1.2, paragraph (b): Criteria for land dedication. All residential subdivisions, regardless of type, shall be required to dedicate suitable land for park or open space development in the amount of five acres per 1,000 ultimate residents of the subdivision.
- LDC Ch. 7, Article 6, Division 1, Section 7.6.1.2, paragraph (f): Fee in Lieu of Dedication. A cash fee for the purchase of offsite parkland may be paid in lieu of all or part of the dedication of onsite parkland. The cash fee in lieu of parkland dedication shall be set by resolution of the City Council (see the Technical Manual).

Proposed Code Revisions – Open Space Standards: The WQPP recommends that the proposed City Land Conservation Program assess Open Space Standards and revise as necessary. The current City of San Marcos ratio of 5 park acres per 1,000 people is low. The WQPP recommends that the ratio double to 10 acres. To provide a benchmark to other Texas cities, the Trust for public land produced the following data in 2012 regarding Total Park Acres per 1,000 residents:

- Arlington – 12.8

- Austin - 37.0
- Dallas -19.5
- Fort Worth – 15.7
- Houston – 23.6
- Laredo- 6.6
- San Antonio- 17.6

Currently, only residential subdivisions are required to dedicate parkland or pay a fee-in-lieu of dedication at the City. The WQPP recommends that the legal authority and precedence for open space dedication for other land uses be explored.

8.4 PROMOTE WATERSHED STEWARDSHIP

Watershed stewardship is an ethic that embodies the responsible planning and management of environmental resources. It is a responsibility shared by all those whose actions affect environmental integrity, economic viability, and social progress in the community. It is reflected as both a value and a practice by individuals, organizations, communities, and competent authorities.

The City of San Marcos Comprehensive Plan includes goals that encourage watershed stewardship. The activities noted in this chapter describe programs and activities that meet the planning and sustainability goals of the city. These activities are considered source controls in that they help to prevent pollution, prevent non-stormwater discharges, and achieve other WQPP-related goals.

Options to improve water quality in existing urbanized areas include education and training to minimize pollutant sources. Education can increase understanding in the development community and public of current water quality impacts and what they can do to potentially lessen the impact of their projects or daily activities. In addition, education can promote better private land stewardship and create a constituency that may be willing to fund and sustain watershed management efforts.

As noted in the Rapid Watershed Planning Handbook, prepared by the Center for Watershed Protection, there are four basic elements of education and training:

- *Watershed awareness*: raising basic awareness through signage, storm drain stenciling, maps
- *Personal stewardship*: identify the role we play in watershed protection and positive behaviors
- *Professional training*: informing City staff/development community on how to apply tools
- *Watershed engagement*: providing opportunities for the public to engage in restoration

Some of the potential activities include:

Staff Training and Workshops

- Pre-development planning assistance to project owners and their engineers to guide designs that minimize water quality impacts and enhance water supplies
- Development review, especially focused on stormwater runoff management
- Erosion and sediment control
- Land conservation and conservation easements

Developer/Engineer/Landscape Architect Training and Workshops

- LID design approaches and procedure to obtain a permit
- Water quality basin design and sizing procedures
- Erosion and sediment control
- Site design to minimize land disturbance

Contractor Training and Workshops

- Erosion and sediment control
- LID construction

General Education and Workshops

- Trash cleanups involving the public at large and Texas State University
- Media campaign: radio, television, newspaper and on-line regarding fertilizers, pesticides, other chemicals, and water conservation
- Watershed organization initiation
- Watershed Protection Plan (WPP) through TCEQ/EPA 319 Grant Program

Getting Started: Watershed education, to work effectively, needs to be an on-going activity, not a one-time event. It should be strategic in nature to build and grow a base of support that can then reach out to other groups and residents to expand the message, change behaviors, and reduce the cost burden to the City. The following programs encourage citizens to become involved in watershed protection activities.

8.4.1 RAINWISE PROGRAM

Numerous cities have initiated programs that encourage citizens to install stormwater and Low Impact Development BMPs on their properties. Programs exist in Missouri, Minnesota, Washington, Ohio, Kentucky, Illinois, Alaska, Connecticut, Rhode Island, Iowa, Indiana, Pennsylvania, California, Florida and elsewhere. The programs include:

- Kansas City “10,000 Rain Gardens” program
- Seattle “Rainwise” program
- Maplewood, Minnesota
- Burnsville, Minnesota

These programs have been highly successful in raising public awareness and incentivizing the implementation of numerous small-scale stormwater BMPs throughout their communities. The WQPP recommends that the City of San Marcos initiate such a program.

8.4.2 INTEGRATED PEST MANAGEMENT (IPM) AND FERTILIZER USE

San Marcos could become a model community in demonstrating “sustainable integrated water management” – a paradigm shift on how water management is done in this country in an effort to integrate wastewater, stormwater, drinking water, and other water resources management (WERF, 2010). If employed widely, this management practice has the potential to reduce demand on water supplies. Landscape irrigation can account for 60-75% of potable water use in Texas (Woodson, 2012), and typically half is wasted as a result of evaporation, wind, improper design, and overwatering (SSI, 2009). Reducing demand of potable water use can also reduce energy consumption (municipal and water and wastewater treatment facilities account for up to 50% of the electricity consumed by city governments in the United States). Reducing potable water use for landscape irrigation by at least 50% is a goal of the Sustainable Sites Initiative (SSI, 2009); captured rainwater and stormwater can be important replacement sources. The WQPP recommends that the City of San Marcos offer free and useful information on proper IPM and fertilizer use by becoming a partner to the Grow Green program in Austin. Refer to Appendix E for more information on the Grow Green Program.

8.4.3 URBAN HOUSEKEEPING

The citizens of San Marcos have often demonstrated a keen interest in identifying water quality concerns when they are observed in and around town. These observations include occurrences such as the spill of a hazardous material and the failure of construction project sediment controls. They may take these complaints to the media however it would be better for everybody if there existed a convenient way for these reports to be submitted directly to the City. The WQPP recommends that the City of San Marcos establish a 311 call center to assist citizens with water quality and drainage concerns. Additionally, the City would be wise to increase the number of inspectors available to follow up with these concerns and establish protocol and a database for these citizen communications.

8.4.4 INCENTIVES PROGRAMS: REUSE AND EFFICIENCY

The following water conservation and water quality programs may serve as models for similar programs in San Marcos.

1. Pressure regulating valve rebate: A win-win program for the City and their water customers http://austintexas.gov/department/pressure-regulating-valve-rebate
2. Waterwise landscape rebate: Establish a modified version of the City of Austin program http://austintexas.gov/department/waterwise-landscape-rebate

Throughout the last decade, the Texas legislature has deemed it necessary to incentivize rainwater harvesting (RWH). For example, SB 2 of the 77th Legislature provides exemptions from rainwater equipment sales tax and ad valorem taxation of installed systems. HB 645, 78th Legislative Session, 2003 Prohibits HOAs from implementing new covenants banning rainwater harvesting systems, but allows them to develop rules for screening. Texas continues to be supportive of RWH expansion in recent legislative sessions to allow more potable rainwater use in the home. The potential is great for this auxiliary water source to offset the use of potable water, thus further protecting critical habitat during periods of drought.

8.5 STORMWATER RETROFIT PROJECTS

A wide range of watershed management strategies are recommended so they can be tailored to different characteristics and needs within the WQPP Plan Area. For example, in undeveloped areas, it is possible to plan ahead for new development and provide treatment on-site to achieve stormwater management goals. However, most existing urbanization in the City of San Marcos (City) has been developed prior to the adoption of modern stormwater criteria thus no treatment was required nor implemented. In these areas, the Plan recommends the implementation of water quality retrofit projects (retrofits) to counteract impacts of existing development on critical habitat.

Retrofits consist of new installations or upgrades to existing Best Management Practices (BMPs) in developed areas lacking adequate stormwater treatment. These projects are often challenging due to existing site constraints that reduce flexibility in selecting and sizing BMPs. Where retrofit opportunities do exist, the goal is often to provide as much hydrologic and water quality benefit as possible by:

- Correcting prior design or performance deficiencies on existing facilities;
- Disconnecting impervious cover;
- Providing flood mitigation;
- Improving infiltration and recharge performance;
- Addressing pollutants of concern;
- Demonstrating new technologies;
- Adding functionality to existing flood or water quality facilities; and
- Supporting stream restoration activities.

8.5.1 Green Infrastructure and Redevelopment

Drainage-related infrastructure (gutters, stormsewer pipe, channels, ponds, and erosion controls) often needs replacement or repair. Costs are ever increasing, which places a strain on the resources necessary to address these concerns. Resilient and affordable solutions meeting many objectives are always in demand for resource-limited municipalities and Green infrastructure (GI) can be such a solution in certain applications. Unlike traditional single-purpose stormwater infrastructure, which often uses concrete to convey stormwater, green infrastructure uses vegetation and soil to manage rainwater where it falls. Gray infrastructure remains an important part of any stormwater conveyance system, but by weaving natural processes into the built environment, GI facilities may serve as landscaped amenities that are functional, educational, and recreational.

It is recommended that the City include GI and other water quality objectives in the planning and design process for all future infrastructure and redevelopment projects, including major repairs. Considerable opportunity exists for incorporating BMPs of different scales and levels of complexity into these types of projects. Implementing BMPs incrementally through the upgrade and replacement of individual infrastructure components is often more cost effective than undertaking a stand-alone water quality retrofit allowing this approach to maximize benefits offered by capital investments. Opportunities exist whenever streets are reconfigured (e.g., Hutchison), buildings are renovated, or new visions for open space are contemplated.

As density increases in the City, with development going up rather than out, opportunities may exist to remove impervious cover and restore green space and the infiltrative capacity of the underlying soils. The City is encouraged to seek opportunities to counteract the adverse impacts of urbanization to the extent possible to make a more sustainable community and a cleaner river.

8.5.2 Water Quality Retrofit Identification and Prioritization

This section discusses the process used to identify and prioritize retrofit opportunities, which has resulted in recommendations for projects to be considered by the City (see Table 8-4). The process has been rigorous in order to identify feasible and cost-effective retrofit opportunities that will likely serve as valuable investments. Also described is the spatial geodatabase created to store and visually display information on all identified opportunities. This database (described in 8.5.2.1) was instrumental in the retrofit prioritization process and provides a solid starting point for an ongoing retrofit program for the City.

The primary focus of this section is larger (centralized or regional) BMPs located on City-owned parcels because these are usually the most cost effective retrofits. Using public land avoids real estate costs and centralized facilities, compared to smaller (GI-type) BMPs, are more cost effective, easier to maintain, and better able to treat large drainage areas with high impervious cover. The downside of centralized facilities is there are few opportunities in the most urbanized parts of the City (e.g., Downtown) due to their size, lack of open land, and the high cost of real estate. Several centralized opportunities do exist in highly urbanized areas, however, and many were identified on City land that are, "low-hanging fruit" for improving watershed hydrology and reducing pollution loads to the San Marcos River.

The City also recognizes the need to investigate and implement smaller-scale (GI-type) BMPs. Despite their lower cost effectiveness and higher maintenance burden, they are often the best option for areas like Downtown, which has very high impervious cover and is directly adjacent to endangered species habitat. They can also be attractive amenities bringing greenery into ultra-urban areas like Bagby Street in Houston, TX where it is claimed that GI has spurred tremendous reinvestment while improving water quality. BMP options for ultra-urban areas are noted in Section 8.2, Section 8.5, and Appendices H-L (see Examples 5 and 6).

8.5.2.1 Potential Project Database

The first step in identifying retrofit opportunities is to build an inventory of potential projects. These may come to the attention of the watershed manager through redevelopment projects, while addressing localized flooding issues, by collaborating with developers to treat off-site runoff area, or various other paths. Areas of high impervious cover such as large parking lots may be targeted for treatment and high visibility areas may provide an opportunity not only for stormwater management but also public education. City owned parcels such as parks, schools, and municipal maintenance yards often make good candidates since a degree of certainty exists regarding land acquisition and land use. Once an inventory of potential projects exists, projects can be selected per City priorities and/or it can be searched to identify opportunities in locations of interest.

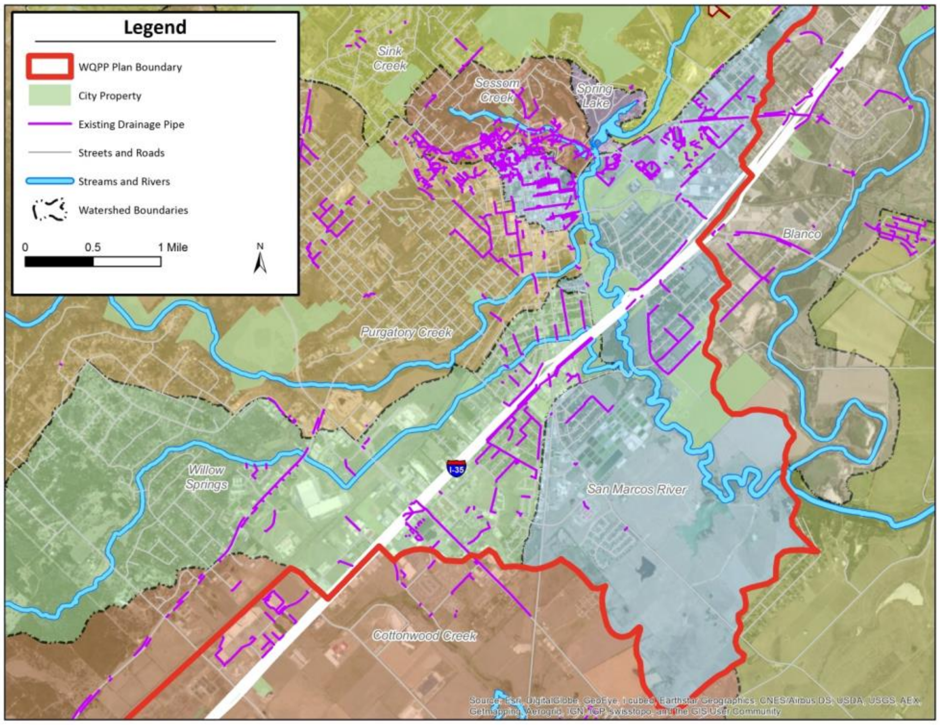
As part of the WQPP effort, the project team has developed a Geographic Information Systems (GIS) database of potential retrofit projects. Population of this database began with a list of opportunities identified collaboratively with the City and the project team. To be thorough, all City-owned parcels (156 parcels per City GIS data) were evaluated for water quality retrofit potential. The following GIS data was gathered from the City and overlaid on aerial photographs to help identify stormwater retrofit opportunities:

- City-owned parcels
- Topography (2-foot contours)
- Drainage areas
- Stream networks
- Storm sewers
- Impervious cover
- Building footprints
- Roads
- Water and wastewater lines

- Soils
- TCEQ aquifer zones
- City Limits
- Regulatory Floodplain Extents
- WQPP Plan Area

A preliminary round of screening was completed to narrow focus to relevant sites. To be considered, areas must lie within City limits, within the WQPP Plan Area, and drain to Critical Habitat. Portions of the following watersheds meet these criteria: Sink Creek (SNK), Spring Lake (SPL), Sessom Creek (SSM), Purgatory Creek (PGY), Willow Springs Creek (WSP), and San Marcos River (SMR). Figure 8-7 illustrates some of the data used to identify retrofit opportunities.

Figure 8-7 Watershed-Scale Data Used to Identify Potential Retrofit Opportunities



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

The next round of screening was completed to find characteristics that create potential for beneficial stormwater management. For example, open spaces draining significant impervious areas are desirable. Where such a location was found, an entry was made into the “Potential BMP Locations” layer in the geodatabase (which has 98 such entries for the City) to record the location and the following attributes:

- Project ID
- Link ID (this field groups related projects)

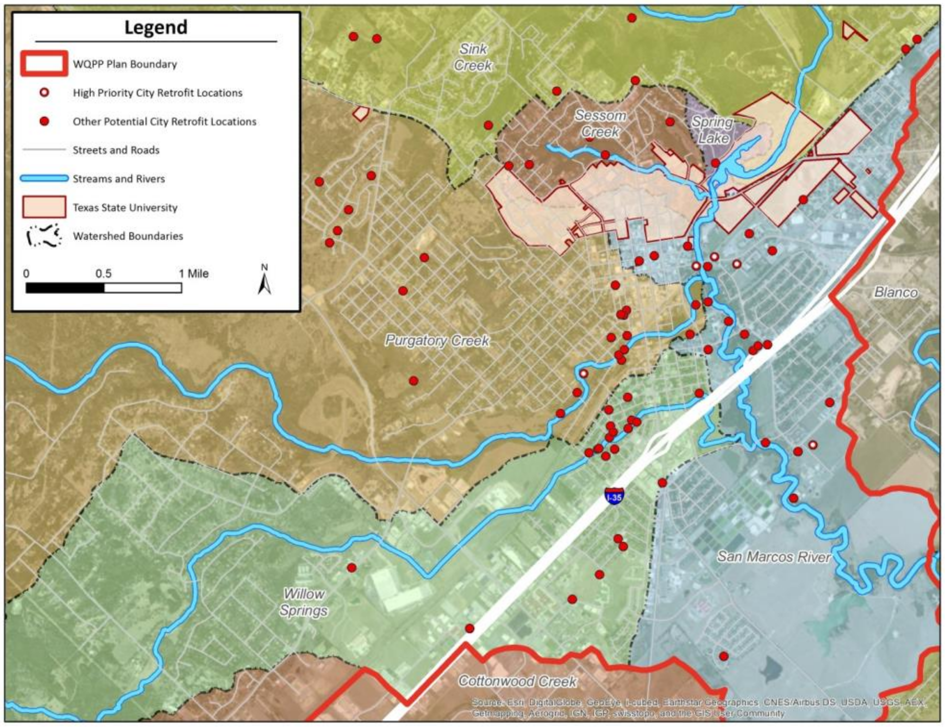
- Name
- Owner
- Proposed land development zone
- Receiving watershed
- Notes

This screening process has provided an early potential retrofit inventory. It is anticipated that new opportunities will be added while other opportunities are ruled out after further investigation.

8.5.2.2 Water Quality Retrofit Identification and Prioritization

While a database of 98 potential projects is a useful tool for the watershed manager, the project team is tasked with making recommendations for implementation. Additional rounds of screening were required to narrow the list as described below and culminating in a prioritized list of 21 “High-Potential Retrofits” for the City (Table 8-4). Of these retrofits, seven “High-Priority Retrofits” were selected for conceptual design described in Section 8.5.3 and listed in Table 8-18. Figure 8-8 illustrates all 98 potential retrofits located citywide and six of the High-Priority Retrofits.

Figure 8-8 Potential City of San Marcos Water Quality Retrofits within the Plan Area



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

8.5.2.3 Drainage Area and Percent Impervious Cover

Delineating drainage areas allows watershed size and percent impervious cover to be applied as discriminating criteria since projects with the larger drainage areas and higher impervious cover create more pollution and erosion potential. Since delineating 98 drainage areas would be time prohibitive, all potential projects were reviewed visually in GIS to judge which have the greatest treatment potential for drainage area delineation. In this level of screening, factors such as stormsewer outfall locations, degree of urbanization, available open space, and utility conflicts were considered along with application of engineering judgement. Additionally, City planning documents such as Vision San Marcos and the Downtown Master Plan were considered to minimize conflicts with future direction. Of the 98 potentials projects, 43 were selected for drainage area delineation and acreage was computed along with percent impervious cover. This information may be found in the geodatabase layer titled Retrofit Drainage Areas.

8.5.2.4 High Potential Retrofits

After considering the drainage area and percent impervious cover of the 43 projects discussed above, 21 “High-Potential Retrofits” were selected for further analysis. These projects are listed in Table 8-14 below along with location, project description, and watershed characteristics.

Table 8-14 High-Potential City Stormwater Retrofit Opportunities

Project Name*	Project ID	Receiving Watershed	Zone	BMP Type	Drainage Area (acre)	IC Treated (acre)**	% IC Area
The Big Ditch	10061	SMR	T/R	Biofiltration	321	138.5	43%
Purgatory Creek Greenspace	10143	PGY	AR	Biofiltration	419	93.2	22%
Wastewater Treatment Plant	10573	SMR	T/R	Biofiltration	173	54.6	32%
Veterans Memorial Park 1	10041	SMR	T/R	Rain Garden	86	48	56%
Dunbar Park	10331	PGY	T/R	Rainwater Harvesting	160	45.7	29%
The Big Ditch Infiltration	10062	SMR	T/R	Biofiltration	321	138.5	43%
Downtown Retrofit Biofilter	10351	SMR	T/R	Multiple	32	25.2	79%
Spring Lake Preserve	10630	SNK	AR	Multiple	101	23.8	24%
City Park 5	10055	SMR	T/R	Multiple	22	11.4	51%
City Park 7	10057	SMR	T/R	Multiple	22	11.6	52%
City Park 1	10051	SMR	T/R	Biofiltration	20	11.3	56%
Hummingbird Hollow	10250	SSM	T/R	Rain Garden	28	6.3	22%
Hopkins Channel 2	10291	SMR	T/R	Biofiltration	15	9.9	66%
Mariposa Street	10550	WSP	T/R	Biofiltration	17	6.2	37%
Hopkins Channel 1	10292	SMR	T/R	Extended Detention (Dry)	10	7	72%
City Park 6	10056	SMR	T/R	Extended Detention (Dry)	9	3.7	39%

City Park 8	10058	SMR	T/R	Biofiltration	9	3.3	36%
Veterans Memorial Park 2	10042	SMR	T/R	Extended Detention (Dry)	31	3.6	12%
City Park 4	10054	SMR	T/R	Biofiltration	7	3	43%
City Park 2	10052	SMR	T/R	Extended Detention (Dry)	2	0.3	14%
City Park 3	10053	SMR	T/R	Biofiltration	1	1	100%

* Numbers after project name indicate multiple scenarios or facilities were evaluated
** Table sorted by IC Treated

8.5.2.5 High Potential Retrofits: Loading Analysis

The next discriminating criterion utilized for retrofit prioritization was pollution load reduction. As discussed in Section 11.3.3, total phosphorus (TP) has been selected as the pollutant of concern due to the phosphorus limited nature of the receiving waters. A spreadsheet model utilizing current recommendations from the International Stormwater BMP Database Project has also been developed by the project team to quantify annual TP removal and satisfaction of Stream Protection Volume goals. In order to perform a loading analysis using this tool, BMP characteristics must be estimated in addition to drainage area parameters determined in 8.5.2.3 above. BMP characteristics (type, water quality volume, and footprint) were estimated and a pollution loading analysis completed for high-potential retrofits as shown in Table 8-15 below. BMP footprints may be found in the geodatabase layer titled Potential BMP Footprint. It should be noted that, in the table below, Water Quality Volume refers to the pond volume available to provide stormwater treatment. Runoff Capture Efficiency is the fraction of runoff captured and treated by the BMP in a typical year (the remainder is bypassed because the facility is full).

Commented [L7]: John, please update this reference per latest report.

Table 8-15 High Potential Retrofits: BMP Characteristics and Phosphorus Removal

Project Name *	BMP Type	Project ID	Prelim Footprint Area (sf)	Prelim Depth (ft)	Prelim WQV (cf)	Runoff Capture Efficiency (%)	Annual Phosphorus Removed (lbs) **
The Big Ditch	Biofiltration	10061	179,351	2	358,702	79%	146
Purgatory Creek Greenspace	Biofiltration	10143	116,254	5	581,268	96%	94
Wastewater Treatment Plant	Extended Detention (Dry)	10573	166,508	2.6	432,920	100%	70
Veterans Memorial Park 1	Biofiltration	10041	67,652	3.5	234,752	95%	64
Dunbar Park	Extended Detention (Dry)	10331	113,719	3.25	369,587	100%	58
The Big Ditch Infiltration	Rain Garden	10062	179,351	0.25	44,838	22%	45
Downtown Retrofit Biofilter	Biofiltration	10351	14,348	4	57,392	85%	24
Spring Lake Preserve	Biofiltration	10630	21,352	6	128,112	94%	24
City Park 5	Multiple	10055	37,610	Varies	85,322	81%	16
City Park 7	Multiple	10057	35,462	Varies	83,317	99%	16
City Park 1	Biofiltration	10051	32,400	2.5	80,255	99%	16

Hummingbird Hollow	Biofiltration	10250	7,672	4.5	34,522	88%	9
Hopkins Channel 2	Extended Detention (Dry)	10291	8,015	4	32,060	87%	9
Mariposa Street	Biofiltration	10550	7,926	3.8	30,119	94%	7
Hopkins Channel 1	Extended Detention (Dry)	10292	4,646	4	18,584	80%	6
City Park 6	Multiple	10056	13,306	Varies	25,141	87%	5
City Park 8	Multiple	10058	13,099	Varies	23,136	99%	4
Veterans Memorial Park 2	Biofiltration	10042	15,000	2.6	39,000	100%	4
City Park 4	Biofiltration	10054	10,037	2	20,074	99%	4
City Park 2	Rain Garden	10052	3,062	1	3,062	99%	0.3
City Park 3	Rainwater Harvesting	10053	201	10	2,005	12%	0.3

* Numbers after project name indicate multiple scenarios or facilities were evaluated

** Table sorted by IC Treated

8.5.2.6 Planning Level Cost Effectiveness

Cost effectiveness is another discriminator applied to prioritize retrofit opportunities. While a project may remove a great deal of pollution, it may also be cost prohibitive. This analysis is meant to help watershed managers achieve the greatest “bang for the buck”. To this end, a range (low, average, high) of planning level capital costs were estimated using unit costs developed from multiple sources including Narayanan and Pitt 2006, the EPA, the University of Texas, the National Cooperative Highway Research Program (NCHRP), Colorado State University, Young et al (1996), and City of Austin bid tab data. Annualized costs were estimated using the whole life cycle cost method considering capital cost, annual operation and maintenance (O&M) costs, an assumed 30-year project life, and with future costs calculated and referred back to the present value. The annualized costs were then divided by the annual TP load reduction to obtain cost per pounds of TP removed, which is the criterion used for cost effectiveness. These costs are strictly planning level and are more useful for comparing potential projects and identifying trends than in estimating actual project costs, which should be done via bid tab after more preliminary engineering has been completed. The following assumptions apply:

- No land costs are included (all projects are on City-owned land)
- External conveyance costs such as storm sewer, channel work, etc. are only included where they are expected to be major cost components
- Cost of construction, engineering, and design are included
- The ENR Construction Cost Index for 20 cities was used to calculate a multiplier, depending on the year, to bring the unit costs to 2014 dollars
- Inflation and salvage costs are not considered

Table 8-16 below summarizes cost effectiveness numbers for potential City retrofits.

Table 8-16 High-Potential Retrofits: Planning-Level Cost Effectiveness

Project Name	Project ID	Annual P Removed (lbs)	Avg Capital Cost ($1000)	Low Capital Cost ($1000)	High Capital Cost ($1000)	Annual O&M Cost ($1000)	Annualized Cost Estimate ($1000)	Annual Cost per Pound TP Removed ($1000)
Dunbar Park	10331	58	$ 840	$ 314	$ 2,217	$ 4.5	$ 53	$ .9
Hopkins Channel 2	10291	8.5	$ 72	$ 27	$ 192	$ 4.5	$ 8	$ 1
Hopkins Channel 1	10292	6.39	$ 42	$ 15	$ 111	$ 4.5	$ 7	$ 1
Wastewater Treatment Plant*	10573	70.4	$ 1,524	$ 908	$ 3,137	$ 4.5	$ 94	$ 1.3
The Big Ditch Infiltration	10062	45	$ 1,087	$ 368	$ 2,770	$ 1.7	$ 65	$ 1.4
The Big Ditch	10061	146.3	$ 4,062	$ 1,844	$ 6,473	$ 3	$ 240	$ 1.6
Downtown Retrofit Biofilter	10351	24.2	$ 650	$ 295	$ 1,035	$ 3	$ 41	$ 1.7
Hummingbird Hollow	10250	9.2	$ 391	$ 177	$ 623	$ 3	$ 26	$ 2.8
Veterans Memorial Park 1*	10041	63.8	$ 3,191	$ 1,740	$ 4,769	$ 3	$ 190	$ 3
Mariposa Street	10550	6.8	$ 341	$ 155	$ 543	$ 3	$ 23	$ 3.3
City Park 1	10051	15.8	$ 908	$ 413	$ 1,448	$ 3	$ 56	$ 3.5
Spring Lake Preserve	10630	24	$ 1,450	$ 659	$ 2,312	$ 3	$ 88	$ 3.6
City Park 7	10057	16.14	$ 983	$ 438	$ 1,637	$ 4	$ 62	$ 3.8
Purgatory Creek Greenspace	10143	94.4	$ 6,582	$ 2,989	$ 10,489	$ 3	$ 388	$ 4.1
City Park 5	10055	16.26	$ 1,062	$ 487	$ 1,757	$ 6	$ 69	$ 4.2
City Park 4	10054	3.6	$ 227	$ 103	$ 362	$ 3	$ 16	$ 4.5
City Park 6	10056	5.21	$ 380	$ 177	$ 671	$ 6.7	$ 29	$ 5.5
City Park 8	10058	3.95	$ 301	$ 128	$ 551	$ 4.7	$ 22	$ 5.6
Veterans Memorial Park 2	10042	3.9	$ 441	$ 200	$ 704	$ 3	$ 29	$ 7.4
City Park 2	10052	0.34	$ 74	$ 25	$ 189	$ 1.7	$ 6	$ 17.7

Table Notes:

1. Numbers after project name indicate multiple scenarios or facilities were evaluated
2. Table sorted by IC Treated
3. *Includes estimate for stormsewer reroutes

8.5.2.7Site Investigation

Site visits were conducted for many retrofit opportunities to ensure that conditions on the ground were consistent with those seen visually in GIS. Site photos and notes for all sites are included electronically in Appendix N and those for High-Priority Retrofits are also included in Section 8.5.3.

8.5.2.8High-Potential Retrofits: Prioritization Matrix

When considering a multitude of High-Potential retrofits, a standard tool to assist with objective decision making is a prioritization matrix, which allows one to apply multiple and sometimes conflicting criteria and weight them according to community/owner values. Criteria, scores, and weights can be modified as additional information is gathered and/or as values become clearer. As a starting point, the information collected in sections 8.5.2.1 through 8.5.2.5 was incorporated into a decision matrix including scores and weights for the following criteria:

- Load reduction (35%)
- Cost effectiveness (25%)
- Feasibility (15%)
- Owner Support (15%)
- Demonstration Value (10%)

Again, all criteria are important to consider for project effectiveness and the suggested weights and criteria should be viewed as a starting point to generate discussion and help define priorities and values of the owner.

Table 8-14 presents the ranking of selected potential projects in the prioritization matrix and Figure 8-3 shows the location of all potential projects including those deemed "High-Priority Retrofits" that are recommended for implementation. The list below is by no means comprehensive. There are currently 98 potential projects in the City's geodatabase and some of these may prove superior to those listed below once more information becomes available. Potential projects on the list may also be ruled out for any number of reasons. New project opportunities will inevitably arise through public/private partnerships, land acquisition, redevelopment, etc. and be added to the list. As these opportunities arise, the geodatabase provides a tool to keep track of them for evaluation and implementation.

Table 8-17 High-Potential Retrofits: Prioritization Matrix

Project Name*	**Project ID**	**Pollution Removal**	**Cost Effectiveness**	**Feasibility**	**Owner Support**	**Demonstration Value**	**Weighted Average****
		35%	**25%**	**15%**	**15%**	**10%**	
The Big Ditch	10061	10	6	6	8	9	7.9
Dunbar Park	10331	4.0	10	8	10	9	7.5
Wastewater Treatment Plant	10573	4.8	7	9	8	4	6.4
Veterans Memorial Park 1	10041	4.4	3	9	9	10	6.0
Downtown Retrofit Biofilter	10351	1.7	5	10	10	10	5.9
Hopkins Channel 2	10291	0.6	9	7	9	10	5.8
The Big Ditch Infiltration	10062	3.1	6	7	8	9	5.8
Hopkins Channel 1	10292	0.4	8	7	9	10	5.7
Purgatory Creek Greenspace	10143	6.5	2	8	5	7	5.5
City Park 1	10051	1.1	3	10	9	10	4.9
City Park 7	10057	1.1	2	10	9	10	4.8
City Park 5	10055	1.1	2	10	9	10	4.8
Mariposa Street	10550	0.5	3	9	10	9	4.6
City Park 4	10054	0.2	2	10	10	10	4.6

City Park 6	10056	0.4	2	10	10	10	4.5
City Park 8	10058	0.3	2	10	10	10	4.5
Veterans Memorial Park 2	10042	0.3	1	9	10	10	4.3
City Park 2	10052	0.02	1	10	10	10	4.1
City Park 3	10053	0.02	0	10	10	10	4.1
Hummingbird Hollow	10250	0.6	3	8	10	3	4.0

* Numbers after project name indicate multiple scenarios or facilities were evaluated

** Table sorted by Weighted Average

8.5.3 City-Sponsored Stormwater Retrofits: Concept Designs

A city-wide search was completed to identify potential cost-effective stormwater retrofit opportunities as described in Section 8.5.2. As shown in Table 8-4 above, the City is presented with a number of High-Potential Retrofits. Of these projects seven have been deemed “High-Priority Retrofits” and selected for conceptual design. These projects are shown in Table 8-15 below and detailed in Sections 8.5.3.1 – 8.5.3.6.

Table 8-18 High-Priority Retrofits Selected for Concept Design

Project Name	Project ID	Watershed	Zone	BMP Description
The Big Ditch	10061	SMR	T/R	Biofiltration and Conveyance
Dunbar Park	10331	PGY	T/R	Infiltration and Extended Detention
Wastewater Treatment Plant	10573	SMR	T/R	Infiltration and Extended Detention
Veterans Memorial Park 1	10041	SMR	T/R	Biofiltration w offsite runoff
Hopkins Channel Pond 2	10291	SMR	T/R	Extended Detention
Hopkins Channel Pond 1	10292	SMR	T/R	Extended Detention
Purgatory Creek Greenspace	10143	PGY	A	Biofiltration

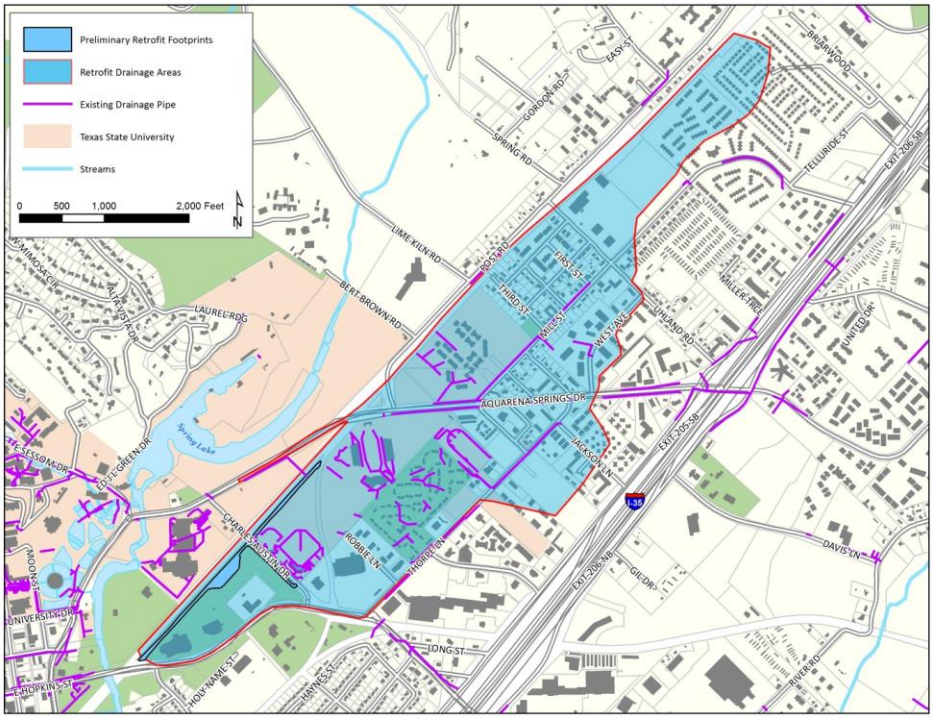
8.5.3.1 The Big Ditch Retrofit (#10061)

The Big Ditch is a large drainage canal that begins near the TXST football stadium and runs parallel to the train tracks to its outlet at the San Marcos River near East Hopkins Street. This canal also happens to be publicly owned and drains 320 acres with 43% impervious cover. It is assumed the canal is a flood conveyance structure so a hydraulic analysis would be needed to ensure any water quality feature does not reduce conveyance or increase water surface elevations (or that any such change is mitigated). However, adding a water quality component to this canal provides a rare opportunity for a large pollution load reduction in a highly urbanized area. A site visit revealed conditions on the ground were consistent with those observed in GIS and portions of the drainage area were field verified. It was confirmed that a great deal of impervious area drains to the channel as shown in Figure 8-9 below.

Figure 8-9 The Big Ditch Retrofit: Photo of Inlet from Existing Parking Lot

Recommended BMP: To add a water quality component to the Big Ditch without affecting flood conveyance, the bottom could be excavated by three feet and refilled with an 18-inch biofiltration media layer containing an underdrain. Sod would be placed on top of this media to protect it from erosion and maintain its appearance as a grass-lined channel. If possible, the finished channel bottom elevation would be two feet lower than the original to provide a significant water quality volume. Due to changes in the elevation along the length of the canal, a series of linear reservoirs could be created with swale block structures creating the ponding volume. Figure 8-10 depicts the drainage area, location and potential footprint of this BMP.

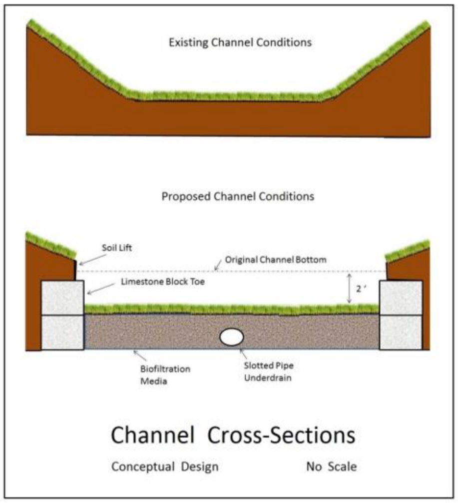
Figure 8-10 The Big Ditch Retrofit: Concept Plan

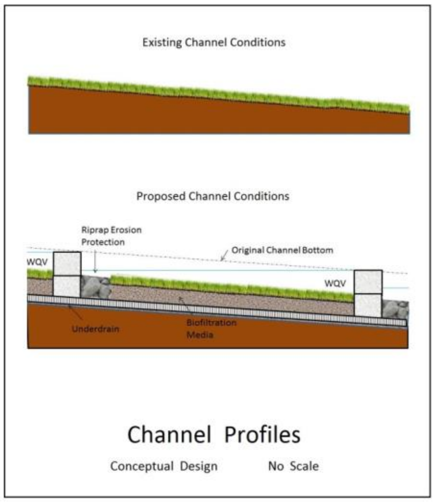


Project Elements: As envisioned, this project would contain the following elements:

- Three to four feet of excavation of the channel bottom to create room for a biofiltration area and ponding volume
- Limestone blocks used to drop the channel bottom while reinforcing the channel toe and allowing the channel side slopes to be reconstructed without expanding the channel footprint
- Placement of biofiltration media and underdrain
- Placement of swale blocks to create a ponding volume in the conveyance channel beneath the current flood conveyance area
- Placement of grass sod to maintain hydraulic conductivity in the biofiltration area and protect against erosion of the biofiltration media
- Create periodic access locations for maintenance
- Figure 8-11 shows a conceptual cross section and profile of this proposed BMP.

Figure 8-11 The Big Ditch Retrofit: Conceptual Cross-Section and Profile





Project Benefits: Assuming an average two-foot ponding depth can be achieved over the preliminary BMP footprint, the model predicts this project would remove 147 lbs of TP annually at an estimated cost of $4.1 million. This project is also an opportunity to improve the aesthetic of the drainage canal, make it multi-functional, and provide regional water quality treatment for the area, which will be helpful when redevelopment occurs. The load reduction meets the proposed goal but limited runoff capture efficiency (79%) and water quality volume cause this project to fall slightly short of the stream protection goal (89% of the required volume is provided). Given the large load reduction and mostly meeting the stream protection goal, this project is expected to provide a solid benefit to the river.

Project Challenges: There are a number of challenges associated with this innovative project. For example, part of the canal is owned by TXST and part is owned by the COSM so the two entities would need to work together to accomplish project objectives. Also, sewer lines and other utilities exist in portions of the canal and these conflicts would need to be resolved. Additional modeling and preliminary engineering would be needed to carefully balance flood and water quality objectives. A high water table could prevent the required excavation. Channel velocities during flood events would need consideration to protect against erosion. This project is large, complex, and less of a known quantity than some others on the list. The potential rewards are high, however, and additional preliminary engineering could help to reduce uncertainty before proceeding.

Alternatives: If a major project is not desired in the canal, a simpler project might be undertaken to excavate a shallow water quality volume that could be infiltrated naturally in 48 hours and improve vegetation along the length of the canal. Type D (clay) soils are expected in this area so the WQV depth might only be 3 or 4 inches. This approach would be much less expensive and has potential to remove approximately 43 lbs of TP per year. The cost would be significantly lower since no filtration media, underdrain, or limestone blocks would be needed and utilities could likely be left in place. Capital cost for this approach is estimated to be $1.1 million and neither pollution load reduction nor stream protection volume goals would be achieved. Infiltration testing should be performed to ensure that a reasonable drawdown time is achieved to avoid nuisance conditions.

Related Planning Documents: Since the Big Ditch crosses both COSM and TXST land, two plans affect this area. The TXST Master Plan mentions collaboration with COSM on the Aquarena Springs Drive Overpass, which is in this project area. The existing detention pond near the San Marcos Public Library will be enhanced to provide additional detention for the overpass project. It is recommended that the Big Ditch project be coordinated with the overpass project to add a water quality component to the detention pond expansion. Vision San Marcos shows the COSM portion of the ditch as existing park land with high intensity use slated for adjacent Midtown. Perhaps the Big Ditch could provide treatment for some of the anticipated high intensity development, in which case a public private partnership might help with construction cost.

8.5.3.2Dunbar Park Retrofit (#10331)

Dunbar Park is located in the southwestern part of San Marcos off of West MLK Drive near its intersection with South Endicott Street. Past the community center and playground is a large, publicly owned parcel that drains approximately 160 acres with 28.5% impervious cover. Anticipation of highly permeable Type A soils makes this site attractive for stormwater management since a great deal of polluted stormwater could be infiltrated. A site visit revealed conditions were consistent with those observed in GIS and portions of the drainage area were field verified. It was confirmed that a large city-owned parcel with well-draining soils exists at this location. The channel was also observed to be undefined in this area. A photo looking upstream at Dunbar Park from Jackman Street is shown below in Figure 8-12. Figure 8-13 depicts the drainage area, location and potential footprint of the Dunbar Park BMP.

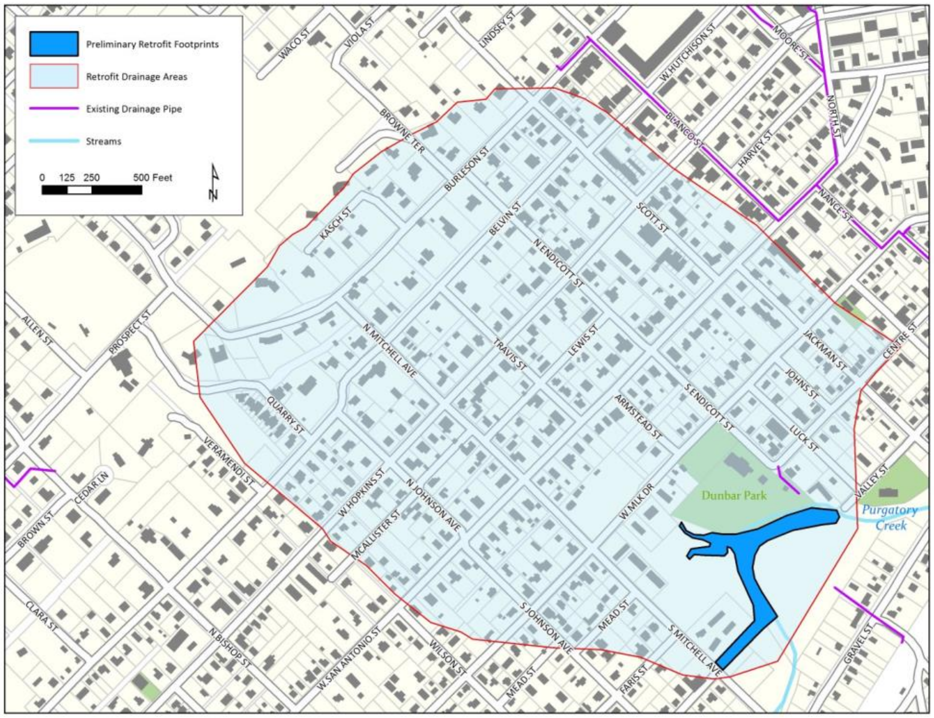
Figure 8-12 Dunbar Park Photo: Looking Upstream from Jackman Street

Recommended BMP: Given the site characteristics, an extended detention basin is recommended at this location to encourage infiltration. There are three outfalls located in this area providing a large volume of stormwater to manage. The creek appears to split into two channels at this location with one continuing north and the other flowing west toward Dunbar Park. It is proposed that the westward flowing channel be used to capture stormwater for treatment while the northward flowing channel would convey normal stream flows. The northward flowing channel might need to be improved to mitigate any flood impacts caused by the western channel being utilized for extended detention.

Project Elements: The following elements are anticipated for this project.

- Stormwater diversion on South Mitchell Avenue to divert flows into the BMP footprint and provide an opportunity for infiltration prior to entering the main channel of Purgatory Creek
- Earth work including excavation and/or berm building to provide sufficient water quality volume for three stormwater outfalls
- An armored overflow weir for any events not fully captured
- Extended detention outlet structure
- Channel improvements for normal creek flows

Figure 8-13 Dunbar Park Retrofit: Concept Plan



Project Benefits: Modeling of this facility predicts 100% runoff capture efficiency and a total annual removal of 58 lbs of TP. Both load reduction and stream protection goals are met.

Project Challenges: The primary challenge associated with this project is routing all three stormwater outfalls to a common BMP. If the soils are very sandy in this location, berms may need to be composed of imported fill and anchored with rock, geosynthetics, vegetation, or otherwise anchored to ensure they are stable enough to satisfy BMP service life.

Alternatives: Given the unusual footprint of the BMP required to capture the three main stormwater outlets, it may be simpler to split the project into separate, smaller infiltration BMPs. Further analysis would be required to determine the viability of this alternative. However, the abundance of open space owned by the City provides a great deal of flexibility for BMP configuration.

Related Planning Documents: Vision San Marcos shows this area as existing parkland and open space with the drainage area designated as "stability area" so it appears no conflict exists for this project.

8.5.3.3Wastewater Treatment Plant Retrofit (#10573)

The City of San Marcos owns and operates a wastewater treatment plan (WWTP) east of I-35 off River Road. The southwest corner of the land containing the WWTP is near a stormsewer outfall that drains 172.5 acres at 32% impervious cover. Given the availability of publicly owned land in this location, it has high potential for stormwater treatment. Based on NRCS Soil Maps, higher infiltrating Type B soils are anticipated in this area, which makes it even more attractive. A site visit revealed the site has reclaimed water infrastructure that was not observed in GIS. A photo is shown below in Figure 8-14.

Figure 8-14 Wastewater Treatment Plant: Photo of Field with Reclaimed Water

Recommended BMP: An infiltration basin is recommended in this location and it is anticipated that a runoff capture efficiency of 100% can be achieved with the available open space and Type B soils.

Project Elements: The project consists of the following:

- Stormsewer diversion to route stormwater to open space
- Earthwork and basic landscaping

Project Benefits: A BMP as described above would be expected to remove approximately 70.4 lbs of TP on an annual basis at an estimated capital cost of $985,000.

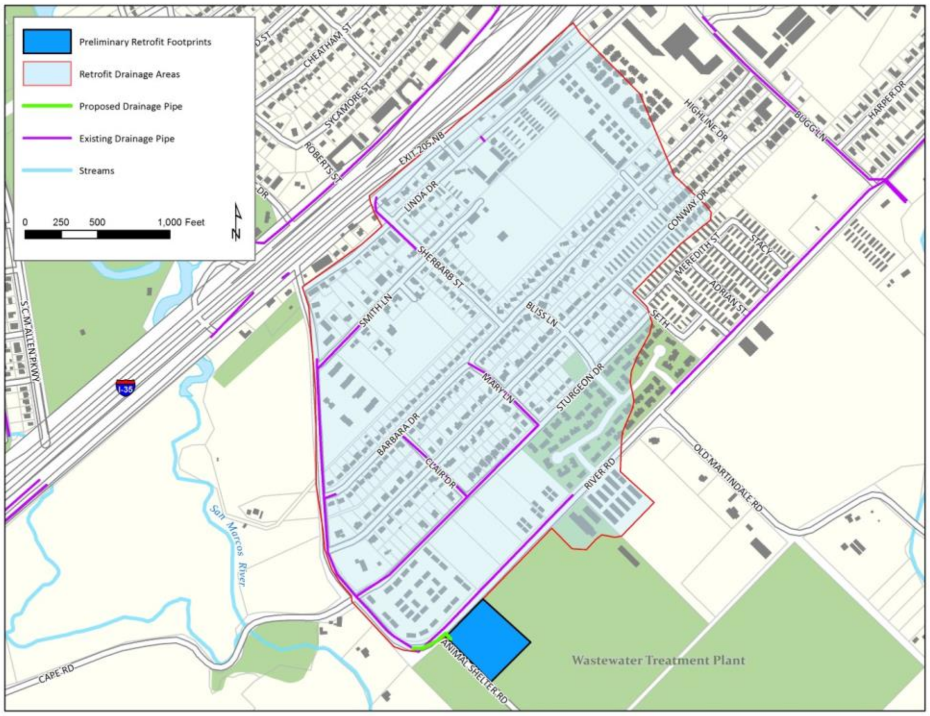
Project Challenges: As discussed above, a field visit revealed that the portion of land closest to the outfall currently contains reclaimed water infrastructure and GIS also shows potential utility conflicts with water and wastewater lines. Another potentially suitable parcel is located just to the northeast and is currently being used as a hay meadow. However, this parcel is further away from the outfall and at a higher elevation. In order to route stormwater to this location, capture it in a basin, and ensure any overflow returns to the same outfall, the storm sewer would need to be re-worked and great deal of excavation provided to achieve the desired bottom elevation of the basin. The abundance of open land owned by the City provides flexibility needed to accomplish this goal.

Alternatives: If reclaimed water infrastructure was moved and utility conflicts resolved, the parcel nearest the stormsewer outfall would be simpler and less expensive to use for stormwater treatment. If soils are slower draining that expected, the pond depth would need to be reduced to achieve a reasonable drawdown time and/or an underdrain would need to be installed and an alternative outfall located.

Related Planning Documents: Vision San Marcos shows this location to be existing park land and no conflicts are apparent.

Figure 8-15 depicts the drainage area, location and potential footprint of this BMP.

Figure 8-15 Wastewater Treatment Plant Retrofit: Concept Plan



8.5.3.4 Veterans Memorial Park Retrofit (#10041)

Not to be confused with Veterans Plaza, Veterans Memorial Park refers to a City owned parcel just east of the Riverside Drive and Hopkins Street intersection. This parcel contains a large open space that has potential to drain 86.4 acres with high impervious cover (55.6%). Given these characteristics and the high visibility of this location, it appears to be a good location for a water quality retrofit.

The site was visited to ensure conditions on the ground were consistent those observed in GIS and to field verify portions of the drainage area. It was confirmed that this is a highly visible location and that the outfall of an underdrain could go into an existing conveyance channel. A photo of the site is shown below in Figure 8-16.

Figure 8-16 Veterans Memorial Park: Photo of Existing Conditions

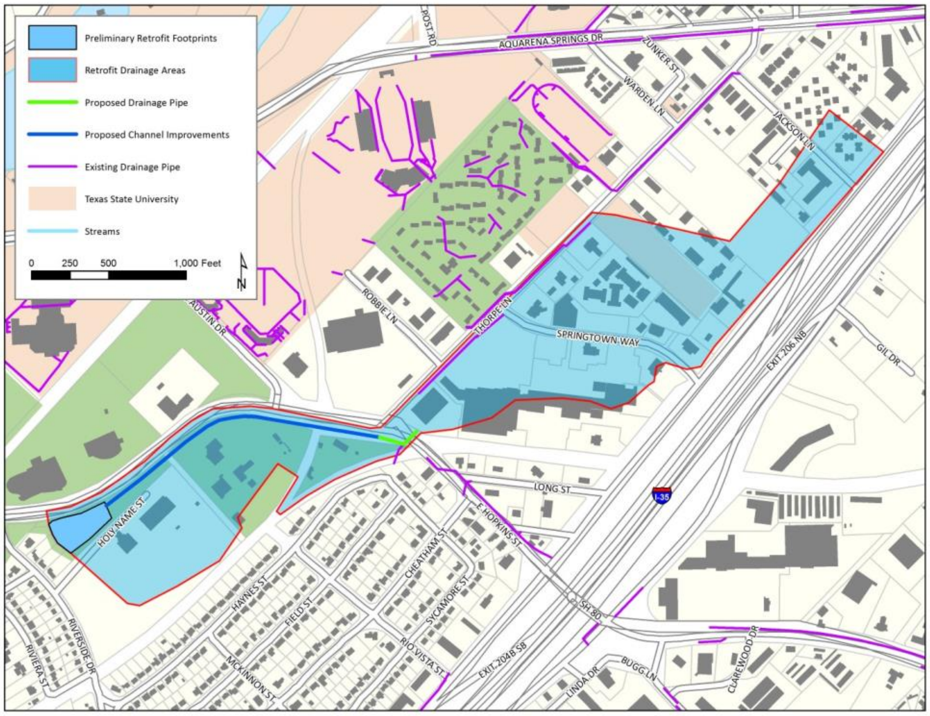
Recommended BMP: A biofiltration facility is recommended for this location with an underdrain that outfalls to the channel that runs beneath Riverside Drive and then to the river.

Project Elements: As envisioned, this project contains the following elements:

- Divert storm sewer near Thorpe Lane and East Hopkins Street into improved conveyance channel to capture an additional 43 acres
- Relocation of waterline in proposed footprint crossing the parcel from East Hopkins Street to Holy Name Street
- Improved conveyance channel along East Hopkins Street to convey runoff from Thorpe Lane to the biofilter near Riverside Drive
- Earthwork and installation of off-line biofilter with underdrain

Project Benefits: Implementing this project would remove 63.8 lbs of TP per year at an estimated capital cost of $2.7 M (including stormsewer re-route cost). It would also provide a highly visible biofilter for a demonstration project and public education opportunity. The model predicts that both load reduction and stream protection goals will be met. Figure 8-17 depicts the drainage area, location and potential footprint of this BMP.

Figure 8-17 Veterans Memorial Park Retrofit: Concept Plan



Project Challenges: With this project, there may be challenges associated with re-routing the utility line that is currently in conflict with the pond footprint. Also, re-routing the storm sewer near Thorpe Lane could be challenging along with ensuring the conveyance channel is large enough to convey the resulting increased flow rate. Driveways and other infrastructure along this channel may need to be re-constructed or moved.

Alternatives: If the Thorpe storm sewer is not re-routed to capture the additional 43 acres, the drainage area to the biofilter would decrease to 43.5 acres compared to 86.3 acres. This would allow a smaller water quality volume and pond footprint and the cost would decrease to an estimated $445,000. With the smaller footprint, there would no longer be a waterline conflict and of the conveyance channel along Hopkins Street would not need enlargement. The annual pollution load reduction would be smaller at 3.9 lbs of TP removed compared to 63.8 lbs, which would make this project less competitive with other available options.

Related Planning Documents: Vision San Marcos shows the area in question as existing parkland. As long as support exists to add a BMP in this park area, no conflicts are foreseen.

8.5.3.5Hopkins Channel 1 Pond Retrofit (#10292)

Two retrofit projects (sedimentation ponds) were recommended in the Edwards Aquifer Habitat Conservation Plan (HCP) for the City of San Marcos. One of those (described here) is to be an expanded drainage ditch along Hopkins Street near San Marcos Plaza where a drainage channel flows in an easterly direction and adjacent to Hopkins Street to the north. The existing tree-lined channel has a storm sewer outfall at the upstream end along with a concrete flume that conveys runoff into the channel from San Marcos Plaza and a second storm sewer outfall near the Grant Harris Jr. Building parking lot. The drainage area of approximately 9.9 acres was delineated in GIS using City of San Marcos data (topography, storm sewer data, aerial photographs) and then field-verified during a rain event. Impervious cover was estimated in GIS to be 7 acres (or 72%) using City of San Marcos impervious cover data supplemented with aerial photography. In 2014, a trail was constructed across the downstream portion of the channel with a corrugated metal pipe conveying wet weather flows beneath to the San Marcos River. Based on NRCS Soil Maps and a site visit, Type D soils exist on site that drain slowly so infiltration-type BMPs are not recommended without an underdrain. Photos of the area are shown in Figures 8-18 through 8-21.

Figure 8-18 Photo of Existing Flume Looking Downstream

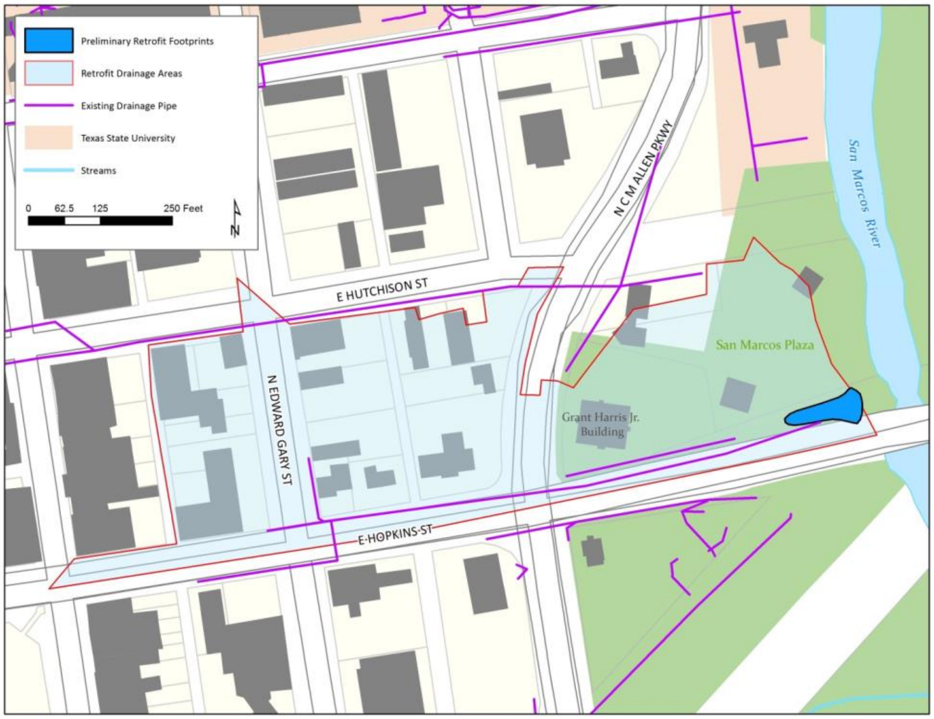
Figure 8-19 Photo of Existing Storm Sewer Outfall Looking Upstream

Figure 8-20 Photo of Existing Trail, Culvert, and Proximity to Bridge and River

Figure 8-21 Photo of San Marcos Plaza Contributing Drainage and Park Amenities

Recommended BMP: An in-line, extended detention basin is recommended in this location as it will make the best use of available space for stormwater treatment. A biofiltration facility with stacked detention might also be feasible but would have a smaller water quality volume, be more expensive to construct/maintain, and with close proximity to the river may experience issues with filtration media scour during flood events. Figure 8-22 depicts the drainage area, location and potential footprint of this BMP.

Figure 8-22 Hopkins Drainage Channel Pond 1 Retrofit: Concept Plan



Project Elements: The following elements are recommended for this project.

- Earthwork to maximize water quality volume
- Earthen berm or concrete wall at downstream end to capture and treat stormwater prior to entering the river
- Outlet structure designed to convey treated stormwater underneath the trail and to the river
- Potential utility relocation
- Landscaping to ensure the pond is aesthetically pleasing for such a high visibility location

Project Benefits: With an estimated surface area of approximately 4,650 square feet and estimated average depth of 4 feet, a water quality capture volume of 18,600 cubic feet would be available. Modeling shows a BMP of this approximate size and a 48-hour drawdown time would treat 80% of all runoff conveyed to it over the course of a typical year and remove approximately 6.4 lbs of Total Phosphorus (TP) at an estimated capital cost of $42,500. The annualized cost per pound of TP removed (including operation and maintenance) would be ($1,100/lb TP), which is competitive compared to others evaluated but smaller scale in terms of pollution removal. For example, the project suggested at Dunbar Park is estimated to remove approximately 58 lbs of TP per year at $925 per lb.

Project Challenges: The ground elevations and site constraints are challenging at this location to create an extended detention pond with significant volume. The site falls approximately 6 feet in the direction of flow and approximately 6 to 8 feet perpendicular to the direction of flow. The channel is also relatively narrow at approximately 53 feet wide. Site constraints include Hopkins Street (and associated bridge supports), the San Marcos River, trails/sidewalks, the existing storm sewer outfall, and amenities such as trees and a gazebo associated with San Marcos Plaza.

Related Planning Documents: Vision San Marcos shows this location to be existing park land and no conflicts are apparent.

8.5.3.6Hopkins Channel 2 Pond Retrofit (#10291)

This is the second of two retrofit projects (sedimentation ponds) that were recommended in the Edwards Aquifer Habitat Conservation Plan (HCP) for the City of San Marcos. The first is described in the previous section. This pond is to be in a drainage channel that flows in an easterly direction through Veramendi Park, adjacent to Hopkins Street to the south. The grass-lined channel contains three storm sewer outfalls, one of which is below-grade and does not drain well. Erosion issues were also observed in the channel along with a gabion-style grade control structure and concrete flume that were likely installed to control these problems (see Figures 8-23 through 8-26). The drainage area of approximately 15 acres was delineated in GIS using City of San Marcos data (topography, storm sewer data, aerial photographs) and then field-verified during a rain event. Impervious cover was estimated in GIS to be 9.9 acres (or 66%) using City of San Marcos impervious cover data supplemented with aerial photography. In 2014, a trail was constructed across the downstream portion of the channel with a corrugated metal pipe conveying wet weather flows beneath to the San Marcos River. Based on NRCS Soil Maps and a site visit, Type D soils appear to exist in this area that drain slowly so infiltration-type BMPs are not recommended without an underdrain.

Figure 8-23 Photo of Two Sewer Outfalls and Proximity to Veramendi Park Amenities

Figure 8-24 Photo of Gabion Grade Control Structure and Hopkins Street Bridge

Figure 8-25 Photo of Storm Sewer Outfall below Grade and Ponded Water

Figure 8-26 Photo of Erosion on Left Bank (Looking Upstream)

Recommended BMP: An in-line, extended detention basin is recommended in this location as it will make the best use of available space for stormwater treatment. A biofiltration facility with stacked detention might also be feasible but would have a smaller water quality volume, be more expensive to construct/maintain and, with close proximity to the river, may experience issues with filtration media scour during flood events. Figure 8-27 depicts the drainage area, location and potential footprint of this BMP.

Figure 8-27 Hopkins Drainage Channel Pond 2 Retrofit: Concept Plan

Map: Complete Watershed Solutions LLC

Project Elements: The following elements are recommended for this project.

- Earthwork to maximize water quality volume and resolve drainage and erosion problems
- Earthen berm or concrete wall at downstream end to capture and treat stormwater prior to entering the river
- Outlet structure designed to convey treated stormwater underneath the trail and to the river
- Potential utility relocation
- Landscaping to ensure the pond is aesthetically pleasing for such a highly visible location

Project Benefits: With an estimated surface area of approximately 8,015 square feet and estimated average depth of 4 feet, a water quality capture volume of 32,060 cubic feet would be available. Modeling shows a BMP of this approximate size and a 48-hour drawdown time would treat 87% of all runoff conveyed to it over the course of a typical year and remove approximately 8.5 lbs of TP at an estimated capital cost of $73,000. The annualized cost per pound of TP removed (including operation and maintenance) would be ($1,030/lb TP), which is cost effective compared to others evaluated but smaller scale in terms of pollution removal. For example, the project suggested at Dunbar Park is estimated to remove approximately 58 lbs of TP per year at $925 per lb. In addition to a water quality benefit, this project would resolve the erosion and drainage issues that currently exist.

Project Challenges: The ground elevations and site constraints are challenging at this location to create an extended detention pond with significant volume. The site falls approximately 6 feet in the direction of flow and approximately 6 to 8 feet perpendicular to the direction of flow. The channel is also relatively narrow at approximately 52 feet wide. Site constraints include Hopkins Street (and associated bridge supports), a wastewater line at the upstream end of the channel, and Veramendi Park amenities such as trees and historical plaques.

Related Planning Documents: Vision San Marcos shows this location to be existing park land and no conflicts are apparent.

8.5.3.7Purgatory Creek Greenspace Retrofit (#10143)

Purgatory Creek Greenspace (or Prospect Greenspace) is preserve land located in Southwest San Marcos near Wonderworld Drive and Craddock Avenue in the Edwards Aquifer Recharge Zone. It drains 419 acres at 22% impervious cover. A small wet pond exists just upstream of this parcel, which might be incorporated as part of a treatment train as it provides some sedimentation prior to runoff reaching the site. If a BMP can be integrated downstream of the pond without negatively affecting endangered species habitat such as that needed by the Golden Cheek Warbler, it would be attractive place to do so. Figure 8-20 depicts the drainage area, location and potential footprint of this BMP. A site visit to this location confirmed its function as a natural area and revealed the presence of a homeless camp, and a drainage path was determined. Photos from the site visit are shown in figures 8-28 and 8-29 below.

Figure 8-28 Photo of Educational Signage: Warbler Habitat

Photo: Lee Sherman

Figure 8-29 Photo of Existing Drainage Path

Photo: Lee Sherman

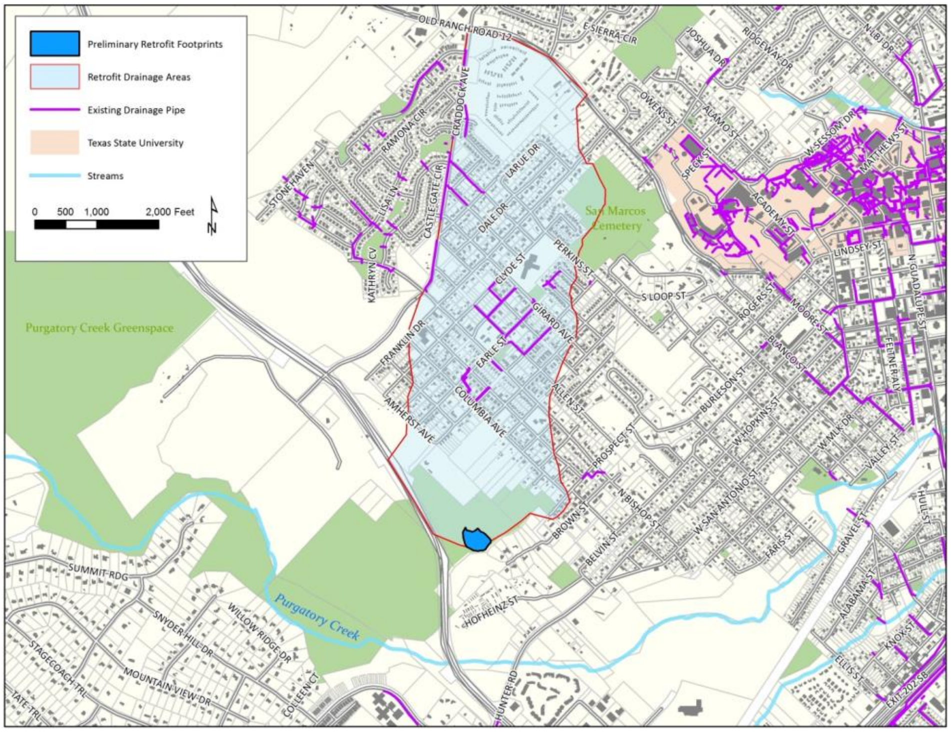
Recommended BMP: Since this area is in the recharge zone, a lined biofiltration facility would likely provide the best effluent quality and be able to meet pollution removal and stream protection goals. Level spreading the treated effluent to encourage infiltration and recharge is also recommended.

Project Elements: The following elements might be considered for this location.

- Biofiltration facility that is lined (EA Recharge Zone requires a liner)
- A level spreader to encourage infiltration of treated effluent downstream of the biofilter
- Trail enhancements

A concept plan for a potential water quality retrofit at this site is shown below in Figure 8-30.

Figure 8-30 Purgatory Creek Greenspace Retrofit: Concept Plan



Map: Complete Watershed Solutions LLC

Project Benefits: Modeling for this site predicts that 94.4 lbs of TP would be removed on an annual basis at a cost of $6.6 million. While it controls the desired stream protection volume, it falls short of the load reduction needed to mimic 0% impervious cover (101.4 lbs) as required in the recharge zone. Nevertheless, it achieves 93% of the load reduction and this would also be an opportunity to improve the water quality of Purgatory Creek and enhance recharge to the aquifer.

Project Challenges: The benefits listed above would need to be considered in the context of this land's function as habitat preserve and the project potentially abandoned if water quality objectives are in conflict with habitat preservation.

Alternatives: If this project is not feasible, there are two opportunities to provide treatment further upstream in the PGY watershed. These are PGY_Westover_Drainage (# 10170) and PGY_Crocket_Elementary (#10360).

Related Planning Documents: Vision San Marcos shows this area as existing park land and no conflict is foreseen.

8.5.4 CITY-SPONSORED STORMWATER RETROFITS: PROJECTS IN PROGRESS

In addition to the projects recommended in Section 8.5.3, the WQPP team has developed conceptual designs for several other projects that are either in progress or are good opportunities. Conceptual designs for these are described below along with WQPP recommendations.

8.5.4.1Downtown Water Quality Pond and Streetscape

The City of San Marcos is piloting a project intended to implement the principles of Low Impact Development (LID) in the downtown area. Impervious cover was disconnected along East Hutchison Drive utilizing shallow rain gardens. Stormwater from the street enters these landscape features through curb cuts. Additionally, a water quality pond has been built near San Marcos Plaza Park (See Figure 8-31). Few opportunities exist for these types of centralized BMPs downtown, which makes this project element desirable. This project was modeled along with other retrofits to evaluate benefits to the river.

Figure 8-31 Photo of Recently Completed Downtown Water Quality Pond

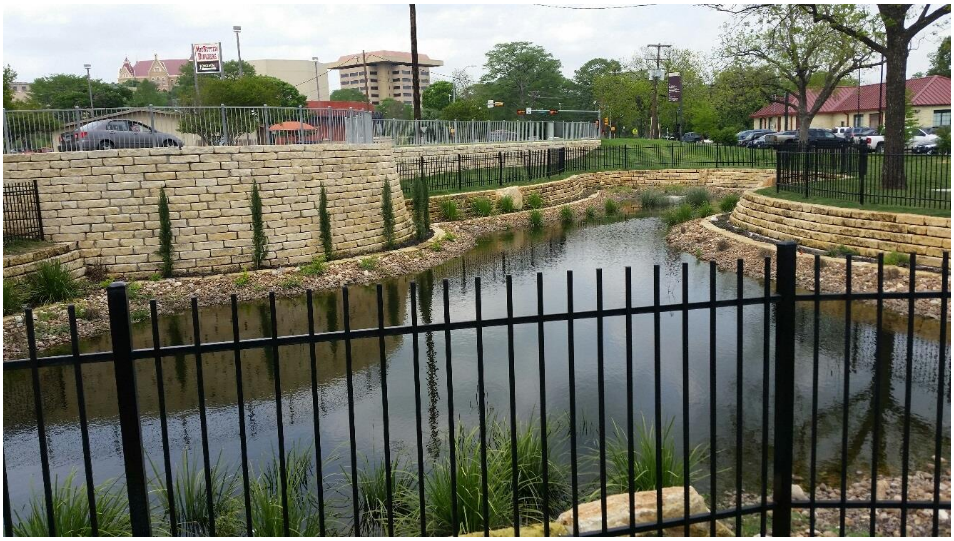


Photo: John Gleason

Project Elements: The project includes the following elements.

- A number of rain gardens are being implemented along East Hutchison Street between North LBJ Street and CM Allen Parkway.
- A water quality facility which drains approximately 32 acres area with 79% impervious cover has recently completed construction.
- Sidewalk and landscaping amenities are also being implemented with the goal of making this area more walkable, aesthetically pleasing, and sustainable.

The illustrative site plan in Figure 8-32 depicts the overall streetscape improvements and water quality pond location.

Figure 8-32 Downtown Water Quality Pond and Streetscape: Illustrative Site Plan

Credit: HNTB

Project Benefits: The modeling predicts the water quality facility will remove 24.2 lbs of TP annually at an estimated cost of $650,000. The predicted 85% runoff capture efficiency meets the load reduction goal and 93% of the stream protection goal is achieved. The facility may be slightly undersized, but provides a significant benefit in an area of great need and could double as a public education opportunity in such a highly visible area. The LID component of the project will provide the City experience with this type of stormwater management strategy. It is strongly encouraged for these types of stormwater management strategies to be incorporated in ultra-urban areas whenever streets or buildings are redeveloped.

Project Challenges: The soils in the project area are slow draining Type D clay soils. It is therefore challenging to infiltrate water in rain gardens. Underdrains are possible when rain gardens are in close proximity with storm sewer drop boxes, but in most cases shallow ponding depths and disconnection of impervious cover were utilized instead. Also, the original design called for rain gardens having no drainage area routed to them. Modifications were made during construction to rectify this situation. A wet pond was also recommended, which would require make-up water to maintain a permanent pool in dry conditions, a great deal of maintenance, and also creates a lower quality effluent compared to a biofilter. Before construction was completed, the design was changed to a biofilter to reduce maintenance costs and need for makeup water. These major changes made during construction were challenges and learning experiences for the City of San Marcos.

Alternatives: The City could have moved forward with the original design and not made recommended changes. However, adding drainage area to the downtown rain gardens made them true LID features rather than planters. Also, the biofilter should require less maintenance and makeup water over time once groundwater issues are resolved and plants can be established. If groundwater issues persist, the pond might be converted into a constructed wetland.

Related Planning Documents: The Downtown Master Plan shows a “Chain of Ponds” concept that includes this location and continues southward parallel to the San Marcos River. This concept is discussed in detail in Section 8.2.1.4. East Hutchison Street and East Hopkins Street are located in an area designated by Vision San Marcos as a high intensity land use area. No conflicts were observed and this stormwater management strategy is consistent with high intensity development zones.

8.5.4.2City Park Retrofit (#10057)

City Park is located near Charles Austin Road and Aquarena Springs Drive and is a popular tubing and swimming destination. An effort is currently underway to improve parking and traffic flow while reducing impervious cover and implementing green infrastructure such as biofiltration and rain gardens. Potential also exists to add rainwater harvesting, porous pavement, and a vegetated filter strip. It should also be noted that an 11-acre, triangular shaped parking lot (owned by Texas State University, north of Charles Austin Drive) drains to the channel on the west side of the train tracks where it flows south into the San Marcos River adjacent to City Park. The biofilter element of the City Park retrofit provides an excellent chance to clean this dirty runoff before it enters the river. This biofilter should be seen as a key component to the City Park project that achieves the majority of pollution removal. A site visit was performed to field verify drainage area and confirm conditions on the ground. The photo in Figure 8-33 shows impervious cover draining towards the open area where a biofiltration facility is recommended. The illustrative site plan in Figure 8-34 depicts the biofiltration pond location and associated relocated and redesigned parking lot.

Figure 8-33 City Park: Photo of Drainage Ditch (left) and Pavement Draining towards Field

Photo: Lee Sherman

Figure 8-34 City Park Retrofit: Concept Plan Showing New Parking Lot and Biofiltration Pond

Design: John Gleason, Graphics: Wade Kolb

Project Elements: The following elements are currently envisioned for City Park.

- Biofiltration facility treating runoff in drainage ditch adjacent to train tracks
- Filtration style rain garden with underdrain discharging level spread effluent to the river
- If soils and budget allow, porous pavement for the parking lot

Project Benefits: Modeling predicts the above elements combined will remove 16 lbs of TP at an estimated capital cost of $983,500. Since porous pavement is not a final recommendation, this cost estimate only includes the biofilter and rain garden elements. The City currently has a budget of $600,000 to improve the parking lot and install a biofiltration facility. While this is lower than the estimated cost, the budget may be sufficient if the City utilizes in-house work forces, streamlines permitting, and collaborates with the WQPP team to implement a water quality retrofit along with the parking lot. The load reduction goals were met for this site as well as the stream protection volume goals. This project is also a strong demonstration project opportunity given the high visibility of this popular tubing destination. While the public enjoys recreating in the San Marcos, they can also learn about green infrastructure and observe how these landscaped amenities are protecting their river.

Project Challenges: Collaboration between the City and University may be a challenge at this location but there is an opportunity to do so. A potential rain garden facility at the northern edge of City Park is divided by the City and TXST property line. Also drainage from a large, off-site, parking lot owned by

TXST is proposed to be treated in a biofilter in City Park. Type D soils are anticipated in this area so infiltration testing is recommended prior to installing infiltration BMPs like porous pavement or full infiltration rain gardens. Another potential challenge will be ensuring the conversion of open space to multi-functional space has community support. Combining stormwater treatment functionality with recreation is desirable and may be able to overcome this challenge.

Alternatives: Many alternatives are possible with this project given the menu of green infrastructure BMPs available. A minimalist alternative would include an impervious parking lot draining to the biofiltration facility. There is a grade break in the parking lot and the portion draining away from the biofilter could be made porous or treated with a vegetated filter strip.

A similar green infrastructure retrofit is recommended for the adjacent Jowers Center on TXST property (see Section 9.3.3.4). One highly recommended element is a filtration-style rain garden in the median between TXST and COSM property. Two area drains capture runoff from upstream parking lots and driveways and send it to a storm sewer in the median. If this project element is not implemented at Jowers Center, COSM may want to coordinate with TXST to close the area drains and route runoff to City Park where it can be treated by the biofilter. This information would be useful prior to final design for City Park so the biofilter can be adequately sized.

It is recommended that this project be completed in conjunction with the Jowers Center (# 10474) to maximize benefits and engage in a cooperative project with the TXST. Water does not respect jurisdictional boundaries and other opportunities exist (like the Big Ditch in Section 8.5.3.1) where both the City and University can work together to reap a mutual benefit. This project would be an opportunity for these entities to build a working relationship prior to undertaking larger projects. If both projects were completed, the total pollution removed would be approximately 30 lbs of TP per year (as opposed to 16 lbs).

Related Planning Documents: Vision San Marcos shows City Park as existing park land and no conflicts were observed. Furthermore, the parking lot project is underway so this appears to fit the City's direction. TXST master plan recommends Jowers Center for renovation in the near-term, which would be a prime opportunity to implement the recommended green infrastructure. The bike path planned along this corridor should not be in conflict with either project.

8.5.5 GREEN INFRASTRUCTURE IN THE RIGHT OF WAY (ROW)

The public right-of-way organizes the flow of energy and matter that courses through the city on a daily basis. The streetscape is also shared public real estate for the social and economic activity that enriches city life. Below grade, the right-of-way houses a complex and vital network of utility infrastructure. The right-of-way is also host to landscapes that can provide shade, improve air quality, and absorb and treat stormwater. Include BMPs whenever feasible within the ROW.

8.5.6 POTENTIAL STORMWATER RETROFITS IN OTHER RECEIVING WATERS

Multiple projects have been recommended for Sessom Creek, Purgatory Creek, and the areas draining directly to the San Marcos River. However, good opportunities also exist in the Sink Creek, Willow

Springs, and Spring Lake watersheds. The following sections discuss a few opportunities discovered in those watersheds that were not recommended in Sections 8.5.3.

Retrofit Opportunities in the Willow Springs Watershed

- WSP_Leah_Avenue (# 10000): 71 acres at 28% IC drain to this publicly owned parcel. However, it is a small parcel with utility conflicts. There is a great deal of open land surrounding this parcel including what appears to be an existing facility associated with Mendez Elementary School. This facility might be improved to treat stormwater from this area. If this is possible, this opportunity would be competitive with those recommended in Section 10.4.
- WSP_Wellington_Pond (# 10180): 37.4 acres drain to an existing detention facility, which could easily be retrofit to add a water quality component.

Retrofit Opportunities in the Sink Creek Watershed

- SNK_Spring_Lake_Preserve (#10630): 100 acres at 24% impervious cover drain to an open field in the preserve. This project was ranked in Tables 10-2 and 10-4 but did not quite make the cut.
- SNK_Schulle_Canyon (#10090): 43.5 acres at 27% impervious cover drain to open space on this publicly owned parcel.

Retrofit Opportunities in the Spring Lake Watershed

- Alta Vista Drive (#10390): A natural drainage flows toward Spring Lake and crosses under Ed J. L. Green near its intersection with Alta Vista Drive. An old culvert flows beneath the road and appears to be mostly filled with accumulated sediment and leaves. A project could be undertaken convert the upstream drainage into a biofiltration facility that discharges beneath the road to Spring Lake.
- Meadows Center (TXST # 10220): A great demonstration project opportunity exists at the Meadows Center where a rain garden might be constructed to treat parking lot runoff.
- Clear Springs Apartments (TXST # 10380): This housing complex is slated for demolition. Any redevelopment should reduce impervious cover and incorporate green infrastructure to treat stormwater runoff.

Retrofit Opportunities in Sessom Creek Watershed: The WQPP understands that retrofit opportunities are being considered in densely wooded areas of the Sessom Creek Watershed. Prior to clearing these wooded areas, the WQPP team suggests The Gulch (TXST #10432) be considered along with the following potential projects: Hummingbird Hollow (# 10250) and Peques Street (TXST # 10450). Of the opportunities on wooded City land, Sessom Creek Greenspace 2 (#10101) appears to be the best and least invasive opportunity.

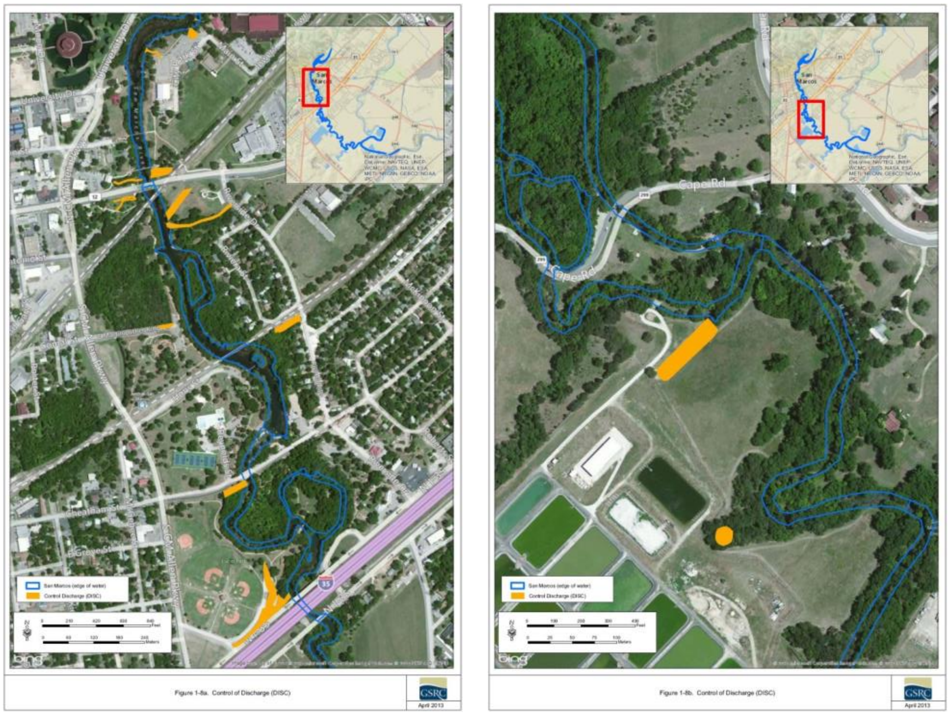
8.5.7 US ARMY CORPS OF ENGINEERS (USACE) SECTION 206 OPPORTUNITIES

In May of 2013, the USACE completed a Draft Biologic Assessment for an Aquatic Ecosystem Restoration Project with City of San Marcos as the local sponsor. This project proposes to improve the San Marcos River ecosystem by removing invasive/exotic vegetation, removing accumulated sediment, and restoring riparian and wetland habitat.

Restoration of Stormwater Discharge Locations: Additionally, the USACE project is considering restoration of 15 stormwater discharge locations. There appears to be some overlap between this proposed activity and the proposed WQPP stormwater retrofits. According to the draft assessment, improvements in these areas will include terracing, creation of vegetated swales, use of wattles, riffle dams, and other soil bioengineering techniques to stabilize drainages and remove sediments and pollutants carried in runoff prior to discharge into the San Marcos River. Figure 8-35, from the Draft Biologic Assessment, shows the locations under consideration.

It is anticipated that retrofits undertaken through the WQPP will be in close proximity to the USACE discharge restoration sites. However, the approach taken for the WQPP will be focused on maximizing stormwater treatment and less on riparian habitat as discussed above. The WQPP project team believes these efforts are complementary and desires to coordinate efforts with USACE such that benefits to the San Marcos River are maximized.

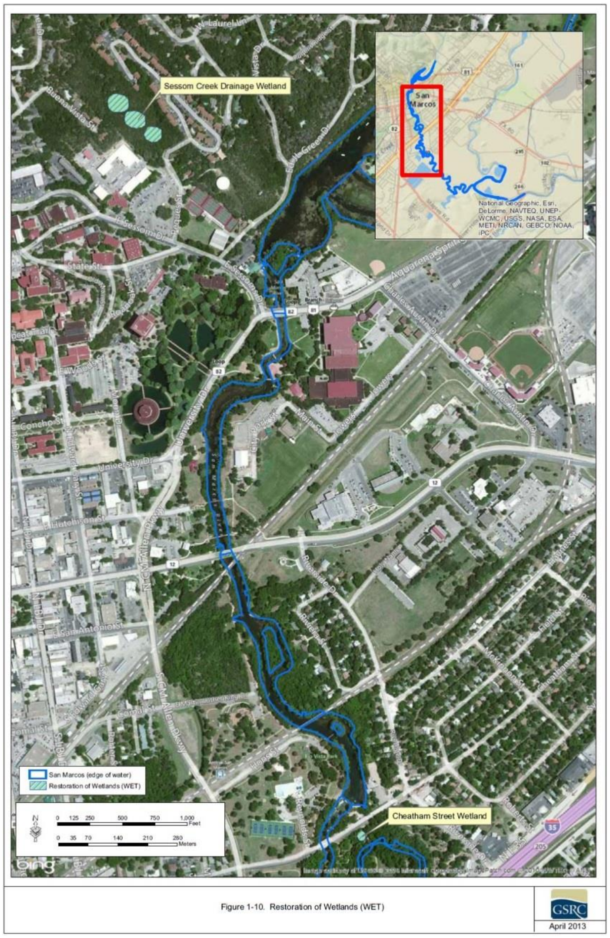
Figure 8-35 USACE Restoration of Discharge Locations – North and South of I-35



Sessom Creek Wet Ponds: A series of three in-line wet ponds will be constructed to capture stormwater runoff in the Sessom Creek drainage approximately 2,000 feet upstream of the San Marcos River. See Figure 8-36. The WQPP project team recommends the City and USACE consider tree impacts and environmental disturbance associated with this concept and consider the projects proposed in the Sessom Creek Watershed prior to undertaking these (See Section 9.3.3.3).

Cheatham Street Wetlands Restoration: An area south of Cheatham Street was identified that could be restored to wetland habitat. This area was previously excavated to develop a wetland for the purpose of filtering stormwater runoff. It does not currently provide suitable habitat because it does not support emergent vegetation. This area is hydrologically connected to the San Marcos River via a small channel that runs alongside Rio Vista Dam. This backwater area fills with water as elevation of the San Marcos River rises and only reconnects downstream during heavy rain events. Habitat suitability could be improved by excavating the area to a depth approximately 1 foot below normal surface water elevation with 4:1 side slopes, removing nonfunctional concrete structures, and constructing a flap-gate to capture backflows as water levels recede. Excess cut material not used on-site will be disposed of at a local landfill and utilized in the future by the City of San Marcos for non-aquatic fill. This site is accessible from the parking lot for which it was designed as a temporary storm-water detention and filtration system. See Figure 8-36.

Figure 8-36 USACE-Proposed Wetlands in Sessom Creek



8.5.8 BMP MAINTENANCE

When it comes to BMP implementation, maintenance is often an afterthought. To protect the investment of public resources in a stormwater management facility, it is vital to ensure proper maintenance and plan ahead so that the design accommodates straight-forward maintenance. Without proper planning and maintenance, an asset can devolve into an unattractive and poorly functioning liability. The City is strongly encouraged to plan ahead for this critical aspect of watershed management and include maintenance personnel in reviewing the design of any BMP that moves forward to construction. Refer to Chapter 11 for information on proper BMP planning and design procedures that will help minimize the time and resources necessary for BMP management and maintenance.

Commented [L8]: John please update these references.

8.5.9 COSTS AND FUNDING

It's important that the City commit to implement high-priority, cost-effective stormwater retrofits within a reasonable time frame. Given such a commitment, many questions arise regarding funding. How will the City pay for potential new drainage improvements? Initial indications are that the City is planning to spend approximately $10,000 per year in the CIP budget on future water quality facilities. It's likely that greater investments will be necessary over the long term. Given how critical the San Marcos River is to the environmental and economic vitality of the city, it seems prudent that the City invest adequately in the integrity and health of the River.

Drainage Utility and CIP Funding for Water Quality Purposes: It's unlikely that current investments on behalf of the City are adequate to meet the goals established in Section 5.7.6 of the EAHCP. The WQPP recommends that the City increase funding for water quality retrofits in order to mitigate the impacts of stormwater runoff from existing impervious cover. Currently, few Drainage Utility dollars are being spent for the purpose of water quality. In order to meet the requirements of the Incidental Take Permit, the WQPP recommends that the City review Drainage Utility rates and spending plans to ensure they are adequate for this purpose.

Grants: The WQPP team is working with the Meadows Center for Water and the Environment to pursue EPA 319 Grants that will help fund future potential stormwater retrofits. Successful applications for grant funding will rely on the contribution of matching funds and resources from the City. If the application for these funds is successful, receipt of the funds will start in 2016 with the life of the grants being a five-year period thereafter.

9. RECOMMENDED MEASURES FOR TEXAS STATE UNIVERSITY

The guiding principles noted in Chapter 2 and the goals and objectives described in Chapter 3 apply equally to Texas State University as to the City of San Marcos. Recommendations for water quality protection requirements, as outlined in this chapter, are similar to those for the City however in this chapter they've been interpreted for the campus environment. In the municipal environment, the water quality requirements are designed to apply to land parcels of varied ownership and oversight. Development standards written for individual property owners and subdivided land parcels do not apply to the campus as they do in the municipal setting. The University is a state entity, not under the jurisdiction of the City, responsible for the infrastructure of a large, contiguous area within the Plan boundary. This is an advantage in that it allows a more holistic approach that may be customized for the needs of the receiving waters. WQPP recommendations for new development and redevelopment are described in Section 9.1 of this chapter. For existing impervious cover, the WQPP recommends that the University implement a retrofit program to reduce impacts as explained in Section 9.3.

9.1 PLANNING AND CAMPUS CONSTRUCTION PROJECTS

A logical approach would be to apply water quality requirements for new development on the basis of the potential impact of the facility to campus subwatersheds (drainage areas). As a starting point, the WQPP proposes that the requirements be applied on a trial basis to selected campus improvement projects as identified in the 2012 – 2017 Campus Master Plan. The WQPP recommends that Texas State University adopt standards requiring enhanced construction sediment controls and permanent, structural BMPs that manage stormwater runoff quality and quantity for all future campus projects that exceed a threshold of 5000 square feet of soil disturbance (whether new construction or redevelopment). Projects that meet this standard will also allow Texas State University to take credit towards meeting the requirements of Minimum Control Measure 4 of the Campus Storm Water Management Program11 (SWMP). Surface facilities (e.g. biofiltration, rain gardens, constructed wetlands) are recommended, and shall be designed based on their location per the recommended water quality zones (see figure 3-2) and the following performance standards.

Table 9-1 BMP Performance Requirements in Aquifer Recharge and Contributing Zones

Zone	Entity	Pollutant Load	Stream Protection	Infiltration	Water Demand/Reuse
Recharge	TCEQ (TxSt*)	80% reduction in TSS load	Optional	None	None
	WQPP	No increase in existing TP load	Provide SPV or equivalent	Maintain or increase existing infiltration	Reduce water use for landscape irrigation by at least 50%
Contributing	TCEQ (TxSt*)	None	None	None	None

	WQPP	No increase in existing TP load	Provide SPV or equivalent	Maintain or increase existing infiltration	Reduce water use for landscape irrigation by at least 50%

*Texas State University is required to comply with TCEQ water quality rules

Table 9-2 lists the minimum stream protection volume as a function of the percentage of site impervious cover.

Table 9-2 Stream Protection Volume

IC	Minimum SPV (in.)
0%	0.00
5%	0.00
10%	0.08
15%	0.15
20%	0.22
25%	0.29
30%	0.37
35%	0.44
40%	0.51
45%	0.58
50%	0.65
55%	0.72
60%	0.80
65%	0.87
70%	0.94
75%	1.01
80%	1.08
85%	1.15
90%	1.23
95%	1.30
100%	1.37

Table 9-3 presents BMP design characteristics for WQPP-recommended stormwater treatment systems as compared to BMPs based on existing regulations in the central Texas region of the Edwards Aquifer Recharge Zone.

Table 9-3 Comparison of BMP Designs in the Edwards Aquifer Zone

Drainage Area IC*	Parameter	City of San Marcos	TCEQ	City of Austin SOS	WQPP
		Biofilt/VFS (25% IC) Ret/Irrig (other)	Sand Filtration	Ret/Irrig	Biofiltration/ Infiltration
25%	WQV (in)**	1.01	0.35	1.05	0.55

Commented [D9]: Biofilt = .39/.47; Infil = 0.08

	BMP Footprint as % of Drainage Area***	22%	2%	67%	6%
	TP Load as Equiv. IC	<0% IC	10% IC	<0% IC	0% IC
50%	WQV (in)	1.21	0.62	1.50	1.40
	BMP Footprint as % of Drainage Area***	61%	3%	96%	12%
	TP Load as Equiv. IC	<0% IC	21% IC	<0% IC	0% IC
75%	WQV (in)**	2.24	1.01	1.95	2.38
	BMP Footprint as % of Drainage Area***	112%	5%	125%	22%
	TP Load as Equiv. IC	<0% IC	35% IC	<0% IC	0% IC
100%	WQV (in)**	4.00	1.80	2.40	4.11
	BMP Footprint as % of Drainage Area***	199%	7%	133%	42%
	TP Load as Equiv. IC	<0% IC	52% IC	3% IC	0% IC

Commented [D10]: Biofilt = 1.01/1.22; Infilt = 0.18

Commented [D11]: Biofilt 1.64/1.97; Infilt 0.41

Commented [D12]: Biofilt 2.71/3.26; Infilt 0.85

Table 9-4 presents BMP performance requirements for WQPP-recommended stormwater treatment systems in the T/R Zone as compared to BMPs based on current campus standards at Texas State University.

Table 9-4 BMP Performance Requirements in Water Quality Zone T/R

Requirement	Pollutant Load	Stream Protection	Infiltration	Water Demand/Reuse
Current Campus Standards	None	None	None	None
WQPP	New development load no greater than site with 10% IC	Provide SPV or equivalent	Optional - Maintain or increase existing infiltration	Optional - Reduce use for landscape irrigation by at least 50%

Table 9-5 presents BMP design characteristics for WQPP-recommended stormwater treatment systems as compared to BMPs based on existing regulations in the central Texas region of non-recharge areas within the Edwards Aquifer Zone.

Table 9-5 Comparison of BMP Designs in Water Quality Zone T/R

Drainage Area IC	**Parameter**	**City of San Marcos Previous LDC**	**City of San Marcos Revised LDC**	**City of Austin**	**WQPP**
		Sedimentation Basin	**Sand Filtration**	**Sand Filtration**	**Biofiltration**
25%	WQV (in)*	0.125	0.50	0.55	0.36
	BMP Footprint as % of Drainage Area**	0.3%	3%	3%	2%
	TP Load as Equiv. IC	***18% IC***	***9% IC***	***8% IC***	***5% IC***
50%	WQV (in)*	0.25	0.50	0.80	0.82
	BMP Footprint as % of Drainage Area**	2%	3%	4%	4%
	TP Load as Equiv. IC	***38% IC***	***23% IC***	***18% IC***	***10% IC***
75%	WQV (in)*	0.375	0.50	1.05	1.61***
	BMP Footprint as % of Drainage Area**	2%	3%	5%	10%
	TP Load as Equiv. IC	***62% IC***	***47% IC***	***32% IC***	***10% IC***

100%	WQV (in)*	0.50	0.50	1.30	3.44****
	BMP Footprint as % of Drainage Area**	3%	3%	6%	23%
	TP Load as Equiv. IC	***88% IC***	***77% IC***	***55% IC***	***10% IC***

*The San Marcos WQV is that for construction purposes: for modeling purposes it is WQV/1.2 to account for sediment accumulation
**Assumes all ponds have 3 ft ponding depth, 3:1 side slopes, and L:W ratio of 2, with exception of WQPP Infiltration Basin for 75% IC site, where ponding depth is a function of soil hydraulic conductivity; 0.06 in/hr is assumed, thus ponding depth ≈ 3 inches to achieve 48 hour drawdown time.
***At IC >61%, volume reduction is required in order to meet the WQPP TP load standard, thus a treatment train is used, in this instance, a biofiltration BMP with 1.51"WQV followed by an infiltration basin with 0.10"WQV
**** Treatment train, a biofiltration BMP with 3.04"WQV followed by an infiltration basin with 0.40" WQV

Table 9-6 presents BMP requirement thresholds in Water Quality Zones A and C for the TCEQ Rules compared to recommendations in the WQPP.

Table 9-6 BMP Requirement Thresholds in Water Quality Zones A and C

Entity	IC at which BMPs are Required	Area of Disturbance at which BMPs are Required
TCEQ Edwards Aquifer Rules	20%	No criteria
WQPP	>0%	5000 ft^2 of IC*

Table 9-7 presents BMP requirement thresholds recommended by the WQPP in the T/R Zone as compared to current campus standards at Texas State University.

Table 9-7 BMP Requirement Thresholds in Water Quality Zone T/R

Entity	IC at which BMPs are Required	Area of Disturbance at which BMPs are Required
Current Campus Standards	None	No criteria
WQPP	≥10%	5000 ft^2 of IC

9.2 PROMOTE CAMPUS WATERSHED STEWARDSHIP

Texas State University made a major commitment to stewardship of the Edwards Aquifer, Spring Lake, and the upper San Marcos River when it acquired the Aquarena Springs amusement park in 1993. The subsequent establishment of the River Systems Institute, since renamed the Meadows Center for Water and the Environment, further cemented the University's commitment to watershed stewardship of the unique aquatic resources located on campus. In addition to these notable commitments, there are numerous other opportunities for Texas State University to engage staff, faculty and students in watershed stewardship activities.

For example, the WQPP recommends that the University engage students and faculty in the annual Campus RainWorks Challenge sponsored by the EPA. The Campus RainWorks Challenge is a green infrastructure design competition for college and university students. Student teams, working with a faculty advisor, will submit design boards, a project narrative, and a letter of support describing a proposed green infrastructure project for a location on their campus. Registration is typically available in September and registrants must submit their entries by December. Winning teams earn a student prize to be divided evenly among student team members, and a faculty prize to support green infrastructure research or training.

9.3 STORMWATER GREEN INFRASTRUCTURE AND RETROFIT PROJECTS

A wide range of watershed management strategies are recommended so they can be tailored to different characteristics and needs within the WQPP Plan Area. For example, in undeveloped areas, it is possible to plan ahead for new development and provide treatment on-site to achieve stormwater management goals. However, a great deal of existing development on the Texas State University campus was developed prior to the adoption of modern stormwater criteria and therefore treatment was not required, implemented, or existing facilities are in need of maintenance/replacement. In these areas, the Plan recommends the implementation of stormwater retrofit projects to counteract impacts of existing development on critical habitat.

Retrofit projects consist of new installations or upgrades to existing Best Management Practices (BMPs) in developed areas lacking adequate stormwater treatment. These projects can be challenging due to existing site constraints that reduce flexibility in selecting and sizing BMPs. Where retrofit opportunities do exist, the goal is often to provide as much hydrologic and water quality benefit as possible by:

- Correcting prior design or performance deficiencies on existing facilities;
- Disconnecting impervious cover;
- Providing flood mitigation;
- Improving infiltration and recharge performance;
- Addressing pollutants of concern;
- Demonstrating new technologies;
- Adding functionality to existing flood or water quality facilities; and
- Supporting stream restoration activities.

9.3.1 GREEN INFRASTRUCTURE AND REDEVELOPMENT

Drainage-related infrastructure (gutters, stormsewer pipe, channels, ponds, and erosion controls) often needs replacement or repair. Costs are ever increasing, which places a strain on the resources necessary to address these concerns. Resilient and affordable solutions meeting many objectives are always in demand for resource-limited universities and Green infrastructure (GI) can be such a solution in certain applications. Unlike traditional single-purpose stormwater infrastructure, which often uses concrete to convey stormwater, green infrastructure uses vegetation and soil to manage rainwater where it falls. Gray infrastructure remains an important part of any stormwater conveyance system, but by weaving natural processes into the built environment, GI facilities may serve as landscaped amenities that are functional, educational, and recreational.

It is recommended that the City include GI and other water quality objectives in the planning and design process for all future infrastructure and redevelopment projects, including major repairs. Considerable opportunity exists for incorporating BMPs of different scales and levels of complexity into these types of projects. Implementing BMPs incrementally through the upgrade and replacement of individual infrastructure components is often more cost effective than undertaking a stand-alone water quality retrofit allowing this approach to maximize benefits offered by capital investments. Opportunities exist whenever streets are reconfigured (e.g., Peques and State, Hopkins), buildings are renovated, or new visions for open space are contemplated.

Projects such as the “Gray to Green” initiatives being undertaken by TXST are good examples of infrastructure improvements that enhance sustainability. Concho Green, Bobcat Trail, and the Commons Courtyard are representative projects. The redevelopment of Clear Springs Apartments is another opportunity to counteract effects of impervious cover draining to critical habitat by retrofitting with green infrastructure. As density increases on campus, opportunities may exist to remove impervious cover and restore green space and the infiltrative capacity of underlying soils. Texas State is encouraged to seek opportunities to counteract the adverse impacts of urbanization to the extent possible to make a more sustainable community and healthier river.

9.3.2 WATER QUALITY RETROFIT IDENTIFICATION AND PRIORITIZATION

The WQPP recommends a campus retrofit plan, which could be a more effective and cost-efficient way to meet water quality goals when compared to an approach that implements BMPs on a project-by-project basis. This section discusses the process used to identify and prioritize retrofit opportunities, which has resulted in recommendations for projects to be considered by TXST (See Table 9-4). The process has been rigorous in order to identify feasible and cost-effective retrofit opportunities that will likely serve as valuable investments. Also described is the spatial geodatabase created to store and visually display information on all identified opportunities. This database (described in 9.3.2.1) was instrumental in the retrofit prioritization process and provides a solid starting point for an ongoing retrofit program for TXST.

The primary focus of this section is larger (centralized or regional) BMPs because these are usually the most cost effective retrofits. Centralized facilities, compared to smaller (GI-type) BMPs, are more cost effective, easier to maintain, and better able to treat large drainage areas with high impervious cover. The downside of centralized facilities is there are few opportunities in the most densely developed parts of the TXST due to their size, lack of open land, and the high value of real estate. Several centralized opportunities do exist in these areas, however, and many were identified on campus that are, “low-hanging fruit” for improving watershed hydrology and reducing pollution loads to the San Marcos River.

TXST also recognizes the need to investigate and implement smaller-scale (GI-type) BMPs. Despite their lower cost effectiveness and higher maintenance burden, they are often the best option for the most developed parts of campus, which have high impervious cover and are directly adjacent to endangered species habitat. They can also be attractive amenities bringing greenery into ultra-urban areas like Bagby Street in Houston, TX where it is claimed that GI has spurred tremendous reinvestment while improving water quality. BMP options for highly developed areas are noted in Section 8.2, Section 8.5, and Appendices H-L (see Examples 5 and 6).

9.3.2.1 Potential Project Database Development

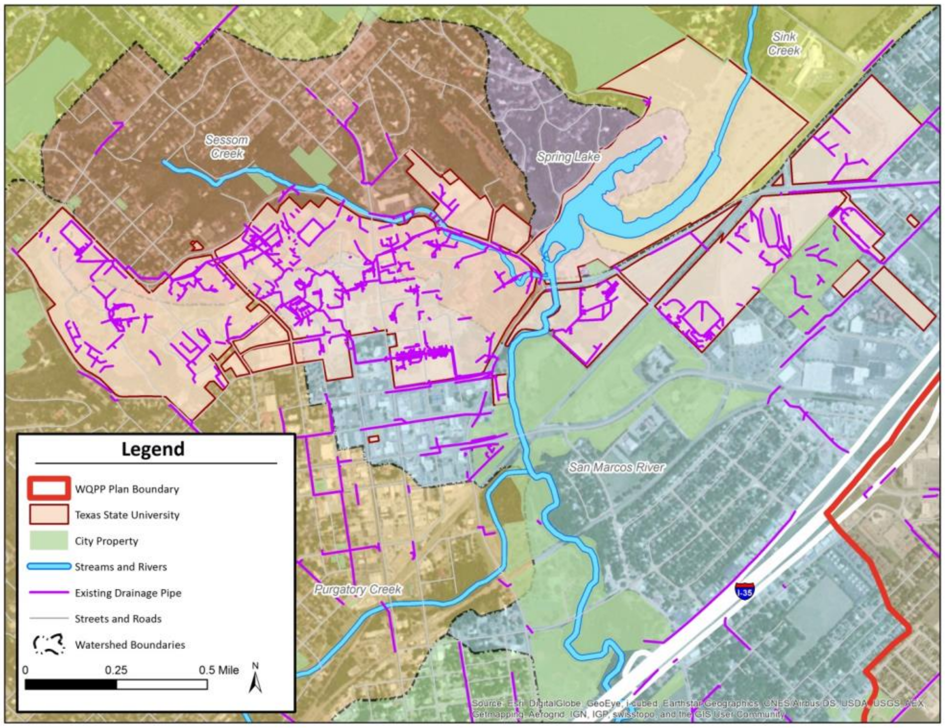
The first step in identifying retrofit opportunities is to build an inventory of potential projects. These may come to the attention of the watershed manager through redevelopment projects, while addressing localized flooding issues, by collaborating with developers to treat off-site runoff area, or various other paths. Areas of high impervious cover such as large parking lots may be targeted for treatment and high visibility areas may provide an opportunity not only for stormwater management but also public education. Once an inventory of potential projects exists, projects can be selected per TXST priorities and/or it can be searched to identify opportunities in locations of interest.

As part of the WQPP effort, the project team has developed a Geographic Information Systems (GIS) geodatabase of potential retrofit projects. Population of this database began with a list of opportunities identified collaboratively with TXST and the project team. To be thorough, all TXST property within the WQPP boundary was evaluated for water quality retrofit potential. The following GIS data was gathered from TXST and overlaid on aerial photographs to help identify stormwater retrofit opportunities:

- Topography (2-foot contours)
- Drainage areas
- Stream networks
- Storm sewers
- Impervious cover
- Building footprints
- Roads
- Water and wastewater lines
- Soils
- TCEQ aquifer zones
- TXST property
- Regulatory Floodplain Extents
- WQPP Plan Area

A preliminary round of screening was completed to narrow focus to relevant sites. Portions of the following watersheds meet these criteria: Sink Creek (SNK), Spring Lake (SPL), Sessom Creek (SSM), Purgatory Creek (PGY), and San Marcos River (SMR). Figure 9-1 below illustrates some of the data used to identify retrofit opportunities for TXST.

Figure 9-1 Watershed-Scale Data Used to Identify Potential Retrofit Opportunities



Plan: Complete Watershed Solutions LLC

The next round of screening was completed to find characteristics that create potential for beneficial stormwater management. For example, open spaces draining significant impervious areas are desirable. Where such a location is found, an entry was made into the “Potential BMP Locations” layer in the geodatabase (which has 35 such entries for TXST) to record the location and the following attributes:

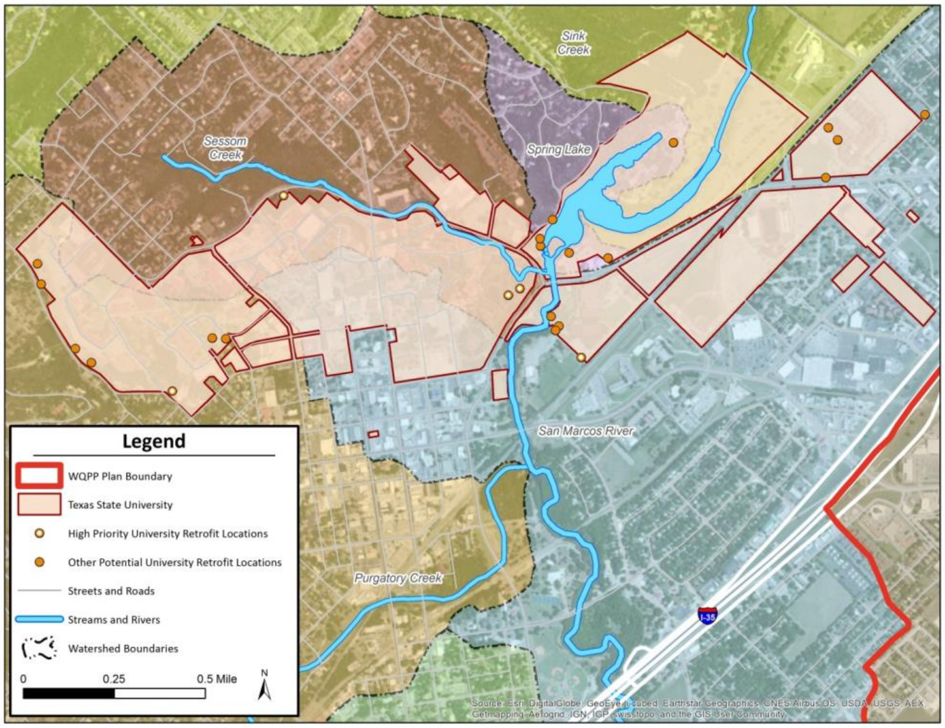
- Project ID
- Link ID (this field groups related projects)
- Name
- Owner
- Proposed Land Development Zone
- Receiving watershed
- BMP Type
- Notes

This screening process has provided an early potential retrofit inventory. It is anticipated that new opportunities will be added while other opportunities are ruled out after further investigation.

9.3.2.2 Water Quality Retrofit Identification and Prioritization

While a database of 35 potential projects is a useful tool for the watershed manager, the project team is tasked with making recommendations for implementation. Additional rounds of screening were required to narrow the list as described below and culminating in a prioritized list of 20 "High-Potential Retrofits" for TXST (Table 9-4). Of these retrofits, five "High-Priority Retrofits" were selected for conceptual design described in Section 9.3.3 and listed in Table 9-5. Figure 9-2 illustrates all 35 potential retrofits and five High-Priority Retrofits.

Figure 9-2 All Potential Stormwater Retrofits on Texas State Property



Map: Complete Watershed Solutions LLC

9.3.2.3 Drainage Area and Percent Impervious Cover

Delineating drainage areas allows watershed size and percent impervious cover to be applied as discriminating criteria since projects with the larger drainage areas and higher impervious cover create more pollution and erosion potential. Since delineating drainage area for all potential locations would be time prohibitive, they were first reviewed visually in GIS to judge which have the greatest treatment potential. In this level of screening, factors such as stormsewer outfall locations, degree of urbanization, available open space, and utility conflicts were considered along with application of engineering judgement. Additionally, the campus master plan was considered to minimize any conflict with future direction to the extent possible. Of the 35 potentials projects, 29 drainage areas were delineated and acreage was computed along with percent impervious cover. This information may be found in the geodatabase layer titled Retrofit Drainage Areas.

9.3.2.4 High-Potential Retrofits

After considering the drainage area and percent impervious cover of the 35 projects discussed above, 20 “High-Potential Retrofits” were selected for further analysis. These projects are listed in Table 9-8 below along with location, project description, and watershed characteristics.

Table 9-8 High-Potential Retrofits: Location and Drainage Characteristics

Project Name*	Project ID	Receiving Watershed	Zone	BMP Type	Drainage Area (acre)	IC Treated (acre)**	% IC Area
Sessom Creek Wetpond 3	10233	SSM	T/R	Wet Pond	482	172.6	36%
Sessom Creek Wetpond 2	10232	SSM	T/R	Wet Pond	482	172.6	36%
Fish Ponds 3	10493	SMR	T/R	Wet Pond	413	139.5	34%
Sessom Creek Wetpond 1	10231	SSM	T/R	Wet Pond	413	139.5	34%
Fish Ponds 2	10492	SMR	T/R	Wet Pond	69	33.12	48%
Fish Ponds 1	10491	SMR	T/R	Wet Pond	52	27.1	52%
The Gulch 1	10431	SSM	T/R	Biofiltration	57	23.8	42%
The Gulch 2	10432	SSM	T/R	Extended Detention (Dry)	57	23.8	42%
Peques Street	10450	SSM	T/R	Biofiltration	65	16.1	25%
The Glade 1	10441	PGY	T/R	Biofiltration	26	8.7	34%
The Glade 6	10446	PGY	T/R	Multiple	26	8.7	34%
The Glade 5	10445	PGY	T/R	Multiple	26	8.7	34%
The Glade 4	10444	PGY	T/R	Biofiltration	26	8.7	34%
Jowers Center 4	10474	SMR	T/R	Multiple	10	6.9	70%
The Glade 7	10447	PGY	T/R	Biofiltration	16	5.95	38%
The Glade 3	10443	PGY	T/R	Rain Garden	16	6.0	38%
The Glade 2	10442	PGY	T/R	Rain Garden	11	4.3	38%
Jowers Center 2	10472	SMR	T/R	Rainwater Harvesting	4	3.5	100%
Jowers Center 1	10471	SMR	T/R	Biofiltration	5	2.36	51%
Jowers Center 3	10473	SMR	T/R	Biofiltration	2	1.0	63%

* Numbers after project name indicate multiple scenarios or facilities were evaluated

** Table sorted by IC Treated

9.3.2.5 High-Potential Retrofits: Loading Analysis

The next discriminating criterion utilized for retrofit prioritization was pollution load reduction. As discussed in Section 7.4.3, total phosphorus (TP) has been selected as the pollutant of greatest concern due to the phosphorus limited nature of the receiving waters. A spreadsheet model utilizing current recommendations from the International Stormwater BMP Database Project has also been developed by the project team to quantify annual TP removal and satisfaction of Stream Protection Volume goals. In order to perform a loading analysis using this tool, BMP characteristics must be estimated in addition to

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drainage area parameters determined in 9.3.2.3 above. BMP characteristics (type, water quality volume, and footprint) were estimated and a pollution loading analysis completed for high-potential retrofits as shown in Table 9-9 below. BMP footprints may be found in the geodatabase layer titled Potential BMP Footprint. It should be noted that, in the table below, Water Quality Volume refers to the pond volume available to provide stormwater treatment. Runoff Capture Efficiency is the fraction of runoff captured and treated by the BMP in a typical year (the remainder is bypassed because the facility is full).

Table 9-9 High-Potential Retrofits: BMP Characteristics and Phosphorus Removal

Project Name *	BMP Type	Project ID	Prelim Footprint Area (sf)	Prelim Depth (ft)	Prelim WQV (cf)	Runoff Capture Efficiency (%)	Annual Phosphorus Removed (lbs) **
Sessom Creek Wetpond 3	Wet Pond	10233	383,211	4	1,532,844	100%	253
Sessom Creek Wetpond 2	Wet Pond	10232	217,214	4	868,856	96%	162
Fish Ponds 3	Wet Pond	10493	170,920	4	683,680	100%	182
Sessom Creek Wetpond 1	Wet Pond	10231	62,160	5.2	325,097	83%	101
Fish Ponds 2	Wet Pond	10492	155,055	4	620,220	100%	61
Fish Ponds 1	Wet Pond	10491	35,571	4	142,284	99%	46
The Gulch 1	Biofiltration	10431	18,868	6	113,208	94%	27
The Gulch 2	Extended Detention (Dry)	10432	18,868	6	113,208	94%	14
Peques Street	Biofiltration	10450	24,558	2	49,116	81%	14
Jowers Center 4	Multiple	10474	15,655	Varies	36,147	99%	14
The Glade 1	Biofiltration	10441	6,779	5.1	34,573	87%	9
The Glade 6	Multiple	10446	11,110	Varies	38,226	93%	9
The Glade 5	Multiple	10445	11,151	Varies	38,226	80%	9
The Glade 4	Biofiltration	10444	11,110	Varies	38,226	92%	9
The Glade 7	Biofiltration	10447	22,261	1	22,261	60%	4
Jowers Center 1	Biofiltration	10471	7,765	2	15,530	99%	4
The Glade 3	Rain Garden	10443	4,372	1	4,372	41%	3
The Glade 2	Rain Garden	10442	4,331	1	4,331	52%	3
Jowers Center 3	Biofiltration	10473	7,623	0.95	31,944	100%	2
Jowers Center 2	Rainwater Harvesting	10472	267	10	2,674	4%	0.5

* Numbers after project name indicate multiple scenarios were evaluated

** Table sorted by annual phosphorus load removed

9.3.2.5 Planning Level Cost Effectiveness

Cost effectiveness is another discriminator applied to prioritize retrofit opportunities. While a project may remove a great deal of pollution, it may also be cost prohibitive. This analysis is meant to help watershed managers achieve the greatest “bang for the buck”. To this end, a range (low, average, high) of planning level capital costs were estimated using unit costs developed from multiple sources including Narayanan and Pitt 2006, the EPA, the University of Texas, the National Cooperative Highway Research Program (NCHRP), Colorado State University, Young et al (1996), and City of Austin bid tab data. Annualized costs were estimated using the whole life cycle cost method considering capital cost, annual operation and maintenance (O&M) costs, an assumed 30-year project life, and with future costs calculated and referred back to the present value. The annualized costs were then divided by the annual TP load reduction to obtain cost per pounds of TP removed, which is the criterion used for cost effectiveness. These costs are strictly planning level and are more useful for comparing potential projects and identifying trends than in estimating actual project costs, which should be done via bid tab after more preliminary engineering has been completed. The following assumptions apply:

- No land costs are included (all projects are on TXST land)
- External conveyance costs such as storm sewer, channel work, etc. are only included where they are expected to be major cost components
- Cost of construction, engineering, and design are included
- The ENR Construction Cost Index for 20 cities was used to calculate a multiplier, depending on the year, to bring the unit costs to 2014 dollars
- Inflation and salvage costs are not considered

The table below summarizes planning-level cost effectiveness for high-potential retrofits at Texas State University.

Table 9-10 High-Potential Retrofits: Planning-Level Cost Effectiveness

Project Name*	Project ID	Annual P Removed (lbs)	Avg Capital Cost ($1000)	Low Capital Cost ($1000)	High Capital Cost ($1000)	Annual O&M Cost ($1000)	Annualized Cost Estimate ($1000)	Annual Cost per Pound TP Removed** ($1000)
The Gulch 2	10432	13.9	$ 257	$ 96	$ 679	$ 4	$ 19	$ 1.4
Sessom Creek Wetpond 1	10231	101.2	$ 2,157	$ 595	$ 4,304	$ 33	$ 159	$ 1.5
Fish Ponds 1	10491	46	$ 944	$ 260	$ 1,884	$ 33	$ 88	$ 1.9
Fish Ponds 3 ***	10493	182.1	$ 5,937	$ 2,651	$ 10,451	$ 33	$ 380	$ 2.0
Sessom Creek Wetpond 2	10232	162	$ 5,766	$ 1,590	$ 11,503	$ 33	$ 370	$ 2.2
Peques Street	10450	13.9	$ 556	$ 252	$ 886	$ 3	$ 35	$ 2.5
The Glade 3	10443	2.85	$ 106	$ 36	$ 270	$ 1.7	$ 8	$ 2.7
Sessom Creek Wetpond 3 ***	10233	253	$ 11,573	$ 4,205	$ 21,695	$ 33	$ 710	$ 2.8
The Gulch 1	10431	27.3	$ 1,282	$ 582	$ 2,043	$ 3	$ 783	$ 2.9
The Glade 1	10441	8.9	$ 391	$ 178	$ 624	$ 3	$ 26	$ 2.9
The Glade 2	10442	2.6	$ 105	$ 35	$ 267	$ 1.7	$ 8	$ 3.0
Jowers Center 4	10474	14.3	$ 643	$ 310	$ 1,016	$ 8	$ 45	$ 3.2
The Glade 5	10445	9.24	$ 497	$ 213	$ 894	$ 3	$ 32	$ 3.5
The Glade 4	10444	9.14	$ 496	$ 213	$ 891	$ 3	$ 32	$ 3.5
Jowers Center 1	10471	3.5	$ 176	$ 80	$ 280	$ 3	$ 13	$ 3.8
The Glade 7	10447	3.9	$ 211	$ 71	$ 538	$ 3	$ 15	$ 3.9

The Glade 6	10446	9.32	$ 602	$ 249	$ 1,161	$ 3	$ 38	$ 4.1
Fish Ponds 2	10492	60.8	$ 4,116	$ 1,135	$ 8,212	$ 33	$ 274	$ 4.5
Jowers Center 3	10473	1.7	$ 362	$ 164	$ 576	$ 3	$ 24	$ 14.2
Jowers Center 2	10472	0.46	$ 106	$ 66	$ 160	$ 2	$ 8	$ 17.8

* Numbers after project name indicate multiple scenarios or facilities were evaluated
** Table sorted by IC Treated

9.3.2.6 Site Investigation

Site visits were conducted for many retrofit opportunities to ensure that conditions on the ground were consistent with those seen visually in GIS. Site photos and notes for all sites are included electronically in Appendix N and those for High-Priority Retrofits are also included in Section 9.3.3.

9.3.2.7 High-Potential Retrofits: Prioritization Matrix

When considering a multitude of potential opportunities, a standard tool to assist with objective decision making is a prioritization matrix, which allows one to apply multiple and sometimes conflicting criteria and weight them according to community/owner values. Criteria, scores, and weights can be modified as additional information is gathered and/or as values become clearer. As a starting point, the information collected in sections 9.3.2.1 – 9.3.2.5 was incorporated into a decision matrix including scores and weights for the following criteria:

- Load reduction (35%)
- Cost effectiveness (25%)
- Feasibility (15%)
- Owner Support (15%)
- Demonstration Value (10%)

Again, all criteria are important to consider for project effectiveness and the suggested weights and criteria should be viewed as a starting point to generate discussion and help define priorities and values of the owner.

Table 9-11 presents the ranking of selected potential projects in the prioritization matrix and Figure 9-2 shows the location of all potential projects including those deemed “High-Priority Retrofits” that are recommended for implementation. The list in Table 9-11 is by no means comprehensive. There are currently 35 projects in the geodatabase for TXST. Some of these may prove superior to those listed below once more information becomes available. Potential projects on the list may also be ruled out for any number of reasons. New project opportunities will inevitably arise through public/private partnerships, land acquisition, redevelopment, etc. and be added to the list. As these opportunities arise, the geodatabase provides a tool to keep track of them for evaluation and implementation.

Table 9-11 High-Potential Retrofits: Prioritization Matrix

Project Name*	Project ID	Pollution Removal	Cost Effectiveness	Feasibility	Owner Support	Demonstration Value	Weighted Average**

		35%	25%	15%	15%	10%	
Sessom Creek Wetpond 3	10233	10.0	5	6	7	10	7.7
Fish Ponds 3	10493	7.2	7	7	6	10	7.2
Sessom Creek Wetpond 1	10231	4.0	9	8	10	8	7.1
Sessom Creek Wetpond 2	10232	6.4	6	7	6	10	6.7
Fish Ponds 1	10491	1.8	7	10	8	10	6.2
The Gulch 2	10432	0.5	10	8	10	3	5.7
The Glade 1	10441	0.4	5	10	10	8	5.1
The Glade 3	10443	0.1	5	10	10	8	5.1
The Glade 2	10442	0.1	5	10	10	8	5.0
Jowers Center 1	10471	0.1	4	10	10	10	5.0
The Glade 5	10445	0.4	4	9	10	8	4.8
The Glade 4	10444	0.4	4	9	10	8	4.8
The Glade 6	10446	0.4	3	9	10	8	4.6
The Gulch 1	10431	1.1	5	8	10	3	4.6
Fish Ponds 2	10492	2.4	3	7	6	10	4.6
Peques Street	10450	0.5	5	10	3	10	4.5
The Glade 7	10447	0.2	4	10	10	5	4.4
Jowers Center 4	10474	0.6	4	8	8	10	4.7
Jowers Center 3	10473	0.1	1	9	8	10	3.8
Jowers Center 2	10472	0.0	1	7	10	10	3.8

* Numbers after project name indicate multiple scenarios or facilities were evaluated
** Table sorted by Weighted Average

9.3.3 Texas State Stormwater Retrofits: High-Priority Retrofits

A campus-wide search was completed to identify potential cost-effective stormwater retrofit opportunities as described in Section 9.3.2. As shown in Table 9-11 above, TXST is presented with a number of High-Potential Retrofits. Of these projects five have been deemed “High-Priority Retrofits” and selected for conceptual design. These projects are shown in Table 9-12 below and detailed in Sections 9.3.3.1 – 9.3.3.6.

Table 9-12 High-Priority Retrofits Selected for Concept Design

Project Name	Project ID	Watershed	Zone	BMP Description
Fish Ponds 3	10493	SMR	T/R	Wetpond and/or Constructed Wetlands
Sessom Creek Wetpond 3	10233	SSM	T/R	Wetpond and/or Constructed Wetlands
The Gulch 2	10432	SSM	T/R	Extended Detention
The Glade 1	10441	PGY	T/R	Biofiltration w Stacked Detention
Jowers Center 1	10471	SMR	T/R	Filtration Rain Garden

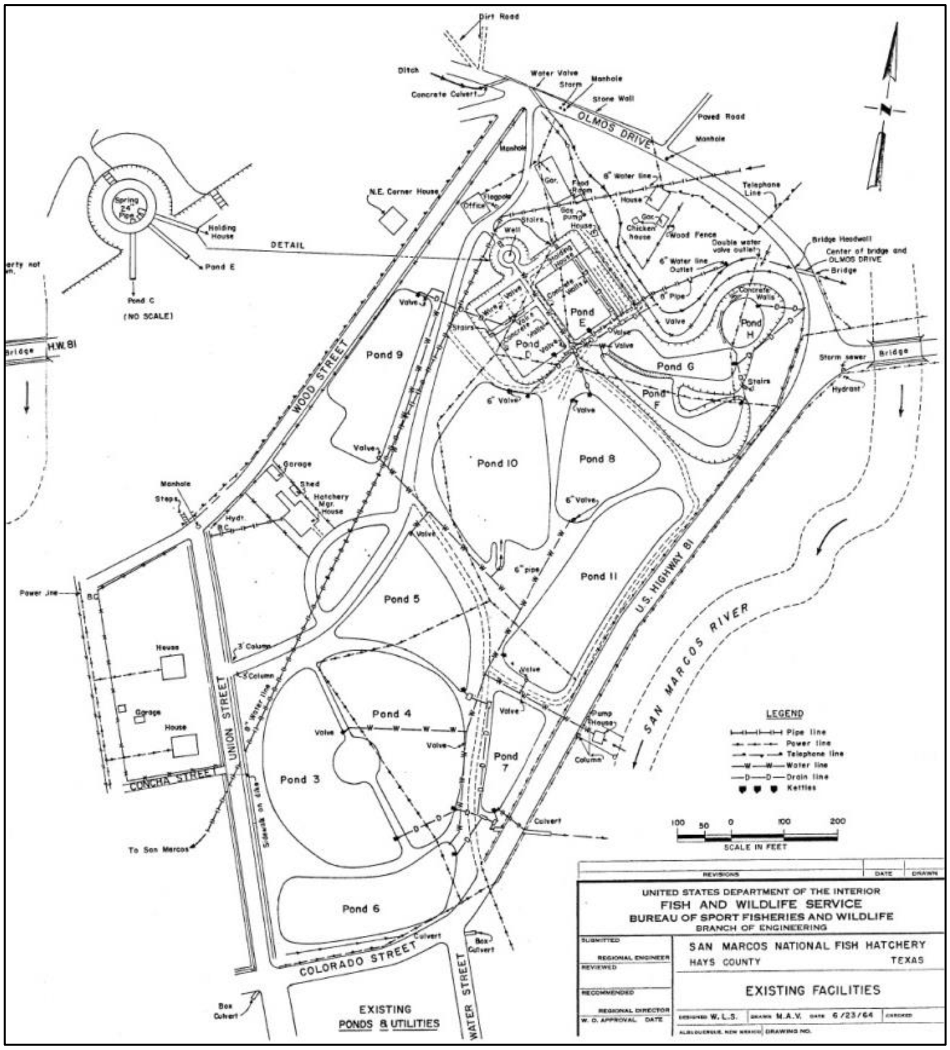
9.3.3.1 The Fish Ponds 3 (#10493)

TXST campus contains seven “Fish Ponds” just west of University Drive near its intersection with Aquarena Springs Drive, which were formerly part of 15 ponds operated by the San Marcos National Fish Hatchery established in 1893 and closed in 1965. Three of the ponds were converted into Sessom Creek Wet Pond located at the intersection of University Drive and Aquarena Springs Drive (see Section 9.3.3.2 below). Two other ponds were converted into the water feature surrounding Theatre Center (THEA). Three ponds adjacent to Freeman Aquatic Biology (FAB) are currently involved in research activity. Another pond (#9) appears to have been filled and covered with the J. C. Kellam Administration Building (JCK). Figures 9-3 and 9-4 show a diagram of the original Fish Ponds including their water supply and drainage. It shows an artesian spring supplying water to Ponds C, D, E, F, G, and H. Water pumped from the river appears to supply Ponds 3 through 11. Ponds 3 through 7 and Pond 11 appear to drain to the river whereas Ponds 8 through 10 drain to an 8-inch pipe that discharges to Sessom Creek near its San Marcos River outfall.

Figure 9-3 University Fish Ponds: USFWS Diagram of Original Pond Grading

Map: US Fish and Wildlife Service

Figure 9-4 University Fish Ponds: USFWS Diagram of Original Facilities and Piping



Map: US Fish and Wildlife Service

Fish Pond Water Source: According to the HCP, TXST has used an average of 36 acre-ft per year to replenish the Fish Ponds over the past five years. It is strongly recommended that TXST find an alternative to pumping river water into the fish ponds to maintain a permanent pool. After long residence times in sunny, shallow reservoirs, river water will be lost to evaporation, temperatures will be elevated, and a smaller volume of lower quality will be returned to the river. TXST staff reported that water quality issues have been identified with the pond effluent triggering limits on discharges to the river. Fortunately, an alternative water source is available that would transform the Fish Ponds in to a stormwater treatment facility rather than a potential source of pollution. It is recommended that stormwater runoff from campus (currently discharging directly to Sessom Creek and the San Marcos River) be routed to the fish ponds and used as an alternative water source. Doing so would clean polluted stormwater that normally enters critical habitat untreated and reduce demand for river and/or reclaimed water to maintain permanent pools.

The WQPP team also understands that reclaimed water is being considered as a source for the fish ponds and recommends against this action due to high nutrient concentrations associated with reclaimed water. Nutrient loading from this source could cause eutrophic conditions and dissolved oxygen problems in the Fish Ponds system, which eventually drains to critical habitat in the San Marcos River.   Testing of reclaimed water by the City of Austin revealed total nitrogen (TN) and total phosphorus (TP) concentrations that were approximately ten times higher than untreated runoff from developed areas. TN in reclaimed water was 25 mg/l rather than 2.22 mg/l for untreated runoff from developed areas while TP was 4.5 mg/l rather than 0.4 mg/l. Six receiving waters were also monitored upstream and downstream of reclaimed water application areas and increased nutrients were found downstream with nitrate plus nitrite being particularly high. Total nitrogen and total phosphorus were also elevated for four of the six sites. A link is provided below to the City of Austin publication. http://austintexas.gov/watershed_protection/publications/document.cfm?id=225012

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A site visit was conducted to the Fish Ponds to ensure conditions on the ground were consistent with those observed in GIS. A complex system of drains and water supply lines was observed, it was noted that they are at a higher elevation than Sessom Creek Wetpond, and potential for stormwater treatment was confirmed. Figure 9-5 below shows a drain and water supply line associated with one of the Fish ponds.

Figure 9-5 University Fish Ponds: Photo of Drain and Water Supply Line

Photo: Lee Sherman

Recommended BMP: Wet ponds or constructed wetlands are suggested as the BMP types in order to maintain the existing aesthetic and history of these ponds as water features. In addition, historic plans show springs in the vicinity suggesting a high water table that may cause the ponds to hold water whether desired or not. Wet ponds are also typically more appropriate for large drainage areas such as this where filtration BMPs might clog too frequently from sediment loading. If further investigation reveals that groundwater is not an issue and support exists for a biofiltration facility, a smaller portion of the drainage area might be routed to such a facility.

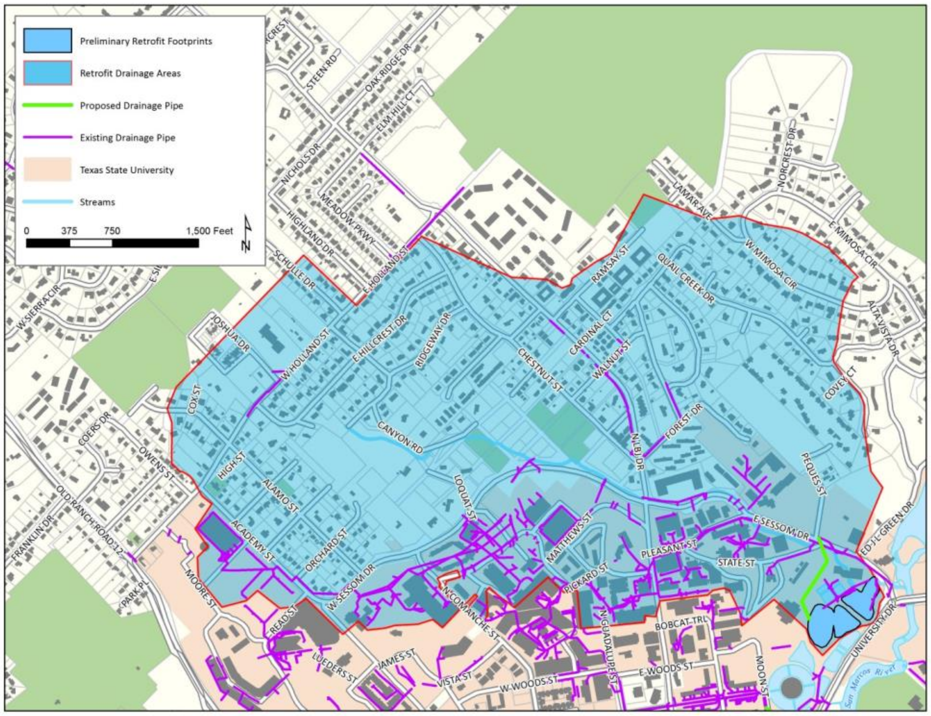
Project Elements: A number of scenarios involving these fish ponds were evaluated. The scenario evaluated having the highest weighted average in the prioritization matrix is Fish Ponds 3 (# 10493). This project would involve several elements as described below:

- Re-route Sessom Creek stormsewer to enter Fish Pond 10
- Connect Fish Pond 10, Fish Pond 8, and Sessom Creek Wet Pond
- Make necessary improvements to Fish Ponds 8, 10, and Sessom Creek Wetpond to maximize water quality benefit:
  - Remove accumulated sediment
  - Expand Sessom Creek Wetpond footprint from approximately 0.5 acres to approximately 1.4 acres

- Provide adequate access for maintenance
- Add or repair pond liners to reduce seepage and demand for makeup water
- Add extended detention to be stacked on top of the water quality volume
- Add trash racks at pond inlets to keep litter out of ponds
- Add aquatic plants in the pond to enhance treatment
- Provide proper management using well-trained staff and/or contractors

Figure 9-6 depicts the drainage area, location and potential footprint of this proposed BMP.

Figure 9-6 Fish Ponds 3: Concept Plan



Plan: Complete Watershed Solutions LLC

Project Benefits: This project would achieve multiple objectives in adding stormwater treatment functionality to the fish ponds while maintaining their aesthetic appeal. In addition, it would replace river water as the source needed to maintain permanent pools in these ponds, and would be a great demonstration project in such a high visibility area. One advantage to this project is that there is no need for a change in land use as these are pre-existing ponds. The modeling predicts this scenario would remove 182 lbs of TP at an estimated capital cost of $5.94 million including $1.4M anticipated in stormsewer re-routing. It should also be noted that, while the pond footprint is on TXST property, a large portion of the drainage area is City of San Marcos property (see Figure 9-6 above), which might justify cost-sharing to implement a mutually beneficial retrofit. Note that the current modeling tool developed for the WQPP project does not currently have the capability to model wet ponds. For this reason the City of Austin's Adams and Papa model was utilized along with runoff concentrations recommended for San Marcos and it is assumed that the hydrology is similar since the cities are close together. Given the runoff capture efficiency is predicted to be 100%, it is also presumed that the desired stream protection goals are achieved along with pollution load reduction goals.

Project Challenges: There are some foreseen challenges associated with this project that might affect feasibility and/or cost. There is an approximate six-foot elevation difference between the water surface of Fish Ponds 8 and 10 (578 ft) and the existing Sessom Creek Wet Pond (572 ft). To overcome the elevation difference and connect Sessom Creek to Pond 10, the Sessom Creek stormsewer would likely need to be re-routed beginning approximately 575 feet upstream of Sessom Creek Wet Pond and routed through the parking lot west of building FAB. This re-route would involve a relatively abrupt turn that would require head losses to be considered in the design to mitigate any potential flooding issues. Additionally, Pond 10 would likely need to be hydraulically connected to the Sessom Creek Wet Pond by a weir and/or a pipe.

Finally it may be a challenge, but this project is a good example of how the City and TXST might work together for mutual benefit. Since a majority of the drainage area lies within the City's jurisdiction, it would be appropriate for them to share in the cost of BMP implementation should Sessom Creek be re-routed into the Fish Ponds. Together, the City and Texas State University could provide a huge benefit to the San Marcos River.

Alternatives: Two other Fish Pond projects were evaluated and also have potential:

- Fish Ponds 1: 47 acres draining from the west could be routed into Pond 6 with the outlet going to the San Marcos River. This would be a less expensive option (~$260,380) but removes much less pollution (46 lbs TP) compared to Fish Ponds 3 (182 lbs TP).
- Fish Ponds 2: This project is similar to Fish Ponds 1 only Ponds 5, 6, 7, and 11 would be connected, which increases the contributing drainage area to 69 acres and the TP removed to 60.8 lbs compared to 46 lbs for Fish Ponds 1. Unfortunately, the cost also increases substantially ($1.14 M) due to the improvements that would be required for all four ponds.

Related Planning Documents: A look at the TXST Master Plan reveals no conflicts with future development and the potential to dovetail with the Concho Green landscaping and grounds project meant to enhance the pedestrian experience and activities on the southern edge of campus. Also if Sessom Creek is re-routed into Fish Pond 10, this effort might be integrated into the Peques and State Realignment project in order to minimize overall disturbance and potentially save money on construction costs.

9.3.3.2 Sessom Creek Wet Pond 3 (#10233)

Sessom Creek Wet Pond is located at the intersection of University Drive and Aquarena Springs Drive and drains to Sessom Creek near its confluence with the San Marcos River. This pond was constructed as an in-line wet pond accepting flow from Sessom Creek. The surface area of a wet pond should generally be in the range of 1% to 3% (4 to 12 acres in this case) of the contributing drainage area (412.9

acres) to make the maintenance frequency reasonable. Since the current pond surface area is 0.5 acres (0.12%) it is well undersized and one objective for a retrofit should be to increase surface area and storage volume such that maintenance tasks such as dredging can be performed on a reasonable schedule. Other objectives for a retrofit include improving access for routine maintenance, adding extended detention functionality, and improving aesthetics.

A site visit was made that confirmed potential for pond expansion, a construction access and maintenance ramp location was found. Figure 9-7 below shows the pond outlet structure entering Sessom Creek and the pond surface can be seen in the background.

Figure 9-7 Sessom Creek and the Wet Pond Outlet Structure

Photo: Lee Sherman

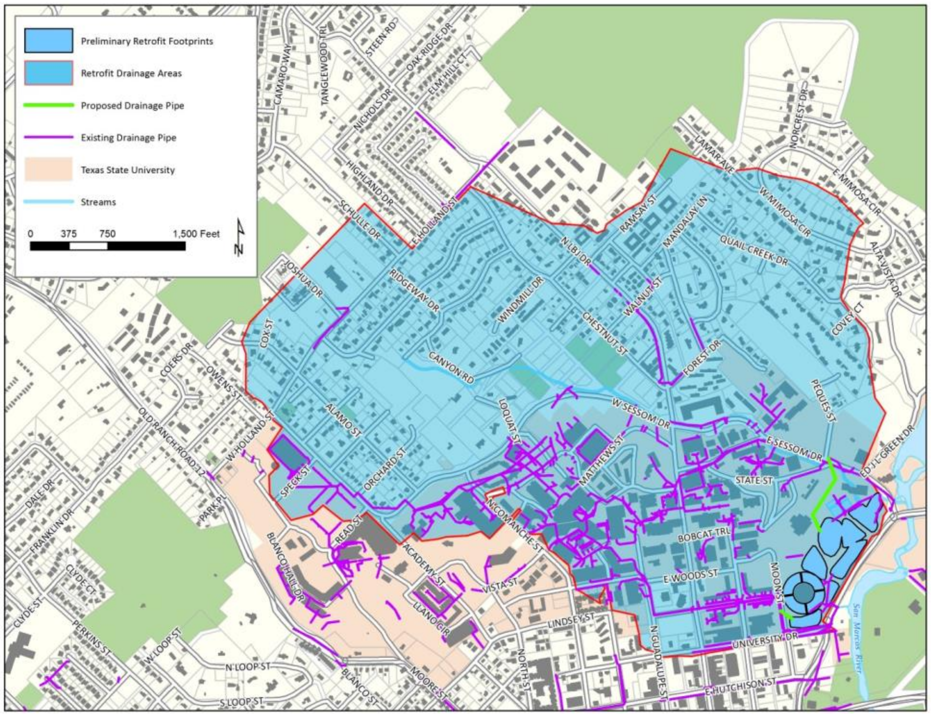
Recommended BMP: Due to the presence of springs and the size of the drainage area, it is recommended that this site remain a wet pond.

Project Elements: Multiple scenarios were evaluated involving Sessom Creek Wet Pond, with the first being to improve the existing pond alone (Project #10231). Even utilizing optimistic assumptions regarding the space available to expand the pond footprint, the resulting surface area (1.4 acres) is only 0.3% of the contributing drainage area whereas greater than 1% is recommended. While maximizing the benefit of the existing pond is advisable, it is likely not possible to achieve an appropriately sized wet pond for the contributing drainage area without combining it with the adjacent Fish Ponds in some manner. Therefore, some scenarios evaluated here involve connecting the Fish Ponds and there is overlap between these scenarios and those described in 9.3.3.1 above. The scenario with the highest weighted average on the prioritization matrix was Sessom Creek Wet Pond 3 (# 10233). This project would involve the following elements:

- Increase storage volume in Sessom Creek Wetpond by excavating accumulated sediment and expanding the pond footprint from approximately 0.5 acres to approximately 1.4 acres
- Improve access for routine maintenance off of University Drive
- Connect all Fish Ponds (3 through 11) such that they outfall to Sessom Creek Wet Pond
- Connect a 52-acre western drainage area to Pond 6 of the Fish Ponds
- Connect a 16.8-acre drainage area to Pond 5
- Connect a 413-acre Sessom Creek Drainage Area to Pond 10 (as described in the Section 9.3.3.1 above)
- Make necessary improvements to Sessom Creek Wetpond and all Fish Ponds to maximize water quality benefit:
    - Remove accumulated sediment
    - Add or replace pond liners to reduce seepage and makeup water demand
    - Add extended detention to be stacked on top of the water quality volume as possible
    - Add trash racks at pond inlets to keep litter out of ponds
    - Add more aquatic plants to enhance stormwater treatment

This project is similar to the one described in Section 9.3.3.1 (Fish Ponds 3) only all Fish Ponds have been connected and 68.8 acres of additional drainage area were added. See Figure 9-8 for a plan view of the preliminary BMP footprint.

Figure 9-8 Sessom Creek Wet Pond 3: Concept Plan



Plan: Complete Watershed Solutions LLC

Project Benefits and Challenges: As described in 9.3.3.1, this project would add stormwater treatment functionality to the fish ponds while maintaining their aesthetic appeal and replacing river water as a source to maintain permanent pools. It would be a good demonstration project in such a high visibility area and there would be no need to completely re-purpose land to use existing ponds. The challenges foreseen in re-routing Sessom Creek into Pond 10 also apply to this project. If these issues can be addressed, the project would remove an estimated 253 lbs of TP annually and cost on the order of $11.6M including $1.4M anticipated for stormsewer re-routing. Of all projects evaluated for Texas State and City of San Marcos, this would be the greatest pollution load reduction. It should also be noted that, while the pond footprint is on TXST property, a large portion of the drainage area is City of San Marcos property (see Figure 9-7 above), which might justify cost-sharing to implement a mutually beneficial retrofit. As explained in Section 10.3.1.3, the City of Austin's Adams and Papa model was used to estimate these load reductions. The runoff capture efficiency is predicted to be 100% and therefore the stream protection and load reduction goals are assumed to be achieved.

Alternatives: Two other Sessom Creek Wet Pond Projects were evaluated and also have potential:

- Sessom Creek Wetpond 1 (# 10231): This is a scaled down project where only Sessom Creek Wetpond is improved and not combined with the Fish Ponds. This would be a much less expensive option (~2.16 M) but also removes less pollution (101.2 lbs TP), and does not address the makeup water demand for the existing fish ponds. Additionally, the resulting wet pond would remain greatly undersized for its drainage area resulting in need for frequent maintenance.

- Sessom Creek Wetpond 2 (#10232): This scenario involves connecting ponds 5, 6, 7, and 11 and having them outfall to the wetpond instead of the San Marcos River. This project would route 68.8 acres into the pond system. However, without re-routing Sessom Creek, the bulk of the drainage area (413 acres) would be routed to Sessom Creek Wetpond without having an opportunity to enter the Fish Ponds. This is due to the 6-foot elevation difference as described above in Section 9.3.3.1. The wetpond would therefore remain undersized resulting in frequent (and expensive) maintenance need. Furthermore, the drainage area to ponds 5, 6, 7, and 11 (~69 acres) would likely be too small to maintain a permanent pool without a great deal of makeup water from the river. Nevertheless, the pollution removal is estimated to be 162 lbs of TP at an estimated cost of $5.8M.

Related Planning Documents: No conflicts with the TXST Master Plan were noticed with this project and it seems consistent with the goals of the Concho Green project, Peques and State Street realignment, and the renovation of THEA.

9.3.3.3The Gulch 2 (#10432)

The Gulch is an existing extended detention pond located on the northern edge of campus and adjacent to the Cogen Plant (CGN) near West Sessom Drive and Tomas Rivera Drive. The pond has some erosion issues on its steep side slopes and near its inlet. It also has an outlet structure that appears to be constructed of welded wire mesh and filter fabric. Vegetation has taken root in accumulated sediment on top of this structure. While the structure appears to be functioning mostly as designed, if someone were to climb on top of this structure they might fall through. Furthermore, the filter fabric will degrade and the welded wire mesh will rust. The drainage area to this facility is approximately 57.3 acres with 41.5% impervious cover and drains to Sessom Creek. Given the highly developed nature of the Sessom Creek watershed and the amount of impervious area draining to this existing facility, the Gulch is an attractive opportunity for a water quality retrofit.

A site visit to the Gulch revealed erosion issues on the pond slopes, a potential safety issue with the pond outlet, nuisance conditions in standing water near the outlet, and confirmed good potential for stormwater treatment. Figure 9-8 below shows the pond outlet structure with weeds growing in accumulated sediment and surrounded by standing water.

Figure 9-9 The Gulch Outlet and Standing Water

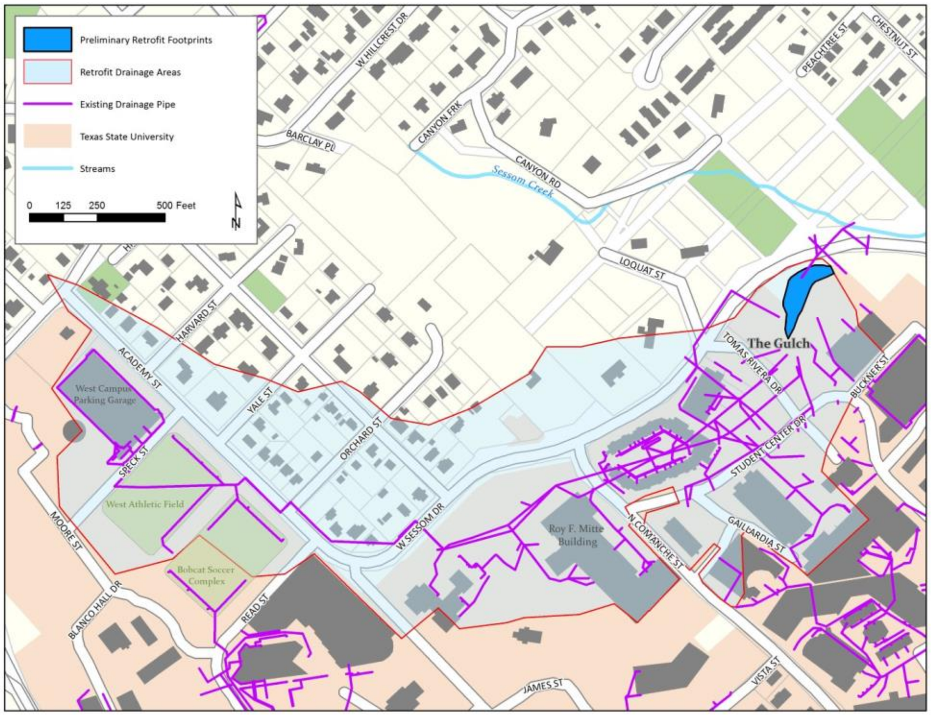
Photo: Lee Sherman

Recommended BMP: The Gulch currently functions as an extended detention pond for this drainage area. Properly designed extended detention ponds can provide modest pollution removal via settling of particulates (and the hydrophobic pollutants attached to them) and also reduce the potential for flooding and erosion in receiving waters. They produce a lower effluent quality compared to a biofilter, which removes smaller particulates and does a much better job removing nutrients and dissolved pollutants. However, in this case the modeling shows this option is more cost effective than implementing a biofilter. It is therefore suggested that the facility remain an extended detention basin and some improvements be made to improve function and safety.

Project Elements: The proposed project elements include the following as shown in Figure 9-7:

- Replace the outlet structure with a more durable alternative and design to ensure a 48-hour drawdown time.
- Add debris screens and a micro-pool to prevent clogging.
- Improve energy dissipation at pond inlet
- Address erosion issues on side slopes with appropriately sized riprap and/or retaining walls

Figure 9-10 The Gulch: Concept Plan



Plan: Complete Watershed Solutions LLC

Project Benefits and Approach to Sessom Creek: The Gulch presents one of the best opportunities to reduce pollution loads within the Sessom Creek watershed. It has a large drainage area with high impervious cover. Also, an existing facility is present that is in need of improvement. Other public lands exist within the Sessom Creek watershed but would require extensive tree removal to construct a BMP, which would offset some of the environmental benefit achieved. The Gulch provides an opportunity to remove approximately 13.9 lbs of TP annually at an estimated capital cost of $257,435 without the need for clearing or re-purposing land and with the added benefit of addressing existing erosion and safety issues. The runoff capture efficiency is predicted to be 94% and both load reduction and stream protection goals are achieved with this project.

Project Challenges: As envisioned, this project seems relatively straight-forward although construction access and limited space for contractor staging do present some challenges. As in most construction projects, especially those that are drainage-related, progress is often periodically delayed throughout the project construction period due to wet weather impacts.

Alternatives: Adding a biofiltration component to this facility was also evaluated. This approach would greatly improve the effluent quality (especially for dissolved pollutants) and result in a much greater load reduction of TP. To accomplish this, planted filter media would be placed near the outlet instead of the current outlet structure. Water would pass through this media to be collected by an underdrain system that would convey treated effluent to the existing outlet pipe. It is common in areas such as Denver, Colorado to combine filtration with detention in this manner. If this was done the cost would increase significantly ($1.3M compared to $257K) as would the pollution removal (27 lbs TP removed compared to 14 lbs).

The WQPP acknowledges that retrofit opportunities are being considered in densely wooded areas of the Sessom Creek Watershed. Prior to clearing these wooded areas, the WQPP team suggests The Gulch be considered along with the following potential projects: Hummingbird Hollow (# 10250) and Peques Street (# 10450). Of the opportunities on public lands that are wooded, Sessom Creek Greenspace 2 (#10101) appears to be the best and least invasive opportunity.

Related Planning Documents: No conflicts were noted with planned development and the 2012 – 2017 Implementation Plan shows a Cogeneration Plant addition near the Gulch. This project might provide an opportunity to make improvements to The Gulch and doing them together might minimize disturbance from construction.

9.3.3.4The Glade 1 (#10441)

The Glade refers to a corridor on the southwestern edge of campus that drains to Purgatory Creek. The Glade Outdoor Theatre (GLA) is located here along with disc golf, trails, and vehicular access for maintenance vehicles. The drainage to this area is significant with an area of 25.7 acres and 34% impervious cover. A recycling facility (RECY) is located at the downstream end of this area where a diversion wall / flume redirects wet weather flows into a roadside ditch along Old Ranch Road 12 and it eventually enters the storm sewer system approximately 350 feet downstream. A site visit revealed opportunity for two rain gardens, scour of a pier supporting the outdoor theatre, and an existing detention facility at the downstream in need of improvement. Figure 9-11 shows a photo of the existing detention facility at the downstream end.

Figure 9-11 The Glade: Photo of Existing Detention Facility Outlet

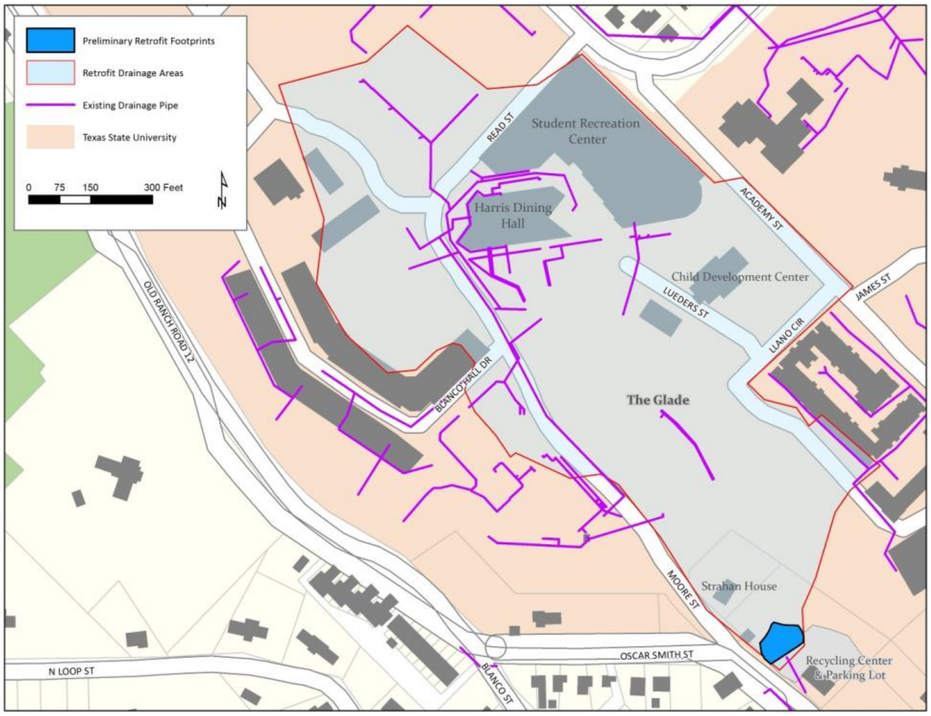
Photo: Lee Sherman

Recommended BMP: At the downstream end, near the recycling center, a biofilter is recommended with stacked detention to improve water quality and better control the stormwater flows in this location. See the Concept Plan shown in Figure 9-12.

Project Elements: The proposed project would consist of the following elements.

- A biofiltration facility with stacked detention is recommended to replace the existing facility at the downstream end of the project near RECY. This would improve water quality and better control flooding of this area.
- While not included in the cost estimate, there is opportunity for trail improvements and erosion repair between the two rain gardens mentioned above as well as below GLA where the storm sewer outlets and has exposed one of the foundation piers. Elements of natural channel design may be used to create an attractive, stable flow path that would be an amenity rather than a safety hazard and potential future structural problem for the stage.
- TXST and COSM coordinate to improve ditch and/or storm sewer system near RECY such that flood flows are directed into a more defined roadside ditch or storm sewer inlet.

Figure 9-12 The Glade Concept Plan



Plan: Complete Watershed Solutions LLC

Project Benefits: The Glade provides an opportunity to improve water quality, repair erosion and drainage issues, and improve trails such that the area is more accessible and aesthetically pleasing. 8.9 lbs of TP are anticipated to be removed annually with this project at an estimated capital cost of $391,500. The model predicts both load reduction and stream protection goals are achieved.

Project Challenges: This project as envisioned is relatively straight forward. The most challenging portion is anticipated to be the collaboration between COSM and TXST to improve conveyance along Old Ranch Road 12 at the pond outlet near RECY.

Alternatives: Areas have been identified for two, filtration style rain gardens at the upstream end of the corridor near Harris Dining Hall (HDH) and another just upstream of the outdoor theatre. Various alternatives were evaluated including combinations of the rain gardens and the stacked detention biofilter at the downstream end of the corridor. If TXST chose to add the both rain gardens, the estimated capital cost would increase from $391,500 to $602,600 and the pollution load reduction would increase from 8.9 lbs to 9.3 lbs, which is a small increase for the extra cost. The rain gardens are therefore not recommended since the biofilter alone does the bulk of the pollution removal for a lower cost. TXST might consider implementing the rain gardens and trail improvements through volunteer efforts and/or engineering class projects for a lower cost. More information on the two rain garden opportunities is provided below:

- A filtration rain garden opportunity is located near HDH where various building drains outlet using an improved vehicular access road as a berm at the downstream end to provide capture volume. The underdrain would outlet into the existing drainage path. This project is estimated to remove 2.6 lbs of TP at a cost of $105,000.
- Filtration rain garden just upstream of the area inlet to the storm sewer pipe running beneath GLA. The underdrain will enter into the existing storm sewer inlet and any overflows will enter through the area drain. This project is estimated to remove 2.9 lbs of TP at a cost of $106,000.

Related Planning Documents: No conflicts have been observed with the TXST master plan. The biofiltration with stacked detention facility might be timely to undertake along with the new Facilities Maintenance building to be constructed adjacent to RECY. Also, new West Campus housing is currently under construction and this might provide an opportunity for retrofitting with rainwater harvesting in the future.

9.3.3.5 Jowers Center 1 (#10471)

Jowers Center provides a great opportunity for demonstration of green infrastructure and decentralized stormwater controls. It is also in a highly visible area near a popular swimming and tubing destination, which provides a unique public education opportunity for those enjoying the resource being protected. A number of rainwater harvesting and rain garden opportunities exist on this site that would treat a total drainage area of 9.8 acres with 70.5% impervious cover. It is recommended that this project be completed together with the retrofit planned for City Park adjacent to Jowers Center. Doing the projects together would maximize pollution removal to the San Marcos in this area and provide an opportunity for positive collaboration between TXST and COSM.

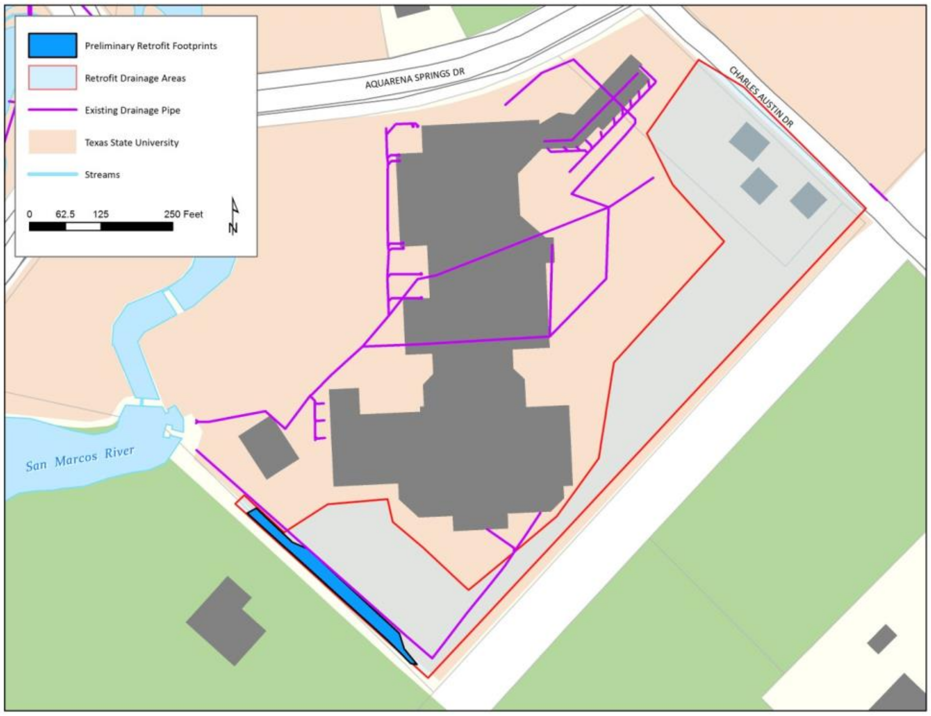
A site visit to this location revealed an opportunity for two rain gardens and a rainwater harvesting system and confirmed the location of a stormsewer outlet for the area drains near the City Park boundary. Though challenging to see due to poor lighting conditions, Figure 9-13 shows this outfall.

Figure 9-13 Photo of Jowers Center Storm Sewer Outfall

Photo: Lee Sherman

Recommended BMP: The WQPP team considered a number of green infrastructure BMPs for Jowers Center. Two, 10,000-gallon rainwater harvesting cisterns were evaluated to treat the rooftops, which would reduce the potable water demand to a landscaped area of 20,000 square feet by over 50%. In addition to this system, a filtration style rain garden was evaluated at the western edge of the property to treat runoff from asphalt driveways prior to entering an area drain that currently sends this runoff untreated into the San Marcos River. Finally, on the concrete patio area overlooking the river near the pedestrian bridge in Sewel Park, an opportunity exists to remove some impervious cover and create a highly visible infiltration rain garden in its place. This project could be a great example of how green infrastructure can be implemented in an aesthetically pleasing manner and also be used as public education. Of all opportunities considered, the project ranking highest in the prioritization matrix was the filtration rain garden at the western edge of the property as shown in Figure 9-14.

Figure 9-14 Jowers Center 1: Concept Plan



Plan: Complete Watershed Solutions LLC

Project Elements:

- Filtration style rain garden with underdrain and overflow connected to the storm sewer draining to the San Marcos River along the southwest boundary adjacent to City Park.
- Educational signage providing public education opportunity to those enjoying the river
- Elaborate landscape plan irrigated by rainwater to demonstrate green infrastructure is aesthetically pleasing and multi-functional

Project Benefits: The filtration raingarden (# 10471) is estimated to remove 3.5 lbs of TP at an estimated capital cost of $176,000. It would also serve as a public education opportunity given the popularity of the destination for river recreation.

Project Challenges: As envisioned, this project is relatively straight-forward.

Alternatives: If all elements were implemented (Project ID 10474), it is estimated that 14.3 lbs of TP per year would be removed at an estimated capital cost of $643,500. It would also be an opportunity for TXST to gain experience with a variety of green infrastructure types, take advantage of a public education opportunity, improve aesthetics of the area near Jowers Center, and reduce potable water consumption. If all project elements are incorporated, the model predicts both load reduction and stream protection goals would be met for 9.8 acres of contributing drainage area

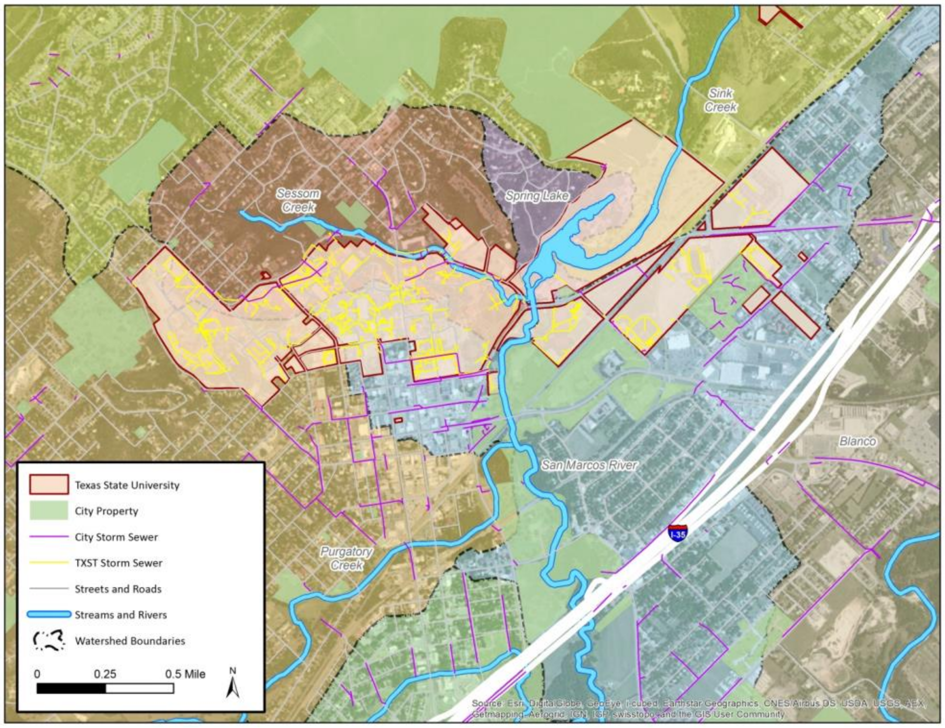
As discussed at the beginning of this section, it is recommended that this project be completed in conjunction with City Park (# 10057 see Section 8.5.4.2) to maximize benefits and engage in a cooperative project with the COSM. Water does not respect jurisdictional boundaries and there are other projects such as the Big Ditch (# 10061 see Section 8.5.3.1) where both the City and University could work together to reap a mutual benefit. This project might provide an opportunity to work together before cooperating on larger projects.

Related Planning Documents: Jowers Center is recommended for renovation in the near-term, which may present an opportunity to implement the recommended green infrastructure. The bike path planned along this corridor should not be in conflict.

9.3.3.6Shared Drainage Infrastructure

A considerable portion of the existing drainage infrastructure downstream of the Campus is shared, in a sense, by both entities. Although ownership of infrastructure can be clearly defined, and separate jurisdictional responsibilities identified, often the water within the pipes and channels is a mix of runoff from both Campus and City areas. Since the University is at the high point of the central urban core, a frequent scenario is that campus runoff is intermingled with that from the City on its way to local creeks and the Upper San Marcos. Figure 9-15 illustrates this concept of shared infrastructure by way of a color-coded map. The map considers all water-related facilities, whether man-made or natural, as drainage infrastructure.

Figure 9-15 Map Showing Drainage Infrastructure Shared with the City



Plan: Complete Watershed Solutions LLC

In consideration of this issue, the Texas Legislature has determined that the University is not responsible for ongoing maintenance and, potentially, improvements to this City-owned infrastructure. Nor is there any requirement to compensate the City for this use of their drainage system. Nevertheless there are costs involved in maintaining shared infrastructure and should be considered when addressing relative responsibilities for stormwater treatment. In particular, stormwater retrofit project opportunities that are intended for comingled runoff provide opportunities for integrated, collaborative projects that benefit both entities.

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The University and the City will want to consider a shared approach to the costs of certain projects when such arrangements are in the best interest of each entity. When might these interests be triggered?

- To protect natural resources such as Critical Habitat and ultimately, public health, by reducing erosion and pollution
- To reduce flooding and property damage as it relates to shared drainage infrastructure
- To reduce long-term costs by protecting the integrity of shared drainage infrastructure

For stormwater transport facilities, including channels and storm sewer pipe, it may be desirable to define a formal policy on cost sharing which sets forth basic policies and procedures (Stockton Council, 1991). The Plan offers the following procedures for discussion:

1. When a definite quantity or benefit ratio can be determined, that method shall be used in developing the cost sharing formula. The formula can be based on the amount of flow carried and/or jurisdictional drainage area accommodated.
2. When a project benefits the City and University on approximately the same basis, and there is not a definite item to spell out the benefits, then the cost sharing shall be split evenly (50-50).
3. In those instances where none of the above formulas are workable, then staff shall develop a cost sharing formula for the project in question and submit same in the form of a report for submission to the City Manager and a University designate.

9.3.3.7BMP Maintenance

When it comes to BMP implementation, maintenance is often an afterthought. To protect the investment of public resources in a stormwater management facility, it is vital to ensure proper maintenance and plan ahead so that the design accommodates straight-forward maintenance. Without proper planning and maintenance, an asset can devolve into an unattractive and poorly functioning liability. The University is strongly encouraged to plan ahead for this critical aspect of watershed management and include maintenance personnel in reviewing the design of any BMP that moves forward to construction. Refer to Chapter 11 for information on proper BMP planning and design procedures that will help minimize the time and resources necessary for BMP management and maintenance.

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9.3.3.8Costs and Funding

It's important that Texas State University commit to implement high-priority, cost-effective stormwater retrofits within a reasonable time frame. Given such a commitment, many questions arise regarding funding. How will the University pay for potential new drainage improvements? Given how critical the San Marcos River is to the environmental and economic vitality of the city, it seems prudent that the University invest adequately in the integrity and health of the River.

Grants: The WQPP team is working with the Meadows Center for Water and the Environment to pursue EPA 319 Grants that will help fund future potential stormwater retrofits. Successful applications for grant funding will rely on the contribution of matching funds and resources from the University. If the application for these funds is successful, receipt of the funds will start in 2016 with the life of the grants being a five-year period thereafter.

10. IMPLEMENTATION AND ACCOUNTABILITY

The San Marcos Water Quality Protection Plan is intended to present numerous, well-considered water quality protection strategies from a holistic viewpoint. In order for the Plan to be successful however, execution is needed. Well prepared plans will provide no real water quality protection if they're not implemented. The following information outlines a general implementation strategy and describes specific implementation mechanisms.

The Edwards Aquifer Habitat Conservation Plan required the development of this Water Quality Protection Plan however it does not mandate that the City of San Marcos and Texas State University implement all of the measures contained herein. Thus it is up to the decision-making bodies of each entity to decide which WQPP recommendations will be implemented. The WQPP team believes that all of the measures recommended in this Plan are worthwhile and necessary for the adequate protection of critical habitat in the Edwards Aquifer, Spring Lake, and the upper San Marcos River. The City of San Marcos and Texas State University each have the legal authority to implement all of the recommended protection strategies.

The WQPP recommends that generally, water quality requirements apply equally to the City and the University. With equal compliance by the City and University, the recommended approach:

- Brings uniformity to protection measures provided by each entity
- Advances the sustainability goals of each entity
- Appeals to an overall sense of fairness

10.1 CITY OF SAN MARCOS

The City of San Marcos is a Home Rule Municipality. This is a subdivision of the state vested with the full power of local self-government through the adoption of a charter conforming to the requirements of the Texas Constitution (Texas Local Government Code, 2005). Home Rule municipalities have relatively broad powers to enact rules and ordinances to protect public health and water quality within their Municipal Boundaries (i.e. City Limits) and their Extra-Territorial Jurisdiction (ETJ).

In response to widespread concerns about governmental intrusions on private real property rights in the mid-1990s (sometimes referred to as the "Take Back Texas" movement), the Legislature enacted the Texas Real Property Rights Preservation Act which is codified in Chapter 2007 of the Texas Government Code. The overriding purpose of the Act was to ensure that governmental entities in Texas take a "hard look" at the effects on private real property rights of the regulations they adopt.

However it appears that reasonable water quality protection measures, such as impervious cover limits and setback requirements from critical environmental features, are not of such an extreme character as would constitute a regulatory taking so long as they do not deprive a landowner of all economically viable uses of his/her property nor impair his/her distinct investment-backed expectations. First, the goal of protecting water quality would clearly appear to qualify as a legitimate state interest since prior U.S. Supreme Court rulings have held that governmental regulations addressing the "ill effects of urbanization" and the preservation of desirable aesthetic features are legitimate state interests. It has also been expressly held by the Supreme Court that governmental restrictions on the use of only limited portions of a parcel of land such as setback ordinances are not considered regulatory takings (Gorieb v. Gox, 1927).

While the imposition of reasonable water quality protection measures does not generally constitute a public regulatory taking of private property, it is also the obligation of development to prevent or mitigate offsite impacts resulting from that development, to prevent a private taking of public or other private property. This concept is also consistent with Stakeholder Guiding Principles Nos. 2 and 3, as described in Chapter 2 of this Plan.

10.2 TEXAS STATE UNIVERSITY

Texas State University – San Marcos is a member of the Texas State University System (TSUS), of which there are eight institutions. The University must comply with Federal and state requirements regarding water-polluting activities. However, the TSUS has sole jurisdiction to regulate development and to own and operate public infrastructure within the boundaries of the Texas State University campus.

The Texas State University System is governed by a Board of Regents, which has authority over the master planning and Capital Improvements Program (CIP) of each institution. Texas State University, the largest member of the TSUS, is, like the others, responsible for developing, maintaining and submitting to the Board of Regents an up-to-date six year CIP that encompasses the capital projects that are needed to preserve, enhance and add to the facilities assets in alignment with their approved Strategic Plan. The Board of Regents has delegated to The Planning and Construction Committee the primary responsibility for making recommendations to the Board regarding the planning, design, construction, maintenance, and use of buildings and other physical facilities.

The application of these water quality requirements to Texas State University will require that they be interpreted for the campus environment. In the municipal environment, the water quality requirements are designed to apply to land parcels of varied ownership and oversight. Individual lot lines and subdivided land parcels do not apply to the campus as they do in the municipal setting. The University is a single owner, not under the jurisdiction of the City, responsible for the infrastructure of a large, contiguous area within the Plan boundary. This is an advantage in that it allows a more holistic approach that may be customized for the needs of the receiving waters. A logical approach would be to apply water quality requirements for new development on the basis of the potential impact of the facility to campus subwatersheds (drainage areas). As a starting point, the WQPP proposes that the requirements be applied on a trial basis to selected campus improvement projects as identified in the 2012 – 2017 Campus Master Plan.

10.3 ADAPTIVE MANAGEMENT

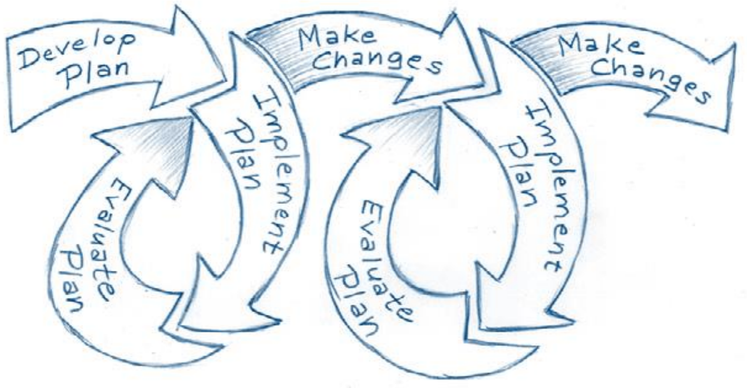
Adaptive management is a process allowing for periodic evaluation and adjustment of programs.
The concept of adaptive management will be applied to assessing the effectiveness of the water quality protection measures implemented, evaluating new technologies and new scientific data, and recommending and implementing solutions for measures determined to be ineffective. The adaptive management process should include all aspects of the plan in all jurisdictions.

The proposed goals and strategies may be said to err on the side of caution, in that prevention is rated a better strategy than remediation. The measures should be periodically reviewed and revised, as necessary, to reflect increased knowledge and experience. These reviews could be a component of the HCP Adaptive Management Process (AMP), thus bringing in needed scientific expertise and rigor.

The process of developing the WQPP plan has been systematic, logical, and well-thought out in order to facilitate stakeholder understanding, input, and agreement. The Plan is iterative and adaptive, so that it can be revised as knowledge and experience are gained. The Adaptive Management Process (AMP) is recommended by the US EPA (see Figure 10-1.) and required under the HCP. Current plans call for the WQPP team to implement the AMP approach to the Plan through the year 2019.

Figure 10-1 Adaptive Management Process Diagram

Figure from EPA "Watershed Handbook"



10.4 CONCLUSION

It's a challenge to understand the structure and functioning of the integrated environmental and socioeconomic systems at work within the Plan Area. An even greater challenge is to combine that understanding with the necessary resources and the commitment to effectively implement a Plan such as the WQPP. Yet many positive environmental impacts will likely result from actions undertaken based on the measures recommended by the Plan. The natural flow regime and water quality of the springs and river inhabited by the covered species will be maintained to the greatest extent feasible.

Socioeconomic impacts are likely to be positive as well. Improved protection of endangered species habitat will help ensure the viability of eco-tourism associated with these species in San Marcos. No significant impact to the City or the University demographics is expected as a result of WQPP implementation. The proposed projects are not located in a low-income area and a disproportionate burden is not expected to fall upon low-income or minority communities as a result of the WQPP recommendations.

The more protective measures should not necessarily be construed as being more expensive than current requirements. In particular, Low Impact Development design may offer considerable advantages when compared to traditional development, e.g., lower cost, more developable lots, and improved site hydrology and water quality (Texas LID Workshop, 2011, USEPA, 2007). Also, the proposed strategies attempt to integrate stormwater management with water conservation and landscape design, e.g., use the landscape to capture and treat stormwater, thus cost benefits can accrue through synergistically combining these elements. As has been demonstrated elsewhere, combining stormwater management with landscape design can result in visual assets that can enhance the quality of development and increase property values (USEPA, 1995). The long term prevention of impacts is another important cost consideration that is typically not incorporated into short-term, profit driven economic models, but long-term sustainable development should be an overall goal for the City of San Marcos and Texas State University.

11. STORMWATER TREATMENT BMPS, HYDROLOGIC AND WATER QUALITY CONSIDERATIONS

The negative effects of urban development on hydrology and water quality can be partially offset by the proper design and implementation of stormwater best management practices (BMPs). Stormwater BMPs are designed to capture runoff and remove pollutants using physical, chemical, and/or biological treatment processes. BMPs should be designed to reduce the flowrate and/or volume of runoff and, in water-challenged Texas, the capture and reuse of runoff can reduce demands on limited potable water supplies. Where possible, infiltration should be incorporated into BMPs in order to reduce runoff volumes and recharge groundwater sources.

The International Stormwater BMP Database Project recommends that the primary measures of BMP performance be the following (BMPDB, 2007):

- To what degree does the BMP reduce runoff volume
- How much runoff is treated (versus bypassed)
- What is the effluent quality of the treated stormwater
- How well does the BMP reduce peak runoff rates, especially for smaller, frequent storms (which helps reduce hydromodification)

Related measures that affect BMP selection include:

- Control channel forming flows (prevent hydromodification)
- Maintain or enhance infiltration and recharge

11.1 TYPES OF STORMWATER TREATMENT BMPS

The BMPs of primary interest in this document are the following:

- Sedimentation, or Extended Detention
- Sand Filtration
- Biofiltration
- Rain Garden
- Retention/Irrigation
- Vegetative Filter Strip
- Vegetated Swale
- Wet Pond
- Constructed Wetland
- Infiltration Basin
- Permeable Pavement
- Rainwater Harvesting
- Green Roof
- Proprietary or other BMPs

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Sedimentation/Extended Detention

A sedimentation basin, also known as an extended detention basin, is a pond that stores runoff and slowly releases it through a riser pipe or similar outlet structure. The outlet structure is designed to detain water for an extended time, typically 24 hours or longer, thus is also known as an extended detention basin. The primary pollutant removal mechanism is settling of particulates, thus the name sedimentation. If the pond does not have an impermeable liner, or the basin bottom has not been compacted or hard-surfaced, some limited infiltration may occur. An alternative design is a Batch Sedimentation Basin, which uses an electro-mechanical system to control detention time, and that can achieve better pollutant removal.

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Sand Filtration

Sand filtration BMPs are in a category of BMPs known as media filters. As the name implies, the primary media is sand. These typically have 1-2 feet of media with an underdrain system that discharges treated effluent as surface water. A typical design drawdown time is 48 hours, which requires the installation of an underdrain orifice, as the sand media itself may have such high permeability, that the BMP would drain too fast (thus would not adequately control hydromodification/erosive flows). If preceded by an extended detention basin, an underdrain orifice is unnecessary. Sand filtration is in widespread use in Austin and the Chesapeake Bay region. The primary removal mechanisms are sedimentation and physical filtration, but some infiltration into the underlying soil also occurs.

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Biofiltration

Biofiltration is also a type of media filter, but is designed to be a “living” system, with vegetation and a more biologically active media than sand. These can be designed as either surface discharge BMPs (underdrain system with orifice) or infiltration BMPs (no underdrain system, no impermeable liner). Removal mechanisms include sedimentation, physical filtration, sorption, plant uptake and biological treatment, and cation exchange (see Figure 11-1).

Figure 11-1 Biofiltration BMP

Credit: John Gleason

Rain Gardens

Rain garden BMPs are similar to biofiltration except have shallow ponding depths, typically less than 1 foot, and small drainage areas (see Figure 11-2). Rain gardens are also known as bioretention systems. These can be designed as either surface discharge or infiltration systems. The removal mechanisms are the same as for biofiltration.

Figure 11-2 Parking Lot Rain Garden in Frisco, Texas

Credit: Patrick Hartigan

Retention/Irrigation

Retention/Irrigation is a dual system, with a retention pond that holds water, and an irrigation area where the stored water is applied to. To protect the irrigation pumping system from clogging, providing pretreatment (e.g., sand filtration) is a good practice. This is a common BMP in the Barton Springs Zone in the Austin area. The removal mechanisms include sedimentation, plant uptake, sorption, and evapotranspiration. A drawback to this BMP is the need for an electro-mechanical operating system, which requires more maintenance than passive, gravity-driven BMPs. Also, only a limited amount of infiltration or recharge is likely, as much of the irrigated water will be lost to evapotranspiration – this can be an important issue in the Recharge Zone, where maintaining or increasing existing infiltration rates is a goal.

Vegetative Filter Strip

A vegetative filter strip is grassed area that runoff is discharged to as sheet flow. Some filter strips near streams may be composed of other vegetation, such as trees and understory plants. Removal mechanisms include physical sedimentation and filtration by vegetation, soil sorption, and infiltration, the latter an important mechanism for reducing runoff volume and recharging groundwater.

Commented [D21]: Revised Dec 2014

Vegetative Swale

A vegetated swale is an open channel that is typically designed for stormwater conveyance, but can be designed to provide runoff treatment during smaller storms, especially via infiltration. Appropriate soil conditions must exist for infiltration to be effective, and special precautions are necessary in the recharge zone.

Wet Pond

Wet ponds are designed to maintain a permanent pool of water where pollutant removal occurs. Extended detention and flood detention can be “stacked” on top of the permanent pool to provide additional stormwater benefits. Pollutant removal mechanisms are numerous, including sedimentation, plant uptake, biological removal, sorption, cation exchange, and solar irradiation. Wet ponds are not recommended, as the need for makeup water is in conflict with the goal to reduce potable and ground water demand.

Constructed Wetlands

Constructed wetlands are similar to a wet pond but have shallower depths and typically a larger surface area. The removal processes are the same as for a wet pond. As with wet ponds, constructed wetlands are not recommended, because the need for makeup water can conflict with the goal to reduce potable and ground water demand.

Infiltration Basin

An infiltration basin is a pond designed to infiltrate runoff in the bottom of the basin. Other removal mechanisms can include sedimentation and sorption. Appropriate soil conditions must exist for this BMP to be effective and the bottom of the basin should be well vegetated to maintain and enhance soil permeability.

Permeable Pavement

Permeable pavement is pavement designed to infiltrate runoff into the underlying soil. It can be made of a variety of materials, including concrete and asphalt. There are two basic applications for permeable pavement: (1) pedestrian use and (2) vehicular use. Appropriate soil and site conditions must exist for this BMP to be effective (see Figure 11-3).

Figure 11-3 Permeable Pavement

Credit: Tom Hegemier

Rainwater Harvesting

Rainwater harvesting (RWH) is the capture and storage of runoff from roofs (typically) for beneficial purposes. The water is often used to replace or augment potable water sources used for non-potable purposes, such as to irrigate landscapes. Storage devices of many shapes and sizes include above-ground cisterns and underground tanks. Irrigation systems that distribute rainwater can be simple or complex, such as “smart” irrigation systems that are activated automatically based on soil and climate conditions. Rainwater harvesting is sometimes assumed to only apply to roof runoff but, for the purposes of this document, the term applies to runoff from any source. Because of significant uncertainty on how this BMP is operated, it is only eligible for “Effective Impervious Cover” credit.

Figure 11-4 Rainwater Harvesting System used to Irrigate Xeriscape

Credit: Patrick Hartigan

Figure 11-5 Parking Lot Rainwater Harvesting System

Credit: Patrick Hartigan

<u>Cost of Rainwater Harvesting for Commercial Sites</u>

Each project is unique, and there is a wide range of features you can include in a design. A rough guide for a commercial scale system capturing an acre of impervious area would be:
Pretreatment: $5,000 to $15,000
Cistern: $20,000 to $40,000 (cisterns often end up sized similar to a Water Quality Volume)
Mechanical System: $5,000 to $40,000 (this varies widely depending on flow rate and treatment)
For larger projects, the cistern would scale up, but the pretreatment and mechanical systems may not need to be larger.

<u>How long it will take to pay off a RWH system?</u>
ROI is very dependent on sizing and what factors are included in the savings. Over a 20-year life, many systems can surpass breakeven and provide a modest ROI based only on the initial capital cost, future maintenance cost and future water utility savings. Many do not, however, and it can be difficult to justify a system solely on water utility savings.

Green Roofs

Green roofs are rooftop systems composed of an absorbent media that can retain water while supporting plant growth however there are design variations. Blue roofs are composed of absorbent media not planted with vegetation, and yet may become naturally vegetated over time. Brown roofs are composed of locally sourced media instead of artificial media typically used for green roofs, and are vegetated with native plants that promote biodiversity over aesthetics. Roofs can be extensive or intensive, the former covering large roof areas and usually having small media thicknesses (< 12 inches), while the latter may cover smaller roof areas but have thicker media (rooftop planters are an example).

When fertilized or over-irrigated, green roofs can become pollutant sources instead of stormwater BMPs, thus operation and management of these systems is critical to their proper functioning.

<u>Green Roof Incentive Programs</u>

Cities that incentivize Green roofs include Washington DC, NYC, Milwaukee, Philadelphia, Toronto, Austin (to be verified: In 2012 Austin passed a green roof density bonus that will enable developers up to an additional 8 square feet of floor space for each square foot of green roof installed.)

<u>Green Roof Loans - Cincinnati</u>: The Ohio Environmental Protection Agency, Metropolitan Sewer District of Greater Cincinnati (MSD), and the Cincinnati Office of Environment and Sustainability have created the Green Roof Loan Program. This program has made $5,000,000 available for below-market-rate loans to install green roofs within the MSD service area on residential, commercial, and/or industrial buildings.

http://www.vegetalid.us/green-roof-systems/green-roof-101/local-incentives

Proprietary BMPs

Proprietary BMPs include a wide range of manufactured devices sold by different companies, some designed only to remove trash and debris, while others incorporate physical, chemical, and possibly biological treatment processes.

Table 11-1 summarizes the applicability of these stormwater treatment BMP's to San Marcos.

Table 11-1 Stormwater BMP Measures for San Marcos

Measure	Receiving Water	Primary Development Category
Rainwater Harvesting and Reuse BMPs	All	All
Infiltration BMPs	All, EARZ after treatment	All
Biofiltration and Rain Gardens	All	All
Vegetative Filter Strips	Primarily EAZ	New
Vegetated Swales	All	New
Retention/Irrigation	EAZ	New
Sand Filtration	Not Recommended	New
Extended Detention (dry) Ponds	All – pretreatment only	New
Wet Ponds and Constructed Wetlands	Only where appropriate	New
Proprietary BMPs	All	All, esp. Existing
Alternative Controls	All	All
Treatment Trains	All	New, Redevelopment
Prohibit Directly Connected Impervious Areas	All	New, Redevelopment
Inspection & maintenance of private & public BMPs	All	All

11.2 RAINFALL CHARACTERISTICS AND SITE HYDROLOGY

Appropriate design of stormwater BMPs in central Texas requires an understanding local rainfall and site hydrology.

11.2.1 RAINFALL CHARACTERISTICS

Characterizing rainfall is important not only for understanding local hydrology, but also for the design of stormwater BMPs. A BMP must be sized such that it has sufficient storage volume and/or treatment rate to provide adequate pollutant removal while emptying its “water quality volume” in sufficient time so that subsequent runoff events can be treated.

Historical rainfall data has been acquired and analyzed for the region from gaging stations in the greater San Marcos area (Sherman, 2012, NCDC, 2013). Following a rainfall characterization procedure recommended by EPA, long-term annual average rainfall statistics were derived using the RAIN block of the SWMM model. Hourly rainfall data was converted into discrete rainfall events, with an “event” defined as any rainfall falling within a 6 hour period or less. For example, if precipitation fell for 2 hours, stopped falling for 3 hours, then resumed for another 4 hours, this would be defined as a single event with a duration of 9 hours. If however precipitation fell for 2 hours, ceased falling for 7 hours, then resumed for another 4 hours, these would be considered as two separate events.

The results of the SWMM RAIN analysis are shown in the following table.

Table 11-2 SWMM RAIN Analysis

Average Annual Rainfall Statistics for Central Texas	
Statistic	Value
Number of events N	80.1
Average event volume v (in.)	0.40
Annual total rainfall P (in)	32.0
Average event duration d (hr)	5.8
Average time between event midpoints Δ (hr)	109.4

This data is input into a probabilistic methodology (Adams and Papa, 2000) that can be used to characterize runoff and analyze BMP performance. In addition, a water quality spreadsheet model has been developed for this project that has expanded BMP analyses procedures, and is described in Appendix G.

Note: The TCEQ Edwards Aquifer technical guidance manual assumes 33 in/yr average rainfall for Hays County, as compared against 32 in/yr shown in the table. The water quality model described in Appendix I uses an average year (1985) that reported 32.49 inches. The authors believe that the difference between these sources is not significant for the purposes of assessing impacts, and BMP selection and design.

11.2.2 RUNOFF CHARACTERISTICS

Runoff Volume

It will be important to be able to estimate the amount of runoff generated by a site that is to be developed. In this section, basic hydrologic relationships are presented and defined, various methods currently in use are described, and a set of procedures and results applicable to the Plan Area are proposed. It should be noted that these procedures are primarily applicable to individual development sites and not large watersheds where more complex surface-ground water interactions occur (e.g., individual development sites are unlikely to have significant baseflow).

A preferred method for estimating runoff would be to calibrate a continuous simulation model (e.g., SWMM, HSPF, SWAT) with monitoring data, from which a flow duration curve can be generated, and various hydrologic metrics calculated, including volume of runoff. Given the complexity of such models, a more simplistic set of procedures will be presented, based on the widely-used approach of estimating annual average conditions. To provide quantitative results, a probabilistic methodology will be utilized (Adams and Papa, 2000) along with an hourly routing model (described in Appendix I). The probabilistic methodology requires that long-term rainfall data be analyzed in order to separate rainfall records into discrete events, which can then be characterized in statistical terms.

For individual rainfall events, it can be assumed that runoff will only begin once the depression storage of the soil has been exceeded, as expressed in the following equation widely used in hydrologic modeling:

$v_r = 0 \text{ if } v \leq S_d$

$v_r = Rv * (v - S_d) \text{ if } v > S_d$

Where v_r is the volume of runoff, v the volume of rainfall, S_d the depression storage, and Rv the runoff coefficient (a dimensionless variable = ratio of runoff volume to rainfall volume). For use in the probabilistic methodology, v is the volume of the annual average rainfall event.

In order to estimate the annual average runoff volume, the following equation can be used:

$R = N_r * v_r$

Where R is the annual average runoff volume, Nr the number of runoff events (i.e., the number of rainfall events where v > Sd, as described above). (Note: the method for estimating Nr is not presented in detail here, but is derived using the Adams and Papa probabilistic methodology).

Other methods for estimating annual average runoff volume

Numerous stormwater manuals use a procedure similar to the one described above, including the following widely used in the Chesapeake Bay regions:

$R = P * Pj * Rv$

Where P is the annual average rainfall volume, Pj is the fraction of annual average rainfall that generates runoff, and Rv is the runoff coefficient.

Both the TCEQ Edwards Rules Technical Manual and the City of Austin Environmental Criteria Manual use a somewhat different equation, e.g.:

$R = P * Rv$

A potential weakness with this equation is that is assumes all rainfall generates runoff.
In order to determine which of the two equations is most appropriate, the derivation of Rv would need to be known. If the dataset used to derive Rv included all rainfall events, i.e., those that did not generate runoff as well as those that did, then the second (TCEQ, COA) equation would be appropriate. However, it is assumed that most Rv data excludes rainfall events that did not generate runoff, thus the first equation would be more appropriate. The probabilistic methodology is preferred over both, as it can more explicitly account for depression storage.

Runoff Coefficient Rv

The runoff coefficient expresses the fraction of rainfall volume that is converted into stormwater runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one acre parking lot can produce 18 times more stormwater runoff than a one acre meadow each year. The increase in stormwater runoff can be too much for the existing natural drainage system to handle. As a result, the natural drainage system is often “improved” to rapidly collect runoff and quickly convey it away (using curb and gutter, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters such as streams, reservoirs, lakes or estuaries.

Confusingly, there are numerous Rv equations in widespread use in the Central Texas area. The TCEQ Edwards Rules manuals (TCEQ, 2005 and TCEQ, 2007a) present three, while the COA Environmental Criteria Manual (COA, 2013) presents two. The following table compares these against the widely-used equation used by ASCE incorporated into the SELECT model (Pomeroy and Rowney, 2012).

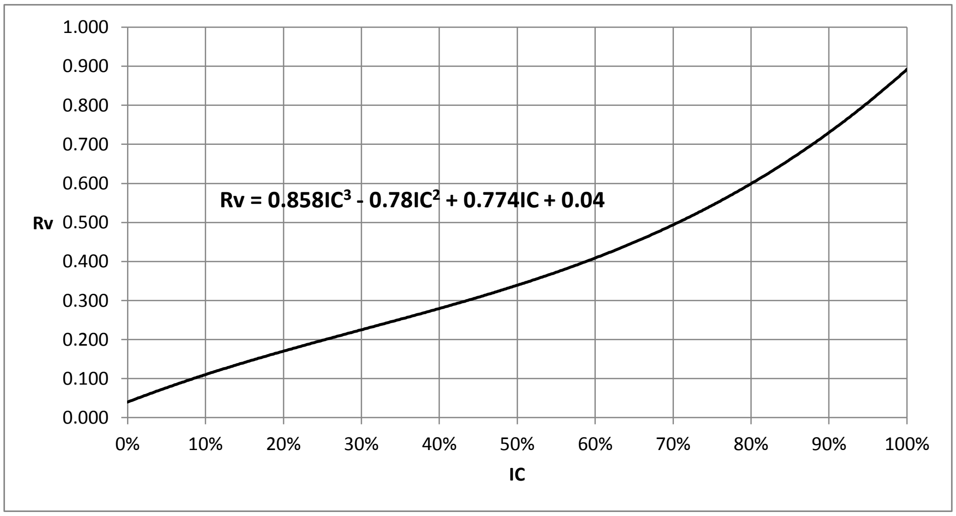
Table 11-3 Comparison of Runoff Coefficient Rv Equations

IC	TCEQ Edwards Rules Manual			COA ECM		ASCE & SELECT Model
	RG-348 Eqn 3.2	RG-348 Eqn. 3.11	RG-348A Eqn. 4.8	Outside Recharge Zone	Recharge Zone	
0%	0.030	0.020	0.050	0.033	0.011	0.040
5%		0.077	0.093	0.049	0.025	0.077
10%		0.125	0.135	0.068	0.043	0.110
15%		0.166	0.178	0.091	0.064	0.141
20%		0.201	0.220	0.116	0.089	0.170
25%		0.231	0.263	0.145	0.117	0.198
30%		0.258	0.305	0.176	0.148	0.225
35%		0.283	0.348	0.211	0.183	0.252
40%		0.307	0.390	0.248	0.220	0.280
45%		0.331	0.433	0.288	0.261	0.309
50%		0.358	0.475	0.330	0.304	0.339
55%		0.387	0.518	0.376	0.351	0.372
60%		0.420	0.560	0.424	0.401	0.409
65%		0.460	0.603	0.474	0.453	0.449

70%		0.506	0.645	0.528	0.509	0.494
75%		0.560	0.688	0.583	0.567	0.544
80%		0.624	0.730	0.642	0.628	0.599
85%		0.698	0.773	0.703	0.692	0.661
90%		0.785	0.815	0.766	0.759	0.730
95%		0.885	0.858	0.832	0.828	0.807
100%	0.900	1.000	0.900	0.901	0.901	0.892

As can be seen, while there can be similar results at the low and high ends of impervious cover, there is considerable variation in-between. Because of its widespread use and incorporation into numerous stormwater quality modeling reference documents and procedures, the ASCE equation is recommended.

Figure 11-6 ASCE Runoff Coefficient vs. Site Impervious Cover (IC)



Depression Storage S_d

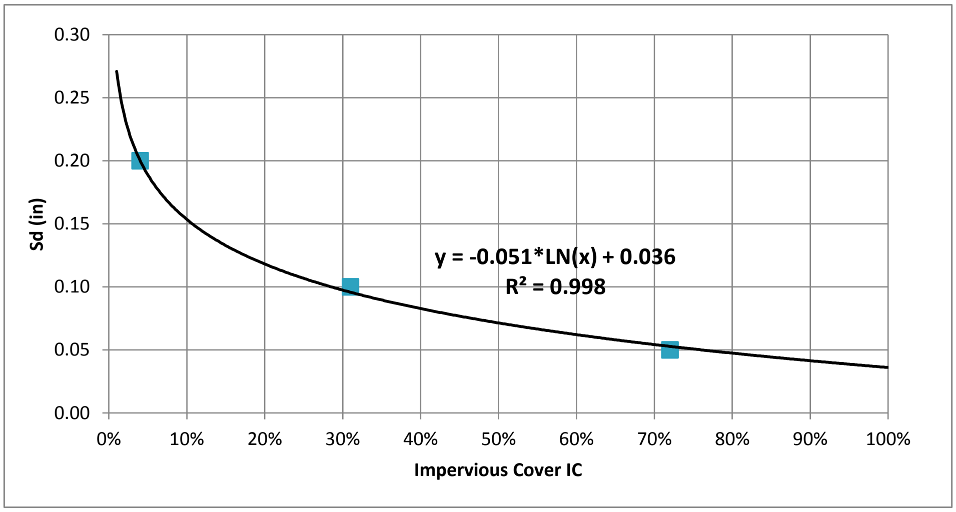
In order to provide reasonable estimates of S_d, the following information from the WERF SELECT model will be used:

Table 11-4 Comparison of Land Use IC and Depression Storage

Land Use	Impervious Cover	Depression Storage Sd (in.)
Undeveloped	4%	0.20
Residential	31%	0.10
Commercial	72%	0.05

Because impervious cover values are provided, a “best fit” curve can be fitted through the data. The results are shown in the following chart. For impervious cover ≤ 0.6%, an S_d value of 0.30 inch should be assumed.

Figure 11-7 Depression Storage vs. Impervious Cover based on WERF SELECT Model Values



Another method for estimating depression storage is to use the SCS Curve Number (CN) method, with the “initial abstraction” (Ia) variable assumed equivalent to depression storage. A potential advantage of this method is that it can more explicitly account for different soil types (e.g., Hydrologic Soil Group or HSG classification), which can be important if soil variations are large in a certain area. In the San Marcos area this can indeed be the case, as soils in the Edwards Aquifer Zone are typically poorly-drained and clayey (HSG C and D), whereas there are pockets of well-drained soils (HSG A and B) along some riparian areas and east of the zone.

Numerous researchers have found that the CN method does not provide good estimates of runoff volume for smaller storms, which are the most frequently occurring, and it should be modified (e.g., COA, 2006) before applying to the annual average runoff procedures described here. At this time, the use of the CN method is not recommended for this purpose.

Results

Incorporating the runoff coefficient, depression storage, and annual average rainfall relationships and statistics into the probabilistic methodology results in the following table, but with runoff volumes provided from both that procedure and from the WQ BMP Model (described in Appendix G). The comparison of volumes shows that results are similar; because the WQ BMP Model has additional capabilities for assessing BMPs, it will be used for subsequent analyses in this chapter.

Table 11-5 Impervious Cover-Runoff Relationships

IC	Sd (in.)	Rv		Runoff Volume (in/yr)

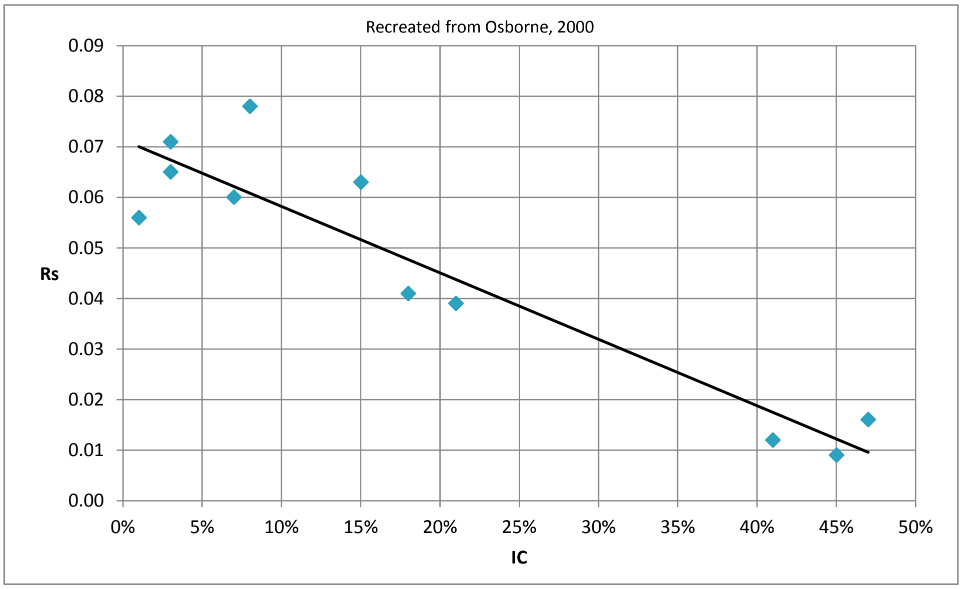
			Nr (events/yr)	**Probabilistic Methodology**	**WQ Model**
0%	0.300	0.040	37.8	0.61	0.80
5%	0.189	0.077	50.0	1.54	1.74
10%	0.153	0.110	54.6	2.41	2.62
15%	0.133	0.141	57.5	3.25	3.47
20%	0.118	0.170	59.6	4.07	4.28
25%	0.107	0.198	61.3	4.86	5.08
30%	0.097	0.225	62.8	5.66	5.87
35%	0.090	0.252	64.0	6.46	6.67
40%	0.083	0.280	65.1	7.29	7.49
45%	0.077	0.309	66.1	8.16	8.36
50%	0.071	0.339	67.0	9.09	9.29
55%	0.066	0.372	67.8	10.11	10.30
60%	0.062	0.409	68.6	11.22	11.40
65%	0.058	0.449	69.3	12.45	12.62
70%	0.054	0.494	70.0	13.82	13.99
75%	0.051	0.544	70.6	15.35	15.51
80%	0.047	0.599	71.2	17.06	17.22
85%	0.044	0.661	71.7	18.97	19.13
90%	0.041	0.730	72.2	21.10	21.26
95%	0.039	0.807	72.7	23.48	23.64
100%	0.036	0.892	73.2	26.12	26.28

Nr is the annual average number of runoff events per year, and ROV is the annual average total runoff. Recall that the annual average number of rainfall events (N) is 80.1, and the annual average total rainfall (P) is 32.0 inches. As can be seen, the number of runoff events and the volume of runoff both increase with impervious cover. This can have important implications in BMP design and performance. Compared to a natural, undeveloped site (0% IC), a site with 100% IC will have almost twice as many runoff events, with more than 30 times the total runoff volume. For the undeveloped site, less than half the rainfall events generate runoff while, for the 100% IC site, over 90% do.

11.2.3 BASEFLOW, INFILTRATION, AND RECHARGE

Stream baseflow is typically sustained by infiltration and recharge of groundwater, thus maintaining or enhancing infiltration in upland areas is important. Urbanization reduces infiltration by replacing pervious areas with surfaces that prevent or reduce infiltration, such as pavement, rooftops, and compacted soils. In Central Texas the volume of baseflow has been found to be correlated to watershed impervious cover. This is illustrated by the following chart (Figure 11-8), which was developed from monitoring of Austin area creeks (Osborne, 2000). In the figure Rs is the ratio of baseflow to rainfall, and is analogous to the runoff coefficient Rv.

Figure 11-8 Stream Baseflow Coefficient Rs vs. Watershed Impervious Cover



Recreated from Osborne, 2000

Estimating Infiltration at the Site Level and for BMPs

Commented [D22]: Much of this is new, and necessary to support the “maintain or increase infiltration” performance standard proposed for WQ Zones A and C.

Maintaining or increasing the existing infiltration rate is a performance standard proposed for Water Quality Zones A and C, thus a procedure is needed to estimate infiltration, on an average annual basis. A simple procedure has been developed that correlates the annual average infiltration volume as a function of site impervious cover, using the widely cited graphics shown below (Figure 11-9).

Figure 11-9 Effects of Urbanization on Water Cycle

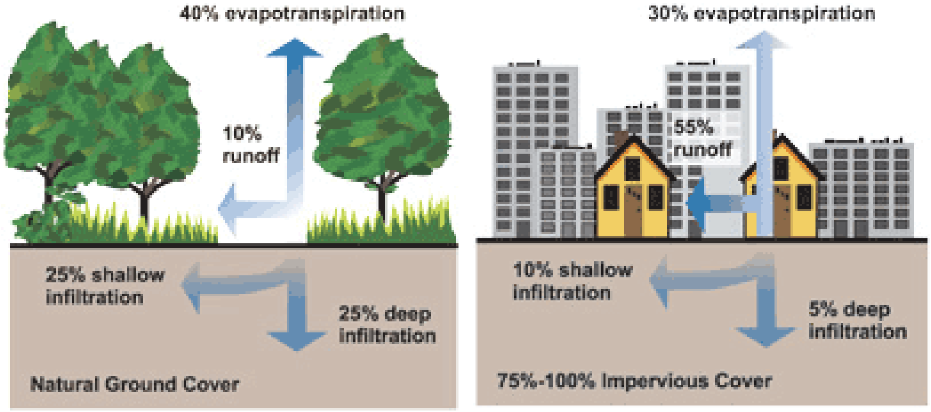


Illustration: US EPA

The figures above represent national data estimates, while Nowlin and Schwartz (2012) made the following assumptions for the Sink Creek watershed, with 94% of the watershed being undeveloped:

- 65% of the rainfall is lost to evapotranspiration
- 10% becomes surface runoff
- 25% is recharged

Nowlin and Schwartz assume more evaporation and less recharge, which is reasonable given the warm and dry Central Texas climate. The hydrologic and water quality model developed for the WQPP calculates a lower runoff volume for undeveloped conditions, though, equating to less than 3% of the average annual rainfall, instead of 10%. Studies by the City of Austin indicate that upland recharge may be higher, also. Recalling that the volume of infiltration for the WQPP model represents both shallow and deep infiltration (latter = recharge), it is reasonable to assume that for an undeveloped site the total infiltration is between 25-50%. It is also reasonable to assume that no infiltration occurs for a completely impervious site: Given these, the following assumptions are made for the WQPP:

- 35% of the rainfall is infiltrated for an undeveloped site
- 0% of the rainfall is infiltrated for a completely impervious site

A simple linear equation can then be derived for estimating infiltration volume, on an average annual basis:

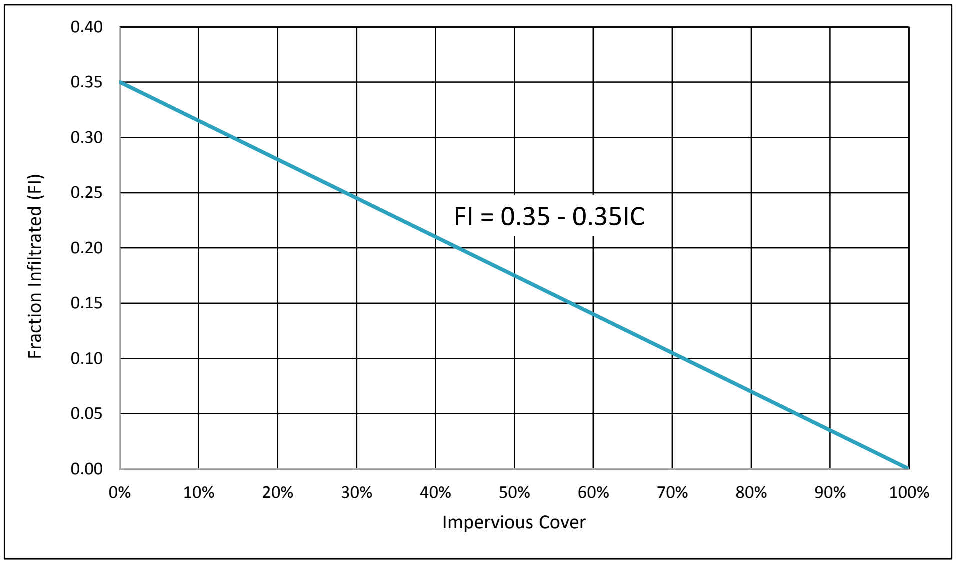
$$VI = FI * P$$

Where VI = volume of infiltration
FI = fraction of rainfall that is infiltrated
P = average annual rainfall = 32.49 inches in the WQPP model

$$FI = 0.35 – 0.35*IC$$

Where IC is the fraction of impervious cover

Figure 11-10 Infiltration Fraction as a Function of Impervious Cover



For a site that implements BMPs, the volume of runoff captured and infiltrated by the BMP can be estimated. This can be readily modeled by the spreadsheet, as the fraction of runoff captured (RCE or Runoff Capture Efficiency) is already calculated. For BMPs specifically designed for infiltration, the volume captured is assumed equal to the volume infiltrated. Example BMPs are Biofiltration or Rain Garden without an impermeable liner, Vegetated Swale, Permeable Pavement, and Infiltration Basin. Vegetative Filter Strips can also infiltrate runoff, in addition to providing treatment of surface runoff that is not infiltrated. A BMP which is assumed to provide only partial infiltration is Retention-Irrigation, as much of the irrigated runoff (estimated 35%) is lost to evapotranspiration, thus only 65% of the capture runoff is assumed to be infiltrated.

BMPs that are assumed to provide no infiltration include Sand Filtration, Sedimentation Basin, any BMP with an impermeable liner, and Green Roofs (the "volume reduction" benefits are due solely to evaporation and/or evapotranspiration). Rainwater Harvesting is not included as this BMP is eligible for Effective Impervious Credit only.

For some of these BMPs, the assumption of no infiltration can be conservative. Monitoring studies have indicated that this may not always be the case. In a study of sand filtration BMPs in Austin (COA, 1990c), typically about 10% of the total inflow was lost to leakage, with evaporation and media storage losses averaged about 5%. The 1990 study also found that an extended detention basin lost about 15% of the inflow volume. The International Stormwater BMP Database Project found that BMP losses could be 30-60% of the total inflow (Geosyntec, 2011c). The leakage rate from BMPs will vary with soil conditions, with less leakage in clayey soil, which are common in Central Texas.

Commented [D23]: Revised Dec 2014; the "Infiltration Coefficient" now only applies to R/I = 65%

Infiltration Volume Example

*A 50% IC site will have a biofiltration (infiltration design) BMP installed, that captures 80% of the annual average runoff volume (RCE = 80%). The annual average runoff for a 50% IC site is 9.29 inches (Table 9-5), thus the BMP is assumed to infiltrate 9.29 * 0.80 = 7.43 inches/year.*

*Based on Figure 12-11, a 50% IC site infiltrates 17.5% (FI = 0.175) of the annual average rainfall, or 32.49 * 0.175 = 5.69 inches*

Thus, the estimated total infiltration volume for the site, with the BMP system, is 7.43 + 5.69 = 13.12 inches per year.

Strategy for Achieving Infiltration in the Edwards Aquifer Recharge Zone

In Water Quality Zone A (recharge zone), the TCEQ requires impermeable liners for pond BMPs designed to meet the 80% TSS reduction standard. While achieving some pollutant removal, this type of design does not help maintain or increase infiltration and recharge, which is a performance standard proposed by the WQPP. The strategy advocated by the WQPP for complying with the TCEQ treatment requirements while also meeting the “maintain or increase existing infiltration” performance standard is to use a “treatment train” as follows:

- Design the first pond BMP to equal or exceed the TCEQ requirements
- Route the discharge from that BMP to an infiltration BMP, e.g., an Infiltration Basin. As the TCEQ treatment requirement has been met by the first BMP, it is assumed there are no infiltration prohibitions for subsequent BMPs (in fact, this is the case for City of Austin BMPs).

Another alternative in Water Quality Zone A is to use either a Vegetative Filter Strip or Vegetated Swale BMP, as these can provide infiltration, but their ability to meet treatment goals is typically limited to small, lower impervious cover sites.

Infiltration Outside the Recharge Zone

Outside the recharge zone, there are no impermeable liner requirements, but proper soils conditions must exist for infiltration to be viable. Rain Gardens and biofiltration BMPs designed with “open” bottoms are examples of BMPs that can provide significant infiltration. Overland flow BMPs such as Vegetative Filter Strips can also provide some infiltration, especially if designed as the second BMP in a series, or “treatment train.” Sidewalks, pedestrian walkways, and other non-vehicular paved areas should be made of permeable pavements as a standard practice. Permeable pavement for vehicular use areas is also an option, but with more restrictive requirements than walkways.

Soils Suitable for Infiltration

Soils used for infiltration should drain well but should not contribute to groundwater pollution, thus should be deep, have organic matter, good cation exchange capacity, and other good filtering characteristics. It appears that San Marcos has several soil series that are acceptable for infiltration of runoff, including Lewisville, Oakalla, Seawillow, Boerne, Altoga, and Sunev. Orif soils have high permeability rates, but may limited filtering capacity. The NRCS categorizes these soils as A and B soils;

these are distinguished from C and D soils which are more poorly drained. Poorly drained soils dominate in the recharge zone, but can still provide some infiltration via overland flow, especially as sheet flow discharge from a storage-based treatment BMP.

11.2.4 HYDROMODIFICATION, STREAM MORPHOLOGY, AND CHANNEL EROSION

Because urbanization can result in significant hydromodification, i.e., increased frequency, magnitude, and volume of runoff, the morphology of streams can be impacted, in particular destabilization of stream beds and banks due to increased shear stress or stream power. These impacts include physical destruction of habitat, erosion threats to in-stream utilities and streamside property, and large sediment loads. Channel erosion can account for 90% or more of in-stream sediment loads (TCEQ, 2005), which can be correlated to the increase in "channel forming" flows caused by increasing impervious cover. As further evidence of the magnitude of stream erosion a local monitoring study (COA, 1990a) reported in-stream Total Suspended Solids (TSS) concentrations during stormflow conditions that were greater than upland runoff by a factor of 10 or more, as shown in the following table.

Commented [D24]: Edited.

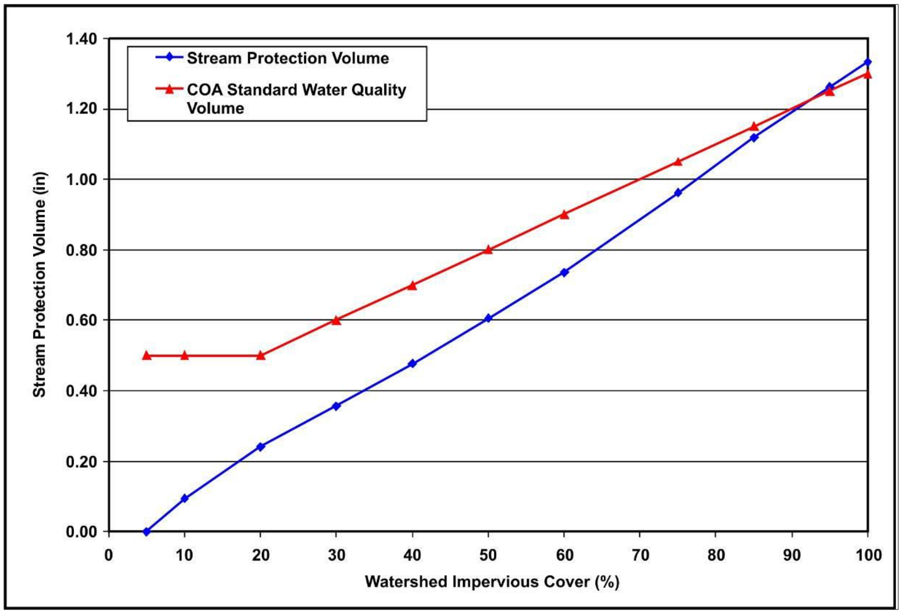
Table 11-6 Austin Monitoring Study: Stormwater Runoff TSS Concentrations

Stormwater Runoff TSS Concentrations (Geometric Mean)					
Uplands Runoff ("small" watersheds)			**In-Stream Stormflow ("large" watersheds)**		
Site	**IC**	**TSS (mg/L)**	**Creek**	**IC**	**TSS (mg/L)**
BC	3%	55	**Barton**	7%	700
RO	21%	173	**Bull**	12%	1600
MI	36%	106	**Williamson**	15%	1000
HL	39%	105	**Boggy**	41%	1936
HI	50%	70	**Shoal**	47%	1839
BCSM	86%	35			
BI	95%	137			

To prevent or mitigate stream morphology impacts, control of "channel-forming" flows is recommended. A typical approach is to provide extended detention of the 1 to 2 year return period rainfall event. The TCEQ Edwards Aquifer "Enhanced Measures" manual (TCEQ, 2007a) has provided criteria under the heading "Measures to Protect Stream Morphology."

A detailed study conducted for the City of Austin (HDR and Kurkijan, 2011) developed an excess stream power erosion index for different stream types, and assessed the effectiveness of the City's stormwater management and water quality treatment requirements. The study found that the City's water quality volume requirements may be greater than necessary for lower impervious cover levels to protect streams, as shown by the following chart (Figure 4-12 from the report).

Figure 11-11 Stream Protection and Water Quality Volumes vs. Watershed Impervious Cover



From the tabulated data provided in the report, a best-fit curve was fitted, and can be used to determine the extended detention volume necessary for different impervious cover levels. The design drawdown time for the volume should be 48 hours.

Figure 11-12 Recommended Stream Protection Volume vs. Impervious Cover

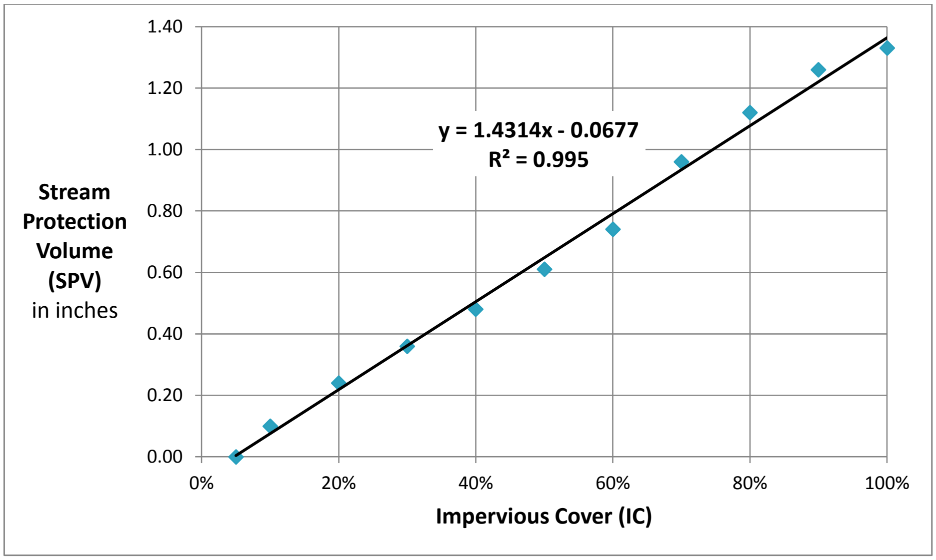


Table 11-7 **Recommended Stream Protection Volumes**
(Values have been rounded up)

IC	SPV (in.)
0%	0.00
5%	0.00
10%	0.08
15%	0.15
20%	0.22
25%	0.29
30%	0.37
35%	0.44
40%	0.51
45%	0.58
50%	0.65
55%	0.72
60%	0.80
65%	0.87
70%	0.94
75%	1.01
80%	1.08
85%	1.15

90%	1.23
95%	1.30
100%	1.37

The stream protection volume requirements can be reduced if volume-reduction BMPs are utilized (e.g., stormwater reuse and/or infiltration). It should be noted that overland flow BMPs, such as Vegetative Filter Strips, will have little ability to mitigate “channel forming flows” unless significant infiltration is achieved.

In order to compare stream protection provided by a BMP system, to account not only for different designs, but also infiltration and possible capture and treatment of off-site runoff (which can be an acceptable practice in certain circumstances), a “flow energy” metric has been developed, and is described in Appendix G (Water Quality BMP Spreadsheet Model).

Commented [D25]: Added Dec 2014

11.2.5 SUSTAINABLE WATER RESOURCE MANAGEMENT AND STORMWATER REUSE

A potentially significant source of water that is currently underutilized is stormwater runoff. Because urban development greatly increases the volume of runoff, capture and reuse of “excess” runoff (i.e., runoff in excess of natural, undeveloped conditions) could be a good strategy for reducing demand on surface and ground water supplies.

Of particular interest is the utilization of captured rainfall and/or stormwater for landscape irrigation, primarily because this is often a high water demand use, frequently applied inefficiently, and is often needed during dry periods when traditional water supplies may be stressed. The amount of water collected may be sufficient to meet many landscape irrigation needs. The use of captured stormwater for landscape irrigation, unfortunately, is still in its infancy in Texas, but efforts such as the Sustainable Sites Initiative (http://www.sustainablesites.org/) have recognized the great potential of this practice. The goal for San Marcos and Texas State University should thus be to convert theory to practice, by maximizing captured runoff as an irrigation source. This is especially relevant in the Edwards Aquifer Zone, where demands on groundwater supplies are a major concern.

Stormwater Reuse – Performance Goals

In the interest of converting theory to practice, and to aid in the development of BMP design criteria, reuse targets are proposed below, based on annual average conditions. It is believed that these targets are modest and imminently achievable, but will require creativity, motivation, and knowledge on the part of the user. When developing these targets it is acknowledged that roof runoff may be most easily captured, that roofs represent only a portion of a site’s total impervious cover, and most users limit their capture and reuse options to roofs. However, runoff from ground level surfaces can also be a resource, e.g., routing runoff from impervious areas to depressed landscape areas can reduce irrigation needs. Parking lot landscape islands are a prime example, but rarely are these opportunities recognized, as curbing of islands in still the norm. Depressed landscape areas receiving runoff is analogous to the Rain Garden BMP, which should be a very widespread practice in areas of new development, as well as a retrofit option for existing development.

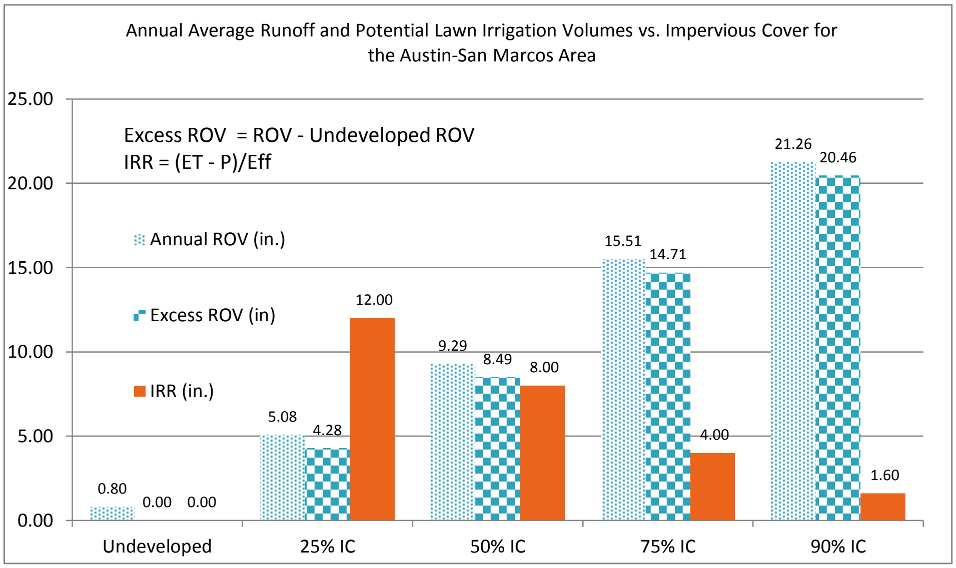
A specific conservation and reuse target is proposed that integrates water conservation with stormwater management:

> **Reduce landscape irrigation with potable water by ≥ 50% by implementing water conservation practices and stormwater capture and reuse**

It should be noted that adoption of this goal may also make a site eligible for credit under the Sustainable Sites Initiative (SSI, 2009), specifically Site Design – Water credits 3.1 and 3.2.

The figure below provides an analysis that demonstrates the feasibility, at least theoretically, of achieving these target levels. On a practical level, it is acknowledged that irrigation system designers and operators typically do not perform the calculations necessary to implement this strategy and, in fact, this may require collaboration between the planning, landscape, and engineering professions. Collaboration is considered desirable, in that common understanding between disciplines promotes efficiency, sustainability and cost-effectiveness. Given the challenges with protecting and efficiently managing the State's water supplies, it is felt that the time is overdue for such collaboration to become a "standard operating procedure" (SOP).

Figure 11-13 Irrigation and Runoff Volumes per Local Impervious Cover Levels



Notes on analyses conducted for this chart:

- Runoff Volume ROV values are based on the analysis provided above.
- Irrigation needs are calculated as (ET – P)/Eff where ET is the estimated evapotranspiration, P is rainfall, and Eff is the irrigation system efficiency. Based on information provided on the Texas ET Network website (http://texaset.tamu.edu/), ET is calculated as PET * Tc * Qf, where PET is potential evapotranspiration, Tc is the Turf Coefficient, and Qf is the Quality Factor. Values of Tc

= 0.6 (Warm season grass) and Qf = 0.6 (Normal Stress) are assumed. Sprinkler systems are most commonly used for lawn areas, and the Texas ET Network provides Eff values of 0.55 – 0.75 (low wind conditions). A value of 0.55 is assumed, which is believed to be conservative but reasonable.

- P and PET values are for Austin, the nearest city that weather data is provided for by the Texas ET Network website. Calculations based on monthly sums vs. total annual rainfall and evapotranspiration values give very similar results, thus an annual value of 8.8 inches is assumed for ET – P.
- The fraction of site that is assumed to be lawn is 1 – IC, e.g., a 25% impervious site is assumed to have 75% lawn area. To convert the volume of irrigation needed to inches based the entire site (necessary for an ”apples-to-apples” comparison with runoff volume values), the irrigation volume is multiplied times 1 – IC. No irrigation is assumed for the Undeveloped site condition.

It should be noted that the calculated irrigation volumes may be less than what is typically applied to lawns. This indicates that overwatering is likely a widespread problem in Texas, thus there is a need for better education and training on water management and irrigation design, installation, and operation. For stormwater capture systems used for landscape irrigation, ultra-high efficiency systems are recommended (e.g., no automatic timers unless linked to “Smart” systems that communicate with moisture sensors).

11.3 WATER QUALITY

11.3.1 CHARACTERIZING WATER QUALITY

Two basic measures of water quality are concentration and load. Concentration is a measure of the “strength” of a pollutant, and is quantified in terms of mass per unit volume, e.g., mg/L. Load is the mass of a pollutant, and accounts for both the volume and quality of runoff, i.e., it is calculated by multiplying runoff volume times concentration. Load flux is another way to characterize loads, e.g., lbs /hour of a pollutant.

Typically the average or “mean” concentration is used in stormwater management programs, preferably with the standard deviation or coefficient of variation also estimated. The mean concentration is usually calculated from monitoring data and the term “event mean concentration” (EMC) is an estimate of the average concentration for an individual event, or the average concentration of a constituent over the entire storm runoff hydrograph. Some studies have investigated intra-event concentrations, in particular the “first flush” phenomena, i.e., the hypothesis that concentrations are higher in the first portion of the runoff hydrograph that later in the runoff event.

Roof Runoff vs. Road Runoff

Road surfaces are commonly identified as the significant source of pollutants in urban runoff. However roof surfaces play an important role in influencing stormwater pollutant characteristics as well. This is especially important if rain water harvesting is being considered as a BMP. Pollutant build-up and wash-off characteristics for roads and roof surfaces are appreciably different. For roof surfaces there is a particular focus on solids, nutrients and organic carbon. Roofing material can significantly influence the quality of runoff. For example, exposed metal roof surfaces may cause heavy metal contamination.

Depending on the intended use, various treatments and disinfections will be required prior to release of roof-runoff water either into surface waters or for more direct consumer usage. Studies suggests that rainwater collection systems which are properly designed, maintained, and treated may provide a valuable supplement to existing water supplies by reducing demand on community water supplies/infrastructure costs, enhancing effective management of storm water runoff, and increasing restoration of underground reservoirs through controlled infiltration (Lye, DJ, 2009).

Roof surfaces influence the first flush phenomenon more significantly than road surfaces. In most urban catchments, as roof surfaces constitute a higher fraction of impervious area compared with road surfaces, it is important that the pollutant generation role of roof surfaces is specifically taken into consideration in stormwater quality mitigation strategies (Egodawatta, P., et al, 2012).

11.3.2 BMP Performance Measures

A widely used procedure for assessing stormwater BMP performance is "percent removal" which is the percent reduction in pollutant concentration and/or load. This procedure is no longer recommended for assessing BMP pollutant removal (BMPDB, 2007), and a current practice is to use "effluent concentration" or the concentration discharged from a BMP after treatment. Primary reasons for this change are (1) the variability of "percent removal" values is typically greater than effluent concentration values, and (2) effluent concentrations are often a function of influent concentrations, thus percent removal gives poor estimates of performance.

Another widely used approach for assessing impacts and designing BMPs is to use the annual average pollutant load, the product of runoff volume and pollutant concentration. This approach is currently used in the Edwards Aquifer Recharge Zone by the City of San Marcos, the TCEQ Edwards Aquifer Rules, and the City of Austin. There are other approaches, such as evaluating concentration "exceedance" frequencies, i.e., how often do concentrations exceed a target value. This procedure can be complicated to apply and it is not felt that the added complexity is justified. Thus, the annual average pollutant load procedure is recommended for use.

In order to estimate the pollutant load removed and discharged by a BMP, the volume of runoff captured must be estimated. The volume that is not captured is considered to be "bypassed" and assumed not treated. Modeling is required in order to capture and bypass volumes. For BMPs that provide storage, the fraction of runoff captured is a function of both the BMP "water quality volume" and the time it takes to discharge this volume ("drawdown time"). Wet ponds are a special case, and the percent runoff treated is related to the frequency that the permanent pool volume is displaced by runoff and/or the ratio of inflow rate to pool surface area. For BMPs that have negligible water quality volume, such as vegetative filter strips, the key design parameter is treatment rate, or the flowrate at which effective pollutant removal occurs (in the case of a VFS, there are two "treatment" rates, infiltration and surface sheet flow).

Commented [D26]: Revised Dec 2014 – VFS now modeled to provide treatment via both infiltration and sheet flow

11.3.3 Target Constituents for BMP Design

It is recommended that both TP and TSS be considered for BMP design, the latter because of historic practices (especially TCEQ Edwards Aquifer Rules), and the former as it may be a better indicator of actual impacts. Adequate control of either, especially TP, will simultaneously provide significant treatment of many other pollutants, including solids, other nutrients, oxygen-demand constituents, pathogens, and heavy metals.

For characterizing the average (mean) concentration of TP in runoff, the equation from a CRWR report (Barrett, et al., 1998) is recommended, which relates the concentration of site impervious cover.

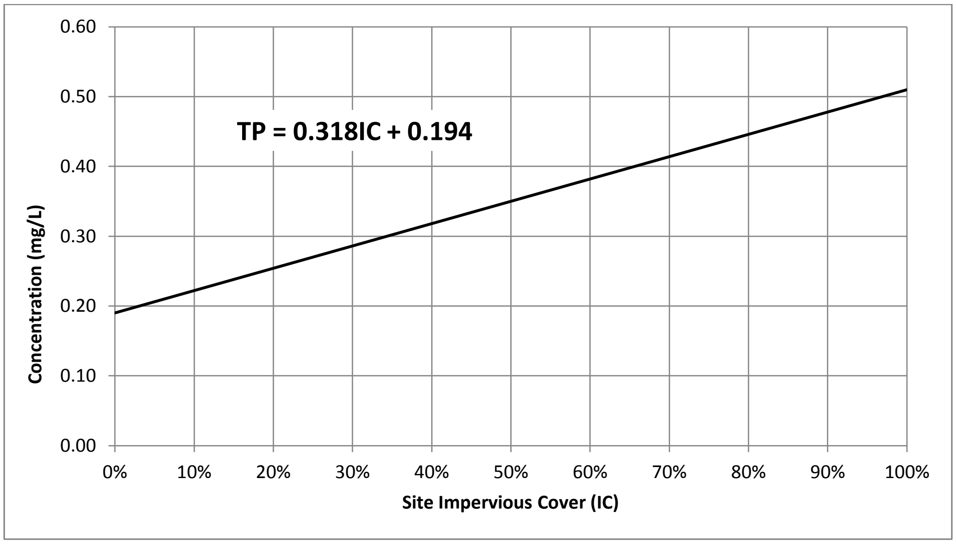
$$TP = 0.318 * IC + 0.194$$

Where TP is mean concentration in mg/L

IC = impervious cover of contributing drainage, as fraction (e.g., 50% IC = 0.50)

Figure 11-13 shows average concentrations of Total Phosphorus (TP) in stormwater runoff in relation to the impervious cover on a site.

Figure 11-14 Average Concentration of Total Phosphorus in Stormwater Runoff



For characterizing the average (mean) concentration of TSS in runoff, the assumptions in the TCEQ Edwards Aquifer Rule manual are used:

- 80 mg/L for undeveloped land
- 170 mg/L for developed land

Recent studies, e.g., City of Austin 2009, indicate that there may be no statistically significant difference in TSS concentrations in runoff from developed vs undeveloped sites. Because of the need to comply with the Edwards Aquifer Rules, the TCEQ manual assumptions will be retained for the time being.

Stormwater BMPs typically can achieve mean TP effluent concentrations in the range of 0.05-0.25 mg/L, and mean TSS effluent concentrations of 5-50 mg/L. Appendix G (Water Quality BMP Spreadsheet Model) provides more information on this issue.

11.4 STORMWATER TREATMENT BMP SELECTION

Selection and design of a BMP system are based on the performance goals for hydrology and water quality, and of site conditions such as impervious cover, site size, soil, slope, and location (e.g., recharge zone). It should be noted that the stormwater BMP system can be an important component of a sustainable site, and may be eligible for Sustainable Site Initiative (SSI, 2009) credit, specifically Site Design – Water credits 3.5, 3.6, and 3.7.

In Water Quality Zones C and T/R, vegetated BMPs and those that provide volume reduction, especially via infiltration, should be considered first, because of typically better pollutant removal, the ability to recharge groundwater (thus sustain baseflow), and because they can often be incorporated as aesthetic landscape features. The International Stormwater BMP Database Project found that some BMPs can provide significant volume reduction, even when not designed specifically to do so (GeoSyntec, 2011c), as shown in the following table.

Table 11-8 Average Volume Reductions by BMP Type

BMP	Average Volume Reduction
Vegetative Filter Strip	38%
Vegetated Swale	48%
Rain Garden with underdrain*	61%
Detention Basin, grass lined	33%

* Also known as Bioretention

Volume reduction can have the added benefit of reducing the Stream Protection Volume needed to offset the hydromodification impacts of urbanization. Infiltration feasibility should be determined based on in-situ soil testing and investigation, and even low permeability soils (e.g., ≤ 0.1 in/hr) may be feasible with good design (e.g., very shallow ponding depths). Soils in the San Marcos area that are suitable for infiltration include the Lewisville, Oakalla, Seawillow, Boerne, Altoga, and Sunev series. Orif soils have high permeability rates, but may limited filtering capacity. Concerns about infiltration effects on the structural integrity of adjacent foundations and pavement can be addressed by installing vertical water barriers along the perimeter of the BMP, thus preventing the lateral movement of water. Low Impact Development BMPs that can be provide volume reduction and be located close to runoff "source" areas include Rainwater Harvesting, Rain Gardens, Biofiltration, Permeable Pavement, and Green Roofs. These can typically be fit into even highly developed areas, e.g., redevelopment in the downtown San Marcos area, especially if incorporated into landscaping, such as streetside tree wells (e.g., Rainwater Harvesting to capture roof runoff, which is then used to irrigate a Rain Garden tree well; overflows from the RWH and runoff from adjacent areas can be routed to the Rain Garden tree well). Sidewalks and walkways should be made of permeable pavement, even in slow draining soils; permeable pavement for vehicular use will have more restrictions, in order to prevent clogging and contamination of the underlying soil. If soils conditions are not conducive for infiltration, Rain Garden and Biofiltration BMPs can have underdrain systems installed, the challenge being to "daylight" the underdrain piping; in high density areas the underdrain system may need to be connected to the subsurface storm sewer system. A hybrid design is to install an underdrain system but with an open bottom, so that partial infiltration can occur.

In larger areas, or those with fewer constraints, larger scale BMPs can be implemented to treat more extensive drainage areas, including existing development if desired. Biofiltration BMPs are a good option, because of high pollutant removal and stream protection capabilities, and for their ability to be attractive landscape features. Sand filters are widely used in the Central Texas area, but these are not recommended due to (1) limited pollutant removal performance, and (2) tendency to become easily clogged by sediment, and (3) aesthetically unpleasing, thus typically located in out of the way areas, making them much more susceptible to poor inspection and maintenance.

Subsurface BMPs are discouraged, because of the much greater likelihood of poor inspection and maintenance (the "out of sight and out of mind" syndrome). Many proprietary BMPs are below ground systems; these have the added disadvantage of providing little or no control of hydromodification impacts.

In Water Quality Zone A, a different BMP selection and design process applies because impermeable liners are required (TCEQ requirement) for pond BMPs. Designing BMPs to meet the non-degradation pollutant removal and the stream protection performance standards is straightforward, but meeting the infiltration performance measure is more challenging. An innovative strategy is proposed, based on an interpretation of the TCEQ Edwards Aquifer Rules. The rules require 80% TSS load reduction, and impermeable liners for pond BMPs in the recharge zone. The innovative strategy is to use a two-BMP treatment train system, whereby the 1st BMP is designed to meet or exceed the 80% TSS load reduction standard, and the 2nd BMP is designed for infiltration, e.g., an Infiltration Basin; it is presumed that the 2nd BMP is not subject to the TCEQ impermeable liner requirement, as it is not required under the State rules (but is needed to meet the more stringent treatment requirements of the WQPP, in addition to meeting the infiltration performance standard). For some sites in Water Quality Zone A, the infiltration performance standard may be achievable with a Vegetative Filter Strip or Vegetated Swale (neither require an impermeable liner), perhaps as a component of a multiple BMP treatment train.

Permeable pavement should be universally used for pedestrian walkways but special considerations are necessary for vehicular use situations, due to concerns with clogging and contamination of the underlying soil and groundwater. The following criteria are recommended when assessing the potential feasibility of permeable pavement for vehicular use (adapted from Urbonas and Stahre, 1993):

- Site is not located in the Edwards Aquifer Recharge Zone
- No off-site runoff enters the BMP
- Seasonal high groundwater table is at least 4 feet below the bottom of the BMP
- Depth to bedrock or impermeable layer is at least 4 feet below the bottom of the BMP
- Infiltrating soil is not fill
- Infiltrating soil has a hydraulic conductivity of at least 0.3 in/hr

Retention/irrigation systems are the standard BMP used in Austin in the Barton Springs Zone, but are not recommended, even though they can provide a high level of hydrologic and water quality control. These BMPs are land-intensive and can have high maintenance costs.

Commented [D27]: Revised to reflect that R/I may be able to meet WQ Zone A and C infiltration performance standard

Wet ponds and constructed wetlands are generally not recommended due to water supply and conservation concerns. These BMPs may be required to obtain water right permits from the TCEQ. In the Central Texas climate wet ponds can lose large volumes of water to evaporation, and leakage of the liner is not an uncommon problem. Wet ponds are often located in drainage channels, which may require a permit from the Corps of Engineers. In addition, if placed in a drainage channel, accounting for effects on flood flows and elevations can be an important issue.

Green roofs are an option for the ambitious designer. In the hot Central Texas climate maintaining a healthy plant community on green roofs can be challenging. Providing irrigation water is an option that, unfortunately, can seriously compromise the stormwater management performance of the system, as can fertilization. The pollutant removal performance of green roofs is not well known, but one system in the Austin area that was fertilized was a net exporter of nutrients (i.e., negative removal efficiency). A logical option could be to link rainwater harvesting with a green roof, irrigating the roof as necessary without fertilization. For this document, green roofs are assumed to be unirrigated and unfertilized, with storage (Water Quality Volume) provided by the green roof media water holding capacity (specifically “field capacity”), and treated runoff “removed” via evaporation and/or evapotranspiration.

The following table provides general selection and applicability information for the BMPs recommended (the symbol **X** denotes that the BMP can generally be expected to provide this function; a small x means that it may be provided, but depends on design):

Table 11-9 Comparison of BMP Selection Criteria

BMP	Volume Reduction	Stream Morphology Protection	Pollutant Removal	Infiltration/ Recharge*	Drainage Area Limitations	Maintenance Costs
Rainwater Harvesting	**X**	**X**	Variable	x	< 10 acres	Low to Medium
Rain Garden (infiltration design)	**X**	**X**	High	**X**	< 5 acres	Medium to High
Rain Garden (with underdrain system)	x	**X**	Medium-High	x	< 5 acres	Medium to High
Biofiltration (infiltration design)	**X**	**X**	High	**X**	> 10 acres	Medium to High
Biofiltration (with underdrain system)	x	**X**	Medium-High	x	> 10 acres	Medium to High
Sand Filtration	x	**X**	Low-Medium	x	> 10 acres	Medium to High
Retention/Irrigation	**X**	**X**	High	x	> 10 acres	High
Permeable Pavement	**X**	**X**	High	**X**	< 10 acres	Low (Pedestrian use) High (Vehicular use)
Infiltration Basin	**X**	**X**	High	**X**	> 10 acres	Medium to High
Vegetative Filter Strip	**X**	**X**	Low-High	**X**	< 10 acres	Low
Vegetated Swale	**X**	**X**	Low-High	**X**	< 10 acres	Low to Medium
Sedimentation Basin	**X**	**X**	Low		> 10 acres	Low to Medium
Green Roof	**X**	**X**	High		< 10 acres	Low to High

*If no impermeable liner is required, e.g, in Edwards Aquifer Recharge Zone

Note: All BMPs have slope constraints, and vegetative filter strips should be the only BMP considered for sites > 6% slope (but < 20%) - from TCEQ, 2005.

11.4.1 KEY DESIGN VARIABLES FOR BMPS

For most BMPs the key design variables are water quality volume (WQV) and drawdown time (DDT), the latter being the time for the entire water quality volume to be discharged. The combination of WQV and DDT, in conjunction with site runoff characteristics, determines the annual average volume of runoff captured for treatment (runoff that is not captured is “bypassed” and assumed untreated). The larger the WQV and/or the shorter the DDT, the greater the runoff capture. The significance of drawdown time is not always well understood, and the following table is provided for illustrative purposes (results based on water quality model described in Appendix G).

Table 11-10 BMP Runoff Capture Efficiency for a 75% Impervious Cover Site

Water Quality Volume WQV (in.)	Drawdown Time DDT (hr)	Runoff Capture Efficiency RCE
0.50	12	87%
0.50	24	82%
0.50	48	78%
0.50	72	75%
0.50	240	67%

The minimum design WQV will be a function of the treatment goal, site runoff quantity and quality, BMP effluent concentration, and drawdown time. Larger volumes are needed in Water Quality Zones A and C due to the non-degradation TP load performance standard.

Sedimentation and filtration BMPs should be designed for a 48 hour drawdown time, as this will provide the best protection from stream erosion (HDR, 2007). Infiltration systems can be designed for shorter drawdown times, depending on soil conditions and design constraints. Retention/irrigation systems should be designed for a 72 hour drawdown time, with intermittent irrigation to prevent oversaturation of irrigated soils. The active irrigation time should be 30 hours, with no irrigation for the first 12 hours after a rainfall event, and no more than 2 hours continuous irrigation of any one area (TCEQ, 2005).

Rainwater harvesting systems are a special case and do not have a specified drawdown time. The key design variables are (1) the volume of the RWH system, and (2) the irrigation or usage rate of the captured rainwater runoff. This BMP is only eligible for “Effective Impervious Cover” credit. The typical design found in some manuals is to design RWH as an extended detention BMP, with the water quality volume required to be emptied within a few days. This design is specifically discouraged by the WQPP as, from a water management standpoint, it is a wasteful practice.

Drawdown time does not apply to either vegetative filter strip (VFS) or vegetated swale BMPs, unless the latter incorporates “swale blocks” in order to provide storage (“Water Quality Volume”). The runoff volume treated by a VFS is a function of both the infiltration rate of the underlying soil and the flowrate through the VFS, which must be sheet flow to be effective. Vegetated swales are sometimes designed to meet a specific “hydraulic residence time”, typically ten minutes or more in order to provide

Commented [D28]: Fixed typo Dec 2014 treatment. However, for this document, soil infiltration is assumed to be the only significant removal mechanism for this BMP. Thus, the "treatment rate" is equal to the infiltration rate, calculated using Darcy's Law.

Commented [D29]: Clarified that VFS now has 2 treatment mechanisms; infiltration and surface flow.

Wet ponds and constructed wetlands (which are not recommended) remove pollutants both during runoff events ("dynamic" treatment) and between events ("quiescent" treatment). The primary design variables are permanent pool volume and pond surface area. These BMPs do not have a drawdown time associated with the permanent pool. Instead, incoming runoff displaces the permanent pool volume. The permanent pool does not provide Stream Protection Volume, but this can be accomplished by "stacking" extended detention volume on top of the permanent pool; flood detention can also be added above the permanent pool.

Commented [D30]: Revised Dec 2014

Proprietary BMPs typically have very small drawdown times, as most of the runoff captured is due to the high treatment rate of these devices. In order to provide protection from stream erosion (stream morphology or hydromodification), these would need to be used in conjunction with a BMP with a 48 hour drawdown time.

For most BMPs, the following good design practices should be followed:

- High length:width ratios are preferred to maximize "plug flow" conditions, which can improve pollutant removal performance
- Flow spreading inlets should be installed
- Vegetation should be used to disperse concentrated flow, when feasible, instead of using "hard" structures (e.g., gabions)
- Irregular shapes that create "dead storage" areas should be avoided
- Pilot channels are highly discouraged, as these create short-circuiting conditions that reduce pollutant removal

11.4.2 TREATMENT TRAIN SYSTEMS

Treatment train simply means multiple BMPs. Some stormwater manuals provide equations for up to 3 BMPs-in-series, with a reduction factor applied to each subsequent BMP. For example, the following is from the TCEQ Edwards Rules Technical Manual (TCEQ, 2005):

$$E_{tot} = [1 - ((1 - E_1) \times (1 - 0.5E_2) \times (1 - 0.25E_3)) \times 100$$

This equation will not be used for two primary reasons:

- Percent removal (E) is no longer a recommended procedure; per the International Stormwater BMP Database Project (BMPDB, 2007), effluent concentrations should be used instead.
- The equation and subsequent guidance give no information on how to size subsequent BMPs. In reality, it may be reasonable to reduce the size of the second and subsequent BMPs to account for the likelihood that the first BMP is discharging at a slower, controlled rate that is less than the flowrate of uncontrolled runoff.

It should be noted that treatment trains do not always have to be BMPs in series. For example, instead of routing the treated effluent from BMP1 to BMP2, the bypasses could be routed, or both treated effluent and bypasses.

When applying the effluent concentration method, the concentration discharged from a BMP is assumed to be the assigned mean value, regardless of where the BMP is located in the treatment train (one exception, if the untreated runoff concentration is less than the mean BMP effluent concentration, the smaller value is used.

Given the assumption that BMP effluent concentrations may be the same regardless of position in a treatment train, why would one consider this option? Actually, the use of a treatment train can be advantageous, e.g.:

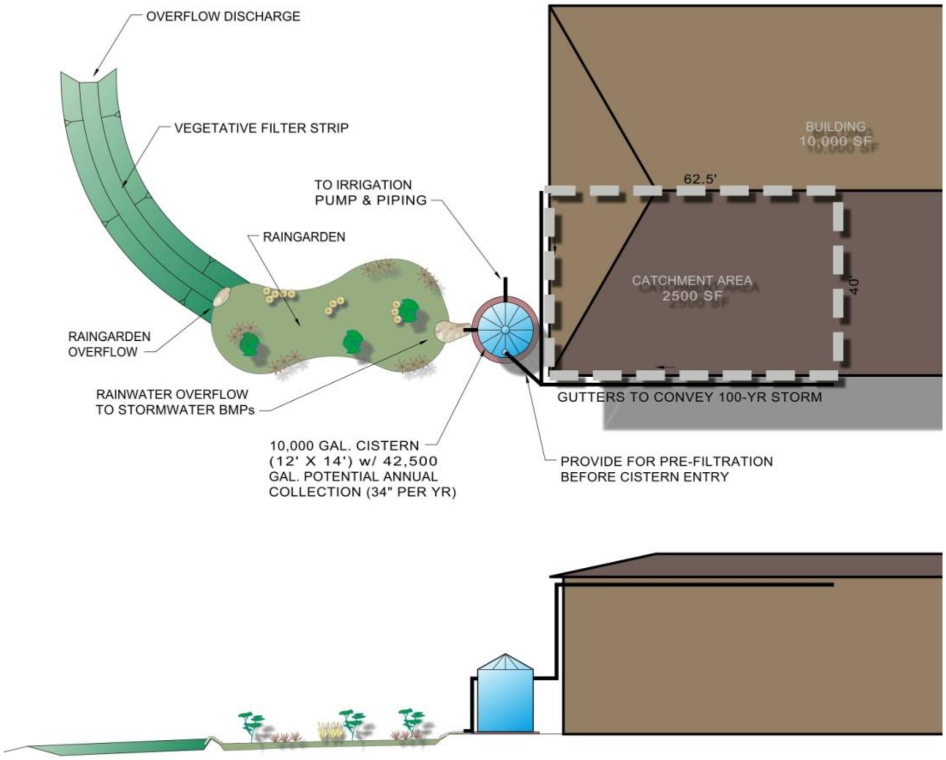
Commented [D31]: Edited Dec 2014

- Space and location constraints on a site may limit where BMPs can be located, and it may be advantageous to locate and link multiple BMPs into the available locations. This can be especially useful for treating multiple drainage areas, and for linking LID BMPs (located close to source areas) to “regional” BMPs.
- In Water Quality Zone A, where the Edwards Aquifer Rules discourage infiltration, the first BMP can be designed to meet the TCEQ 80% TSS reduction standard, while the second BMP can be designed to provide infiltration, while also providing the additional pollutant removal required to meet the WQPP treatment standard.
- Rainwater Harvesting – Rain Garden System, whereby the RWH reduces the site Effective Impervious Cover, provides water for landscape irrigation (thus reducing demand on water supplies), while the rain garden meets the effluent concentration needs, while also achieving sufficient Stream Protection Volume.
- Proprietary BMP followed by Extended Detention (Sedimentation) Basin, or vice-versa – A high flowrate Proprietary BMP System may provide most of the pollutant removal, but little or no stream protection, but the latter can be provided by the Extended Detention Basin.

Commented [D32]: Revised to be clearer

Biofiltration-Vegetative Filter Strip whereby the biofiltration system provides the Stream Protection Volume and a high level of water quality treatment, then discharges at a slow rate to the VFS, where infiltration can provide additional water quality treatment (effluent concentration = 0 mg/L when infiltrated) sufficient to meet requirements.

Figure 11-15 Rainwater Harvesting/Rain Garden System



Graphic Credit: Wade Kolb

11.4.3 ALTERNATIVE BMPS

The use of alternative BMPs is encouraged, but the hydrologic and water quality performance must be well-documented, and is subject to staff approval. In certain instances monitoring may be required, and useful guidance is provided in Chapter 4 of the TCEQ Edwards Rules technical manual (Innovative Technology: Use and Evaluation). One significant difference is that a range of pollutants should be monitored, especially Total Phosphorus. In some cases modeling may be sufficient to demonstrate equivalency, in particular continuous simulation models such as SWMM. All model assumptions, procedures and results must be well documented, and are subject to staff approval.

11.4.4 INCENTIVES AND CREDIT FOR LID AND SOURCE CONTROLS

Disconnecting directly connected impervious cover is an excellent strategy, and often easily accomplished. By applying this practice a site’s “effective” impervious cover can be reduced. Direct credit can be applied in two ways:

- Reduces the runoff volume by adjusting the runoff coefficient Rv and depression storage Sd based on the effective impervious cover, instead of the total impervious cover.
- Reduce the mean pollutant concentration, again using the effective impervious value instead of total impervious cover.

For example, if a site has 50% impervious cover but is reduced to 40% *effective* impervious cover through application of LID techniques, the annual average runoff volume can be reduced from 9.29 to 7.49 per year, a 19% reduction, while the assumed TP concentration is reduced from 0.35 to 0.32 mg/L, a 9% reduction. The net effect is reduction of the annual average pollutant load by 26% which, in practical terms, reduces the size of the BMP treatment system.

Procedures for calculating effective impervious cover are described in Appendix J.

11.4.5 OTHER DESIGN ISSUES

On-line vs. Off-line

On-line BMPs means that the system is located in a main channel and is subject to receiving all runoff flows, not all which can be effectively treated. Wet ponds are often on-line systems. In contrast, off-line systems are off the main drainage channel, with runoff diverted to them in some manner (e.g., a "splitter box"). Advantages of off-line systems include (1) the BMP is protected against potentially damaging high flows and, (2) trapped pollutants are less likely to be resuspended and washed out by large storm events.

For BMPs with small drainage areas, such as rain gardens, rainwater harvesting systems, and proprietary BMPs, an off-line design is probably unnecessary, as long as high flows can be safely conveyed out of the system (e.g., via an overflow pipe or weir). Vegetative filter strips and vegetated swales are typically on-line systems, the latter simply because swales are primarily used for stormwater conveyance. In general, sedimentation, sand filtration, and biofiltration systems should be off-line to prevent damage and pollutant resuspension from large but infrequent storm events. Wet ponds and constructed wet ponds can be designed as either on-line or off-line systems, and there may be little effect on performance either way.

Off-site Drainage

Most BMP manuals recommend that off-site runoff be routed around the BMP system, but there may be numerous instances where treating the off-site drainage can be beneficial. In particular, if off-site drainage includes areas of existing development that are not being treated, then providing treatment where none currently exist can be justified. The City of Austin has implemented a successful program that incentivizes treatment of off-site drainage in certain cases. For some developments, financial incentives are made available to the developer, with funds partially coming from the City's fee-in-lieu program (described elsewhere in the WQPP). The BMP selection and design process becomes more complicated in these instances, and use of a computer model may be necessary, but the both public and private benefits can be substantial. Off-site drainage should thus be evaluated on a case-by-case basis, and the City of San Marcos should consider developing an incentive-based program.

Untreated Site Areas

It is possible that a development will have a portion of the site which does not drain to a BMP location, and thus runoff from that area would be discharged without treatment. This situation can and should be avoided by careful site planning, as areas that are not treated must be accounted for when assessing hydrologic and water quality goals. In general, it is highly unlikely that "enhanced" treatment of treated areas (i.e., exceed the treatment goals) can fully offset the effect of untreated areas.

Accounting for Sediment Accumulation in BMPs

Numerous technical manuals assume sediment accumulation will reduce the water quality volume of BMPs over time, and require that this be accounted for in the sizing calculations. The WQPP agrees with this, especially as there is uncertainty as to how effective BMPs in the San Marcos area will be inspected and maintained. As a general rule of thumb, the Water Quality Volume should be increased by 20%, and all subsequent calculations based on the WQV + 20% value. This will be a more conservative approach than is used in current manuals, e.g., TCEQ Edwards Aquifer technical manual.

- Standalone BMPs – add 20% to the Water Quality Volume (WQV) that is necessary to meet the performance standards, and size filtration or infiltration area on the WQV with the 20% factor.
- BMP treatment train – add 20% to the WQV for the 1st BMP, but apply no sediment accumulation factor to the 2nd or 3rd BMPs IF the intervening drainage areas are negligible; otherwise add 20% to the 2nd and/or 3rd BMPs. Examples:
    - "Full" Sedimentation-Filtration – add 20% to the Sedimentation WQV, and size the filtration area based on the WQV + 20%
    - "Partial" Sedimentation-Filtration, Biofiltration and Rain Gardens, including infiltration design – add 20% to the WQV, and size the filtration and infiltration areas based on the WQV + 20% factor.
    - Retention/Irrigation – add 20% to the WQV of the Retention pond, and base the irrigation area on the WQV + 20%
- Vegetative Filter Strips – assume no sediment accumulation.
- Vegetated Swales
    - If the swale has a WQV (i.e., check dams or "swale block" installed), add 20% to the WQV, and size the infiltration area based on WQV + 20%
    - If there is no WQV, then no sediment accumulation factor is applied.
- Rainwater Harvesting – add 20% to the WQV.

Commented [D33]: Deleted "Green Roof" item as not particularly relevant

NOTE: For modeling BMP performance, use the WQV without the 20% sediment accumulation factor. For construction purposes, use WQV + 20%.

NOTE: It is important that "freeboard" (typically required for flood detention ponds) NOT be added to water quality BMPs since, if combined with the sediment accumulation storage, this could add significant additional volume, resulting in longer drawdown times that could create nuisance conditions.

Hazardous Material Traps

Hazardous material traps (HMTs) are an optional measure under the Edwards Aquifer Rules "Enhanced Measures" (TCEQ, 2007a) for roadways conveying at least 25,000 vehicles per day. Hazardous material trapping can also be incorporated into some BMPs, such as sand filtration systems (TCEQ, 2005). In areas of high traffic, this can be a prudent measure, and is thus recommended.

Flood Detention Credit for Water Quality Controls

Procedures are being investigated at this time, and recommendations will be provided in the future.

11.4.6 BMP Selection and Sizing

The recommended BMP sizing procedure is composed of the following general steps:

1. In Water Quality Zones A and C, size the system for rainwater capture and reuse, typically assuming that the captured rainwater will be used for landscape irrigation. The spreadsheet described in Appendix J will then calculate an Effective Impervious Cover for the portion of the site draining to the RWH system.
2. Recalculate the site impervious cover, taking into account the Effective Impervious Cover for the RWH system, and any other EIC measures implemented.
3. Size the system for stream erosion protection, or the Stream Protection Volume (SPV).
4. Size the system for water quality, i.e., runoff capture volume and treatment necessary to meet the annual average TP and/or TSS load goal
5. In Water Quality Zones A and C, size the system to meet the infiltration performance standard, if it has not already been met.
6. Finalize the design based on the results of the previous steps

Commented [D34]: Edited Dec 2014; recommend sizing for SPV before WQ, which is reverse of previous version

For simpler BMP systems, e.g., single BMPs or a 2 BMP "treatment train" with no intervening drainage area to the 2nd BMP, a series of tables can be provided to the User that does not require running the BMP spreadsheet model.

Step 1. Rainwater Capture, Reuse, and Landscape Irrigation (Required in Water Quality Zones A and C only)

See Appendix K on how to run the landscape-irrigation-rainwater harvesting model, which outputs an "Effective Impervious Cover" for the drainage area to the RWH system.

Step 2. Recalculate Drainage Area Impervious Cover accounting for RWH (required in WQ Zones A and C only)

The RWH BMP may change the EIC of the drainage area and, if the RWH captures runoff from only a portion of the site, the overall site IC will need to be recalculated, as follows:

$$EIC_{site} = [(DA_{RWH}*EIC_{RWH}) + (DA_{non\text{-}RWH} * IC_{non\text{-}RWH})]/ (DA_{RWH} + DA_{non\text{-}RWH})$$

Where EIC_{site} = Site Effective Impervious Cover

DA_{RWH} = Drainage Area size for RWH system

EIC_{RWH} = Effective Impervious Cover for RWH drainage area

$DA_{non\text{-}RWH}$ = Drainage Area for areas not draining to RWH system, but do drain to another BMP

$IC_{non\text{-}RWH}$ = Impervious Cover for the drainage area to the BMP, not including the RWH drainage area

The EIC_{site} value is then used as input into the WQ BMP Model.

<u>RWH EIC Example</u>

A 1 acre site will be developed at 50% IC (= 0.5 impervious acre). Runoff from 0.25-acre roof will be routed to a RWH system, which provides sufficient runoff capture that the 100% IC roof will have an Effective Impervious Cover of 90%. The entire site will drain to a Biofiltration BMP. The drainage area *not treated by the RWH system will be 0.75-acre (= 1 – 0.25) with 0.25 impervious acre (=0.50 – 0.25), or33% IC.*

The Effective Impervious Cover EIC for the 1 acre draining to the Biofiltration BMP will thus be:

$EIC_{site} = [(0.25*0.90) + (0.75*0.33)]/1.00 = 47\%$

NOTE: The following steps are described in general detail, but it is highly recommended to use the Water Quality Spreadsheet Model described in Appendix G. Use of the model avoids the need to manually calculate values described below. In cases where there are multiple BMPs and/or multiple drainage areas the complexity of the hydrologic and water quality regimes render the manual calculation method infeasible.

Commented [D35]: Added Dec 2014

Step 3. Stream Erosion Protection and Stream Protection Volume

Commented [D36]: The remainder of this chapter has been revised to incorporate TSS, to size for SPV prior to WQ, and other edits (Dec 2014)

To offset hydromodification effects on stream morphology due to impervious cover extended detention should be provided with a 48 hour design drawdown time as described earlier in this chapter. The recommended Stream Protection Volume is provided by the following equation, and is based on an HDR modeling study of Central Texas stream systems (HDR and Kurkijan, 2011).

$$SPV = 1.4314*IC - 0.0677$$

Where SPV is the Stream Protection Volume in inches

IC = Impervious Cover of the contributing drainage area

(Note: the calculated SPV is rounded up to the second decimal place)

A “flow energy” metric (energy ~ square of flowrate) has been developed in order to compare the level of stream protection provided by a BMP system, as compared against the hypothetical SPV BMP. This is described briefly below, and in more detail by Appendix G (Water Quality BMP Spreadsheet Model).

BMPs with short drawdown times (< 24 hours) may provide little stream protection, unless a significant amount of volume reduction occurs. Wet ponds without extended detention and most proprietary BMPs are examples of BMPs that provide little stream protection.

If there is existing site impervious cover, the SPV is based on controlling the additional runoff from the new impervious cover. A simplified procedure is used, as follows:

- The minimum required SPV is assumed equal to the difference in the SPV values for the developed vs. existing conditions, i.e.:

  $$SPV = SPV_{dev} - SPV_{ex}$$

- The WQ BMP spreadsheet calculates the runoff captured vs bypassed by a hypothetical extended detention facility with this SPV, and a 48 hour drawdown time, for the developed on-site condition. The “flow energy” (square of flowrate) is calculated for each hourly discharge, and summed up for the entire year to calculate the “flow energy” metric, normalized by drainage area, i.e. metric is (∑ft3/hr)/acre.

Commented [D37]: Revised to introduce new “flow energy” metric as basis for determining adequacy of stream protection.

If significant volume reduction is provided (e.g., infiltration), then the SPV can be reduced. The resulting SPV can be derived using the spreadsheet model (Appendix G). For example, assume a 50% impervious cover site has an extended detention pond with 0.65-inch SPV and 48 hour DDT. Using the spreadsheet model, this equates to 95% runoff capture (= RCE). If 15% of the runoff volume is infiltrated prior to or after runoff enters the extended detention pond (i.e., a treatment train), then SPV is only required for the remaining 80% of the captured runoff (= 95% - 15%). Using the spreadsheet model with a 48 hour drawdown time, the SPV could be reduced from 0.65-inch to 0.34-inch, a 48% reduction. This illustrates one of the potential advantages of a volume reduction strategy.

Step 4. Water Quality – Sizing for Runoff Capture and Treatment

The first step is to calculate the annual average pollutant load:

(1) $L = A * ROV * C * 0.226$

Where L is load in lb/year, ROV is runoff volume in inches/year, C is the mean runoff concentration of TSS or TP in mg/L, and 0.226 is a conversion factor. Both ROV and C are functions of impervious cover, as described above.

In Water Quality Zones A and C (Edwards Aquifer Zone), the performance standard is that there is no increase in the existing load being discharged from the site, or:

(1A) $L_{target} = L_{ex}$

If the existing condition is undeveloped, i.e., with 0% impervious cover, ROV = 0.80 inches/year and TP = 0.194 mg/L, thus the annual average TP load = 0.035 lb/ac/yr. For TSS, the mean concentration is 80 mg/L and load 14.5 lb/ac/yr.

In Water Quality Zone T/R, the performance standard is that new development discharge a TP load no greater than that for a site with 10% impervious cover. For a site with 10% IC, ROV = 2.62 inches/year and TP = 0.226 mg/L, thus the annual average TP load = 0.134 lb/ac/yr. For TSS, the concentration is 170 mg/L and load 100.7 lb/ac/yr. As there is always a background load of 0.035 lb/ac/yr, the TP and TSS target loads to be discharged is calculated as:

(1B) TP $L_{target} = L_{ex} + A*(0.134 – 0.035) = L_{ex} + A*0.099$

(1C) TSS $L_{target} = L_{ex} + A*(100.7 – 14.5) = L_{ex} + A*86.2$

Where A is drainage area in acres

The load reduction required to meet target conditions is given the term “Removal Efficiency” or RE, and is calculated as:

(2) $RE = (L_{dev} – L_{target})/L_{dev}$

Where L_{dev} is the load for the developed condition and L_{target} is the load for the target condition.

In order to achieve the required RE, a sufficient amount of runoff must be captured and treated to a sufficiently high level (i.e. the effluent concentration). The fraction of runoff volume captured is given the term “Runoff Capture Efficiency” or RCE. The fractional reduction in the mean concentration is termed “Efficiency Ratio” (Geosyntec, et al., 2009), labeled ER and is calculated as:

(3) $ER = (C_{dev} – C_{bmp})/C_{dev}$

$= 1- (C_{bmp}/C_{dev})$

Where C_{dev} is the mean runoff concentration for the developed condition and C_{bmp} is the mean BMP effluent concentration.

Note that ER is a type of "percent removal" calculation, but that it is *not* a constant, which is the assumption in many BMP manuals (recall that the constant percent removal rate procedure is no longer recommended). The value of ER will vary with both influent (C_{dev}) and effluent (C_{bmp}) values.

Combining the above information results in the following equation:

(4) RE = RCE * ER

As both RE and ER can be directly calculated, the fraction of runoff captured, or RCE, is calculated:

(5) RCE = RE/ER

The Water Quality Volume (WQV) and Drawdown Time (DDT) combination necessary to meet the target RCE value must then be determined. For BMPs that do not have a WQV (e.g., VFS), the treatment rate (QT) must be determined. The water quality BMP spreadsheet model (Appendix G) can be used to determine the WQV/DDT or QT values required, and will perform routing of runoff from the catchment area to the BMP system. A key assumption is that once the BMP volume is full, or the BMP treatment rate is exceeded, all subsequent runoff is assumed to be "bypassed" and not treated (i.e., the untreated runoff volume is assumed to have the same mean concentration as C_{dev}).

It is possible, and likely for higher impervious cover sites, that a BMP system will be unable to meet the treatment goal unless volume reduction is incorporated into the design. This occurs when the Efficiency Ratio value ER is less than the Removal Efficiency value RE, i.e.:

(6) If ER < RE, Volume Reduction required

Recall that volume reduction can be achieved by BMPs that provide infiltration, reuse, evapotranspiration, and/or evaporation. In all these cases, there is no surface water discharge of the BMP effluent, thus the BMP effluent concentration (C_bmp) is 0 mg/L, equating to ER = 100%.

In order to determine the volume reduction required, a "Loss Factor" (Lf) will be incorporated into the removal efficiency equation, where Lf is the fraction of runoff volume "lost" due to volume reduction.

(7) RCE = [RE – (Lf * (1 – ER)]/ER

The value of Lf cannot exceed the value of RCE to be physically plausible, i.e., the volume of runoff lost to volume reduction cannot exceed the total volume of runoff captured by the BMP system. As the equation has two unknowns, RCE and Lf, a solution must be reached via iteration. To expedite this process, set RCE = 1 (i.e., represents capture of 100% of the runoff by the BMP system), and solve for the *minimum* Lf value:

(8) Lf ≥ (RE – ER)/(1 – ER)

Once the minimum Lf value is determined, the WQ BMP spreadsheet model can determine the WQV and DDT of an appropriate infiltration BMP, or the infiltration rate if a flowrate-based BMP (e.g., VFS). Darcy's Law is used to estimate the infiltration rate:

(9) $Q_{inf} = k\ i\ A$

Where Q_{inf} is the infiltration rate, k is the hydraulic conductivity, i is the hydraulic gradient and can be set to a value of 1, and A is the infiltration area, usually the bottom area of the BMP. The resulting equation is:

(10) $Q_{inf} = kA$

The WQ BMP spreadsheet model can then be used to design the non-infiltration BMP, e.g., the WQV and DDT, or treatment rate QT.

The spreadsheet model can perform the above calculations very rapidly, eliminating the need to perform the above steps manually. Also, a set of sizing tables can be provided for simple BMP systems, in which case running the model is not required.

Step 5. Size the System to Maintain or Increase Existing Infiltration (Required in Water Quality Zones A and C only)

The procedures for estimating annual average infiltration are described earlier in this chapter, and the following steps explain the calculation steps.

Calculate the volume of rainfall infiltrated on the site under existing conditions:

(1) $VI_{ex} = A * P * FI_{ex} * 3630$

VI_{ex} = Annual average infiltration volume in ft^3/yr for the existing site condition

A = site area (acres)

P = annual average rainfall = 32.49 inches assumed in WQ BMP spreadsheet model

FI = Fraction of rainfall infiltrated, calculated as a function of IC:

$FI_{ex} = 0.35 - 0.35IC$

3630 = conversion factor

Calculate the infiltration volume for the developed site condition, before BMPs are implemented:

(2) $VI_{dev} = A * P * FI_{dev} * 3630$

Calculate the volume of runoff infiltrated by the BMP system:

(3) $VI_{bmp} = ROV * RCE * 3630$

ROV = runoff volume to the BMP

RCE = BMP Runoff Capture Efficiency

(For Retention-Irrigation, 65% of the volume is assumed to be infiltrated)

Calculate the total infiltration volume for the developed site:

(4) $VI_{tot\_dev} = VI_{dev} + VI_{bmp}$

Compare the infiltration volume for the developed site against the volume under the existing site condition:

(5) If $VI_{tot\_dev} \geq VI_{ex}$ then the BMP design is acceptable

If $VI_{tot\_dev} < VI_{ex}$, then additional infiltration is necessary, either by reducing site “effective” impervious cover, or by increasing the size of the BMP system

Step 6. Finalize Design

Once all the above analyses have been conducted, the design can be finalized based on meeting the required performance standards, depending on Water Quality Zone (rainwater capture-landscape irrigation, water quality load, stream protection, infiltration volume). The BMP volume must be the larger of the WQV and SPV in Water Quality Zone T/R, and/or infiltration volume in Water Quality Zones A and C. The spreadsheet model(s) can be used to iterate to optimize a design. For simple BMP systems, running the WQ BMP model may not be necessary, as a set of sizing tables can be provided.

11.5 SUMMARY OF STORMWATER TREATMENT BMP MEASURES

BMPs should be designed to provide both hydrologic and water quality benefits, specifically:

- Hydrologic
    - Prevent hydromodification and protect stream morphology by controlling channel-forming flows, specifically by runoff volume reduction and/or extended detention of a "Stream Protection Volume" (SPV)
    - Infiltrate stormwater in order to reduce runoff volume and to recharge groundwater
    - Reduce demand on surface water, potable water and groundwater supplies by using captured rainwater (in addition to having more water-efficient landscapes)
- Water Quality
    - Reduce annual average Total Phosphorus (TP) and/or TSS load to achieve target conditions:
        - No increase from the existing site condition in Water Quality Zones A and C
        - New development to have a load equivalent to a site with 10% impervious cover in Water Quality Zone T/R

Low Impact Development techniques can be a cost-effective option for achieving these performance goals, including reducing the "effective" impervious cover of development by disconnecting directly connected impervious cover. Source controls to reduce the generation and/or transport of nutrients and bacteria are important.

APPENDIX A GLOSSARY OF TERMS AND ABBREVIATIONS

1. Abate – means to eliminate or remedy by removal, repair, rehabilitation, or demolition. Abatement of a nuisance may be by prohibition or control of access; and/or by removal, remediation, storage, transportation, disposal, or other means of waste management.
2. Ac-ft – Acre-Feet
3. Adequately covered - Species are considered to be "adequately covered" by a habitat conservation plan if the plan meets all of the incidental take permit issuance criteria contained in ESA Section 10(a)(2)(B) with respect to that species.
4. AM – Adaptive Management
5. AMF – Aquifer Management Fee
6. AMP – Adaptive Management Program
7. AR – Aquifer Recharge
8. ARCSA – American Rainwater Catchment Systems Association
9. ASCE – American Society of Civil Engineers
10. ASPE – American Society for Professional Engineers
11. ASR – Aquifer Storage and Recovery
12. Baseflow – the portion of streamflow that comes from the sum of deep subsurface flow and delayed shallow subsurface flow
13. BCV – Abbreviation for the "black-capped vireo," which is one of the covered species in the RHCP.
14. Biofiltration - A landscaping feature adapted to provide on-site treatment of stormwater runoff. It functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. These facilities can consist of a buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. See also: Bioretention and Rain Garden.
15. Biological Advisory Team (BAT) – A committee of scientific and resource management experts assembled to assist with the development of the RHCP, in accordance with the requirements of Texas Parks and Wildlife Code Chapter 83.
16. Bioretention – A landscaping feature adapted to provide on-site treatment of stormwater runoff. It functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. These facilities can consist of a buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. See also: Biofiltration and Rain Garden.
17. BMP – Best Management Practice
18. BMPs – Best Management Practices
19. BSZ – Barton Springs Zone
20. C – Celsius
21. CAD – Abbreviation for "Computer Aided Design," which is computer software typically used by engineers to design development and other land-based projects.
22. CAPCOG – Abbreviation for "Capital Area Council of Governments."
23. Catchment – A land area or structure where water is captured
24. CEQ – Council on Environmental Quality
25. Certificate of Participation – Document issued by Hays County to a RHCP participant upon execution of a Participation Agreement and payment of mitigation fees. Hays County will record the issued Certificate of Participation, which will include a specific designation of the land to which the certificate applies, in the Real Property Records of Hays County. A copy of the recorded

Certificate of Participation must be posted at the relevant property site during any activities affecting the potential habitat of species addressed in the Certificate of Participation.

26. Cfh – Cubic feet per hour
27. CFR – Code of Federal Regulations
28. Cfs – Cubic feet per second
29. CFU – Colony Forming Units
30. Changed circumstances – Changed circumstances are defined in federal regulations as "circumstances affecting a species or geographic area covered by a conservation plan that can reasonably be anticipated by plan developers and the Service and that can be planned for..."
31. CHU – Critical Habitat Unit
32. CIP – Capital Improvement Project
33. Citizens Advisory Committee ("CAC") – A committee of community stakeholders, including landowner representatives, assembled to assist with the development of the RHCP, in accordance with the requirements of Texas Parks and Wildlife Code Chapter 83.
34. CO2 – Carbon dioxide
35. COA – City of Austin
36. Confluence – A flowing together of two or more streams or rivers
37. Conservation – The careful utilization of a natural resource to prevent depletion
38. Covered species – Species included in the RHCP for which incidental take authorization under the ESA is sought.
39. CPM – Critical Period Management
40. Critical habitat – Specific geographic areas, whether occupied by a listed species or not, that are essential for its conservation and that have been formally designated by rule published in the Federal Register.
41. CRWR – Center for Research in Water Resources
42. CZ – Contributing Zone
43. Detention – The temporary storage of stormwater runoff (in ponds, underground systems or depressed areas) to allow for controlled discharge at a later time.
44. Determination Letter – A letter issued to a RHCP applicant by Hays County that identifies the applicant's cost of participation in the RHCP.
45. Discharge or spill – An act or omission by which oil, hazardous substances, waste, or other substances are spilled, leaked, pumped, poured, emitted, entered, or dumped onto or into waters in the State of Texas or by which those substances are deposited where, unless controlled or removed, they may drain, seep, run, or otherwise enter water in the State of Texas. To discharge includes to deposit, conduct, drain, emit, throw, run, allow to seep, or otherwise release or dispose of, or to allow, permit, or suffer any of these acts or omissions.
46. Disconnection – Disconnection is a non-structural control which can reduce total runoff volume, promote infiltration, and increase time of concentration. Disconnection is typically implemented in two main areas: disconnection of impervious surfaces and disconnection of downspouts.
47. DO – Dissolved Oxygen
48. DOR – Drought of record
49. EAA – Edwards Aquifer Authority
50. EARIP – Edwards Aquifer Recovery Implementation Program
51. EARZ – Edwards Aquifer Recharge Zone
52. Effluent – Stormwater that flows out of a treatment system
53. EIS – Environmental Impact Statement
54. Emergency response team – A unit of the agency that is responsible for the coordination of response to spills and discharges under the agency's jurisdiction

55. Endangered Species Act ("ESA") – The Endangered Species Act of 1973, as amended, is federal legislation intended to provide a means to conserve the ecosystems upon which endangered and threatened species depend and provide programs for the conservation of those species, thus preventing extinction of plants and animals.
56. Engineered soil (aka engineered media) – Engineered soil refers to the planting media used in BMPs which has been modified or augmented from its original condition. For example, engineered soil can be native soil mixed with additional materials (sand, organic matter etc), or, a predetermined combination of media components developed off-site, both designed to meet performance goals of the BMP.
57. Environmental Impact Statement ("EIS") – A document that describes and evaluates the environmental impacts of a proposed action under the National Environmental Policy Act ("NEPA").
58. EPA – Environmental Protection Agency
59. ER – Efficiency Ratio
60. Erosion Hazard Zone – An area where future stream channel erosion is predicted to result in damage to or loss of property, buildings, infrastructure, utilities, or other valued resources
61. ERPA – Environmental Restoration and Protection Area
62. ESA – Endangered Species Act
63. ESC – Erosion and Sediment Control
64. ET – See Evapotranspiration
65. ETJ – Extra Territorial Jurisdiction
66. Evapotranspiration – the combined amount of evaporation and plant transpiration from the earth's surfaces to the atmosphere.
67. F – Fahrenheit
68. Facility – Any structure or building, including contiguous land, or equipment, pipe or pipeline, well, pit, pond, lagoon, impoundment, ditch, landfill, storage container, motor vehicle, rolling stock, aircraft, or any site or area where a discharge or spill has occurred or may occur
69. FBOC/CBOC – Fine/Coarse Benthic Organic Carbon
70. FEMA – Federal Emergency Management Agency
71. Filtration Media (aka, planting bed, growing medium) –
72. Filtration – The sequestration of sediment and other pollutants from stormwater runoff by the movement of runoff across a vegetated area and through media.
73. FIRM – Flood Insurance Rate Map
74. Ft – foot
75. FTE - full-time equivalent is a unit that indicates the workload of an employed person in a way that makes workloads comparable across various contexts. FTE is often used to measure a worker's involvement in a project, or to track cost reductions in an organization. An FTE of 1.0 means that the person is equivalent to a full-time worker while an FTE of 0.5 signals that the worker is only half-time.
76. Garbage – means decayable waste from a public or private establishment or restaurant. The term includes vegetable, animal, and fish offal and animal and fish carcasses, but does not include sewage, body waste, or an industrial by-product
77. GBRA – Guadalupe-Blanco River Authority
78. GCW – Abbreviation for the "golden-cheeked warbler," which is the primary covered species in the Hays County RHCP.
79. GHG – Greenhouse gas
80. GIS – Abbreviation for "Geographic Information System," which is computer software that processes geographic data and is commonly used to map and analyze landscape features.

81. Green Roofs – A green roof is a roof that is partially or completely covered with vegetation.
82. Habitat Conservation Plan (HCP) – A document prepared to support an application to the USFWS for an incidental take permit under Section 10(a)1(B) of the Endangered Species Act. A habitat conservation plan must describe the impacts to the species, the steps to minimize and mitigate such impacts, the alternatives considered, and other measuresrequired by the USFWS.
83. Habitat determination – Habitat determinations are prepared by Hays County for potential RHCP participants and document the location and extent of potential habitat within a project area, as delineated from the review of background information and the on-site assessment. The habitat determination will also include a calculation of the acreage of potential habitat on a project area.
84. Harm – An action defined by the ESA as an "act that actually kills or injures wildlife and may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns including breeding, feeding or sheltering." Harm of federally endangered wildlife is prohibited by Section 9 of the ESA.
85. Hazardous substance – Any substance designated as such by the administrator of the United States Environmental Protection Agency under the Comprehensive Environmental Response, Compensation, and Liability Act, 42 USC 9601-9675, regulated under the Clean Water Act, § 311, 33 USC 1321, or designated by the commission
86. HCAD – Abbreviation for "Hays Central Appraisal District."
87. HCP – Habitat Conservation Plan
88. HHW – Household Hazardous Waste
89. HMT – Hazardous Materials Trap
90. HSC – Texas Health and Safety Code
91. HSPF – Hydrologic Simulation Program Fortran
92. Hydraulic residence time – The length of time a specific volume of water resides in a stormwater treatment system
93. Hydrozone – A grouping of plants that have similar watering or irrigation requirements
94. IA – Implementing Agreement
95. IC – Impervious Cover
96. IH – Interstate Highway
97. Impervious – Not permitting penetration or passage; impenetrable
98. Incidental Take – Take that results from, but is not the purpose of, carrying out an otherwise lawful activity.
99. Incidental Take Permit ("Permit") – A permit issued by the USFWS to a non-federal entity that authorizes incidental take of a federally endangered or threatened species under Section 10(a)1(B) of the ESA. "Permit" in this document refers to the incidental take permit associated with the RHCP.
100. Infiltration – The vertical movement of stormwater runoff through plants and soil; and in unlined systems, recharging groundwater.
101. IPCC – International Panel on Climate Change
102. IPM – Integrated Pest Management
103. Issuance criteria – Before issuing an incidental take permit, the USFWS must find that a habitat conservation plan meets certain "issuance criteria" described in Section 10(a)(2)(B). The USFWS must find that the take of listed species will be incidental to an otherwise lawful activity; that the applicant will, to the maximum extent practicable, minimize and mitigate the impacts of the taking; that adequate funding sources are available and committed to long-term implementation of the plan; and that the taking covered by the permit will not jeopardize the survival and recovery of the species in the wild.
104. ITP – Incidental Take Permit

105. Jeopardy – An action defined by the ESA as an action that would reasonably be expected, directly or indirectly, to appreciably reduce the likelihood of the survival and recovery of the species.
106. JFA – Joint Funding Agreement
107. Karst – An area of limestone terrain characterized by sinks, ravines, and underground streams
108. Land clearing operation – The uprooting, cutting, or clearing of vegetation in connection with conversion for the construction of buildings, rights-of-way, residential, commercial, or industrial development, or the clearing of vegetation to enhance property value, access, or production. It does not include the maintenance burning of on-site property wastes such as fallen limbs, branches, or leaves, or other wastes from routine property clean-up activities, nor does it include burning following clearing for ecological restoration.
109. LDC – Land Development Code
110. LEED – Leadership in Energy and Environmental Design
111. LID – Low Impact Development
112. Litter – means decayable or nondecayable waste
113. Local government – means an incorporated city, a county, a river authority, or a water district or authority acting under Article III, Section 52, or Article XVI, Section 59 of the Texas Constitution
114. M&O funds – Abbreviation for “Maintenance and Operations Funds.”
115. MCL – Maximum Contaminant Levels
116. mg/L – milligrams per liter
117. Mitigation – Actions that compensate for adverse impacts to a resource.
118. Mitigation assessment – The amount of mitigation needed to authorize incidental take associated with a specific project under the RHCP, based on the results of an on-site habitat determination and a site plan review. Mitigation assessments are prepared by Hays County for RHCP applicants.
119. MPO – Metropolitan Planning Organization
120. MS4 – Municipal Separate Storm System
121. MSA – Metropolitan Statistical Area
122. MSL (or msl) – Mean Sea Level
123. NAFTA – North American Free Trade Agreement
124. NAICS – North American Industrial Classification System
125. National Environmental Policy Act (“NEPA”) – The National Environmental Policy Act requires federal agencies to undertake an assessment of the environmental effects of their proposed actions prior to making decisions. Two major purposes of the environmental review process are better informed decisions and citizen involvement.
126. Neighborhood – A platted subdivision or property contiguous to and within 300 feet of a platted subdivision
127. NEPA – National Environmental Policy Act
128. NFHTC – National Fish Hatchery and Training Center
129. NLCD – Abbreviation for “National Land Cover Dataset.”
130. NMFS – National Marine Fisheries Service
131. No Surprises Rule – Assurances provided by the USFWS that provide certainty as to a permittee’s future obligations under a habitat conservation plan. So long as an approved habitat conservation plan is being properly implemented, no additional land use restrictions or financial compensation will be required of the permittee with respect to the covered species, even if unforeseen circumstances arise after the permit is issued indicating that additional mitigation is needed.
132. Non-Point Source – Non-discrete conveyance (i.e. urban runoff)
133. NPDES – means the National Pollutant Discharge Elimination System under which the Administrator of the United States Environmental Protection Agency can delegate permitting

authority to the State of Texas in accordance with Section 402(b) of the Federal Water Pollution Control Act

134. NPS – Nonpoint Source Pollution
135. NRI – National Resources Inventory
136. NTU – Nephelometric turbidity units
137. Pan evaporation – a measurement that combines or integrates the effects of several climate elements: temperature, humidity, rain fall, drought dispersion, solar radiation, and wind.
138. Participation Agreement – An agreement between the County and a RHCP applicant whereby the applicant agrees to be bound by and comply with the applicable terms of the Permit, and in return, benefits from the authorizations granted by the Permit. In each Participation Agreement, the USFWS shall be named as a third-party beneficiary with the right to enforce all terms of the Participation Agreement.
139. PCB – polychlorinated biphenyls
140. PCE –Primary Constituent Elements
141. PCL –Protective Concentration Levels
142. PDSI – Palmer Drought Severity Index
143. Perennial – (of plants) having a life cycle of more than two years
144. Permeable – Capable of being penetrated through pores, etc.
145. Permit – means an order issued by the commission in accordance with the procedures prescribed in this chapter establishing the treatment which shall be given to wastes being discharged into or adjacent to any water in the state to preserve and enhance the quality of the water and specifying the conditions under which the discharge may be made
146. pH – measure of acidity/alkalinity of a solution
147. Plan Area – The area of operation for the WQPP and other plans (e.g. the Hays County RHCP). The geographic area of each Plan is dependent on regulatory, jurisdictional and environmental conditions.
148. Platted subdivision – means a subdivision that has its approved or unapproved plat recorded with the county clerk of the county in which the subdivision is located
149. POC/DOC – Particulate/Dissolved Organic Carbon
150. Point Source – means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants or wastes are or may be discharged into or adjacent to any water in the state
151. Pollutant – means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, filter backwash, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into any water in the state
152. Pollution – means the alteration of the physical, thermal, chemical, or biological quality of, or the contamination of, any water in the state that renders the water harmful, detrimental, or injurious to humans, animal life, vegetation, or property or to public health, safety, or welfare, or impairs the usefulness or the public enjoyment of the water for any lawful or reasonable purpose
153. Polycyclic aromatic hydrocarbons –
154. Ponding depth – The determined allowable depth of water able to pond at the surface of the BMP. Ponding depth influences the sizing of the BMP.
155. Porous Pavement – Porous pavement is a permeable pavement surface that allows water to flow through, usually to a reservoir underneath. Porous pavement incorporates void spaces that allow for infiltration.
156. POS – Public Outreach Subcommittee

157. Potable – Fit or suitable for drinking
158. Practical alternative – An economically, technologically, ecologically, and logistically viable option
159. Prescribed burn – The controlled application of fire to naturally occurring vegetative fuels under specified environmental conditions and confined to a predetermined area, following appropriate planning and precautionary measures
160. PVC - Polyvinyl chloride
161. Rainwater Harvesting – Rainwater harvesting is the accumulation and storage of rainwater for reuse. Typically, rooftop runoff is collected into cisterns or barrels and water can be used at a later point for irrigation, non-potable indoor uses or in more advanced application, potable uses.
162. Recharge – (Geology) the processes by which groundwater is absorbed into the zone of saturation
163. Refuse – Garbage, rubbish, paper, and other decayable and nondecayable waste, including vegetable matter and animal and fish carcasses
164. Reservoir Course (or Stone Reservoir) – a stone layer typically found below porous pavement
165. Responsible person – A person who is:
    a. the owner or operator of a vessel from which a discharge or spill emanates; or
    b. the owner or operator of a facility from which a discharge or spill emanates; or
    c. any other person who causes, suffers, allows, or permits a discharge or spill
166. Retention – The storage of stormwater runoff on site (and not released at a later time, but possibly used for an additional purpose such as irrigation).
167. RETF – Regional Environmental Task Force
168. RHCP – Abbreviation for the "Hays County Regional Habitat Conservation Plan." The RHCP supports an application by Hays County for an ESA Section 10(a)1(B) incidental take permit from the USFWS.
169. RHCP participants – Any non-federal entity, including private citizens, businesses, organizations, or state or local governments or agencies, that voluntarily obtains incidental take authorization for the golden-cheeked warbler and/or black-capped vireo through the Hays County RHCP.
170. Riparian – A riparian zone is the interface between land and a river, stream, or other water body. Riparian zones dissipate stream energy, provide habitat and shade, improve water quality and support a diversity of species.
171. ROD – Record of Decision
172. ROW – Right -of-way
173. RWH – Rain Water Harvesting
174. SAWS – San Antonio Water System
175. SB – Senate Bill
176. SCTRWP – South Central Texas Regional Water Plan
177. SCTRWPG – South Central Texas Regional Water Planning Group
178. SCTWAC – South Central Texas Water Advisory Committee
179. SCUBA – Self-contained Underwater Breathing Apparatus
180. Sedimentation – The process whereby suspended material settles out of a liquid in which they are transported. Suspended materials includes particles, such as clay or silt, which are dropped by gravity from the liquid once the velocity is decreased to a point below which the particles can remain in suspension.
181. SEP –Southern Edwards Plateau
182. Sewage – means waterborne human waste and waste from domestic activities, such as washing, bathing, and food preparation
183. Sewer system – means pipelines, conduits, storm sewers, canals, pumping stations, force mains, and all other constructions, devices, and appurtenant appliances used to transport waste
184. SIC – Standard Industrial Classification

185. SmartCode – A form-based zoning approach which regulates the form of buildings and public spaces, rather than their use.
186. SMCISD – San Marcos Consolidated Independent School District
187. SMR – San Marcos River
188. SNA – State Natural Area
189. Sorption – Sorption refers to the processes of adsorption and absorption. Adsorption is the physical bonding of ions or molecules onto the surface of another molecule. Absorption is the incorporation of a substance in one state into another substance of a different state. For example, in processes of remediation, adsorption refers to the attraction between the outer surface of a solid particle and a contaminant, where the contaminant assimilates on the surface. In a similar condition, absorption refers to the uptake of the contaminant into the structure of the solid particle, where the contaminant permeates another substance.
190. Stormwater – refers to water that can be harvested from overland flow or from stormwater collection systems prior to entering a natural watercourse
191. SPV – Stream Protection Volume
192. SSC – Science Subcommittee
193. SVOC – Semi-volatile Organic Compounds
194. Swales – A vegetated swale is a broad, shallow channel with a dense stand of vegetation covering the side slopes and bottom. Swales can be natural or manmade, and are designed to trap particulate pollutants, promote infiltration, and reduce the flow velocity of storm water runoff.
195. SWMP – Storm Water Management Plan
196. TAC – Texas Administrative Code
197. Take – An action defined by the ESA meaning to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct with respect to a federally listed species. Take may include significant habitat modification or degradation if it kills or injures wildlife by significantly impairing essential behavioral patterns including breeding, feeding, or sheltering. Take of federally endangered wildlife is prohibited by Section 9 of the ESA.
198. TC – Texas Transportation Code
199. TCEQ –Texas Commission on Environmental Quality
200. TDS –Total Dissolved Solids
201. TMDL – Total Maximum Daily Load
202. TNRIS – Abbreviation for "Texas Natural Resources Information Service."
203. TOC – Total Organic Carbon
204. TPDES – Texas Pollutant Discharge Elimination System
205. TPWD – Abbreviation for the "Texas Parks and Wildlife Department."
206. TRCA - Texas Rainwater Catchment Association
207. Treatment facility – means any plant, disposal field, lagoon, incinerator, area devoted to sanitary landfills, or other facility installed for the purpose of treating, neutralizing, or stabilizing waste
208. Trophic – (Lake Ecology) Trophic status is a useful means of classifying lakes and describing lake processes in terms of productivity of the system. Basins with infertile soils release relatively little nitrogen and phosphorus leading to less productive lakes, classified as oligotrophic or mesotrophic
209. TRRP –Texas Risk Reduction Program
210. TSDC –Texas State Data Center
211. TSS – Total Suspended Solids
212. TSWQS –Texas State Water Quality Standards
213. Turbidity – Not clear or transparent because of stirred-up sediment or the like; clouded; opaque
214. TWC: Texas Water Code
215. TWDB – Texas Water Development Board

216. TXST – Texas State University
217. Type D soils – Clay soils
218. Underdrain – Drain pipe that lies below the surface of a stormwater treatment system
219. Unforeseen circumstances – Changes in circumstances affecting a species or geographic area covered by a habitat conservation plan that could not reasonably have been anticipated by plan developers and the USFWS at the time of the conservation plan's negotiation and development, and that result in a substantial and adverse change in the status of any covered species.
220. USACE – United States Army Corps of Engineers
221. USC – United States Code
222. USDA – United States Department of Agriculture
223. USEPA – Abbreviation for "U. S. Environmental Protection Agency."
224. USFWS – United States Fish and Wildlife Service
225. USGS – United States Geological Survey
226. VFS, Vegetated Filter Strips – are evenly sloped vegetated areas that treat stormwater runoff from adjacent surfaces, flowing through it as sheet flow, by filtering it through vegetation.
227. VISPO – Voluntary Irrigation Suspension Program Option
228. VOC – Volatile Organic Compound
229. Waste – means waterborne liquid, gaseous, or solid substances that include sewage, industrial waste, municipal waste, recreational waste, agricultural waste, or other waste
230. Water pollutants – include refuse, oil, waste, sewage and/or stormwater runoff
231. Waters of the state: means groundwater, percolating or otherwise, lakes, bays, ponds, impounding reservoirs, springs, rivers, streams, creeks, estuaries, wetlands, marshes, inlets, canals, the Gulf of Mexico, inside the territorial limits of the state, and all other bodies of surface water, natural or artificial, inland or coastal, fresh or salt, navigable or nonnavigable, and including the beds and banks of all watercourses and bodies of surface water, that are wholly or partially inside or bordering the state or inside the jurisdiction of the state.
232. Wet ponds – Stormwater treatment systems comprised of an ever-present pool of water
233. Wildland – Uncultivated land other than fallow, land minimally influenced by human activity, and land maintained for biodiversity, wildlife forage production, protective plant cover, or wildlife habitat
234. WORD – Water-oriented Recreation District
235. WPAP – Water Pollution Abatement Plan
236. WQ – Water Quality
237. WQPP – Water Quality Protection Plan
238. WQV – Water Quality Volume

APPENDIX B REFERENCES

Adams, Barry and Papa, Fabian, 2000, Urban Stormwater Management Planning with Analytical Probabilistic Models, John Wiley Sons, Inc.

Agins v. City of Tuburon, 447 U.S. 255 (1980); *Penn Central Trans. Co. v. City of New York*, 438 U.S. 104 (1978).

Allen, Richard G., Pereira, Luis S., Raes, Dirk, and Smith, Martin, 1998, FAO Irrigation and Drainage Paper No. 56: Crop Evapotranspiration (guidelines for computing crop water requirements), United Nations Food and Agriculture Organization, Rome, Italy.

Ashworth, J.B., 1983, "Groundwater Availability of the Lower Cretaceous Formations in the Hill Country of South-Central Texas", Texas Department of Water Resources, Report 273.

Attorney General's Private Real Property Rights Preservation Act Guidelines, 2005, § 1.32.

Attorney General's Private Real Property Rights Preservation Act Guidelines, 2005, § 1.33.

Austin Association of Realtors Multiple Listing Service (MLS), 2005.

Barrett, M.E., Keblin, M.V., Walsh, P.M., Malina, J.F. Jr., and Charbeneau, R.J., 1997, Evaluation of the Performance of Permanent Runoff Controls: Summary and Conclusions, University of Texas at Austin Center for Research in Water Resources Online Report 97-3.

Barrett, Michael E., Quenzer, Ann M., and Maidment, David R., 1998, Water Quality and Quantity Inputs for the Urban Creeks Future Needs Assessment, University of Texas at Austin Center for Research in Water Resources Online Report RPT-98-10.

Barrett, Michael E., 2010, Evaluation of Sand Filter Performance, University of Texas at Austin Center for Research in Water Resources Online Report 10-07.

Beaulieu, Karen M., Bell, Amanda H., and Coles, James F., Variability in Stream Chemistry in Relation to Urban Development and Biological Condition in Seven Metropolitan Areas of the United States, 1999-2004, USGS Scientific Investigations Report 2012-5170.

Blome, C.D., Faith, J.R., Pedraza, D.E., Ozuna, G.B., Cole, J.C., Clark, A.K., Small, T.A., and Morris, R.R., compilers, 2005, Geologic map of the Edwards aquifer recharge zone, south-central Texas: U.S. Geological Survey Scientific Investigations Map 2873, scale 1:200,000.

Bluntzer, R.L., 1992, "Evaluation of Groundwater Resources of the Paleozoic and Cretaceous Aquifers in the Hill country of Central Texas", Texas Water Development Board, Report 339. BMP Tools within HSPF: (http://www.epa.gov/athens/research/HSPFWebTools/)

BMPDB, 2007, Why does the International Stormwater BMP Database Project omit percent removal as a measure of BMP performance?, International Stormwater BMP Database.

Brandywine Conservancy Environmental Management Center, 2003, "Transfer of Development Rights: A Flexible Option for Redirecting Growth in Pennsylvania".

Broaddus Planning, 2012 – 2017 Campus Master Plan Update: Texas State University

Brown, Larry R., Cuffney, Thomas F., Coles, James F., Fitzpatrick, Faith, McMahon, Gerard, Steur, Jeffrey, Bell, Amanda H., and May, Jason T., 2009, Urban streams across the USA: lessons learned from studies in 9 metropolitan areas, Journal of North American Benthological Society, 28(4): 1051-1069.

Bureau of Economic Geology, 1974, “Geologic Atlas Map of Texas, Austin Sheet”, University of Texas.

Bureau of Economic Geology, 1974, “Geologic Atlas Map of Texas, Llano Sheet”, University of Texas.

California State Water Resources Control Board, 1963, “Water Quality Criteria, Second Edition”, Publication No. 3-A.

Chow, V.T., et al, 1964, McGraw-Hill Publishing, Handbook of Applied Hydrology, p.27, the surface water definition was derived from this publication and modified to include water in watercourses or storage features.

Chow, V.T., et al, 1964, McGraw-Hill Publishing, Handbook of Applied Hydrology, p.13-3, (groundwater definition)

City of Austin Watershed Protection and Development Review Department, 2005, Portion Within/Outside the Planning Region was determined from GIS mapping data results.

City of San Marcos Parks and Open Space Master Plan, 2010, Land Design Partners, Austin Texas

City of San Marcos, 2011, San Marcos Green Infrastructure – LID Practices, San Marcos, Texas.

City of San Marcos, 2013, Vision San Marcos: A River Runs Through Us, City of San Marcos Comprehensive Plan

COA, 1990a, Stormwater Pollutant Loading Rates for Various Land Uses in the Austin Area, City of Austin, Environmental and Conservation Services Department, Austin, Texas.

COA, 1990b, The First Flush of Runoff and Its Effects on Control Structure Design, City of Austin, Environmental and Conservation Services Department, Austin, Texas.

COA, 1997, The Barton Creek Report, Water Quality Report COA-ERM/1997, City of Austin, Drainage Utility Department, Austin, Texas.

COA, 2006, Stormwater Runoff Quality and Quantity from Small Watersheds in Austin, TX, City of Austin Watershed Protection Department Water Quality Report COA-ERM/WQM 2006-1, Austin, Texas.

COA, 2010, Bull Creek Update Report 2010, City of Austin Watershed Protection Water Quality Report SR-10-17, Austin, Texas.

COA, 2013, City of Austin Environmental Criteria Manual downloaded from website, Austin, Texas.

COA-ATCHHSD, 2011, Lower Bull Creek District Park Contact Recreation Use Assessment Update, January, 2011, City of Austin Watershed Protection Department and Austin/Travis County Health and Human Services Department, Watershed Protection Department Publication SR-11-07, Austin, Texas.

Code of Federal Regulations (CFR), 2003, Title 40, Chapter 261, [40 CFR §261] “Identification and Listing of Hazardous Wastes”, 40 CFR §403, "General Pretreatment Regulations for Existing and New Sources of Pollution", Appendix G, and 40 CFR §503, “Standards for the Use or Disposal of Sewage Sludge”.

Code of Federal Regulations, 2005, 43 CFR §11, "Natural Resource Damage Assessments".

Contech, 2012, The Stormwater Blog, www.contech.com, Contech stormwater experts, 10/11/12

Cuffney, Thomas F., Brightbill, Robin A., May, Jason T. and Waite, Ian R., 2010. Responses of benthic macroinvertebrates to environmental changes associated with urbanization in nine metropolitan areas, Ecological Applications, 20(5), pp. 1384-1401.

Deliman, Patrick, Willard J. Pack, and E. James Nelson. 1999. *Integration of the Hydrologic Simulation Program-FORTRAN (HSPF) Watershed Water Quality Model into the Watershed Modeling System (WMS).* US Army Corps of Engineers-Engineer Research and Development Center. Technical Report W-99-2.

Diamond, David, Lee Elliott. 2009. Texas Ecological Systems Project: Phase 1 Interpretive Booklet. Missouri Resource Assessment Partnership prepared for Texas Parks and Wildlife Department and Texas Natural Resources Information System.

Dolan v. City of Tigard, 1994, 512 U.S. 374.

Dorman, T., M. Frey, J. Wright, B. Wardynski, J. Smith, B. Tucker, J. Riverson, A. Teague, and K. Bishop. 2013. San Antonio River Basin Low Impact Development Technical Design Guidance Manual, v1. San Antonio River Authority. San Antonio, TX.

Duda, P.B, P.R. Hummel, A.S. Donigian Jr., J.C. Imhoff. June 2012. BASINS/HSPF: Model Use, Calibration, and Validation. Soil and Water Division of ASABE. Vol 55(4): 1523-1547.

EAHCP, November 2012, Edwards Aquifer Recovery Implementation Program Habitat Conservation Plan, Prepared by RECON Environmental, Inc., Hicks & Company, Zara Environmental LLC, and BIO-WEST.

EAHCP Workplan, Attachment 5, May 2014, Howard, Melani, et. al.

Earl, Richard A., “The October 1998 Flood of the Upper Guadalupe River System, Central Texas” (2007). *Great Plains Research: A Journal of Natural and Social Sciences*. Paper 886

Earl, Richard A., and Wood, Charles R., 2002, “Upstream Changes and Downstream Effects of the San Marcos River of Central Texas”. The Texas Journal of Science, Volume 54.

Edgerton, Dan, and Raymond Hozalski. January 2011. Minnesota Water Sustainability Framework – Domestic Use Technical Work Team Report.

Egodawatta, P., Miguntanna NS, Goonetilleke A., 2012, Impact of roof surface runoff on urban water quality, www.Pubmed.gov

Environmental Protection Agency (EPA). Accessed on June 3, 2013 at Water.epa.gov/polwaste/nps/whatis.cfm.

Federal Register, 1997, Volume 62, Number 39, (62 FR 23377-23392, Service 1997).

Federal Register, 1980, Volume 45, Number 136, (45 FR 47355-47364, Service 1980).

First English Evangelical Lutheran Church v. County of Los Angeles, 482 U.S. 304 (1987).

Fitzpatrick, Faith A., and Peppler, Marie C., 2010. Relation of Urbanization to Stream Habitat and Geomorphic Characteristics in Nine Metropolitan Areas of the United States. USGS Scientific Investigations Report 2010-5056.

GBRA, 2013, Guadalupe-Blanco River Authority, Clean Rivers Program; SMR Watershed: River Segments, Descriptions and Concerns.

GBRA, 2015, Guadalupe-Blanco River Authority, Clean Rivers Program 2015 Basin Highlights Report.

GEAA, 2013, Watershed Stewardship for the Edwards Aquifer Region: A Low Impact Development Handbook, Greater Edwards Aquifer Alliance, San Antonio, Texas.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc., 2009, Urban Stormwater BMP Performance Monitoring, Appendix B, International Stormwater BMP Database.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc., 2010, International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Nutrients, International Stormwater BMP Database.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc., 2011a, International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Solids (TSS, TDS, and Turbidity), International Stormwater BMP Database.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc., 2011b, International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Metals, International Stormwater BMP Database.

Geosyntec Consultants, Inc. and Wright Water Engineers, Inc., 2011c, International Stormwater Best Management Practices (BMP) Database Technical Summary: Volume Reduction, International Stormwater BMP Database.

Glick, Roger H., Gosselink, Leila, Bai, Baolin, and Herrington, Chris, 2010, Impacts of Stream Hydrologic Characteristics on Ambient Water Quality and Aquatic Health in the Austin, Texas Area, City of Austin Watershed Protection Report SR-10-18.

Gorieb v. Fox, 1927, 274 U.S. 603.

Gregg, Tony T., Strub, Dan, and Gross, Drema, 2007, Water Efficiency in Austin, Texas, 1983-2005: A Historical Perspective, Journal of the American Water Works Association 99:2.

Groeger, Alan W., Brown, Patrick F., Tietjen, Todd E., and Kelsey, Travis C., 1997, Water Quality of the San Marcos River, Texas Journal of Science 49(4): 279-294

Groffman et al. 2003, Down by the riverside: Urban riparian ecology. Frontiers in Ecology and Environment 6:315-321.

Haan, C.T., Barfield, B.J., and Hayes, J. C., 1994, Design Hydrology and Sedimentology for Small Catchments, Academic Press, San Diego, California.

H.B. No. 3391, Texas Legislature, May 20, 2011 (Requires rainwater harvesting for any new state building with a roof measuring at least 10,000 sf)

HDR and Kurkijan, 2007, Quantification of the Long-Term Benefits of On-Site Erosion Detention for Developing Austin Watersheds, HDR Engineering, Inc. and Kurkijan Engineering Corporation.

HDR and Kurkijan, 2011, Quantification of the Long-Term Benefits of On-Site Erosion Detention for Developing Austin Watersheds: Stream Protection Curve, HDR Engineering, Inc. and Kurkijan Engineering Corporation.

Hiers, Scott E., 2002, Total Triazine Levels in Austin Area Springs, Watershed Protection and Development Review Water Quality Report SR-02-08, Austin, Texas.

Herrington, Chris, Hiers, Scott, and Johns, David, 2005, Update of Barton Springs Water Quality Temporal Trend Analysis – 2005, City of Austin Watershed Protection Water Quality Report SR-05-09, Austin, Texas.

Herrington, Chris, Hiers, Scott, Pope, Sylvia, and Clamann, Andrew. 2007. Differential Changes in Groundwater Quality Due to Urbanization Under Varying Environmental Regulations in Austin, Texas, City of Austin Watershed Protection Water Quality Report SR-07-05, Austin, Texas.

Herrington, Chris, and Hiers, Scott, 2010, Temporal Trend Analysis of Long-term Monitoring Data at Karst Springs, 2009, City of Austin Watershed Protection Water Quality Report SR-10-06, Austin, Texas.

Hummel, Paul, John L. Kittle, Paul B. Duda, Avinash Patwardhan. *Calibration of a Watershed Model for Metropolitan Atlanta.* AQUA TERRA Consultants. Year

Jackson, Todd and Herrington, Chris. 2012. Supplemental Monitoring of Selected Water Bodies with Contact Recreation Impairments, City of Austin Watershed Protection Water Quality Report SR-11-04, Austin, Texas.

Johnson, Steven B, Schindel, Geary M, 2008, Evaluation of the Option to Designate a Separate San Marcos Pool for Critical Period Management, Edwards Aquifer Authority, Report No. 08-01

Keblin, Michael V., Barrett, Michael E., Malina, Joseph F., and Charbeneau, Randall J., 1997, The Effectiveness of Permanent Highway Runoff Controls: Sedimentation/Filtration Systems, University of Texas at Austin Center for Research in Water Resources Online Report 97-4.

Limouzin, Maelle, Lawler, Desmond F., and Barrett, Michael E., 2010, Performance Comparison of Stormwater Biofiltration Designs, University of Texas at Austin Center for Research in Water Resources Online Report 10-05.

Loáiciga, H.A., Maidment, D.R., Valdes, J.B., 2000, Climate-change impacts in a regional karst aquifer, Texas, USA, Journal of Hydrology 227 (2000) 173-194.

Lucas v. South Carolina Coastal Council, 1992, 505 U.S. 1003.

Lye, DJ, 2009, Rooftop runoff as a source of contamination: a review, www.Pubmed.gov

Mahler, Barbara J., Van Metre, Peter C., Crane, Judy L., Watts, Allison W., Scoggins, Mateo, and Williams, E. Spencer, 2012, Coal-Tar-Based Pavement Sealcoat and PAHs: Implications for the Environment, Human Health, and Stormwater Management, Environmental Science and Technology, 46(6), pp. 3039-3045.

Malina, J. F., 1996, “Chapter 8: Water Quality”, Water Resources Handbook. L. W. Mays, ed. McGraw-Hill. New York, NY.

Mayhew v. Town of Sunnyvale, 964 S.W.2d 922, 935 (Tex. 1998).

Mayhew v. Town of Sunnyvale, 964 S.W.2d 922, 936 (Tex. 1998).

McKinney, D.C., Watkins, D.W., Jr., 1993, Management of the Edwards Aquifer: A Critical Assessment, University of Texas at Austin Center for Research in Water Resources, Print Publication CRWR 244.

MDE, 2009, Maryland Department of the Environment Stormwater Design Manual, Chapter 1: Introduction.

Middleton, John R., Barrett, Michael E., and Malina, Joseph F., 2006, Water Quality Performance of a Batch Type Stormwater Detention Basin, University of Texas at Austin Center for Research in Water Resources Online Report 06-02.

Naismith Engineering, Inc., June 2005, Regional Water Quality Protection Plan for the Barton Springs Segment of the Edwards Aquifer and Its Contributing Zone

NCTCOG, 2009, iSWM Criteria Manual for Site Development and Construction, North Central Texas Council of Governments.

Nollan v. California Coastal Commission, 1987, 483 U.S. 825.

Nowlin, Weston, and Schwartz, Benjamin, December 13, 2012, Spring Lake Watershed Characterization and Management Recommendations Final Report, *Nonpoint Source Protection Program CWA §319 (h)*. The Meadows Center for Water and the Environment, Texas State University – San Marcos, San Marcos, Texas.

Osborne, Katherine Grace, 2000, A Water Quality GIS Tool for the City of Austin Incorporating Non Point Sources and Best Management Practices, University of Texas at Austin Center for Research in Water Resources Online Report RPT-00-10.

Parker, Richard, August 13, 2011, “As Texas Dries Out, Life Falters and Fades”, The New York Times

Pennsylvania and New Jersey DOT, 2007, Smart Transportation Guide

Pine, Robert T., 2005, ,letter from Austin Office of the USFWS, to Mr. Terry Tull, Executive Director of the Regional Water Quality Planning Project, received May 2, 2005.

Pomeroy, C.A., and Rowney, A. Charles, 2012, User's Guide to the BMP SELECT Model Version 1.3 Final Report, Water Environment Research Foundation, Alexandria, Virginia.

Price, Asher, 10/15/2013, Austin American Statesman, Austin voters to consider water quality protection purchases on November ballot

Prince George's County, 2007, Bioretention Manual, Department of Environmental Resources, Prince George's County, Maryland.

River Systems Institute (RSI). August 31, 2010. Cypress Creek Project Watershed Characterization Report. Texas State University-San Marcos.

Rock, Kathy and Green Stormwater Infrastructure Team, 2012, City of Austin Green Infrastructure Benchmarking Questionnaire, City of Austin Watershed Protection Department

Rubey, H., et al, Reference: Table Ia, "Engineering Surveys: Elementary and Applied", One acre is equivalent to 43,560 square feet, MacMillan Company, New York, New York, 1950.

Saunders, Kenneth, Kevin B. Mays, Tim A. Jurgensen, Joseph F. Trungale, Leroy J. Kleinsasser, Karim Aziz, Jacqueline Renee Fields, Randall E. Moss. 2001. *An Evaluation of Spring Flows to Support the Upper San Marcos River Spring Ecosystem, Hays County, Texas*. Texas Parks and Wildlife Department. River Studies Report No. 16.

Schueler, T. 1994, The Importance of Imperviousness: Watershed Protection Techniques 1(3):100-111.

Scoggins, Mateo, 2002, Effects of Hydrology on Bioassessment in Austin, Texas, City of Austin Watershed Protection Report SR-00-02.

Senate Bill 873, 2001, An Act of the Legislature of the State of Texas, Amending Title 7, Chapter 232 and a portion of Title 7, Chapter 242, of the Texas Local Government Code, 77th Regular Legislative Session.

Senate Bill 1477, 1993, An Act of the Legislature of the State of Texas, 73rd Regular Legislative Session.

Shaver, E., Horner, R., Skupien, J., Macy, C., and Ridley, G, 2007, Fundamentals of Urban Runoff Management: Technical and Institutional Issues, 2nd Edition.

Sherman, Lee, 2012. Personal communication: analysis of long term rainfall data using RAIN Block of SWMM model. Austin, Texas.

Singh, Jaswinder, H. Vernon Knapp, and Misganaw Demissie, 2004. Hydrologic Modeling of the Iroquois River Watershed Using HSPF and SWAT. Illinois Department of Natural Resources and The Illinois State Geological Survey. Illinois State Water Survey Contract Report 2004-08

SITES: Sustainable Sites Initiative v2 Rating System and Reference Guide, Lady Bird Johnson Wildflower Center, US Botanic Garden, and the American Society of Landscape Architects http://www.sustainablesites.org/

Slade, R.M., et al., 1986, “Hydrology and Water Quality of the Edwards Aquifer Associated with Barton Springs in the Austin Area, Texas”, Report 86-4036., U.S. Geologic Survey, 1986.

Smith, Brian A., Ph.D., P.G., Gary, Robin H., and Hunt, Brian B., P.G. Barton Springs/Edwards Aquifer Conservation District, Fieldtrip Guidebook: Recharge and Discharge Features of the Edwards and Trinity Aquifers, Central Texas, Karst Horizons 15th International Congress of Speleology, July 22, 2009.

SSI, 2009. The Sustainable Sites Initiative: Guidelines for Performance Benchmarks 2009, American Society of Landscape Architects, Lady Bird Johnson Wildflower Center of the University of Texas at Austin, United States Botanic Garden.

Stallworth, Holly, Harrison, Lisa A. and Wise, Gwen F., 1997, The Economics of Sustainability, Watershed Academy Web, U. S. Environmental Protection Agency, Washington, D.C.

Stanard, Christina E., Barrett, Michael E., and Charbeneau, Randall J., 2008, Stormwater Quality Benefits of a Permeable Friction Course. University of Texas at Austin Center for Research in Water Resources Online Report 08-03.

Steur, Jeffry J., Stensvold, Krista A., and Gregory, Mark B., 2009, Determination of biologically significant hydrologic condition metrics in urbanizing watersheds: an empirical analysis over a range of environmental settings. Hydrobiolgia,, Published online: July 19, 2010.

SSI, 2014, The Sustainable Sites Initiative (SITES v2): Guidelines for Performance Benchmarks 2014, American Society of Landscape Architects, Lady Bird Johnson Wildflower Center of the University of Texas at Austin, United States Botanic Garden.

Stockton Council Policy Manual, Policy No. 800-2 Cost Sharing Formula, Effective date: 3/25/91

Tate, Cathy M., Cuffney, Thomas F., McMahon, Gerard, Giddings, Elise M., Coles, James F., and Zappia, Humbert, 2005, Use of an Urban Intensity Index to Assess Urban Effects on Streams in Three Contrasting Environmental Settings, American Fisheries Society Symposium, 47:291-315.

TCEQ, 2005, Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices, Texas Commission on Environmental Quality publication RG-348, Austin, Texas.

TCEQ, 2007a, Optional Enhanced Measures for the Protection of Water Quality in the Edwards Aquifer (Revised): Appendix A to RG-348, Texas Commission on Environmental Quality publication RG-348A, Austin, Texas.

TCEQ, 2007b, Chapter 307 - Texas Surface Water Quality Standards, Texas Commission on Environmental Quality, Austin, Texas.

TCEQ, 2012, Addendum Sheet Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices RG-348 (Revised July 2005), Texas Commission on Environmental Quality publication, Austin, Texas.

Texas Administrative Code (TAC), 1997, Chapter 290, “Public Drinking Water”. [30 TAC §290.38(21)], The definition for “groundwater under the direct influence of surface water” as presented in the TCEQ’s Public Drinking Water regulations, codified in Title 30.

Texas Commission on Environmental Quality (TCEQ). 2001. Public notice of State Highway 123 PCE Plume. Texas Register.

Texas Commission on Environmental Quality, 2004, Section III.A.2A, “Instructions to Geologists for Geologic Assessments on the Edwards Aquifer Recharge/Transition Zones”, Application Form 0585.

Texas Commission on Environmental Quality (TCEQ). December 9, 2004. Proposed Remedial Action Document for State Hwy 123 PCE Plume. (Accessed on June 10, 2013) http://www.tceq.texas.gov/assets/public/remediation/superfund/statehwy123/pdf0303.pdf

Texas Constitution, 1876, Article IX, Section 1, "Creation of Counties".

Texas Constitution, 1876, The 5th Amendment of the U.S. Constitution states that “private property [shall not] be taken for public use without just compensation.” Similarly, Article I, Section 17 of the Texas Constitution provides that no “person’s property shall be taken, damaged, or destroyed for or applied to public use without adequate compensation being made….”

Texas ET, 2013, download from website http://texaset.tamu.edu/, Texas A&M University, College Station, Texas.

Texas Government Code, 2005, § 2007.024.

Texas Government Code, 2005, § 2007.021(b).

Texas Government Code, 2005, § 2007.026.

Texas Government Code, 2005, § 2007.044.

Texas Government Code, 2005, §§ 2007.041 - 2007.045.

Texas Government Code, 2005, §§ 2007.021 - 2007.023.

Texas Local Government Code, 2005, Title 2, “Organization of Municipal Governments”, §5.004, §51.072-§51.079.

Texas Local Government Code, 2005, Title 7, Chapter 232, “Infrastructure Planning in Certain Urban Counties”, §232.100, applicable to counties with a population greater than 700,000 or counties adjacent to a county with a population of 700,000 and within the same metropolitan statistical area, or if not within the same MSA, has a population that has increased at least 40% from one decennial census to the next.

Texas Local Government Code, 2005, Title 7, “Regulation of Land Use, Structures, Businesses and Related Activities”, Chapter 212, “Municipal Regulation of Subdivisions and Property Development”, §212.004-§212.903.

Texas Local Government Code, 2005, Title 7, Chapter 232, “Infrastructure Planning in Certain Urban Counties”, §232.101(a).

Texas Local Government Code, 2005, 2005, Title 7, Chapter 232, “Infrastructure Planning in Certain Urban Counties”, §232.101(b)(1)-(4).

Texas Local Government Code, 2005, Title 7, Chapter 242, “Authority of Municipality and County to Regulate Subdivisions in and Outside Municipality's Extraterritorial Jurisdiction”, §242.001(c).

Texas Local Government Code, 2005, Title 13, “Water and Utilities”, Chapter 401, “Water Control by Municipalities”, §401.003, “Protection of Streams and Watersheds by Home-Rule Municipality”.

Texas LID Workshop, 2011, sponsored by Lady Bird Johnson Wildflower Center, University of Texas Center for Research in Water Resources, US Environmental Protection Agency, and the Texas Commission on Environmental Quality, Austin, Texas.

Texas State Legislature, 1935, 44th Regular Legislative Session.

Texas State University, June 2013, Texas State University Construction Standards, Facilities Planning, Design & Construction.

Texas State University, May 2014, Stormwater Management Program (SWMP) for MS4 General Permit TXR040000.

Texas State University, September 10, 2015, University News Service, Texas State sets enrollment record for 18th consecutive year.

Texas Water Code, 2005, Title 2, Chapter 26, “Water Quality Control”, §26.0136(a).

Texas Water Code, 2005, Title 2, Chapter 26, “Water Quality Control”, §26.175.

Texas Water Code, 2005, Title 2, Chapter 26, “Water Quality Control”, §26.175 and §26.177.

Tolman, Kristina, Clary, Chris, and Hardy, Thomas, 2013, Assessing Water Quality Changes under Existing and Future Build-Out Scenarios in the Upper San Marcos Watershed, The Meadows Center for Water and the Environment, San Marcos, Texas.

Thurow, T.L., W.H. Blackburn, and C. A. Taylor, Jr. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. Journal of Range Management. Vol. 39-6: 505-509.

Toth, Gary, 11/17/2011, Are Complete Streets Incomplete?, Projects for Public Spaces, www.pps.org

Turner, Martha, 2005a, Impacts of Lawn Fertilizers on the Environment in Austin, Texas, City of Austin Watershed Protection Water Quality Report SR-03-07, Austin, Texas.

Turner, Martha, 2005b. Leachate, Soil and Turf Concentrations of Nutrients from Fertilizer; Results from the Stillhouse Neighborhood Fertilizer Leachate Study, City of Austin Watershed Protection Water Quality Report SR-05-03, Austin, Texas.

Turner, Martha, and Herrington, Chris, 2005, Linking BMPs to Receiving Water Impact Mitigation in Austin, TX, City of Austin Watershed Protection Water Quality Report SR-05-07, Austin, Texas.

Turner, Martha, 2007, Analysis of Changes in Creek Storm Water Quality following the Enactment of the Comprehensive Watershed Ordinance and the Urban Watershed Amendments, City of Austin Watershed Protection Water Quality Report SR-07-08, Austin, Texas.

TWDB Staff, the underlying census data was obtained by the State of Texas directly from the U.S. Census Bureau for the years 1990 and 2000.

TWDB, 2012, 2012 State Water Plan, Texas Water Development Board, Austin, Texas.

TXP and CMR. 2008. Hays County population projections and land development analysis. Prepared for the County of Hays, Texas.

UDFCD, 2010, Urban Storm Drainage Criteria Manual: Volume 3 – Best Management Practices, Urban Drainage and Flood Control District, Denver, Colorado.

USACOE Fort Worth District, May 2013, Draft Biological Assessment – San Marcos Section 206 Aquatic Ecosystem Restoration Project

USEPA, 1995, The Economic Benefits of Runoff Controls, publication EPA-841-S-95-002, United States Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, D.C.

U.S. EPA, 1999, "Preliminary Data Summary of Urban Storm Water Best Management Practices", Publication No. 821-R-99-012.

USEPA, 2000a, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservoirs in Ecoregion IX, publication EPA 822-B-00-011, U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2000b, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Ecoregion IX, publication EPA 822-B-01-019, U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2001a, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservoirs in Ecoregion IV, publication EPA 822-B-01-009, U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2001b, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservoirs in Ecoregion V, publication EPA 822-B-01-010, U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2001c, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Ecoregion IV, publication EPA 822-B-01-013, U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2001d, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria for Rivers and Streams in Ecoregion V, publication EPA 822-B-01-014, U.S. Environmental Protection Agency, Washington, D.C.

USEPA, 2007, Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices, publication EPA 841-F-07-006, United States Environmental Protection Agency, Nonpoint Source Control Branch, Washington, D.C.

USEPA, 2008, Handbook for Developing Watershed Plans to Restore and Protect Our Waters, United States Environmental Protection Agency, Office of Water Nonpoint Source Control Branch, EPA 841-B-08-002, Washington, D.C.

USEPA, 2009, WaterSense Water Budget Approach and spreadsheet Version 1.0, United States Environmental Protection Agency, Washington, D.C.

USEPA, 2011a, Watershed Assessment, Tracking & Environmental Results, download from website http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T#causes_303d

USEPA, 2011b, Assessment of Water Quality from Sealed Asphalt Surfaces, United States Environmental Protection Agency, Office of Research and Development, EPA/600/R-10/178, Washington, D.C.

USEPA, 2013a, Causal Analysis/Diagnosis Decision Information System , CADDIS Volume 2: Sources, Stressors & Responses, downloaded from USEPA website http://www.epa.gov/caddis/

USEPA, 2013b, Eight Tools of Watershed Protection in Developing Areas, downloaded from USEPA website http://www.epa.gov/watertrain

U.S. Environmental Protection Agency, 1999, "Preliminary Data Summary of Urban Storm Water Best Management Practices", Publication No. 821-R-99-012, August.

USFWS, 1996a, San Marcos and Comal Springs and associated aquatic ecosystems (revised) recovery plan. U.S. Fish and Wildlife Service. 121 pp.

U.S. Fish and Wildlife Service, 2004, “Draft Recovery Plan for the Barton Springs Salamander (Eurycea sosorum)”, Albuquerque, NM.

USFWS, 2013, Federal Fish and Wildlife Permit TE63663A-0, Albuquerque, NM.

USGS, 2002, Effects of Urbanization on Stream Ecosystems, Fact Sheet FS-042-02, United States Geological Survey, Reston, Virginia.

USGS, 1999, The Quality of Our Nation’s Waters – Nutrients and Pesticides, USGS Circular 1225, United States Geological Survey, Reston, Virginia.

USGS, 2013, Effects of Urbanization on Stream Ecosystems, download from USGS NAWQA website http://water.usgs.gov/nawqa/urban/

US Pet Ownership and Demographics Sourcebook . 2012. https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-Pet-Ownership-Demographics-Sourcebook.aspx (Accessed on June 01, 2011)

Walsh, Patrick M., Barrett, Michael E., Malina, Joseph F. and Charbeneau, Randall J., 1997, Use of Vegetative Controls for Treatment of Highway Runoff, University of Texas at Austin Center for Research in Water Resources Online Report 97-5.

Ward, George H., 2009, Chapter 3: Water Resources and Water Supply from The Impact of Global Warming on Texas, Second Edition, University of Texas Press, Austin, Texas.

WERF, 2010, Sustainable Integrated Water Management State of the Knowledge, Water Environment Research Foundation.

White, J. Allen, Giggleman, Craig M., and Connor, Patrick J., 2006, Recommended Water Quality for Federally Listed Species in Texas, USFWS Technical Report, U.S. Fish and Wildlife Service Region 2 Environmental Contaminants Program, Austin, Texas.

Woodson, Dotty, 2012. Irrigation Efficiency presentation, Texas A&M University AgriLife Urban Solutions Center, Dallas, Texas.

Wright Water Engineers, Inc. and Geosyntec Consultants, Inc., 2007, Frequently Asked Questions Fact Sheet for the International Stormwater Best Management Practices (BMP) Database: Why does the International Stormwater BMP Database Project omit percent removal as a measure of BMP performance? (as posted on www.bmpdatabase.org)

Wright Water Engineers, Inc. and Geosyntec Consultants, Inc., 2010, International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Fecal Indicator Bacteria, International Stormwater BMP Database.

APPENDIX C STAKEHOLDER INVOLVEMENT

The WQPP team met numerous times with representatives of the City of San Marcos and Texas State University the past few years. Presentations and discussions occurred in 2013, 2014, and 2015 in support of efforts to prepare the Water Quality Protection Plan. A brief listing of stakeholder meetings is provided in this Appendix.

Meeting with Texas State University staff on 8/25/14 re: WQPP University Executive Summary

The following abbreviations are used in the tables below.

BMPs – Best Management Practices
CoSM – City of San Marcos
EAA – Edwards Aquifer Authority
HBA – Home Builders Association (Austin Area)
HSPF – Hydrologic Simulation Program FORTRAN
LID – Low Impact Development
LDC – Land Development Code
MCWE – Meadows Center for Water and the Environment
RPS – RPS Office (meeting location)
SMR – San Marcos River
SMWI – San Marcos Watershed Initiative
STM – Stormwater Technical Manual
TXST – Texas State University
WQPP – Water Quality Protection Plan

Date	Representatives	Agenda
5/6/13	TxSt	Gather information on Construction Standards
5/6/13	CoSM	Planning Dept. & CIP Dept. development-related objectives
5/8/13	MCWE-SMWI	WPP Core group, protocol, ground rules
5/16/13	TxSt	University Drainage Master Plan
5/22/13	MCWE-SMWI	WPP subcommittees, MCWE modeling effort
7/3/13	CoSM	Land Conservation strategies
7/22/13	CoSM	Land Conservation strategies, City Park stormwater mgt
7/23/13	CoSM	Proposed land development/WQ zones
8/6/13	CoSM	Concept plan for City Park stormwater mgt
8/28/13	MCWE-SMWI	Subcommittee input on WQPP BMPs
9/10/13	CoSM	Comprehensive Watershed Master Plan & WQPP
9/11/13	MCWE	City Park stormwater mgt
10/14/13	TxSt	Construction Standards, potential WQ retrofits on campus
10/16/13	CoSM	Downtown LID, City Park stormwater mgt
10/23/13	CoSM	Proposed LDC & STM revisions
11/4/13	CoSM	Proposed LDC & STM revisions
11/12/13	CoSM, citizens	CodeSMTX presentation & LDC revisions
11/20/13	MCWE-SMWI	WQPP presentation to the SMWI Core Committee
12/9/13	CoSM	Proposed LDC revisions, including the downtown area
12/16/13	CoSM	Provide WQPP information at Open House event
3/4/14	CoSM	Integrating WQPP into City operations and programs
3/6/14	CoSM	WQPP presentation at DREAM team meeting
3/24/14	CoSM	Hopkins drainage swale retrofit project sites
4/3/14	CoSM	WQPP regulations presentation at DREAM team meeting
4/10/14	CoSM	WQPP retrofits presentation at DREAM team meeting
4/22/14	MCWE-SMWI	HSPF-BASINS Watershed characterization and modeling
4/24/14	CoSM	Integrating WQ into downtown area
5/6/14	CoSM	WQPP input on CodeSMTX environmental revisions
5/22/14	CoSM, TxSt	WQPP Executive Summary
6/5/14	CoSM, TxSt	WQPP Executive Summary
6/5/14	MCWE	Discuss proposed WQPP retrofits
6/12/14	CoSM, TxSt	WQPP Executive Summary
7/25/14	CoSM	CodeSMTX and WQPP recommendations
8/19/14	TxSt	Stormwater mgt at Glade and Recycling Center
8/19/14	Hays County	Collaborative land conservation efforts
8/25/14	TxSt	WQPP University Executive Summary
8/27/14	CoSM	WQPP draft City Council presentation
9/8/14	CoSM, City Mgr.	Review of City Council presentation
9/16/14	CoSM City Council	WQPP recommendations
9/17/14	MCWE-SMWI	WQPP-recommended BMPs
9/19/14	CoSM	WQPP maps, example development projects, Code Rodeo
9/22/14	TxSt	Maps, Charts, Executive Summary, regulatory compliance
10/1/14	CoSM	CIP & Planning, Greater SM Partnership presentation

Date	Representatives	Agenda
10/6/14	TxSt	Revised University Executive Summary
10/8/14	RPS; HBA	Mtg w/HBA on proposed LDC revisions
10/20/14	TxSt	Revised University Executive Summary
10/24/14	CoSM	CodeSMTX Rodeo WQPP environmental recommendations
11/14/14	MCWE-SMWI	Provided comments re: HSPF-BASINS modeling results presentation
11/21/14	Downtown	Site assessment to identify small-scale retrofit opportunities
12/10/14	Downtown	Site assessment to identify small-scale retrofit opportunities
12/16/14	RPS; HBA	Mtg w/HBA on proposed LDC revisions
1/30/15	RPS; HBA	Mtg w/HBA on proposed LDC revisions
2/18/15	EAA	WQPP 2014 progress & 2015 Work Plan
2/20/15	RPS; HBA	WQPP recommendations, HBA, regulations on home builders
3/3/15	CoSM	CodeSMTX environmental workshop, WQPP recommendations
3/4/15	CoSM	CodeSMTX environmental workshop, WQPP recommendations
3/5/15	CoSM	CodeSMTX environmental workshop, WQPP recommendations
4/1/15	TxSt	Requirements for advancing WQPP to President and Board
4/7/15	EAA	WQPP presentation to EAHCP Science Committee
4/20/15	CoSM; City Mgr	WQPP regulatory recommendations
5/4/15	CoSM; City Mgr	Apply WQPP regulations to Springtown redevelopment site
6/15/15	CoSM; TxSt	Mt. Tom T & Juan re: 2015 – 2019 WQPP Spending Plans
6/23/15	CoSM	Environmental elements of the City Land Development Code
6/30/15	CoSM	CodeSMTX, WQ retrofit CIPs, and grant opportunities
7/29/15	CoSM	Stagecoach Trail bioswales BMP
8/11/15	CoSM	City Park parking lot & biofiltration pond design
8/17/15	CoSM	Potential retrofits for WPP 319 Grant application
8/26/15	CoSM; field sites	Visit sites of potential retrofits for WPP 319 Grant application

Meeting with SMWI-WPP Subcommittee on 5/22/13 re: HSPF-BASINS modeling results

Presentation to City of San Marcos staff at DREAM Team meeting on 4/10/14 re: WQPP recommendations

APPENDIX D ANALYSIS OF WATER QUALITY PARAMETERS FOR BMP DESIGN

In the San Marcos area, public water supply, recreation, aquatic life, and endangered species are supported uses in the aquifer, Spring Lake, and/or Upper San Marcos River. A report of recommended water quality for the local endangered species identified constituents of concern to include nutrients, bacteria, sediment, debris, turbidity, metals, temperature, pesticides, and petroleum hydrocarbons (White, et al., 2006). A study of the Spring Lake system identified a similar list (Nowlin and Schwartz, 2012). Given these studies and the type of receiving waters under consideration, the following constituent categories are candidates to use as target pollutants for BMP design:

- Solids, included suspended, dissolved, turbidity, and gross solids
- Nutrients, especially nitrogen and phosphorus species
- Metals, including copper, lead, zinc, arsenic, nickel, cadmium, and silver.
- Bacteria, including E. coli and/or fecal coliform.
- Petroleum hydrocarbons
- Pesticides and herbicides
- Trash and debris

Extensive information exists for the first four categories, thus it is possible to reasonably characterize runoff quality and BMP effectiveness, but data is limited for the remaining categories. The list of constituents used for BMP design is limited to those that dictate design, e.g., are most difficult to effectively treat. A review of several target constituents has been conducted and, based on this analysis, the recommended target constituent is Total Phosphorus.

D-1 Solids

For the purposes of this discussion, solids include:

- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)
- Turbidity
- Gross Solids

An excellent source of information on solids in stormwater runoff is provided by the International Stormwater Best Management Practices Database Project (Geosyntec, et al., 2011a).

D-1.1. Total Suspended Solids (TSS)

Total Suspended Solids are generally particles in runoff between 2 microns – 4.75 mm in size. Smaller particles (< 100 microns) may account for a disproportionate amount of heavy metals, bacteria, and nutrients. High TSS loads can silt in aquatic habitat, impair water quality by increasing turbidity, and clog drainage infrastructure. Sources of TSS in urban runoff include bare or poorly vegetated ground, atmospheric deposition of dust, wear of brake linings and engine components in motor vehicles, leaves and grass clippings, and channel erosion.

TSS is the most commonly used indicator of stormwater quality and its impacts, but its use to the exclusion of other pollutants can be problematic. Why? TSS is generally the easiest pollutant to treat and, while other constituents are typically correlated to TSS, this does not assure a high level of treatment for other pollutants, especially those associated with small particle sizes or present in dissolved form. For example, in an assessment of Austin sand filtration performance (Barrett, 2010), TSS removal of 91% was reported, but only 13%, 27%, and 42% removal of Total Nitrogen, Fecal coliform, and Total Copper, respectively. Also, while stormwater management programs often focus on controlling TSS concentrations and loads from uplands washoff, in-stream concentrations and loads can be much higher, as a result of impervious cover-induced hydromodification and resulting accelerated stream erosion. The following table of TSS concentrations in the Austin area show that in-stream concentrations are generally greater than upland washoff concentrations by a factor of ten or more (COA, 1990a):

Stormwater Runoff TSS Concentrations (Geometric Mean)					
Uplands Runoff (“small” watersheds)			**In-Stream Stormflow (“large” watersheds)**		
Site	**IC**	**TSS (mg/L)**	**Creek**	**IC**	**TSS (mg/L)**
BC	3%	55	Barton	7%	700
RO	21%	173	Bull	12%	1600
MI	36%	106	Williamson	15%	1000
HL	39%	105	Boggy	41%	1936
HI	50%	70	Shoal	47%	1839
BCSM	86%	35			
BI	95%	137			

Thus, it should be recognized that achieving a high level of TSS removal at the site level does not ensure high removal in receiving waters, such as streams, rivers, and lakes. To protect streams from hydromodification will require control of “channel forming” flows.

TSS in runoff from small upland sites does exhibit a strong first flush at higher impervious cover levels (COA, 1990b), especially for small sites (COA, 2006). Because in-stream TSS concentrations are typically the result of hydromodification, accounting for the first flush in upland runoff is much less important that controlling “channel forming” flows. The WERF SELECT model (Pomeroy and Rowney, 2012) does not assume a first flush when modeling runoff pollution and BMP design.

Nonetheless, the use of TSS is allowable simply because of its historic use, and because TCEQ requires development in the Edwards Aquifer Zone to use TSS

Commented [D38]: Added Dec 2014

D-1.1.1 Mean TSS Concentration Value

In order to determine a reasonable value for the mean or average TSS concentration in runoff from upland sites, the following sources are cited:

Information Source	Is TSS correlated to Impervious Cover?	Is TSS for Undeveloped Different that for Developed condition?	Mean TSS Concentration (mg/L)
COA 1990 and TCEQ Edwards Rules	No	Yes	Undeveloped 80 Developed 170
COA 2006	No	No	154
CRWR (Barrett, et al., 1998)	No	No	190
WERF SELECT Model	No	Yes	Undeveloped 70 Residential 101 Commercial 69

As the CRWR report is based on local monitoring data, and used analysis procedures consistent with those recommended by WERF, its value of 190 mg/L is recommended, and is assumed to apply to all development conditions. No accounting for the first flush effect is recommended.

D-1.1.2 BMP Treatment and Mean TSS Effluent Concentrations

As noted above, prevention of hydromodification impacts on receiving streams is important, and BMPs should be designed to reduce runoff volumes (e.g., reuse, infiltration) and/or by providing extended detention. For treating TSS in upland runoff, the two most important removal mechanisms are sedimentation and filtration. Filtration is necessary to remove smaller particles (< 20 microns) that carry a disproportionate amount of pollution. Unvegetated filtration systems are prone to clogging and surface crusting, but vegetated systems (e.g., biofiltration, rain gardens) are much more resistant to these problems, and are preferred.

The International Stormwater BMP Database Project found that all BMP types were effective at removing TSS, i.e., there was a statistically significant reduction in concentrations (Geosyntec, et al., 2011a).

Sufficient information exists to estimate TSS effluent concentrations for several BMPs, as shown in the following table. The water quality spreadsheet model will use these values as a starting point, and may apply unit process theory and/or empirical or semi-empirical relationships for some BMPs, in which case effluent concentrations may vary with BMP design (see Appendix G for more information).

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BMP	Assumed Mean Effluent Concentration (mg/L)	Source
Sand Filtration	17	Barrett (2010), COA (2013), WERF (2012)
Biofiltration (with underdrain system)	9	Limouzin et al (2010), WERF (2012)
Biofiltration (infiltration design)	0	
Rain Garden (with underdrain system)	9	Assumed same as Biofiltration
Rain Garden (infiltration design)	0	
Extended Detention (Sedimentation Basin)	25-100	COA (2013), Middleton et al (2006), WERF (2012)
Batch Sedimentation Basin	1-10	Middleton et al (2006)
Wet Pond	6-70	COA (2013), WERF (2012)
Vegetative Filter Strip	25	Walsh et al (1997)
Vegetated Swale	0	
Retention/Irrigation	0	
Rainwater Harvesting	0	
Permeable Pavement – lined	0	
Permeable Pavement – unlined	0	
Permeable Friction Course	0	
Green Roof	0	

Other BMP	To be input by User	

Biofiltration and Rain Garden BMPs deserve special consideration, as they can provide both very effective treatment while serving as landscape features and aesthetic amenities. The role of vegetation in these systems is important, as plants both enhance pollutant removal and can reduce the potential for clogging, a frequent problem with unvegetated filtration systems, such as sand filters. Because these systems can remove smaller particle sizes than other BMPs, effluent TSS concentrations are lower, and other pollutants associated with smaller particles (e.g., nutrients, metals, bacteria) can be more effectively treated.

D-1.2 Total Dissolved Solids (TDS)

Total Dissolved Solids are very small particles, less than 0.45 microns in size. TDS is a concern in the Upper San Marcos River basin as the State criteria of 400 mg/L has been exceeded, thus this segment is now on the 303(d) list of impaired water bodies.

While there is evidence that urban development can increase TDS concentrations in groundwater, the direct cause and effect relationship is not well known. Stormwater runoff typically has TDS concentrations well below the 400 mg/L criteria. In a model developed by CRWR (Osborne, 2000), predicted mean TDS concentrations were always less than 200 mg/L, and decreased with increasing impervious cover. In an International Stormwater BMP Database report (Geosyntec, et al., 2011a), the 95% confidence interval for TDS in runoff entering BMPs was 27-165 mg/L, with the BMP effluent range being 46-181 mg/L. In no cases were BMPs found to reduce TDS concentrations, and typically there was no statistically significant difference between influent and effluent concentrations. Given these findings, TDS is a poor constituent to use as the basis of BMP design.

D-1.3 Turbidity

There is limited turbidity data available for urban runoff, but it is well known that turbidity is often associated with small particle sizes (e.g., fine silts, clays), thus BMPs that are effective at removing smaller particles will probably be effective at reducing turbidity. An International Stormwater BMP Database report (Geosyntec, et al., 2011a) provides collaborating evidence for this, as “media filters” were reported to be very effective at reducing turbidity, while sedimentation basins much less so – sedimentation basins typically have limited capability of removing the smaller particles in runoff. Also, organic matter in filtration media can create turbidity problems, especially through the leaching of tannins, thus limiting the type and amount of organic matter in filtration media is recommended.

D-1.4 Gross Solids

Gross solids are particles 4.75 mm or greater in size, and can include floating trash, debris, leaves, and other materials that are not necessarily well characterized by TSS measurements. Gross solids can account for a large percent of the volume of solids deposited in BMPs, and thus can be a major factor affecting the frequency and extent of maintenance activities. Because there is very little monitoring data in which to characterize gross solids, it is not an appropriate constituent for BMP design, but users, especially operation and maintenance personnel, should be aware of it.

D-2 Nutrients

The primary nutrients of concern are nitrogen and phosphorus. High levels of these constituents can contribute to nuisance plant algae conditions in streams, rivers, and lakes, creating both unsightly and unhealthy conditions for aquatic life and recreational uses. Excessive plant or algae growth can also contribute to depressed dissolved oxygen concentrations, which can impact aquatic life, and cause taste and odor problems for water users. Nutrients are a major cause of use impairment; the National Water Quality Inventory (EPA, 2002) reported that nutrients contribute to roughly 25-50% of impairments nationally. Sources of nutrients in runoff include soil erosion, grass clippings, leaf litter, fertilizer, animal waste, atmospheric deposition, detergents, flame retardants, and wastewater overflows and/or leakage.

Commented [D40]: Added some sources.

Nutrient concerns apply to the Upper San Marcos River system, and Spring Lake is known to be susceptible to phosphorus, in particular (Nowlin and Schwartz, 2012). Nutrient criteria under development by the EPA defined the following reference conditions for Total Nitrogen (TN) and Total Phosphorus (TP) for Central Texas ecoregions (USEPA, 2000a, 2000b, 2001a, 2001b, 2001c, 2001d):

Ecoregion	Lakes and Reservoirs	Rivers and Streams
Edwards Plateau	TN no criteria TP 0.010 mg/L	TN 0.027 mg/L TP 0.008 mg/L
Texas Blackland Prairies	TN no criteria TP 0.025 mg/L	TN 0.77-0.82 mg/L TP 0.045 mg/L
East Central Texas Plains (aka “Post Oak Savanna”)	TN 0.807 mg/L TP 0.055 mg/L	TN 0.681-0.935 mg/L TP 0.10 mg/L

TN and TP concentrations in stormwater runoff often exceed these criteria, thus impacts are likely unless effective source control and treatment BMPs are implemented.

Neither nitrogen nor phosphorus exhibits a particularly strong first flush effect (COA, 1990b). The WERF SELECT model does not assume a first flush when modeling runoff pollution and BMP design.

Phosphorus is considered the greater concern because it is typically the limiting nutrient in most freshwater systems, and Spring Lake is known to be extremely phosphorus limited (Nowlin and Schwartz, 2012). Stormwater discharges of phosphorus, especially soluble reactive phosphorus (SRP), can cause significant water quality impairment to receiving waters (Geosyntec, et al., 2010). Particulate phosphorus is also a concern because organic particulate phosphorus can be broken down and eventually converted to orthophosphates by bacteria (Geosyntec, et al., 2010). Thus, Total Phosphorus (TP), which includes both soluble and particulate phases, is recommended as the indicator of nutrient impacts.

D-2.1 Mean Nutrient Concentrations

The primary nitrogen species which adequate monitoring data exist are Total Kjeldahl Nitrogen (TKN), Ammonia (NH_3), Nitrate (NO_3) and/or Nitrite plus Nitrate ($NO_2 + NO_3$), and Total Nitrogen (TN). Nitrate (NO_3), typically resulting from oxidation of ammonia (NH_3), is soluble and can easily move through the soil column into groundwater.

The primary phosphorus species that can be well characterized from monitoring data is Total Phosphorus (TP), with less data available for Orthophosphate (PO_4) and Dissolved Phosphorus (DP). Much of the phosphorus in runoff is associated with particulate matter, reported as 50-80% by CRWR (Barrett, 2010).

Information Source	Is TN or TP correlated to Impervious Cover?	Is TN or TP for Undeveloped Different that for Developed condition?	Mean TN and TP Concentrations (mg/L) – range may be given in parentheses
COA 1990	TN – No TP – N/A	TN – Yes TP – N/A	Undeveloped TN 0.62

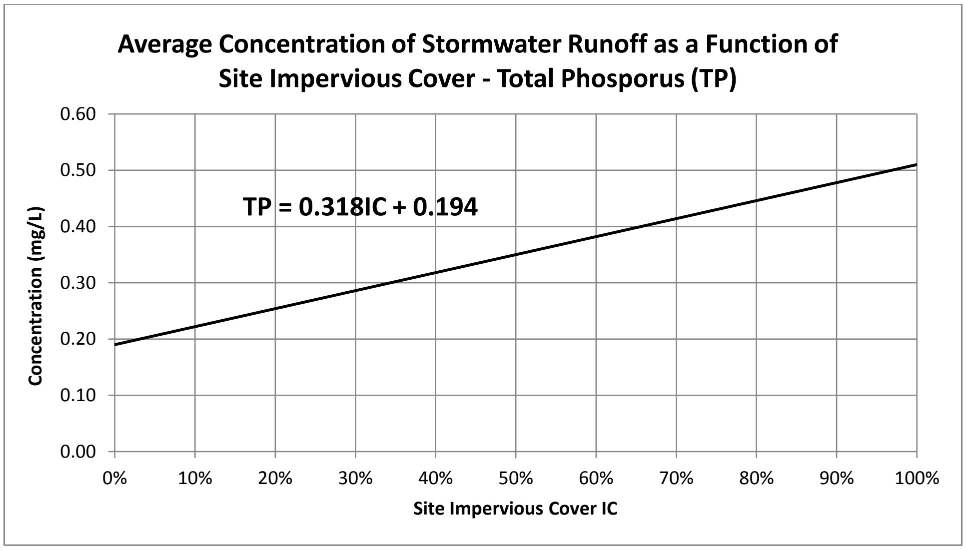
			TP N/A Developed TN 1.40 – 2.20 TP N/A
COA 2006	TN – No TP - No	TN – Yes TP – Yes	Undeveloped TN 0.90 TP 0.122 Developed TN 1.78 TP 0.337
CRWR (Barrett, et al., 1998)	TN – Yes TP - Yes	TN – No TP - No	TN = 1.53IC + 0.95 (0.95-2.48) TP = 0.318IC + 0.194 (0.194-0.512)
WERF SELECT Model (Pomeroy and Rowney, 2012)	TN – No TP - No	TN – Yes TP - Yes	Undeveloped TN 0.543 TP 0.121 Developed TN 0.572-0.736 TP 0.201-0.383

All the sources give similar values, except for the WERF SELECT model. As the CRWR report is based on local monitoring data, and used analysis procedures consistent with those recommended by WERF, its relationships are recommended. Total Phosphorus (TP) is the recommended indicator of nutrient impacts, and the following equation should be used to estimate mean concentration:

$TP = 0.318IC + 0.194$

Where TP is concentration in mg/L and IC is fraction impervious cover of the contributing drainage area (e.g., 50% impervious cover = 0.50)

As illustrated in the following chart, the equation will result in a TP concentration of 0.194 mg/L for an undeveloped site, 0.226 mg/L for the “10% impervious cover threshold” condition, with a maximum value of 0.512 mg/L for a site with 100% impervious cover.



D-2.2 BMP Treatment and Mean TP Effluent Concentrations

Removal mechanisms for nutrients include plant and microbial uptake, sorption, sedimentation and, for nitrogen, nitrification (oxidation of NH_3 to NO_2 then to NO_3), and denitrification (conversion of NO_3 to N gas). Denitrification, while very effective, may require anaerobic conditions. Because landscape areas can be significant sources of nutrient pollution, an effective program should place a high priority on source control, including public education and outreach, and Integrated Pest Management (IPM) requirements.

The International Stormwater BMP Database Project found that filtration systems and wet ponds were effective at removing TP, while vegetative filter strips and vegetative swales were not, i.e. effluent concentrations were not lower than influent concentrations, in terms of statistical significance (Geosyntec, et al., 2010). The primary treatment mechanism for filter strips and swales is assumed to be infiltration.

Sufficient information exists to estimate TP effluent concentrations for several BMPs, as shown in the following table. The water quality spreadsheet model will use these values as a starting point, and may apply unit process theory and/or empirical or semi-empirical relationships for some BMPs, in which case effluent concentrations may vary with BMP design (see Appendix G for more information).

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BMP	Assumed Mean Effluent Concentration (mg/L)	Source
Sand Filtration	0.08	Barrett (2010), COA (2013), WERF (2012)
Biofiltration (with underdrain system)	0.05	Limouzin et al (2010), WERF (2012)
Biofiltration (infiltration design)	0	
Rain Garden (with underdrain system)	0.05	Assumed same as Biofiltration

Rain Garden (infiltration design)	0	
Extended Detention (Sedimentation Basin)	0.10-0.35	COA (2013), Middleton et al (2006), WERF (2012)
Batch Sedimentation Basin	0.14	Middleton, et al., 2006
Wet Pond	0.06-0.34	COA (2013), WERF (2012)
Vegetative Filter Strip	0.24	Walsh et al (1997)
Vegetated Swale	0	
Retention/Irrigation	0	
Infiltration Basin	0	
Rainwater Harvesting	0	
Permeable Pavement	0	
Green Roof	0	
Other BMP	To be input by User	

Biofiltration and Rain Garden BMPs can provide effective treatment while serving as landscape features and aesthetic amenities, thus can be attractive options, especially for Low Impact Development projects. It is important that the filtration media have little or no leachable organic matter. The role of vegetation in these systems is important, as plants both enhance pollutant removal and can reduce the potential for clogging, a frequent problem with unvegetated filtration systems, such as sand filters. Plants with extensive root systems are recommended. An additional design feature that was not tested in the CRWR biofiltration study (Limouzin, et al., 2010), but was recommended, is to incorporate crushed limestone in the underdrain system, which should improve phosphorus removal.

Commented [D42]: Edited Dec 2014

A source control strategy should be adopted as a major component of any nutrient reduction program, especially an effective fertilizer and pesticide management program.

D-3 Metals

Metals are a concern because of their potential toxicity is surface and ground waters. Metals can be a significant cause of use impairment, and the EPA reports that over 7400 water bodies in the US are listed as impaired due to metals, with Mercury being by far the most common cause of impairment (USEPA, 2011a). Mercury is typically associated with atmospheric deposition from fossil fuel power plants. Locally, metals data for urban runoff is generally limited to copper, lead, and zinc, in the total recoverable form (as opposed to the dissolved, or soluble form).

Numerous studies have shown that metals in runoff are primarily found in particulate form, instead of the more bioavailable and toxic soluble form. Less than 2% of metals in runoff have been found to be leachable and most metals are readily sorbed to soil. Reflecting this, a study of vegetated filter strips, stated “Hence, only the small soluble portion of metal mass deposited onto vegetated buffer strips is likely to pose a risk to plants, animals that eat the plants, and groundwater resources” (Walsh, et al., 1997).

Deposition and accumulation of metals in soil and the environment has also been identified as a concern. A study conducted of highway runoff (Walsh, et al., 1997) found, however, that these concerns were minimal, stating that “the metal loading rate on the filter strips was less than one tenth of the rate limits for application of metals in biosolids to cropland. Therefore, metal deposition from highway runoff on roadside grassy areas may not pose any risk to human health and the environment."

It is thus apparent that the primary concern with metals in urban runoff is the dissolved form. The acute and chronic toxicity of dissolved copper, lead, and zinc in freshwater systems is a function of both metal concentration and water hardness (TCEQ, 2007b). The alkalinity (hardness) of Central Texas surface and groundwater's is high, typically 200-300 mg/L (as CaCO3) for the San Marcos springs (Sanders, et al., 2001). This high alkalinity significantly limits metals toxicity.

Metals in runoff are often associated with automobile-related sources, building materials, treated wood, industrial facilities, and landscape chemicals (Geosyntec, et al., 2011b). Common sources of metals in urban runoff are shown in the following table (Shaver, et al., 2007).

Metal	Source
Copper	Building materials Paints and wood preservatives Algaecides Brake pads
Zinc	Galvanized metals Paints and wood preservatives Roofing and gutters Tires
Lead	Gasoline (particularly prior to leaded gasoline phase-out) Paint Batteries
Chromium	Electro-plating Paints and preservatives
Cadmium	Electro-plating Paints and preservatives

D-3.1 Metal Concentrations

While there is an extensive database for total recoverable metals, little data exist for dissolved metals, especially in the Central Texas area. Also, metal concentrations in runoff are often below detection limits, thus making assessment of impacts particularly difficult. As stated above, the dissolved form of metals is the primary concern.

Mean total recoverable metal concentrations reported for the Central Texas area (in ug/L)*:

Information Source	Total Copper	Total Lead	Total Zinc
COA, 1990a	10	4 - 30	8 – 50
COA 2006	5 - 14	2 - 36	7 – 134
CRWR (Barrett, et al., 1998)	6 - 22	3 - 41	0 190

* In all cases except one (COA, 1990a for Total Copper) the mean concentration was found to be lowest for the undeveloped condition, and increased with impervious cover and/or conversion of land to residential and commercial uses.

First flush data is available for the total recoverable forms of copper, lead, zinc, and iron, and all except copper exhibit a first flush effect (COA, 1990b). The WERF SELECT model does not assume a first flush when modeling runoff pollution and BMP design.

Because of the limited data available for the dissolved form of metals, and also because of the high alkalinity of local surface and ground waters, the use of heavy metals as an indicator of impacts and for BMP design is not recommended.

D-3.2 BMP Treatment

Despite the fact that the use of metals as a target constituent is not recommended, BMPs should be selected that can provide effective removal of metals. As many metals are associated with smaller particulate sizes, sedimentation and filtration can be dominant treatment processes (Geosyntec, et al., 2011b). Removal through biochemical processes (e.g., microbial transformation, plant uptake) can improve removal but require longer retention times (days to weeks). Sorption processes can also be effective, thus treatment with soil or media with high cation exchange capacity is recommended. A treatment train system, i.e., multiple BMPs that provide different treatment processes, may be required to achieve effective metals removal.

The International Stormwater BMP Database Project found that metals removal by BMPs varied widely between types and metal constituent, and that large numbers of non-detection data hampered analysis of performance (Geosyntec, et al., 2011b).

It should be recognized that effective treatment of the target constituent Total Phosphorus will likely also provide effective treatment of metals, as many of the same treatment processes are important (e.g., sedimentation, filtration, sorption with ion exchange).

D-4 Bacteria

Pathogenic bacteria are a concern because of potential health effects on recreational and public water supply uses. In recent years the bacteria indicator being monitored has changed from Fecal coliform to Escherichia coli (E. coli). Most stormwater runoff data is for Fecal coliform, though this can be converted to an estimate of E. coli by applying a multiplication factor, often 0.63 (Nowlin and Schwartz, 2012). Known sources of bacteria in runoff include human and animal wastes and leaking wastewater systems, and bacteria are also naturally present in the environment.

Fecal coliform and E. coli concentrations in runoff, even from undeveloped areas, are typically much greater than contact recreation standards. However, the relationship between fecal bacteria indicators and actual pathogens is unclear; and there does not appear to be a relationship between the presence of pathogens and concentrations of indicators in runoff (Wright Engineers, et al., 2010) is a problem as reducing bacteria in runoff may not necessarily have a significant effect on pathogens.

D-4.1 Bacteria Concentrations

Predicting bacteria indicator concentrations entails significant uncertainty, as available monitoring data exhibits high variability, with standard deviations typically greater or much greater than the mean concentration (COA, 1990a, Barrett, et al., 1998, COA, 2006). This uncertainty is at least partially due to the fact that bacteria, unlike other pollutants, are living organisms that can find refuge in soil, and have the ability to reproduce extremely rapidly.

The following table provides a summary of relevant mean concentration data for Fecal coliform (FCOL; E. coli data for urban runoff is lacking):

Information Source	Is FCOL correlated to IC?	Is FCOL for Undeveloped Different that for Developed condition?	Mean FCOL Concentration (col/100mL)
COA 1990	No	Yes	Undeveloped 9,000 Residential and Multifamily 26,600 Commercial 210,000
COA 2006	No	Yes	Undeveloped 16,206 Developed 42,625
Osborne 2000	Yes	Yes	FCOL = 81193IC + 5322 Range 5,322 to 86,515

Fecal coliform concentrations in runoff do not exhibit a particularly strong first flush effect (COA, 1990b).

As the table illustrates, there are large variations in predicted concentrations. Given this information, in conjunction with the high degree of uncertainty when predicting BMP removal performance, fecal bacteria indicators are not proposed to be identified as a target constituent.

D-4.2 BMP Treatment

Despite the fact that the use of bacteria as a target constituent is not recommended, BMPs should be selected that can provide effective removal, even though it is unlikely that concentrations can be reduced to primary contact standards (Wright, et al., 2010).

Treatment BMPs should be selected that incorporate treatment mechanisms that can remove bacteria. Primary treatment mechanisms include predation by microbes in soil or filtration media, exposure to sunlight, and sorption.

The International Stormwater BMP Database Project found that filtration systems and wet ponds can be effective at removing bacteria, but swales, filter strips, and sedimentation basins are not, unless infiltration is provided (Wright, et al., 2010).

It should be recognized that effective treatment of the target constituent Total Phosphorus will likely also provide effective treatment of bacteria, as many of the same treatment processes are important.

A source control strategy should be adopted as a major component of any bacteria reduction program, including a program to reduce pet waste near waterways.

D-5 Petroleum Hydrocarbons

There is insufficient data for characterizing these pollutants, and for estimating BMP removal performance. However, these are pollutants of significant concern, thus BMPs with appropriate removal mechanisms should be selected. Primary mechanisms include sorption, filtration, and sedimentation. A primary source of petroleum hydrocarbons are motor vehicles, and the rainbow sheen of oil on paved surfaces during and after storm events is a common sight. Thus, requiring runoff treatment for parking lots and roadways should be a priority.

Of special concern are polycyclic aromatic hydrocarbons, or PAHs. Recent studies of PAH-contaminated sediment near Barton Springs in Austin have implicated coal-tar sealants as a significant source of PAHs in runoff and sediment (Mahler, et al, 2012, USEPA, 2011b). Austin is one of several communities that have now banned the use of coal-tar sealants for sealing parking lots.

D-6 Pesticides and Herbicides

There is insufficient data for characterizing these pollutants in runoff, and for estimating BMP removal performance. Nonetheless, they are of considerable concern and should be targeted for control, specifically an effective source control program. Pesticide concentrations in water reflect uses on land (USGS, 1999), and residue concentration in Edwards Aquifer groundwater are associated with residential, commercial, and industrial land uses (COA, 1997). In a study of 54 springs in the Austin area, 55% of samples were found to have total triazine concentrations above quantifiable levels (Hiers, 2002). All the relatively high concentrations (above 100 ng/L) were found in the Northern Edwards Aquifer, a karst aquifer where significant urbanization has occurred. Atrazine, a triazine herbicide, is an active ingredient in many “Weed and Feed” products, and is suspected to be a primary source of contamination in natural waters.

An effective integrated chemical and pest management program should be implemented throughout the study area and, because the Edwards Aquifer is highly susceptible to contamination, IPM plans should be mandatory in the entire zone.

D-7 Trash and Debris

Most treatment BMPs that provide storage (i.e., ponds) can be effective at capturing trash and debris, but regular maintenance will be required to remove buildup. Flow through or overland flow BMPs, such as Swales and Vegetative Filter Strips, may have limited ability to capture trash and debris. An effective trash and debris program should put a high priority on source control, including public outreach and education, and well-publicized trash cleanup events.

Discussion

The recommendation is to use total phosphorus (TP) as the primary constituent for BMP design, but other constituents are also significant pollutant concerns, especially TSS, metals, pesticides, and PAHs. Also, the transport and fate of TP in the Edwards Aquifer is not well known, but much of it could be precipitated within the aquifer, and not be discharged into the San Marcos River. On the other hand, nutrients, including TP, have clearly been identified as a significant pollutant concern. The USFWS report *Recommended Water Quality for Federally Listed Species in Texas* (White, Giggleman, Connor, 2006) identified “excess nutrients” and/or “supersaturation” (a nutrient-related impact) as threats to all 5 of the endangered species in the Upper San Marcos River system. Phosphorus in surface runoff from the Sink Creek watershed can definitely impact Spring Lake, in particular the Slough Arm, contributing to algae blooms, excessive plant growth, and associated dissolved oxygen and supersaturation problems that could negatively affect downstream reaches, including the main body of the lake, as well as into the San Marcos River below. Thus, the selection of TP as a BMP design constituent is reasonable. Effective control of TP, which exist in both dissolved and particulate phases, should provide effective treatment of most other constituents.

It has been argued that TSS should be used as the BMP design constituent, primarily because it is used in the Edwards Aquifer Rules. This is a legitimate argument, though somewhat weak because the TSS load caused by stream erosion (a result of hydromodification) can be much greater than that in upland runoff.

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In summary, there is no single pollutant constituent that is ideal for the complex groundwater-surface water system. Total Phosphorus is the primary water quality constituent recommended, but TSS can be utilized as well.

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APPENDIX E GROW GREEN PROGRAM INFORMATION

The Grow Green Program is a partnership between the City of Austin and the Texas AgriLife Extension Services. The program promotes the use of earth-wise practices around the home, yard, and other built environments for the purposes of managing pests and the efficient use of resources, especially water. Implementing the practices of the Grow Green Program can save you time, energy, and money while helping to protect our precious water resources – our streams, lakes, and aquifers. All educational materials are designed by the City using the technical expertise of the Texas AgriLife Extension Services. The City manages the program within the City limits while the Extension Service manages the program in remaining areas of Travis County. Printed publications are available free to the public at many nurseries and home improvement stores in the Austin area. You will find the online information here: http://www.austintexas.gov/department/grow-green

Limited use of landscape chemicals in a responsible manner is considered a Best Management Practice in stormwater management. The Grow Green Program is an excellent example of this BMP that could serve as a model for a similar program in the City of San Marcos.

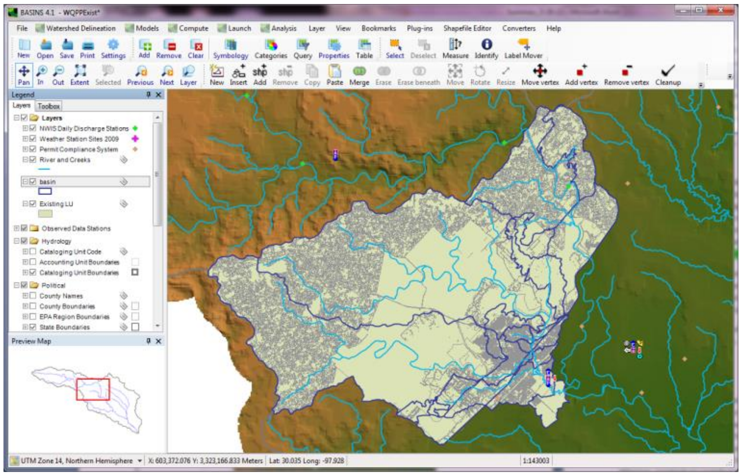
APPENDIX F HSPF-BASINS MODELING ANALYSIS

Appendix F was prepared by the Meadows Center for Water and the Environment.

Modeling Summary:

BASINS (Better Assessment Science Integrating point and Nonpoint Sources) is a multipurpose environmental analysis system designed for use by regional, state, and local agencies in performing watershed and water quality-based studies. This system makes it possible to quickly assess large amounts of point and non-point source data in a format that is easy to use and understand (EPA BASINS). While BASINS has many useful plug-in tools, Windows HSPF (Hydrologic Simulation Program FORTRAN), developed by Aquaterra, a national environmental consulting firm, was the primary program utilized for computing model outputs. Generation of Model Simulation Scenarios for Watersheds (GenScn) was used for displaying simulation results.

Figure F-1. BASINS interface. The light blue polygons represent the boundaries of basins used for this analysis.



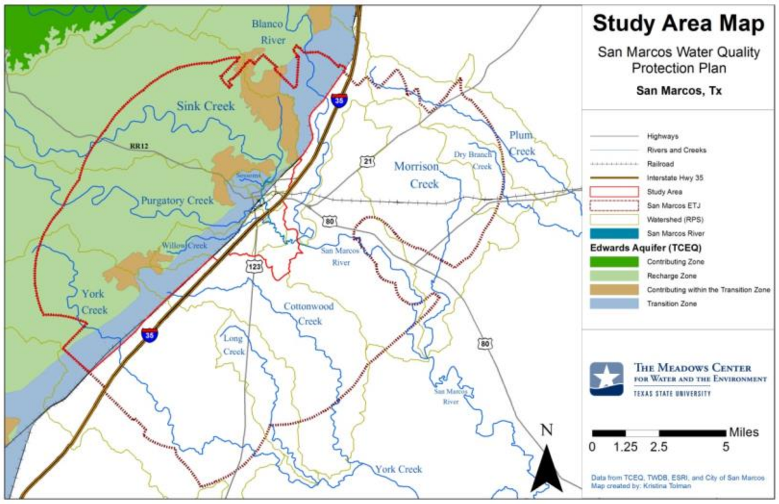
The Hydrological Simulation Program - FORTRAN (**HSPF**) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale Agricultural Runoff Management (ARM) and Non-point Source Pollution (NPS) models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is a comprehensive model of watershed hydrology and water quality that enables the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of these simulations is a time series of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time series of water quantity and quality at any point in a watershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to organic chemical and transformation products (EPA-HSPF). The modeling system provides the user with a wide array of graphical, tabular, and statistical comparison of results for a single scenario or comparison of multiple scenarios.

Watershed delineation:

Subwatershed boundaries were developed and verified by RPS Espey consulting. RPS Espey delineated the boundaries by utilizing national and local spatial datasets such as the national hydrography dataset (NHD), topographic data derived from LiDAR data, field observations, location of major roads and digital elevation model (DEM). This process produced an accurate and precise boundary layer for each watershed and its contributing basins. The subbasins were merged into individual watersheds. The consolidated watershed layer was then subdivided into aquifer zones based on the Texas Commission on Environmental Quality (TCEQ) aquifer layer. The Edwards Aquifer layer from TCEQ was utilized because it has a higher resolution than aquifer layers from other agencies such as Texas Water Development Board (TWDB) and Texas Parks and Wildlife Department (TPWD). The final delineated basins layer contains 25 areas of interest. The following displays the city's extra territorial jurisdiction (ETJ), watershed boundaries, and the TCEQ aquifer layer used for this analysis.

Some watersheds were subdivided into smaller drainage basins defined by the Edwards Aquifer zones. Therefore, flow paths and outflow points were delineated with digital elevation model data, stormwater data from the city of San Marcos, and large topographic features.

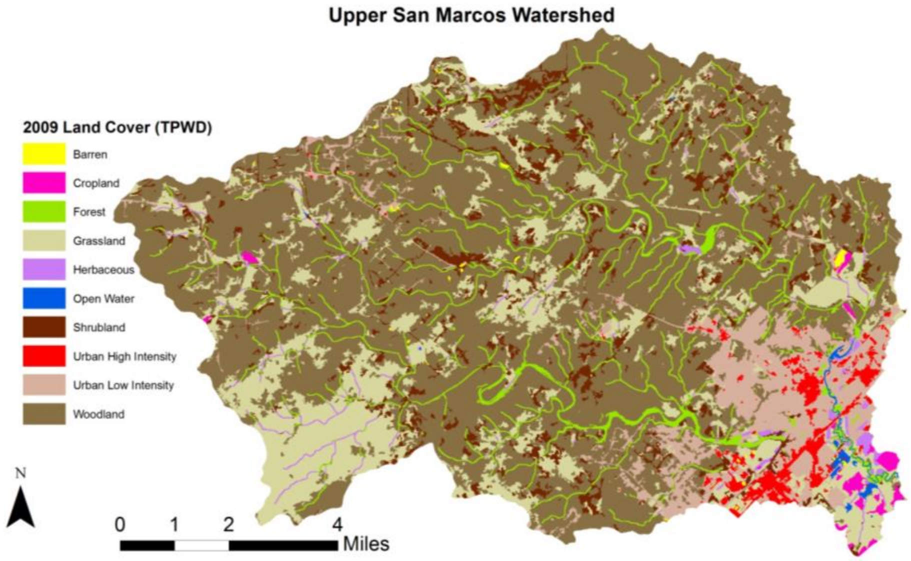
Figure F-2. Study Area Map for WQPP



Land Use and Land Cover:

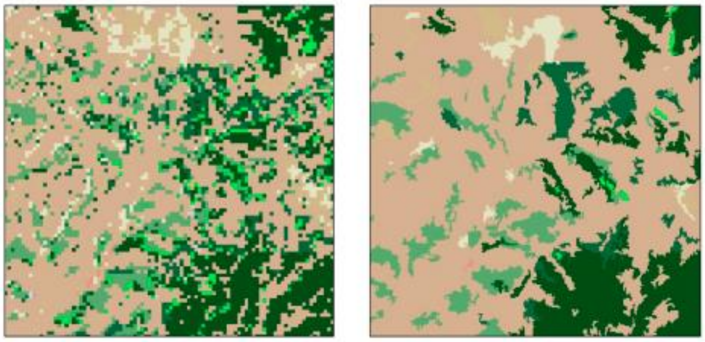
Accurate land cover data is essential for estimating the amount and type of nonpoint source pollutant loadings within each watershed. Various data sources were incorporated or referenced to improve the accuracy of the land cover data. Data sources included a 2009 vegetation coverage layer from Texas Parks and Wildlife Department, parcel and roads data from Hays County Tax Appraisal District, building and roads layer from the City of San Marcos, parking lot layer from Texas State University, and aerial imagery from Bing.

Figure F-3. The 10m Resolution Vegetation Coverage for the Upper San Marcos Watershed from Texas Parks and Wildlife (TPWD 2009).



Vegetation coverage data from Texas Parks and Wildlife were created as part of their Ecological Systems Classification and Mapping Project. The project was split into seven phases; data used for this analysis came from phase 1 which covers the majority of Central Texas. The vegetation coverage layer has a 10m resolution compared to the National Land Cover Dataset (NLCD) which is derived from 30m resolution imagery (Figure 3). There were 55 vegetation types within this study area, the vegetation types were aggregated into the HSPF model land cover categories: woodland, grassland, shrubland, deciduous, barren, forest, open water, cropland, urban undeveloped, and urban developed (impervious cover).

Figure F-4. 30 meter compared to 10 meter resolution imagery. (Diamond and Elliot, 2009)



30 Meter Land Cover

10 Meter Land Cover

Hays County Tax Appraisal District parcels were used to cross-reference and verify lands used for crops and grazing. Classification and attribute data are routinely updated; therefore, this layer served as an accurate account of existing land use conditions. Parcels zoned for agricultural use could be separated into two categories: rangeland or cropland. The distinction between the two classes was critical for accurately estimating fecal coliform contributions to the tributaries. Land utilized for livestock grazing yields more fecal coliform bacteria than land used for crops (citation). Whereas, cropland treated with fertilizers can contribute potentially more nitrates and phosphorous to adjacent tributaries than land used for livestock grazing.

Impervious cover was enumerated by building footprints, driveways, parking lots, and roads. A buildings layer from the city of San Marcos was used to ascertain the amount of impervious cover from buildings regardless of the land use classification. Large parking lots were manually delineated by The Meadows Center staff and comprised a large portion of the urban impervious cover values. Although the city and county have a comprehensive road dataset which was irrelevant for this analysis because it is stored as a line feature which prevents calculations of areal coverage. Therefore, the gaps between parcel lots were converted into a polygon shapefile to represent roads. Recent aerial imagery coupled with the city's road layer was used to modify and correct the newly created polygon roads feature. The final layer not only covered most of the major and minor roads within the city limits but also included some adjacent green space along major roads as well as sidewalks. Do to the inclusion of small amounts of green space; the roads polygon layer was assigned an impervious cover value of 85 percent.

Depending on the area, driveways can sometimes have a larger impervious cover footprint than some homes. The size of driveways varies greatly within the Upper San Marcos Watershed. Therefore, two driveway polygons were made for each neighborhood to devise the average amount of impervious cover per neighborhood. The polygons for homes within the neighborhood were selected to get a count of the number of homes; the driveway value was multiplied by the number of homes and added to the numerical values for impervious cover.

Table F-1. Upper San Marcos Watershed Soil data (NRCS, 2012)

Soil Type	Area (mi^2)	% Area	Description
AgC3	0.0153	0.02	Altoga silty clay, 2 to 5 percent slopes
AgD3	0.0204	0.02	Altoga silty clay, 5 to 8 percent slopes
AnA	0.5328	0.56	Anhalt clay, 0 to 1 percent slopes
AnB	0.9092	0.96	Anhalt clay, 1 to 3 percent slopes
AuB	0.0487	0.05	Austin-Castephen complex, 1 to 3 percent slopes
BrB	0.2310	0.24	Bolar clay loam, 1 to 3 percent slopes
BtD	0.0235	0.02	Brackett-Rock outcrop-Comfort complex,undulating
ByA	0.9941	1.05	Branyon clay, 0 to 1 percent slopes
ByB	0.1949	0.21	Branyon clay,1 to 3 percent slopes
CrD	32.1689	33.94	Comfort-Rock outcrop complex, undulating
DeB	1.8522	1.95	Denton silty clay, 1 to 3 percent slopes
DeC3	0.1912	0.20	Denton silty clay, 1 to 5 percent slopes
DoC	0.6500	0.69	Doss silty clay, 1 to 5 percent slopes
ErG	1.2022	1.27	Eckrant-Rock outcrop complex,steep
FeF4	0.1317	0.14	Ferris clay, 5 to 20 percent slopes, severely eroded
GrC	0.1926	0.20	Gruene clay, 1-5 percent slopes

HeB	0.5702	0.60	Heiden clay, 1 to 3 percent slopes
HeC3	0.4489	0.47	Heiden clay, 3 to 5 percent slopes, eroded
HeD3	0.6091	0.64	Heiden clay, 5 to 8 percent slopes, eroded
HoB	0.9763	1.03	Houston Black clay,1 to 3 percent slopes
HvB	0.0081	0.01	Houston Black gravelly clay, 1 to 3 percent slopes
HvD	0.0098	0.01	Houston Black Gravelly clay, 3 to 8 percent slopes
KrA	0.2426	0.26	Krum clay, 0 to 1 percent slopes
KrB	1.1750	1.24	Krum clay, 1 to 3 percent slopes
KrC	0.0806	0.08	Krum clay, 3 to 5 percent slopes
LeA	0.0526	0.06	Lewisville silty clay, 0 to 1 percent slopes
LeB	0.2772	0.29	Lewisville silty clay, 1 to 3 percent slopes
MEC	0.5285	0.56	Medlin-Eckrant association, undulating
MED	0.9345	0.99	Medlin-Eckrant association, hilly
Oa	0.7072	0.75	Oakalla silty clay loam, rarely flooded
Ok	0.4379	0.46	Oakally soils, frequently flooded
Or	0.5500	0.58	Orif soils, frequently flooded
Pt	0.1481	0.16	Pits
PuC	0.2727	0.29	Purves clay,1 to 5 percent slopes
RUD	45.2164	47.71	Rumple-Comfort association, undulating
RaD	0.4909	0.52	Real gravelly loam, 1 to 8 percent slopes
TaB	0.3784	0.40	Tarpley clay, 1 to 3 percent slopes
Tn	1.0163	1.07	Tinn clay, frequently flooded

Weather data:

There are various climate stations within the study area that cover a wide range of sample periods. These stations include San Marcos 417983, San Marcos Municipal Airport 722539, and Blanco 410832. Stations 417983 and 410832 were actually closer to the river and contributing watersheds, however, both stations lacked the necessary data for the simulation period. The San Marcos Municipal Airport station was selected as the primary source of comprehensive hourly precipitation data for the modeling period, 2009-2013. These years coincide with extensive water quality monitoring conducted by various entities.

Due to recurrent drought, the average annual rainfall is highly variable (Figure 5). 2009 and 2011 had below average rainfall, 2011 was one of the driest years on record. The dry conditions of 2009 eased up in late fall and an El Nino pattern brought substantial rain during the winter months. The drought of 2011 dried up intermittent creeks, rivers, and drastically diminished reservoirs. The winter months brought some much needed rain to the parched region. In contrast, the spring of 2012 was wet and verdant. Therefore, rainfall during this 3.5 year survey period varied drastically, yet, according to some estimates this variability could resemble future conditions and patterns of rainfall.

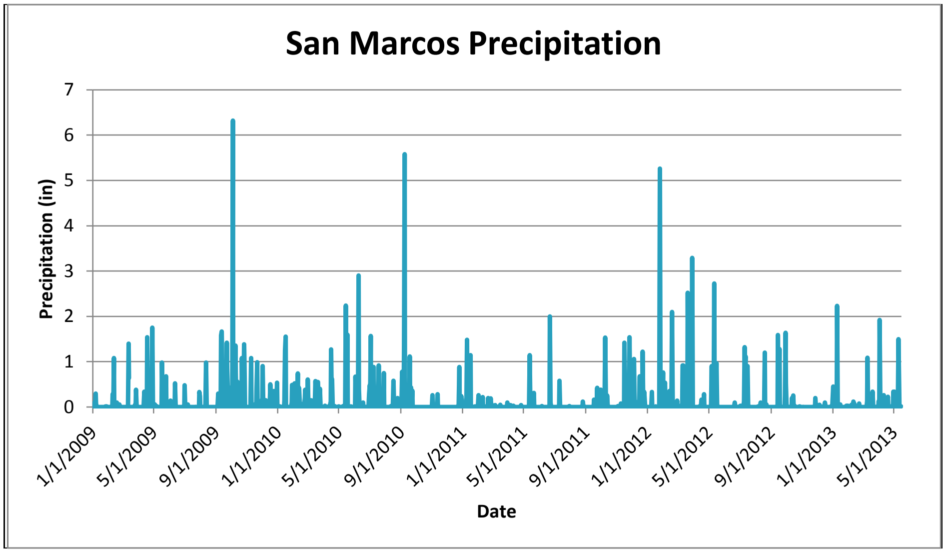
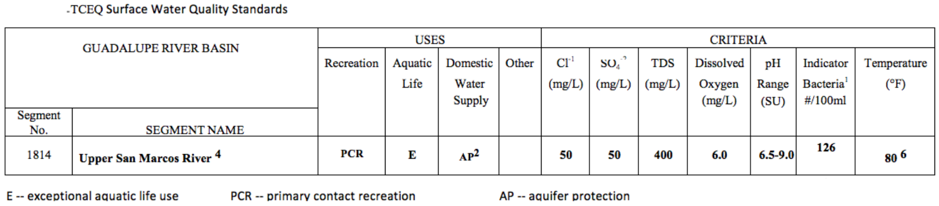


Figure F-5. Precipitation values measured from January 1, 2009 to June 1, 2013 at the NCDC weather gauge #722539 located at the San Marcos Municipal Airport

Water Quality:

Surface water quality standards for each river basin are set by Texas Commission on Environmental Quality (TCEQ). This includes criteria standards for recreation, drinking water, aquatic use, and fishing as well as other important constituents. These standards are in the table listed below (Table 1). Since San Marcos River is spring fed and has exceptional water quality, these standards may be lower than the ideal or existing conditions. However, they will be used as thresholds to assess the water quality modeling outputs.

Table F-2. TCEQ surface water quality standards for the Upper San Marcos River (TCEQ, 2012)



-TCEQ Surface Water Quality Standards

GUADALUPE RIVER BASIN		USES				CRITERIA						
Segment No.	SEGMENT NAME	Recreation	Aquatic Life	Domestic Water Supply	Other	Cl^{-1} (mg/L)	SO$_4^{-2}$ (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L)	pH Range (SU)	Indicator Bacteria[1] #/100ml	Temperature (°F)
1814	**Upper San Marcos River** [4]	**PCR**	**E**	**AP**[2]		**50**	**50**	**400**	**6.0**	**6.5-9.0**	**126**	**80** [6]

E -- exceptional aquatic life use PCR -- primary contact recreation AP -- aquifer protection

Nonpoint Source:

Nonpoint source pollution (NPS) comes from many diffuse natural and artificial sources, often entrained and transported by water. Organic sources of nonpoint source pollution include suspended sediments from denuding of topsoil, fecal matter from animals, and transport of nutrient rich vegetation debris. Urban areas are great contributors of NPS pollutants through various human activities, these activities include but are not limited to: fertilizer and pesticides from agricultural practices, sediment from improperly managed construction sites, oil debris from parking lots, and leaking septic tanks.

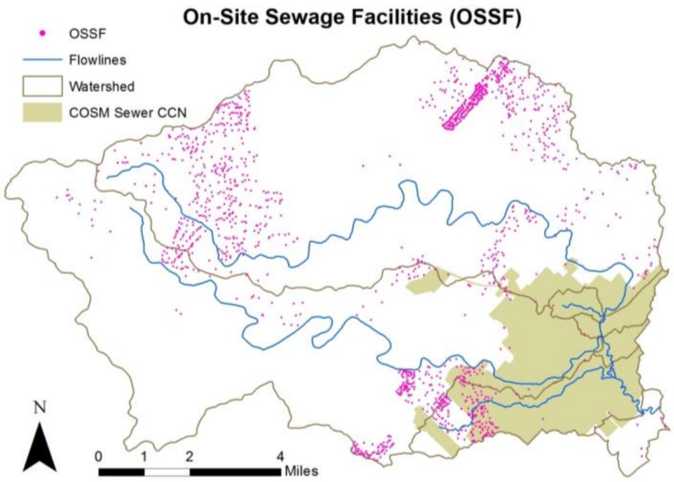
Due to the myriad of sources of nonpoint source pollutants, various runoff coefficients and algorithms have been developed and integrated into BASINS with respect to the land use. BASINS differentiates pollutants into three categorical sources: natural, agricultural, and urban. Natural pollutant loadings are estimated based on the type and amount of land cover. Reference layers for these calculations combine topographic data with forest, open undeveloped, and barren land cover classifications. This information is also aggregated with estimates of wild animals such as deer and hogs. Agricultural land use has two distinct classes: land used for crops and land used for livestock grazing. Cropland contributes nutrient loadings linked to synthetic and natural fertilizers. Whereas, areas used for livestock will have a higher incidence of runoff containing fecal coliform bacteria.

Various studies have found that increased impervious cover causes more surface water runoff due to the lack of infiltration (Cite). Calculations for urban areas account for higher runoff coefficients as well as the transport of metals particulates, nutrients from fertilizers, and fecal matter from urban wildlife and more. Identification of urban runoff sources is very challenging; therefore, the urban category is very broad and focuses primarily on pollutants associated with impervious cover as well as bacteria from domesticated animals such as dogs.

The effects vary depending on the amount, rate of transport as well as the source, time, and location. Water quality data was obtained from various sources in order to calibrate the simulated water quality values with observed values during a storm event. The modeled period of record is from January 2009 to May 2013 which corresponds with the time interval from all the surveying entities.

On-site Sewage Facilities

On-site sewage facilities (OSSF) commonly referred to as septic tanks, can potentially degrade and leak over time if not properly cared for. Properties within the city limits receive water and wastewater utilities from the city of San Marcos. However, some properties that are within the ETJ but outside of the city limits still use OSSF and wells. OSSFs were included within the model and considered a potential source of nonpoint source pollutants, primarily bacteria. To account for the prospect of leakage from OSFFs, the estimated number of OSSFs per basin was integrated within the HSPF Bacteria module. HSPF calculates the percent failure rate and then the estimated amount of bacteria from failing OSSFs. Because most OSSFs are undocumented, obtaining an accurate number per watershed is difficult. In 2011, Hays county GIS and 911 Addressing Department had various interns georeference housing information to develop a septic shapefile. This layer served as the input source for the OSSF spatial data. There are an estimated 1545 OSSFs within the Upper San Marcos Watershed.



Estimating fecal coli form loadings:

The Texas Agrilife extension office produces an annual report estimating the amount of livestock within each county. According to Hays County Agrilife Extension most recent 2012 animal estimates the values are as follows: Cattle (7750), Goats (7400), Sheep (1100), and Horses (1000). These values were subdivided into per acre calculations and then assigned to modeled watersheds based on the amount of land zoned for agriculture.

HSPF utilizes a set of EPA approved algorithms to simulate and calculate the e coli bacteria loadings based on the amount of each livestock animal. These values are then embedded within the entrainment calculations for suspended particles based on the spatial characteristics such as slope, land cover, soil, flow, and proximity to the water body. As previously mentioned the animal numbers are based on countywide estimates that were then divided and assigned to agriculture parcels within each watershed. Hence, these values may not be exact but resemble general characteristics observed within the watershed.

Due to the small amount of agriculture within the study area, the most likely source of e. coli loadings in tributaries is attributed to pet waste, primarily from dogs. We conducted an informal survey by asking the local veterinary clinics their opinion on the amount of dogs per house hold. Out of the four veterinary clinics surveyed, the average range was between 2-4 dogs per household. The first veterinary contact estimated that there were 2 dogs living in each household. The second veterinary secretary suggested an average of 2-4 dogs per household. The third veterinary assistant estimated 2-4 dogs per home. She also emphasized the City of San Marcos Animal Ordinance which states that the maximum number of dogs per household is 4, and the total number of animals per household cannot exceed 7. Our final estimate was a conservative 0.5 dogs per household because a large percentage of pet owners pick up their animal’s waste. Moreover, these surveyed estimates were high and potentially biased towards pet owners. The conservative value of 0.5 dogs per house accounts for households that do not own pets.

Horses:

The exact number of horses in the watershed is unknown. However, Texas Agrilife Extension estimates that a maximum number would be close to 75 horses. Horses in the watershed are typically used for recreational purposes. While the exact location of all horses is not known, horse numbers were distributed equally across agricultural land and home sites larger than 5 acres.

Deer:

White-Tailed deer are a notorious nuisance throughout the Texas Hill Country. A Texas Parks and Wildlife Department report notes that the Texas Hill Country has one of the largest populations of white-tailed deer in Texas (TPWD, 2000). In 2012, Texas Parks and Wildlife released a report citing the influence the spatial configuration of urban areas has on resident deer populations. They found that urban areas with random plots of undeveloped land are an ideal habitat for deer populations. The urban areas provide food, in the form of lawns, and protection from predators. This creates a haven for deer that often overpopulate these areas due to the lack of environmental constraints. Consequently, deer estimates varied for each basin. The basins that are urban with a high percentage of impervious cover (20-35%) had an approximate rate of 1 deer per 10 acres. Whereas, areas with moderate impervious cover per area (10-20%) were assigned an average of 1 deer per 3 acres due to the ideal spatial configuration. The areas that have a relatively low percent impervious cover per area were assigned the average 1 deer per 10 acres.

Feral Hogs:

Populations of feral hogs have rapidly increased over the last 20 years. Feral Hogs are often travel in herds and are found near riparian areas. Their impact is enumerated within the model as a potential source of bacteria based on their numbers. However, they also degrade habitat by causing soil erosion and killing trees due to their burrowing nature. Therefore, they are not only responsible for fecal matter within adjacent waterways, but they cause soil erosion and change the plant and animal community. Texas Agrilife extension office estimates that statewide they cause an estimated $500 million worth of damage annually (Texas Agrilife, 2012). There are various state, local, and regional initiatives to eradicate these nuisances. Texas Department of Agriculture has created a program called Hog Out County Grants Program. Moreover, local businesses are even offering bounties to the highest collector of hog tails.

Due to their roaming nature, it is hard to surmise an accurate estimate of the amount of feral hogs within the study area. They travel at night, move great distances, and populations change seasonally. They typically stay away from highly urban areas; therefore, they are likely relegated to areas outside the city limits in watersheds such as Purgatory, Sink Creek, and the recharge zone of Cottonwood and Blanco. Based on some estimates, there is an average 1 hog per 75 acres. Applying this number to the rural unpopulated areas of the watershed, there are an estimated 135 number of hogs within the study area. This number is divided into various modeled segments that correspond to their preferred habitat characteristics.

Cattle:

Due to the high amount of urbanization within the modeled area, there is a small amount of land dedicated to agriculture namely rangeland and cropland. The majority of these areas are located east of IH 35, near Martindale. However, there are a few plots listed as rangeland located adjacent to Sink Creek which are routinely used for cattle grazing. Properties east of IH35, downstream of Willow Creek watershed also have crops and grazing cattle. According to the Texas Agrilife Extension, there is 1 cow per 40 acres of land zoned for agriculture in the watershed; therefore, there is an estimated 215 number of cattle within the modeled area.

Goats:

The 2009 Hays County estimates from Texas AgriLife Extension lists 7,400 total goats in Hays County. According to Texas AgriLife, as much as one-quarter of farms in Hays County have goats. These values seem rather high and are not representative observed trends within the modeled watersheds. Therefore, a more conservative value for the number of goats within each subwatershed was calculated based on the stocking rate of 1 goat per 40 acres on 10% of total agricultural land. This resulted in a total of 72 goats estimated in the watershed. This may underestimate the true number of goats; however, there is no citable evidence or data to enhance the accuracy of the estimation.

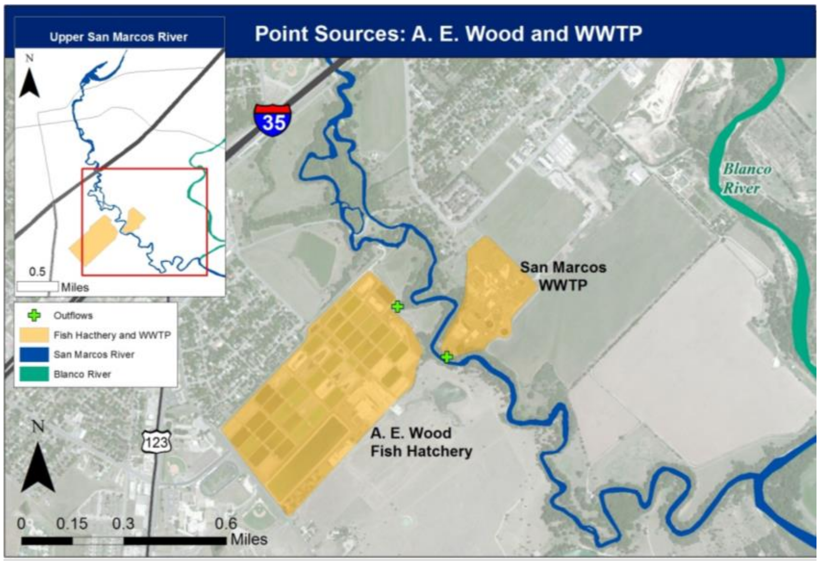


Figure 7. Two permitted sources that discharge back into the river.

Point source pollution is from a discrete, discernable source such as effluent from a water treatment plant or concentrated animal feeding operation (EPA 2013). Discharge from a point source is permitted by TCEQ and is subject to standards set by section 502 (14) of the federal Clean Water Act. Each permit varies depending on the source; however, the permit holder must routinely monitor the amount and quality of their outflow. There are two point sources along the Upper San Marcos River: A.E. Wood State Fish Hatchery and the San Marcos Waste Water Treatment Plant (WWTP). The WWTP and A. E. Wood Fish Hatchery is located downstream of Thompson’s Island, between Interstate Highway 35 and the confluence with the Blanco River, within the Willow Creek watershed.

The Meadows Center for Water and the Environment has obtained discharge data for both point sources from January 1, 2009 to May 30, 2013. The WWTP discharges an average of Data for the WWTP includes daily measurements of discharge, TSS, ammonia, e coli, biochemical oxygen demand (BOD), nitrate, turbidity, dissolved oxygen, and total phosphorous. Data for the A. E. Wood Fish Hatchery includes average monthly estimates of discharge and daily amounts of TSS. A point source function was created within HSPF to account and calibrate the amount and type of inflow from these sources.

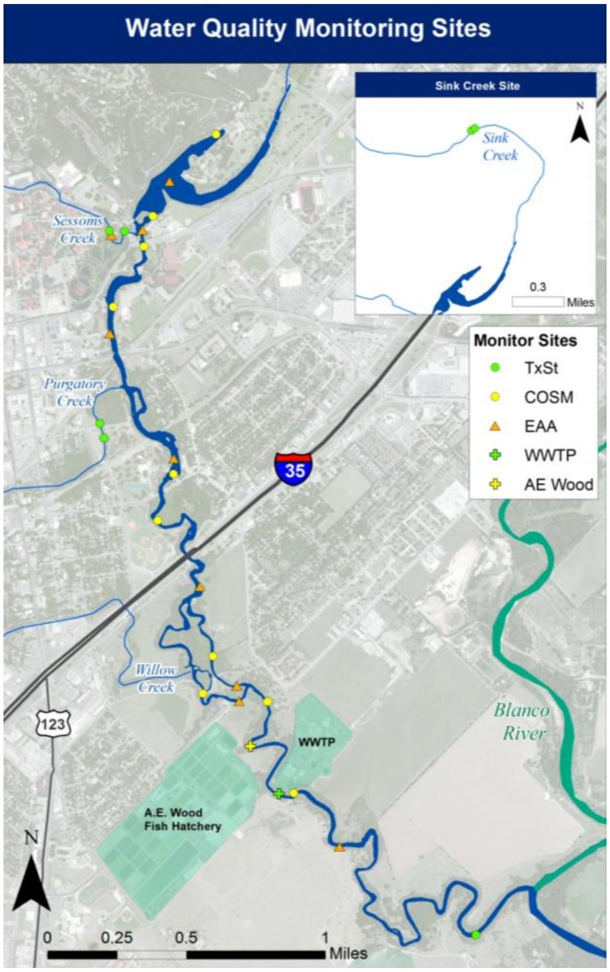


Figure 8. Water quality sites used for this analysis.

Table 2. List of water quality data and sources used for calibration of simulated results

	USGS	COSM	TxSt	EAA	WWTP	A.E.Wood
Discharge	X		X	X	X	X
Ecoli		X			X	
Ammonia			X	X	X	
Nitrate			X	X	X	
Phosphorous			X	X	X	

BOD			X	X	X	
TSS			X	X	X	X
DO			X	X	X	X

Texas State University

Water quality used to calibrate the model came from numerous sources. The primary stormwater data utilized for calibration efforts was collected by Dr. Ben Schwartz and Dr. Weston Nowlin from the Biology Department at Texas State University as part of the San Marcos Observing System (SMOS) at the Meadows Center for Water and the Environment. Stormwater data was collected during stormflow events. A Teledyne ISCO automated water sampler was installed at tributaries including Sink Creek, Sessoms, Purgatory, and the lower river reach before the confluence with the Blanco River (Schwartz and Nowlin, 2012). Therefore, all modeled tributaries have stormflow data except for Willow Creek. Parameter data from the water quality monitoring includes: discharge, ecoli, ammonia, nitrate, phosphorous, biooxygen demand, total suspended sediments, and dissolved oxygen. Although the monitored data was one of the most extensive datasets used for the model, results were contingent upon storm flow at each location. Therefore, certain locations have more data than others due to limited stormflow. For example, Sessom Creek had the most observed stormflow events with a total of 11 events, whereas, the station located on Sink Creek only recorded one event. For each event, the sensors recorded various parameters for 24 hour duration after it detected the first pulse of discharge. This hourly time interval restricted us to use hourly instead of daily precipitation data.

City of San Marcos

The City of San Marcos conducts surveys on the fecal coliform counts after rain events within various segments of the river. This data was integrated into the model in order to assist in the calibration process. The data utilized for the model ranged from January, 2009 to May 2013 at 11 sampling sites. The highest recorded fecal coliform observation during the modeling period occurred on February 3, 2010.

Edwards Aquifer Authority

The Edwards Aquifer Authority has contributed data gathered in 2009 and 2011 as part of the variable flow study. Data were collected during low flow periods in 2009 and 2011 within designated sampling sites. Most of the monitoring sites were located close to the Texas State Monitoring sites, yet some covered areas not included within the Texas State study. The data contains values for every modeled parameter except fecal coliform bacteria. According to the 2014 Habitat Conservation Plan, additional stormwater and continuous surface water modeling will be conducted; however, the results will not be available for this modeling analysis.

WWTP and Fish Hatchery

As stated by section 502(14) of the Clean Water Act, all point sources are required to document their flow and quality of water discharged. The frequency and parameters measured are set by the type of discharge permit. Since WWTP discharge is a regulated and permitted from a waste water treatment plant, the water quality constituents are more comprehensive than the permitted discharge from the A. E. Wood Fish Hatchery. The constituents are monitored by the Wastewater treatment plant daily and include all the parameters modeled within HSPF. Whereas, the A. E. Wood Fish Hatchery discharge data was a monthly average along with daily TSS. The monthly average amounts were subdivided into daily estimates of discharge in order to calibrate the inflow data.

USGS Discharge

Lastly, discharge data from the solar-powered United State Geological Survey (USGS) station # 8170500 at Sewell Park was incorporated into the model. The gauge station monitors discharge at 15 minute intervals. The average annual discharge for 2009, 2010, 2011, and 2012 was respectively 113, 218, 118, and 174 cfs (Figure 9). To ensure accuracy of the discharge sensor, the USGS staff routinely check and calibrate the instrument, especially during periods of low-flow discharge.

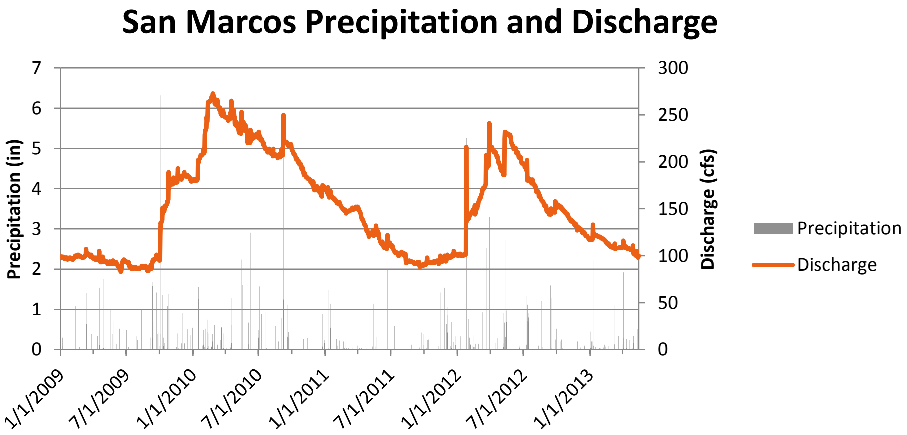


Figure 9. Discharge and precipitation data for San Marcos between January 2009 to May 2013.

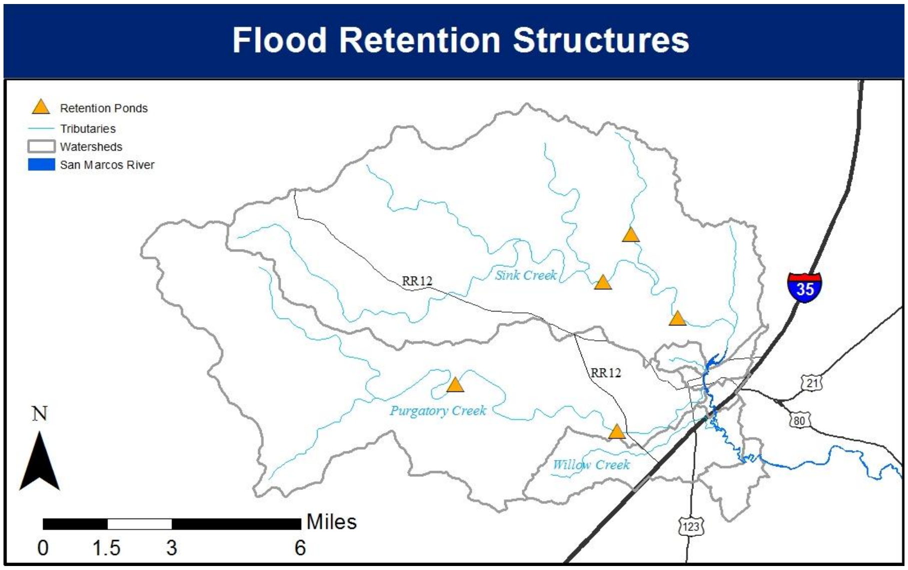


Figure 10. NRCS Flood control structures in Purgatory and Sink Creek watershed.

The initial pulse from peak stormflow has decreased over the last forty years due to the presence of five flood-control structures in the San Marcos watershed. The Natural Resource Conservation Service

(NRCS) have built three flood retention structures in the Sink Creek watershed and two flood retention structures in the Purgatory watershed. These impoundments were installed to reduce the amount and frequency of runoff during severe rain events (Saunders et al., 2001). In 1970, a flood of intense magnitude caused severe destruction in San Marcos. The NRCS built the structures in the 1980's to reduce the likelihood of catastrophic damage from flash flooding. October 17-21, 1998, San Marcos received an estimated total of 590 mm (19 inches) of rain for five days (Earl, 2007). According to Earl (2007), the flood-control structures retained a significant amount of the initial pulse. While these structures proved effective at reducing the amount of initial runoff entering the river, they do not eliminate downstream flooding. The flood control structures were added to the model as an existing best management practice prior to calibration efforts (Figure 10).

Calibration:

Calibration of simulated results is a crucial step to ensuring accuracy of simulated results. Different water quality data were implemented to verify modeled results. As previously mentioned, water quality data from various sources, at different locations within the watershed, and at a range of time intervals were used to corroborate the simulated results to observed results. Due to the variation of time intervals, amount, resolution, and location of collected data, the calibration process was very extensive and time consuming.

The HSPF model process is split into three phases (Figure 11). Phase one is consists of the data collection, model input preparation, and parameter evaluation. Preparation of the input data and parameter evaluation is very tedious process. Relative to the study area and resolution of available data, phase one can be as crucial and time consuming as phase two. The precision and accuracy of the input data will dictate the accuracy of the modeled results. Phase two is often referred to as the calibration and validation stage where the model outputs are evaluated based on available water quality data. This is a critical step that guages how well the model represents real conditions. A series of steps are employed to adjust the variables so the outputs are parsimonious. Phase three of the HSPF model is utilization of the model as a decision support tool for regulatory and management purposes (Duda et al., 2012). This will include simulated the reduction coefficients potential best management practices that are recommended by the stakeholders will have on areas of .

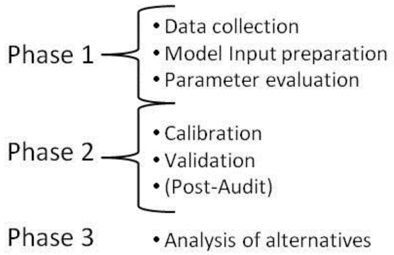
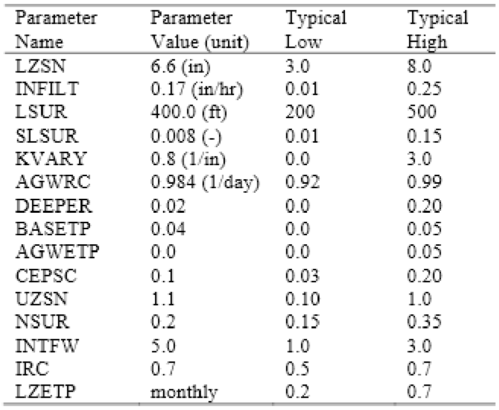


Figure 11. HSPF modeling phases (Duda et al., 2012).

The initial phase one model preparation process required retrofitting the stream channel characterization. FTABLE, also known as the hydraulic function table, stores the channel characteristics. These values define the rate, flow, volume, and surface area of each modeled reach (Hummel et al., Year). Input values for these characteristics are derived from USGS flow data as well as continuous water quality monitoring data. Only three drainage basins contained sufficient water quality data for full calibration. However, 8 of the modeled basins have observed values for at least one constituent.

There are three main modules within HSPF: PERLAND, IMPLND, AND RCHRES. PERLAND and IMPLND calculate the amount pervious and impervious cover per land cover category for each modeled basin. PERLAND module accounts for land cover categories plant species characteristics such as root structure, density, and maturity- variables that influence the rate of erosion and the amount of sediment transported. Such characteristics are generalized into broad land cover categories including forest, grass, urban undeveloped, pasture, and cropland.

RCHRES module contains information about the modeled basins flow characteristics, width, length, particle size, infiltration rate, transport coefficient, and more. HSPF calculates the route of water by employing a storage routing function between reaches.



Parameter Name	Parameter Value (unit)	Typical Low	Typical High
LZSN	6.6 (in)	3.0	8.0
INFILT	0.17 (in/hr)	0.01	0.25
LSUR	400.0 (ft)	200	500
SLSUR	0.008 (-)	0.01	0.15
KVARY	0.8 (1/in)	0.0	3.0
AGWRC	0.984 (1/day)	0.92	0.99
DEEPER	0.02	0.0	0.20
BASETP	0.04	0.0	0.05
AGWETP	0.0	0.0	0.05
CEPSC	0.1	0.03	0.20
UZSN	1.1	0.10	1.0
NSUR	0.2	0.15	0.35
INTFW	5.0	1.0	3.0
IRC	0.7	0.5	0.7
LZETP	monthly	0.2	0.7

Table**. Example of calibrated values for infiltration and sediment transport (Zang and Wren, 2005)

Only one meteorological station, San Marcos Municipal Airport station, had the required hourly time-series precipitation data. Two additional meteorological stations are located in the modeled area, yet they store daily instead of hourly weather information. The hourly time-intervals are crucial for the calibration because most of the observed water quality data was collected hourly to capture the short duration of stormwater pulses. The Watershed Data Management Utility (WDMUtil) within HSPF was used to disaggregate the daily data into hourly data which improved the simulated results and enhance the calibration process.

Phase two calibration of instream water quality involves adjusting various parameters within HSPF to make the simulated flow resemble the observed flow conditions. This process is highly contingent upon the input data for the weather stations, topographic characteristics, and the flow regimes set within the F-tables of each segment. Due to the extreme variability between landscape characteristics, weather conditions, chemical processes, and physical characteristics, there are a wide range of values to represent the processes observed in nature. The variability is difficult to account for due to different sources and conditions for the modeled areas. For this reason, calibration is complex and in-depth.

The purpose of the phase two validation is to verify the calibrated model adequately calculates the variables and conditions. According to Duda et al, there are numerous procedures to validate the model, however, the split-sample calibration/validation approach is one of the most commonly used and effective methods to assess model accuracy. For this procedure, a portion of the observed water quality data is used for the calibration period and the remaining data is input after the calibration. The model is then run for the remaining period of the observed values. A measure of goodness-of-fit between the simulated and the observed results quantifies the accuracy between to two. This process is reiterated until the modeled system and natural system variables are reconciled.

Phase three of the modeling process is defined as the application and interoperability of the modeled results.

APPENDIX G WATER QUALITY BMP SPREADSHEET MODEL

The use of a well-defined procedure or model can greatly expedite assessment of sites and design of BMPs. Ideally, the procedure or model should incorporate recent scientific and technical advances in stormwater management, especially those from the Water Environment Research Foundation (WERF), International Stormwater BMP Database Project (IBMPDBP) and their cooperators. Of particular interests are the following:

- Describe BMP pollutant removal performance in terms of effluent concentration, instead of the now-discredited "percent removal" procedure, widely used in many BMP manuals.
- Determine how much runoff is captured and treated by a BMP, and how much is bypassed (untreated)
- Promote runoff volume reduction
- Control hydromodification effects of urbanization, i.e., the increase in the frequency and magnitude of flows, which contribute significantly to excess stream erosion, as well as flooding.
- Multiple BMP "treatment trains" can be a viable option for many sites, including "Low Impact Development" (LID) BMPs such as rainwater harvesting, rain gardens, permeable pavement, and disconnection of impervious cover.

In addition to incorporating these issues, a procedure or model should be reasonably easy to use, and flexible enough to accommodate different site and BMP design variables. A review of current procedures and models was conducted. National and local procedures included the "Simple" model used primarily in the Chesapeake Bay region, the TCEQ Edwards Aquifer technical guidance manual, City of Austin Environmental Criteria Manual, and the LCRA Highland Lakes Water Quality Management Technical Manual. None of these are adequate, as none use the "effluent concentration" method, do not directly estimate runoff capture, and have weak or overly simplistic procedures for evaluating "treatment train" and/or LID systems. The inability to account for intervening drainage areas for multiple BMP "treatment trains" is seen as a significant weakness, as this is a common occurrence. Models that were investigated included a probabilistic one (Adams and Papa, 2000), and several continuous simulation models (SWMM, HSPF, WinSLAMM). None fit these criteria well. One model that has significant promise is the SELECT model, an Excel-based spreadsheet developed for the WERF. It is a continuous simulation model that incorporates the "effluent concentration" method for assessing BMP performance. However, the current version of the model is not sufficiently developed, in the option of this author, for widespread use. Given the lack of available models and procedures, a spreadsheet has been developed for the WQPP that attempts to fill the design and assessment needs. The model is in Excel 2013 format (and can be run in "compatible" mode for Excel 2010 users), and does not require the use of macros.

The spreadsheet has the following capabilities:

- Models an "average annual year" of rainfall and evaporation; the year 1985 is used.
- Calculates runoff volume captured vs. bypassed, and estimates volume reduction (via infiltration and/or evapotranspiration).
- Uses the effluent concentration method for calculating BMP pollutant removal performance; for infiltration-type BMPs, no surface discharge is assumed, thus the effluent concentration and load are equal to 0
- Models storage-based BMPs (e.g., ponds) and flow or conveyance-based BMPs (e.g., vegetative filter strips).
- Includes both conventional and LID BMP options.

- Models up to 3 BMPs in a “treatment train” system, where BMPs are linked by routing treated effluents and/or bypass flows, and accounting for intervening drainage areas between BMPs.
- Up to 2 drainage areas per BMP can be incorporated into the model; these are labeled Subarea A and Subarea B. This may be useful for assessing different on-site drainage areas, as well as for accounting for an off-site drainage areas. For two BMPs, Green Roof and Permeable Pavement, the size of the BMP MUST be equal to Subarea A, and any off-site drainage MUST be input as Subarea B.

Commented [D45]: Revised to clarify Green Roof and Permeable Pavement inputs.

Attempts have been made to make the model as user-friendly, but a series of “sizing tables” will be developed to facilitate BMP selection and design for simpler BMP systems, i.e., single BMPs or “treatment trains” with negligible intervening drainage area.

The following table provides a list of BMPs that are incorporated into the model. There are 3 “Other BMP” options whereby the User must input design values; the reason for 3 is that up to 3 BMP drainage areas are allowed in the model. There is also a “No BMP” option; this can help avoid confusion when BMPs in series are used but there is no intervening drainage area (i.e., the “No BMP” option only applies to the 2nd or 3rd drainage areas).

BMP Choices in Spreadsheet Model	
BMP	**Notes**
Sand Filtration	
Biofiltration (with underdrain system)	
Biofiltration (infiltration design)	
Rain Garden (with underdrain system)	
Rain Garden (infiltration design)	
Extended Detention (Sedimentation Basin)	
Batch Sedimentation Basin	
Wet Pond	
Vegetative Filter Strip	
Vegetated Swale	
Retention/Irrigation	
Infiltration Basin	
Rainwater Harvesting	
Permeable Pavement	
Green Roof	
Other BMP X	Can be non-standard or proprietary BMP
Other BMP Y	Can be non-standard or proprietary BMP
Other BMP Z	Can be non-standard or proprietary BMP
No BMP	

Model Theory and Application

Estimating Runoff Volume from Drainage Areas

Commented [D46]: Added “from Drainage Areas” to heading

The spreadsheet uses a one hour time step, and calculates depression storage and runoff volume at each time step as follows:

If P = 0, f = fo + PAN

If P > 0 and P ≤ fo, ROV = 0

If P > 0 and P > fo, ROV = (P – fo) * Rv

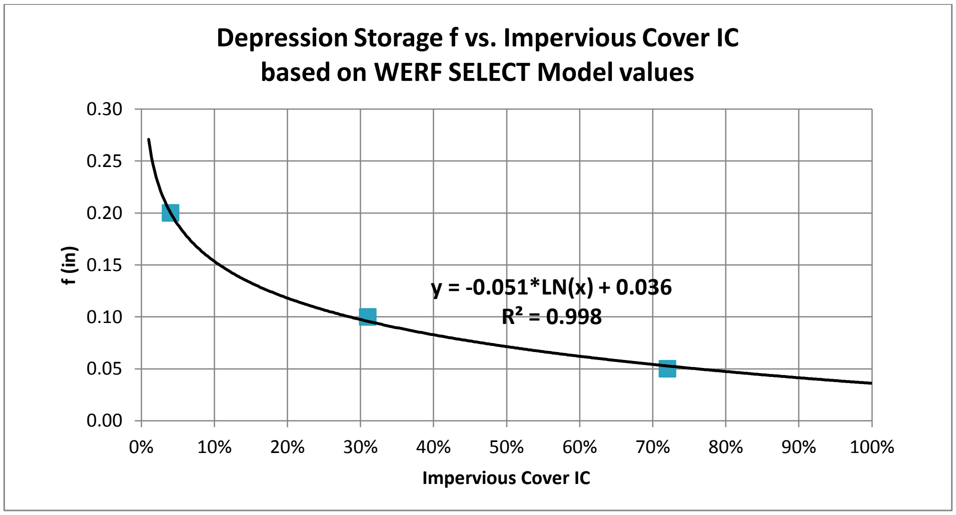
Where P = rainfall (in)

f = depression storage at end of time step

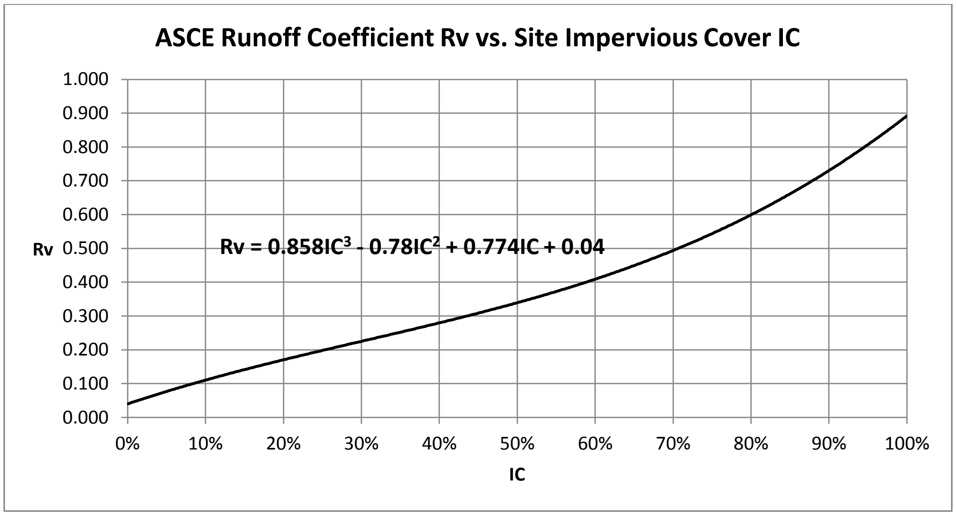
fo = depression storage at start of time step

Rv = runoff coefficient

Depression storage is a function of impervious cover, based on the following relationship derived from the WERF SELECT model (Pomeroy and Rowney, 2012). Because the equation is logarithmic, an upper boundary has to be set at 0% IC; from the curve a maximum f value of 0.30 in/hr appears reasonable.



The runoff coefficient Rv equation used is from ASCE, and also the one used in the SELECT model:



Exceptions to these general procedures are made for two BMPs, Green Roof and Permeable Pavement. Each of these BMPs is considered to be its own drainage area, and direct rainfall onto the BMPs is modeled, rather than runoff (though runoff from adjacent drainage areas can be routed to these BMPs). Stated another way, these BMPs do not runoff coefficients; runoff is generated when their Water Quality Volume is exceeded.

Commented [D47]: Edited Dec 2014

Routing Runoff and BMP Runoff Capture Efficiency

Routing of flows into and out of BMPs is based on the continuity equation:

$S_i = S_{i-1} + I – O$

Where S_i is the volume stored in the BMP at the end of the time step

S_{i-1} is the volume stored at the start of the time step

I is the inflow during the time step

O is the outflow during the time step

The maximum value of S is the Water Quality Volume (WQV), which is input by the user. Inflow I is the sum of all inflows from one or more drainage areas, and/or inflows from one or more BMPs (treated effluents and/or bypass flows). The outflow O is the sum of treated effluent flows and bypass flows. The effluent treatment rate is assumed to be a constant or maximum value, equal to the Water Quality Volume (WQV) divided by the Design Drawdown Time (DDT), both which are input by the user:

QT = WQV/DDT

The assumed QT at each time step is the lesser of WQV/DDT or the actual inflow volume.

If the calculated S_i value is greater than the WQV, a bypass is assumed to occur:

Bypass = Calculated S_i - WQV

For flow or conveyance-based BMPs that have no WQV (e.g., Vegetated Swale), the continuity equation is used for routing, but the S values are equal to 0, and the volume of runoff treated or bypassed is based on the BMP treatment rate. If the total inflow volume during a time step exceeds the hourly treatment rate, a bypass is assumed to occur, equal to:

Commented [D48]: Changed VFS to vegetated swale – see next comment for explanation.

Bypass = I_{total} - QT

For example, if a vegetated swale has a design treatment rate of 0.10 cfs, or 360 cfh, and inflows during a time step total 450 ft^3, a bypass of 450 – 360 = 90 ft^3 is assumed to occur.

Commented [D49]: Changed VFS to vegetated swale because VFS procedure changed so that surface flows are NOT bypasses unless Q > 0.05 cfs/ft width

The total inflow to a BMP is the sum of flows from the immediate or intervening drainage area(s), plus treated effluent and/or bypass flows from upgradient BMPs. The user is prompted to define the linkage between BMPs by answering a few simple questions:

Define BMP Routing

Is Treated Effluent from BMP 1 routed to BMP 2?	YES
If NO, is Treated Effluent from BMP 1 routed to BMP 3?	NO
Are Bypasses from BMP 1 routed to BMP 2?	YES
If NO, Are Bypasses from BMP 1 routed to BMP 3?	YES
Is Treated Effluent from BMP 2 routed to BMP 3?	YES
Are Bypasses from BMP 2 routed to BMP 3?	NO

All inflows, captured and treated flows, and bypass flows are calculated so that the cumulative runoff capture effectiveness of the BMP system can be determined. Of specific important is the Runoff Capture Efficiency RCE:

RCE = (Total Inflow Volume – Volume Bypassed)/Total Inflow Volume

Commented [D50]: Was "Volume Captured", which is incorrect

Stream Protection Volume Performance Measure

Commented [D51]: This is a new section that presents a new methodology for determining if adequate stream protection is provided.

The standard for assessing whether adequate stream protection has been provided is to size an extended detention BMP for a specified volume, known as the Stream Protection Volume (SPV, a function of impervious cover), with a drawdown time of 48 hours. The spreadsheet model calculates the runoff volume and flowrates captured and bypassed by a hypothetical extended detention BMP sized per this criteria, known as the SPV BMP. When comparing the resulting hydrology against other scenarios, e.g., existing condition, developed condition with and without BMPs, a "metric" is needed in order to determine if a site is meeting the equivalent "hydromodification" control.

A simple metric has been developed that is based on the following:

- Excess stream erosion is caused by an increase in the energy of stream flow

- From the Bernoulli equation, given constant stream slope, depth of flow, and channel elevation, with an open water surface (unpressurized flow), the energy becomes a function of the square of the velocity
- Velocity is a function of flowrate and cross-sectional flow area, or v = Q/A
- Assuming a constant flow area A, then v is a function of Q only, and thus energy is a function of Q^2

Admittedly these are simplistic assumptions, but the purpose of this procedure is to assess the potential impacts due to change in flow energy, without having to design a channel during the modeling and assessment stage. Using these assumptions, the proposed metric is the sum of the squares of the hourly flowrates for an average annual year, a measure of flow energy. To account for different drainage areas and also when a BMP system treats off-site runoff (which can be a desirable practice in some cases), the final proposed metric normalizes the "flow energy" on a per acre basis:

$$\text{Flow Energy Metric} = (\sum_{n=1}^{8760} Q^2)/\text{A}$$

n = hours per year, from 1 to 8760

Q = flow rate for each time step (cfh)

A = drainage area

BMP systems that reduce volume, e.g., via infiltration, will tend to have lower (better) Flow Energy Metric values because less surface flow is being discharged.

The actual performance standard is the flow energy metric based on the on-site flows discharged with the hypothetical SPV BMP in place PLUS undetained off-site flows.

The following example is provided to illustrate the use of this metric.

Example

A 0.5 acre drainage area has the following inflow and outflow rates during a specified period, including outflow rates from a hypothetical SPV BMP. Determine if the proposed BMP meets the SPV BMP performance standard (note: because the time step is 1 hour, the flow volume in ft^3 is equivalent to the flowrate in ft^3/hr. Also note that the BMP outflow is the sum of treated effluent and bypass flows.)

Example Table A Hourly Flow Volumes (ft^3) and Flowrates (cfh)

Time (hr)	*Runoff Volume = Qin*	*Hypothetical SPV BMP Avg Q_{SPV}*	*BMP Treated Effluent Avg. Q_{TE}*	*BMP Bypass Q_{BP}*	*Total BMP Outflow $Q_{TE} + Q_{BP}$*
1	*42*	*18*	*15*		*15*
2	*150*	*18*	*15*		*15*
3	*34*	*18*	*15*		*15*
4	*21*	*18*	*15*	*6*	*21*

5	0	18	15		15
6	0	18	15		15
7	0	18	15		15
8	0	18	15		15
9	0	18	15		15
10	0	18	15		15
11	0	18	15		15
12	0	18	15		15
13	0	18	15		15
14	0	13	15		15
15	0	0	15		15
16	0	0	15		15
17	0	0	1		1
Total	247	247	241	6	247

Example Table B Flow Energy Metrics = Q^2 and Q^2/A

Time (hr)	Runoff Volume	Hypothetical SPV BMP Outflow	Total BMP Outflow
1	1764	324	225
2	22500	324	225
3	1156	324	225
4	441	324	441
5	0	324	225
6	0	324	225
7	0	324	225
8	0	324	225
9	0	324	225
10	0	324	225
11	0	324	225
12	0	324	225
13	0	324	225
14	0	169	225
15	0	0	225
16	0	0	225
17	0	0	1
$\sum Q^2$ (cfh^2)	25,861	4,381	3,817

$\sum Q^2/A$ (cfh^2/ac)	***51,722***	***8,762***	***7,634***

The spreadsheet model makes a simplifying assumption of a constant, average outflow rate from BMPs (= WQV/DDT), unless the hourly volume to be discharged is less than this value. Note that even though the runoff volumes are identical for all 3 scenarios, the Flow Energy Metrics are different, because the metric is a function of the square of the flowrate. For this example, the Performance Standard is the SPV BMP Flow Energy Metric of 8,762. The BMP system is acceptable as its value of 7,634 is less than that of the SPV BMP.

Calculating Pollutant Loads before and after BMP Treatment

While hydrologic calculations are made on an hourly time step, pollutant loads are calculated on an annual average basis, after flows and volumes have been summed, and assuming mean (average) pollutant concentrations.

Commented [D52]: Clarified how pollutant numbers are calculated.

Pollutant load is calculated as:

L = ROV * C * CF

L = load in lb/yr
ROV = Runoff Volume
C = pollutant concentration
CF = conversion factor

When the drainage area is given in acres, runoff volume in inches, C in mg/L, the equation becomes (TCEQ, 2005):

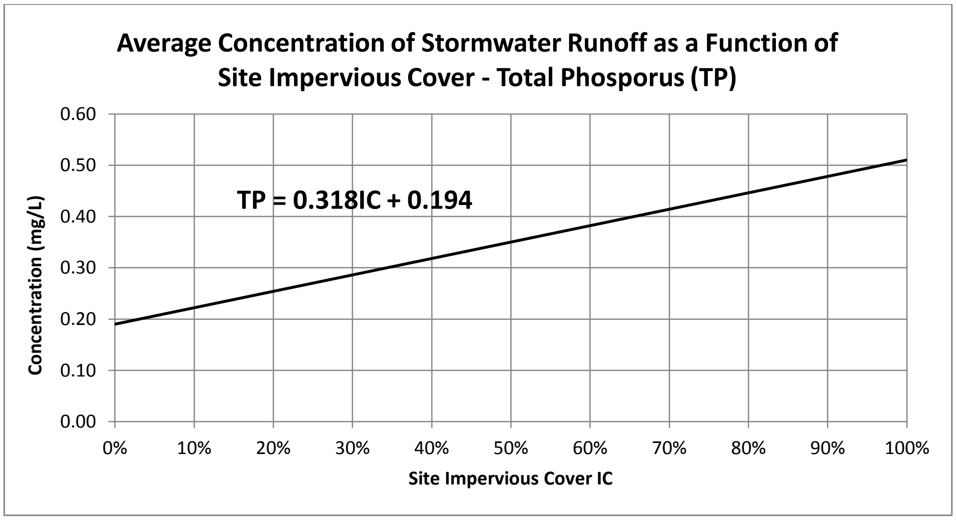
$$L = A * ROV * C * 0.226$$

Multiple drainage areas are often the case when BMP treatment trains are used, and using ROV in terms of inches must account for different drainage area sizes. It is simpler to calculate loads in these cases using ROV in ft^3 (C is still in mg/L):

$$L = (ROV * C)/16{,}061.95$$

The primary target pollutant is Total Phosphorus TP, and TP concentrations in runoff are calculated as a function of site impervious cover (Barrett, et al., 1998):

$$TP = 0.318IC + 0.194$$



An alternative pollutant constituent is Total Suspended Solids (TSS), with the following assumptions:

If impervious cover = 0%, TSS = 80 mg/L
If impervious cover > 0%, TSS = 170 mg/L

These assumptions are extrapolated from the City of Austin report (COA, 1990a) used as the basis for the TSS assumptions in the Edwards Aquifer Rules technical manuals (TCEQ, 2005 and TCEQ, 2007a).

Rainfall water quality is relevant for two BMPs, Green Roof and Permeable Pavement, because the input into these BMPs is direct rainfall (though runoff from adjacent areas can be included). Concentrations in rainfall are estimated based on a City of Austin report (Turner, 2003):

TP = 0.09 mg/L
TSS = 0 mg/L

Assumed effluent concentrations (mg/L) for BMPs are shown in the following table. See the section below “Modeling of Individual BMPs” for more information. Note that up to “Other” BMPs can be input into the model; these can be proprietary devices or other non-standard BMP. Also not that reduce volume via infiltration, reuse, and evaporation have no effluent concentration since there is no surface discharge of “treated” runoff.

Commented [D53]: Edit Dec 2014

Commented [D54]: TSS additions

Assumed BMP Effluent Concentrations (mg/L)			
BMP	TP	TSS	Notes
Sand Filtration	0.10	17	Barrett (2010), COA (2013), WERF (2012)
Biofiltration (with underdrain system)	0.05	9	Limouzin et al (2010), WERF (2012)
Biofiltration (infiltration design)	0	0	
Rain Garden (with underdrain system)	0.05	9	Assumed same as Biofiltration
Rain Garden (infiltration design)	0	0	
Extended Detention (Sedimentation Basin)	0.10-0.35	25-100	COA (2013), Middleton et al (2006), WERF (2012)
Batch Sedimentation Basin	0.03-0.33	1-10	Middleton et al (2006)
Wet Pond	0.06-0.34	6-70	COA (2013), WERF (2012)
Vegetative Filter Strip	0.24	25	Walsh et al (1997)
Vegetated Swale	0	0	
Retention/Irrigation	0	0	
Infiltration Basin	0	0	
Rainwater Harvesting	0	0	
Permeable Pavement	0	0	
Green Roof	0	0	
Other BMP	To be input by User	To be input by User	

The treated effluent load from a BMP, or load out L_o, is calculated as:

L_o = Volume Treated * Effluent Concentration

Bypass flows are assumed to have the same concentration as the untreated runoff, and the bypass load L_b is calculated as:

L_b = Bypass Volume * Influent Concentration

The model does not distinguish between on-line vs. off-line BMPs, as bypass flows would be modeled the same regardless of design.

Modeling Infiltration

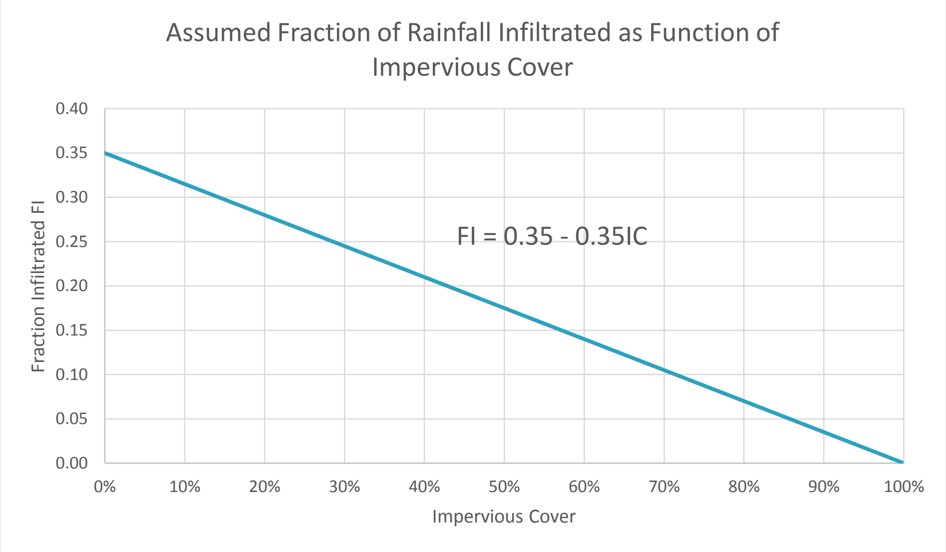
A performance standard proposed for Water Quality Zones A and C is to maintain or increase the existing infiltration rate. This is interpreted as meaning the average annual volume of infiltration. Infiltration is necessary for recharge, but the two are not equal, as recharge will necessarily be less than infiltration. At this time, no direct numerical correlation between the two is available. A simple procedure for estimating the annual average infiltration volume has been described in Chapter 11, *Stormwater Treatment BMPs*. The fraction of rainfall that is infiltrated is estimated as a function of impervious cover, using the following equation:

Commented [D55]: Added for clarification.

$FI = 0.35 - 0.35IC$

Where FI = fraction of annual average rainfall that is infiltrated

This equation will be used for existing or undisturbed pervious areas. For pervious areas in



To calculate the annual average volume infiltrated:

$VI_{site} = P * FI$

Where VI_{site} is the volume infiltrated (in/yr)

P = average annual rainfall, or 32.49 inches in the model

The volume of runoff infiltrated by a BMP is estimated as:

$VI_{BMP} = ROV * RCE$

Where VI_{BMP} = volume of runoff infiltrated by a BMP

ROV = site runoff volume

RCE = BMP Runoff Capture Efficiency

The total volume infiltrated at a site is thus:

$VI_{tot} = VI_{site} + VI_{BMP}$

Modeling of Individual BMPs

A description of modeling procedures is provided for each BMP. Consistent with WERF recommendations, the concept of "irreducible concentration" is incorporated into the procedures. This is the lowest effluent concentration typically expected for a BMP. The following irreducible concentrations are assumed, based on reports by CRWR, the City of Austin, and WERF. Note that for BMPs that treat runoff via infiltration, reuse, or evapotranspiration, the concentration is 0, which reflects the fact that there is no treated surface effluent discharged.

BMP Effluent Irreducible Concentrations

	Irreducible Concentration (mg/L)	
BMP Type	TP	TSS
Green Roof	0	0
Biofiltration (lined)	0.02	0.3
Biofiltration-infiltration	0	0
Rain Garden (lined)	0.02	0.3
Rain Garden-infiltration	0	0
Sand Filtration	0.02	0.3
Sedimentation Basin	0.03	1
Retention/Irrigation	0	0
Wet Pond or Constructed Wetland	0.01	1
Vegetative Filter Strip	0.02	1
Vegetated Swale	0	0
Vegetated Swale (swale blocks)	0	0
Infiltration Basin	0	0
Batch Sedimentation Basin	0.02	0.3
Permeable Pavement-infiltration	0	0
Other BMP	If infiltration, 0, else default value 0.03 (same as Sedimentation)	If infiltration, 0, else default value 1 (same as Sedimentation)

<u>*Filtration BMPs*</u>

Filtration BMPs include Sand Filters, Biofiltration, and Rain Gardens. These typically have 18 inches of filtration media, with an underdrain system that includes an underdrain orifice or similar system in order to achieve the target 48 hour drawdown time. No infiltration is assumed, and the volume discharged is equal to the runoff volume captured (i.e., not bypassed), with a concentration equal to the BMP effluent concentration. Bypass flows are assumed to have the same concentration as the influent concentration.

For modeling purposes, the User must input the Water Quality Volume WQV and Drawdown Time DDT; 48 hours should be the typical value for DDT. For final design, the surface area of the filtration media must be determined, as described below.

Total Phosphorus TP

For Sand Filtration BMPs, including combined Sedimentation/Filtration systems, the average (mean) TP effluent concentration is assumed to be 0.10 mg/L, based on assessments by Barrett (2010) and the City of Austin (2013). Barrett's research indicated that the effluent concentration may be a function of the influent concentration, but the correlation was weak. The average effluent concentration for all sand filters was 0.08 mg/L, but for those meeting the City of Austin design criteria, the average was 0.09 mg/L. The City of Austin study reported average TP effluent concentrations of 0.09-0.11 mg/L for sand filters meeting the City's design criteria, with an average of 0.10, so the findings were very similar to Barrett's.

For Biofiltration BMPs, including Rain Gardens, better TP treatment is expected, based on a CRWR study (Limouzin, Lawler, and Barrett, 2011). In that study, the preferred biofiltration design (no compost in media, vegetated, with saturated zone) discharged effluent concentrations that were 63-96% lower than sand filtration, with an average of 79% lower. A reasonable assumption is that the effluent concentration is 50% less than sand filtration, or 0.05 mg/L.

Commented [D56]: Revised to reflect 2013 COA BMP report, and to make more conservative assumption for biofiltration (25% less than sand filtration instead of 50%).

Total Suspended Solids TSS

For Sand Filtration BMPs, including combined Sedimentation/Filtration systems, the mean TSS effluent concentration is assumed to be 17 mg/L, based on assessments by Barrett (2010) and the City of Austin BMP (2013). Barrett reported an average effluent concentration of 17 mg/L value, while the City's study for filtration systems meeting the City's design criteria was about 16 mg/L. Barrett (2010) and WERF (GeoSyntec, 2010) found that the effluent concentration may be a function of the influent concentration, but Barrett's study found the correlation to be weak, and not significant for typical TSS concentrations (<400 mg/L), thus no such correlation is assumed here.

For Biofiltration BMPs, including Rain Gardens, better TSS treatment is expected, based on a CRWR study (Limouzin, Lawler, and Barrett, 2011). In that study, the preferred biofiltration design (no compost in media, vegetated, with saturated zone) typically discharged effluent concentrations that were 46-74% lower than sand filtration, with an average of 65% lower. A reasonable assumption is that the effluent concentration is 50% less than sand filtration, or about 9 mg/L.

Commented [D57]: Revised to reflect 2013 COA BMP report, and to make more conservative assumption for biofiltration (25% less than sand filtration instead of 50%).

Sizing Filtration BMPs

Adequate surface area of the filtration media must be provided in order to meet the drawdown time criteria. The surface area required will depend on the level of pretreatment provided, and the City of Austin equations are recommended:

- "Full" Sedimentation-Filtration – the filtration basin is preceded by a sedimentation basin sized to hold the entire WQV, and with a riser pipe outlet designed for a 48 hour drawdown time. Because of the controlled discharge from the sedimentation basin, the filtration basin does not require an underdrain orifice. In this design, much of the filter media-clogging sediment is removed, thus a higher hydraulic conductivity value can be assumed for the filtration media; a value of 3.5 ft/day is assumed.
- "Partial" Sedimentation-Filtration – The filtration basin is preceded by a "sediment chamber", a ponded area separated from the filtration basin by a permeable barrier (e.g., vegetated hedgerow, gabion wall), and there is no riser pipe. The drawdown time is controlled by the filtration basin, specifically the underdrain orifice. Because less sediment is removed before entering the filtration basin, a lower hydraulic conductivity value is assumed; 2 ft/day is typical.

Given these design options, the sizing equations for the filtration area are as follows:

Full Sedimentation-Filtration: A_f = WQV/(7 + 2.33H)

Where Af is the media surface area in ft^2

WQV is the Water Quality Volume in ft^3

H is the maximum ponding depth over the filtration media in ft

Partial Sedimentation-Filtration: A_f = WQV/(4 + 1.33H)

(Recall that the WQV used in these calculations is WQV + 20%)

At this time, the Partial Sedimentation-Filtration equation is recommended for Rain Gardens, which typically have little or no pretreatment provided (but may be unnecessary, as the vegetation helps maintain the hydraulic conductivity, a distinct advantage over Sand Filters). Biofiltration and Sand Filtration BMPs usually treat larger drainage areas, have deeper ponding depths, and some level of pretreatment is provided.

Infiltration BMPs - Infiltration Basins, Biofiltration and Rain Garden without Impermeable Liner and Underdrain System

For these BMPs, the only treatment mechanism assumed is infiltration, i.e., there is no treated effluent discharged as surface water. The continuity equation is solved based on the inflow, water quality volume, and infiltration rate and bypasses occur when the WQV is exceeded: bypass flows are assumed to have the same concentration as the influent concentration.

Commented [D58]: Revised to clarify this section applies specifically to these 3 BMPs

The User must input the Water Quality Volume and Drawdown Time DDT, the latter determined as described below.

Darcy's Law is used to size the media surface area:

Q = k i A

Q = flowrate, e.g., cfs

k = soil hydraulic conductivity (in/hr)

i = hydraulic gradient, assumed equal to 1 for infiltration BMPs

A = infiltration media surface area

The flow rate Q can also be expressed as:

Q = WQV/DDT

Setting the two equal, and assuming i = 1, gives:

kA = WQV/DDT

This equation can be rearranged as necessary to solve for the desired design variable, e.g., A, DDT. Recall that the WQV used is WQV + 20%, unless the BMP is the 2nd or 3rd in a treatment train series, with negligible intervening drainage area.

For Rain Gardens in particular, which have shallow ponding depths, a specific procedure is recommended to ensure that both the WQV and infiltration surface area requirements are met; this is especially important when slow draining soils are present:

Step 1. Run the WQ BMP Model to determine the required Water Quality Volume (WQV) and Drawdown Time (DDT) necessary for the BMP to meet the performance standards (TP load and Stream Protection, plus Infiltration in Water Quality Zones A and C).

Step 2. Given the hydraulic conductivity of the infiltration soil, calculate the minimum required infiltration area using Darcy's Law:

$$A_{inf} = WQV/(k * DDT)$$

Step 3. Calculate the ponding depth in the infiltration BMP necessary to hold the WQV+20%:

$$d = (WQV+20\%)/A_{inf}$$

Infiltration BMP Sizing Example

To meet the TP load and Stream Protection performance standards for a 1 acre site in Water Quality Zone T/R, a Rain Garden BMP designed for infiltration must have a 0.50-inch WQV, with a 48 hour drawdown time. Determine the minimum surface area required for the infiltration area (= biofiltration media area). Based on in-situ soil testing, a soil hydraulic conductivity of 0.15 in/hr is assumed (= 0.0125 ft/hr).

Step 1.Determine required WQV. The 0.5-inch WQV for a 1 acre site equates to 1815 ft^3*. To account for sediment accumulation, 20% is added, thus assume a WQV of 1815*1.2 = 2178* ft^3

Step 2.Calculate the minimum required infiltration surface area:

$$Ai_{nf} = WQV/ (k*DDT) = 2178/ (0.0125 * 48) = 3630\ ft^2$$

Step 3. Calculate ponding depth in Rain Garden:

$$d = WQV/A_{inf} = 2178/3630 = 0.6\ ft = 7.2\ inches$$

Note that in this example, there is no pretreatment, i.e., the entire WQV is stored above the Rain Garden media. Also note that hydraulic conductivity of the Rain Garden media itself (assumed = 2 ft/day) is *not* used for design, as the drawdown time is controlled by the underlying soil. For an Infiltration Basin BMP, there is no filtration or biofiltration media, only the underlying soil.

Sedimentation Basin BMP (aka Extended Detention)

Commented [D59]: Extensively revised to clarify modeling procedure

The primary purpose of this BMP is to provide Stream Protection Volume, in order to mitigate the impacts of hydromodifcation. Some pollutant removal can be provided as well, as described below.

The User must input the Water Quality Volume WQV, Drawdown Time DDT, and pond surface area A.

Total Suspended Solids TSS

Numerous technical references recommend that TSS removal be modeled as a “dynamic” settling process, and one equation widely used is the following (GeoSyntec, 2011, and Fair and Geyer, 1954):

$$Co \;=\; Ci * \left(1 \;+\; \frac{1}{n} * \frac{Vs}{OFR}\right)^{-n}$$

Co = Effluent concentration

Ci = Influent concentration

n = turbulence or short circuiting factor, or apparent number of “reactors”, with values:

- n = 1 poor performance
- n = 3 good performance
- n > 5 very good performance
- n = ∞ ideal performance

Vs = particle settling velocity

OFR = Overflow Rate = BMP Outflow Rate/Surface Area (= Q/A)

[Note: Numerous references define Q as the inflow rate, but this is incorrect]

The equation is solved for each of the following particle size classes (GeoSyntec, 2011):

Total Suspended Solids (TSS) Assumed Particle Size Distribution and Settling Velocities			
Particle Size Class	Pct. Mass	Settling Velocity (cm/s)	Settling Velocity (ft/hr)
1	10%	$3x10^{-4}$	.035
2	40%	0.008	0.95
3	25%	0.07	8.3
4	20%	0.25	29.5
5	5%	1.9	224

(Example: If the TSS influent concentration is 170 mg/L, it is assumed that 10%, or 17 mg/L, would be in particle size class 1, 40%, or 68 mg/L, would be in particle size class 2, etc.)

A conservative assumption recommended by Urbonas and Stahre (1993) is to set n = 1. The User must input the pond WQV, DDT, and surface area. The value of Q is the average flowrate of the BMP treated effluent, and is calculated by the spreadsheet model based on the hourly time step for an average annual year.

Modification to this procedure: The predicted TSS effluent concentrations using the above procedure are typically lower than that indicated by monitoring data. A factor of safety of 2 is thus applied to the final predicted concentration; when doing so, the results are much more similar to monitoring data, especially the 2013 City of Austin report.

For BMPs in series ideally the distribution of particle masses would be adjusted for subsequent BMPs, because upstream BMPs will typically preferentially remove larger particles. However, if there is intervening drainage area, then the particle size distribution could be similar to that of untreated runoff. This issue becomes less problematic because if the influent concentration is less than the assumed BMP effluent concentration, the influent concentration is assumed. Because of this feature, and to avoid overly complicated calculations, the particle size distribution will not be adjusted to account for upstream treatment.

Total Phosphorus TP

Total Phosphorus is composed of separate dissolved and particulate fractions. Removal of dissolved phosphorus (DP) typically requires a biological or chemical treatment process that is mostly lacking in sedimentation BMPs. This assumption is supported by a recent City of Austin study (2013) that reported removal of TP by sedimentation basins, but no DP removal. Thus, only removal of particulate phosphorus (PP) is assumed. The spreadsheet model predicts TP effluent concentration as:

$TPo = DPi + (1 - f_{sp})*PPi$

Where TPo = Total Phosphorus effluent concentration
DPi = Dissolved Phosphorus influent concentration
f_{pp} = Fraction of Particulate Phosphorus removed
PPi = Particulate Phosphorus influent concentration

To estimate the fraction of TP that is dissolved vs. particulate, several sources were investigated. A report by CRWR (Barrett, Quenzer, and Maidment, 1998) showed the DP:TP ratio in runoff to vary between 0.2-0.55, with an average around 0.40. In a recent CRWR report, Barrett (2010) stated that the particulate fraction in runoff is 50-80%, equating to a dissolved fraction of 20-50%. WERF (GeoSyntec) recommends a range of 0.2-0.4, with an average of 0.3. A more recent and detailed report of BMPs by the City of Austin (2013) reported a range of 0.2-0.8, with a mean of about 0.4. Based on the CRWR and the City of Austin reports, which utilize Central Texas data, it is assumed that urban runoff TP is 40% DP and 60% PP.

Particulate phosphorus removal will be modeled as a dynamic settling process, using the TSS procedure described above, but assuming a particle size distribution recommended by WERF (GeoSyntec, 2011).

Particulate Phosphorus (PP) Assumed Particle Size Distribution and Settling Velocities			
Particle Size Class	Pct. Mass	Settling Velocity (cm/s)	Settling Velocity (ft/hr)
1	30%	$3x10^{-4}$	.035
2	25%	0.008	0.95
3	20%	0.07	8.3
4	8%	0.25	29.5
5	17%	1.9	224

This procedure predicts effluent concentrations that are similar to values seen in monitoring reports, thus it is considered reasonable.

Wet Ponds and Constructed Wetlands

Wet ponds and Constructed Wetlands are assumed to maintain a constant water level year round, or a permanent pool volume (PPV). Incoming runoff displaces part or all of the permanent pool. When the runoff volume is greater than the permanent pool volume, a bypass is assumed to occur, equal to the difference between the two. Bypass flows are assumed to be untreated and have the same pollutant concentration as the inflow. These BMPs do not provide stream protection volume unless followed by an extended detention or volume reduction BMP. Extended detention can be “stacked” above the permanent pool, and modeled as the 2nd BMP in series.

The User must input the permanent pool volume PPV and pond surface area A; no drawdown time is associated with the permanent pool.

Total Phosphorus TP

Wet ponds can remove pollutants utilizing physical, biological, and chemical processes, which can be time dependent, especially for removal of nutrients and dissolved constituents. Based on classic trophic modeling of water bodies, the time variable recommended is Hydraulic Residence Time (HRT), or the average time a parcel of water resides in a pond, on an average annual basis. HRT is calculated from the spreadsheet model as:

HRT = 365/(Average Annual Runoff Volume Captured//Permanent Pool Volume)

where HRT is in days, and 365 is the number of days in the modeled year (1985)

Consistent with classic water quality modeling theory, TP removal is assumed to be reasonably well described as a 1st order decay rate process, or:

$Co = Ci * e^{-kt}$

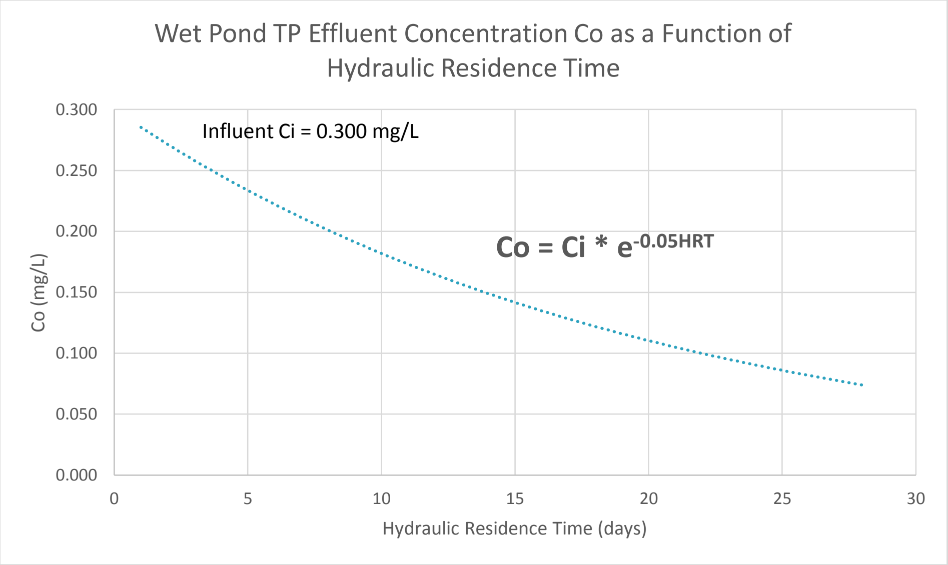
Where Co = outflow or effluent concentration

Ci = influent concentration
e = exponential
k = decay rate constant (d^{-1})
t = time, in this case HRT (d)

In order to derive a reasonable value for k, a review of wet pond monitoring data was conducted, in particular a recent City of Austin study (2013). Several wet ponds in the study are of recent design, and should have met the City's criteria of achieving a 14 day HRT for the statistically wettest month of the year (May). On an average annual basis, the 14 day HRT for May equates to about 22 days. With these assumptions, a k value of between 0.05 – 0.06 d^{-1} predicted TP effluent concentrations similar to those reported in the 2013 City. For the spreadsheet model, the lower value is assumed, or:

$k = 0.05\ d^{-1}$

The following graphic illustrates this procedure for a hypothetical inflow concentration of 0.30 mg/L TP:



Total Suspended Solids TSS

Removal of TSS is assumed to be a combination of "dynamic" treatment *during* runoff events, and "quiescent" removal *between* runoff events.

Dynamic removal is modeled the same as for Sedimentation Basins, as described above, using the Fair and Geyer and WERF equations and assumptions. Because incoming runoff simply displaces permanent pool volume, the BMP outflow rate is equal to the inflow, when calculating the overflow rate variable.

Quiescent removal is modeled using a procedure derived from Adams and Papa (2000) and is calculated as:

Fraction Removed = Vs/Vo
If Vs/Vo is ≥ 1 the Fraction Removed is 100%
If Vs/Vo < 1, then the Fraction Removed is the ratio Vs/Vo
    Where Vs is the particle settling velocity
    Vo is the quiescent surface loading rate = Q/A

To estimate the quiescent flowrate Q, it is assumed to be represented by how often the permanent pool is entirely displaced. To do this the Hydraulic Residence Time HRT is used, which is the average time that a parcel of water resides in the pond; HRT is calculated as:

HRT = 365/(Average Annual Runoff Volume Captured//Permanent Pool Volume)
    where HRT is in days, and 365 is the number of days in the modeled year (1985)

Thus Q = PPV/HRT
And Vo = (PPV/HRT)/A
    Where A is the permanent pool surface area

The total TSS removal is:

Total Fraction Removed = 1 – (F_D * F_Q)
    Where F_D = fraction of TSS mass NOT removed by dynamic settling = 1- fraction removed
    F_Q = fraction of TSS mass NOT removed by quiescent settling = 1 – fraction removed

The effluent concentration Co is then calculated as:

Co = Ci * (1 – Total Efficiency)

The following example illustrates this procedure:

Particle Size Class	**Pct. Mass**	**Settling Velocity Vs (ft/hr)**	**Inflow TSS Ci (mg/L)**	**Dynamic Settling Fraction Removed**	**Quiescent Settling Fraction Removed**	**F_D**	**F_Q**	**Total Fraction Removed**	**Effluent Co (mg/L)**
1	10%	.035	17	0.12	0.18	0.88	0.82	0.28	12.3
2	40%	0.95	68	0.45	0.72	0.55	0.28	0.85	10.5
3	25%	8.3	42.5	0.88	0.98	0.12	0.02	.998	0.1
4	20%	29.5	34	0.95	1.00	0.05	0.00	1.00	0
5	5%	224	8.5	0.99	1.00	0.01	0.00	1.00	0
Total	100%		170					0.865	22.9

Vegetative Filter Strip VFS

The User must input the VFS size, treatment rate (cfs), and width (dimension perpendicular to direction of flow) into the model. A VFS is assumed to have a Water Quality Volume equal to the depression storage, assumed to be 0.30-inch based on the WERF SELECT model. Two treatment mechanisms are assumed to be available, infiltration into the soil and surface treatment. Infiltration is modeled using Darcy's Law:

$Q = k\, i\, A$
Q = flowrate, usually in cfs
k = soil hydraulic conductivity, usually in in/hr
i = hydraulic gradient, assumed equal to 1 for infiltration BMPs
A = VFS area, usually in ft^2 or acres

The User must estimate the area and soil hydraulic conductivity, in order that the infiltration rate can be calculated and input; a separate "BMP Design Tools" worksheet is provided for this purpose, from which the User inputs VFS size and infiltration rate (cfs) into the BMP model worksheet. The reason the VFS area is input into the BMP model worksheet is that filter strips can constitute a large area, relative to the contributing drainage area to the VFS, and can thus generate significant runoff volume that should be accounted for in the routing calculations.

If surface runoff occurs within the VFS (i.e., the WQV and infiltration rate are insufficient to capture all runoff), the runoff is assumed to be "treated effluent" if the hydraulic loading rate (HLR) is ≤ 0.05 cfs/ft width. In such a case, the effluent concentration is assumed to be 25 mg/L TSS and 0.24 mg/L TP, based on the CRWR report 97-5. If the HLR exceeds 0.05 cfs/ft width, then the runoff is assumed to have a concentration equal to the inflow runoff.

Vegetated Swale

If the swale is designed without storage ("swale blocks" or check dams), the User only inputs the treatment rate (cfs). Because the only significant treatment mechanism assumed is infiltration, the treatment rate is the same as the infiltration rate. The infiltration rate is estimated using Darcy's Law, with hydraulic gradient set equal to 1 (see VFS above):

$Q = kA$

To be conservative, the swale infiltration area A is based solely on the bottom area. The "BMP Design Tools" worksheet can be used for swale design, when storage (WQV) is not provided.

Swales are typically designed to convey surface flows, but surface flow conveyance is assumed to provide no pollutant removal. If a swale is used as a BMP in Water Quality Zone A (recharge zone), it should be designed to meet or exceed the requirements of the TCEQ Edwards Aquifer Rule technical manual (TCEQ, 2005); the procedure in that manual is based on conveyance, not infiltration.

If a swale provides water quality volume (WQV) via check dams or "swale blocks", then it is modeled the same as an infiltration basin, so the User must input a WQV and drawdown time (DDT). The WQV is calculated based on the cross-sectional area at the swale block/check dam height, multiplied times the swale length. For construction purposes, 20% is added to the WQV, unless the swale is the 2nd or 3rd BMP in a treatment train system, and with negligible intervening drainage area.

As with all infiltration BMPs, there is no surface discharge for the treated volume (the effluent concentration is assumed equal to 0 mg/L), and bypass flows are assumed to have the same concentration as the influent.

Retention/Irrigation

Retention/Irrigation BMPs are a type of partial infiltration design that requires sizing of both the retention basin and the irrigation area. The irrigation efficiency is assumed to be 65%, equivalent to that of a rotor spray system, thus 65% of the captured runoff is assumed to be infiltrated (35% is assumed lost to evapotranspiration). The user should input a 72 hour drawdown into the WQ BMP model but, for sizing the irrigation area, 30 hours is used as the "active" irrigation time, using the TCEQ Edwards Aquifer Rules technical manual equation (TCEQ, 2005), which assumes a lag time before irrigation begins:

$A_{irr} = (12 * V)/(T * r)$

Where A_{irr} is the irrigation area in ft^2
V is the Water Quality Volume in ft^3
T is the active irrigation time, equal to 30 hours
r is the soil permeability in in/hr

The spreadsheet does not model lag time at this point, and simply assumes a constant discharge rate over 72 hours.

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The WQV held in the Retention basin is the calculated WQV with 20% added, to account for sediment accumulation, thus the irrigation area calculation uses V = WQV + 20% (this is more conservative than the TCEQ procedure, as V is the WQV without the 20% added).

The volume of water captured and irrigated is not discharged as surface flow, thus an effluent concentration of 0 mg/L is assumed. Bypass flows are assumed to have the same concentration as the influent.

R/I BMPs will not be recommended by the WQPP because of (1) high operation and maintenance needs, and (2) limited amount of infiltration provided; much of the water is lost to evapotranspiration (35% is assumed, based on 65% irrigation efficiency).

Rainwater Harvesting

This BMP is currently only eligible for Effective Impervious Cover (EIC) credit, and the design procedure is described in Appendix L. The EIC for the RWH drainage area is then incorporated into the drainage area calculations in the WQ BMP spreadsheet model.

Permeable Pavement

Permeable pavement BMPs are infiltration systems and the user must input the area, water quality volume (WQV), and drawdown time (DDT). The area must be input because the drainage area to the BMP is the BMP area itself; furthermore this area must be input as subarea "A", e.g., if it is the BMP for drainage area 1, subarea 1A and the permeable pavement area must be the same (this also holds true for drainage areas 2 and 3). While it is highly recommended that no off-site runoff be routed to permeable pavement, the model allows this and these areas must be input as subareas "B". The WQV is based on the pore space volume of the subsurface storage reservoir, and the drawdown time is calculated using Darcy's Law, as described above for *Infiltration BMPs*. For modeling purposes, the WQV is used, for calculating drawdown time and for construction purposes, 20% is added to the WQV. The drawdown time should not exceed 72 hours, in which case the site may not be feasible, or the WQV may have to be reduced.

Permeable pavement for vehicular use areas has a mixed history of performance, due to clogging and contamination of the underlying soil. More specific feasibility and design criteria will be developed at a future date, but the following may be adopted (adapted from Urbonas and Stahre, 1993):

- Site is not located in the Edwards Aquifer Recharge Zone
- No off-site runoff enters the BMP
- Seasonal high groundwater table is at least 4 feet below the bottom of the BMP
- Depth to bedrock or impermeable layer is at least 4 feet below the bottom of the BMP
- Infiltrating soil is not fill
- Infiltrating soil has a hydraulic conductivity of at least 0.3 in/hr

Green Roof

The User must input the Green Roof area and water quality volume (WQV). The area must be input because the BMP's drainage area is the same as the size of the BMP. Furthermore, this must be input as Subarea 1A in the model (Off-site drainage can be routed to the green roof,typically from another roof area, and must be input as Subarea 1B). When selecting the WQV in inches, it will be necessary to account for any off-site areas. The WQV is equal to the volume held in the media at "field capacity":

$$WQV = A_{roof} * d * \Theta_{FC}$$

Where d is the depth of the Green Roof media

Θ_{FC} is the field capacity of the media; this design variable is not always provided by the media suppliers, but must be determined.

The "BMP Design Tools" worksheet can be used to make these calculations. Because of uncertainties about the characteristics of the green roof media, a 20% reduction factor is applied to the WQV for modeling purposes.

For Green Roofs, the only mechanism whereby flows are treated is evapotranspiration from the green roof media. Thus, there is no design drawdown time, as the rate water exits the system depends on the evapotranspiration (ET) rates. As Green Roofs can absorb considerable heat and can be exposed to windy conditions, ET is assumed equal to pan evaporation.

Green roofs can be "extensive" systems whereby a relatively thin depth of media (≤ 12 inches) is placed over most or all of roof, or can be "intensive" whereby a smaller area is covered using thicker media (often these are rooftop planters).

The model assumes no irrigation of the green roof, and the only inflow is assumed to be direct rainfall. Though rainfall is assumed, the influent concentration is assumed to be the same as any other 100% impervious cover surface, thus the spreadsheet models the potential pollutant removal that would be associated with a conventional roof.

A significant issue when selecting green roofs is that this BMP can achieve significant volume reduction, it does not maintain or enhance recharge. All runoff "treated" is assumed lost to evapotranspiration, and thus there is no direct return of water to the soil or surface, thus no infiltration or recharge occurs. Thus, this is not an appropriate stand-alone BMP in the Edwards Aquifer Recharge Zone, where maintaining or enhancing existing recharge rates is a goal. However, it may be a good option in Water Quality Zone T/R, especially for building in the downtown area, where space for BMPs may be limited. Green Roofs can also provide energy conservation benefits.

Batch Sedimentation Basin

This is a sedimentation basin that incorporates an electro-mechanical "smart" system to control the detention time and rate of outflow from the BMP. This BMP can produce effluent concentrations much lower than a conventional sedimentation basin. A CRWR study (2006) reported TP and TSS mean concentrations that were 56% and 82% lower, respectively, then a conventional sedimentation basin. Compared to effluent concentrations from a recent City of Austin study (2013), the batch sedimentation basin concentrations were 37% and 93% lower for TP and TSS, respectively. The same analytical procedures for modeling sedimentation basins are used, but with the following assumptions:

- TP effluent concentration is 30% less than a conventional sedimentation basin
- TSS effluent concentration is 75% less than a conventional sedimentation basin

Source Data for Rainfall and Evaporation

The source data for input into the spreadsheet is rainfall and precipitation data downloaded from the National Climatic Data Center website (http://noaa.ncdc.gov). Sufficient data was available from two gaging stations in the Central Texas area, the Camp Mabry site in Austin, and the Canyon Dam site west of San Marcos. As the regulatory standard is based on "annual average" conditions, a period of record that approximately represents annual average rainfall and evaporation was investigated. It was found that summary statistics for the two sites were typically very similar, thus it is felt either site would be appropriate to use. While adequate *daily* rainfall data was generally available, *hourly* datasets were more problematic (missing data), and evaporation data was often missing. As a result, the spreadsheet only models a one year period of record, in this case the year 1985 from the Camp Mabry station. A complete record of hourly rainfall data was available, and daily evaporation data was adequate (missing records were filled in by assuming the average of the immediate preceding and following days). Daily pan evaporation data was converted to hourly data by dividing by 24, a simplifying assumption. For the 1985 Camp Mabry station:

Rainfall 32.49 inches
Pan Evaporation (est.) 72.54 inches

The average annual rainfall for the two sites for longer periods of record area 32-34 inches/year, with pan evaporation estimated at 70-80 inches/year, thus the 1985 Camp Mabry dataset is a reasonable input into the spreadsheet.

How to Use the Model

The following is a brief summary of using the model.

1. In order to comply with the "reduce water use for landscape irrigation…" performance standard, and/or and to reduce "effective" impervious cover, open the separate *RWH-IRR and EIC* spreadsheet, then run the *RWH-IRR* worksheet (the *RWH-IRR* tool is described in Appendix J). Note that Rainwater Harvesting may not be required to meet the performance standard; if it is used, the spreadsheet will display at the bottom the resulting "effective" impervious cover for the area draining to the RWH system.

An alternative for calculating effective impervious cover is to open and run the *Other EIC Credit* worksheet in the *RWH-IRR and EIC* spreadsheet. This worksheet can be used to investigate several impervious cover "disconnection" options. See Appendix I for a description of these procedures (NOTE: credit cannot be given for both impervious cover disconnection and BMP implementation, e.g., Permeable Pavement can be used for one or the other, but not both).

Once the EIC values have been derived, incorporate these into drainage area calculations that will be input into the BMP model, i.e., the drainage area impervious cover values should be "effective" and not "total" impervious cover.

2. Open the *WQ BMP Model* spreadsheet, and review the following before beginning:

Cells highlighted in YELLOW indicate that User input is required. Texts in RED font are alerts, error messages, or provide important information, e.g., Performance Standard values.

If the development is in WQ Zone A, the new impervious cover is limited to 20%, thus this calculation is necessary. NOTE: This is TOTAL impervious cover, not EFFECTIVE impervious cover. For example, an undeveloped 5 acre site is limited to 1 acre of impervious cover. A conservation design strategy can be useful, e.g., develop 2 acres at 50% IC, and leave 3 acres undisturbed. It is generally desirable to limit the amount of pervious area draining to BMPs, or to use those areas as BMPs (e.g., Biofiltration, Rain Garden, Vegetative Filter Strip); if the latter, then these BMP areas are <u>not</u> included in the drainage area calculations. Likewise, any areas left in a natural state (e.g., not disturbed or treated with chemicals) that do not drain to BMPs can be discounted from the drainage area calculations.

3. Open the *BMP Model* worksheet and go through the following steps:

<u>Step 1. Select Pollutant Constituent</u>, either Total Phosphorus TP or Total Suspended Solids TSS

<u>Step 2. Select the Water Quality Zone</u> the development is located in:

A = Edwards Aquifer Recharge Zone

C = Edwards Aquifer Contributing Zone

T/R = Edwards Aquifer Transition Zone and/or San Marcos River Zone

Step 3. Characterize the EXISTING on-site condition in terms of acres and impervious cover. Up to two subareas can be input. This can allow for inclusion of existing development, for example.

Step 4. Characterize the DEVELOPED condition in terms of acres and impervious cover, keeping in mind the proposed BMP system and the following factors:

- Up to 3 BMPs can be input, and each can have its own intervening drainage area. By definition, Drainage Area 1 goes to BMP 1, Drainage Area 2 to BMP 2, and Drainage Area 3 to BMP 3. The BMPs can also be modeled in series without any intervening drainage areas, e.g., flow from BMP 1 can be routed to BMP 2, with the only drainage area being Drainage Area 1.
- The footprint area of BMPs should NOT be included in the drainage area calculations, with the exception of the Green Roof and Permeable Pavement BMPs (see next bullet).
- Up to 2 subareas per drainage area can be input; these are identified as “A” and “B”. For Green Roof and Permeable Pavement BMPs, Subarea “A” and the BMP size are one and the same, thus the areas must be identical. For example, if a 1 acre Green Roof is proposed in Drainage Area 1, then Subarea 1A must equal 1 acre (and be input as 100% impervious cover).
- Off-site drainage can be routed to any BMP, thus the total drainage area for the system can be larger than the EXISTING drainage area.
- Any on-site area that will not be treated by BMPs can be accounted for, and is identified as Drainage Area 4, with subareas 4A and 4B.
- It is highly recommended that the EXISTING and DEVELOPED ON-SITE areas match in the spreadsheet. If they do not, then attempt to resolve this discrepancy before proceeding. Related to this issue is that any on-site areas that left in a natural state AND which do not drain to a BMP, can be excluded from the calculations, and this should be reflected in both

Step 5. Review Performance Standards for the proposed development:

The *BMP Model* worksheet will calculate and display the numeric standards, except as noted.

WQ Zones A and C

- Reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50% from a baseline condition (determined from separate *RWH-IRR* spreadsheet)
- No increase in existing pollutant load (the actual performance standard is load removed)
- Provide stream protection via extended detention and/or runoff volume reduction (performance standard is “flow energy” metric)
- Maintain or increase existing infiltration

WQ Zone T/R

- Reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50% from a baseline condition (determined from separate *RWH-IRR* spreadsheet)
- Pollutant load for new development to be no greater than that of an area with 10% IC (actual performance standard is load removed).
- Provide stream protection via extended detention and/or runoff volume reduction

Step 6. Select and Design BMPs, and define BMP routing.

Note that there is a separate worksheet named *BMP Design Tools* that can be used to determine design variables and inputs for several of the BMPs (e.g., Vegetative Filter Strip, Vegetated Swale, Green Roof, Permeable Pavement).

For WQ Zone A, the User should first select and size a BMP system that complies with the TCEQ Edwards Aquifer Rules, as the proposed WQPP strategy is to first comply with those rules, then provide additional treatment and infiltration in order to meet the more protective WQPP performance standards. The worksheet *EAZ Procedures* can be used for this purpose.

General recommendations:

WQ Zone T/R – First size to meet Stream Protection performance standard, then adjust to meet Pollutant Load performance standard

WQ Zones A and C – A treatment train system is typically required:

- The 1st BMP should be selected primarily to provide Pollutant Removal and Stream Protection, whereas the primary purpose of the 2nd BMP is to meet the Infiltration performance standard
- Select and size BMP 1 to meet Stream Protection performance standard
- Select and size BMP 2 to meet the Infiltration performance standard
- Adjust the size and designs to meet the Pollutant Load performance standard (often increasing the size of BMP 1 is the best first option, while minimizing the WQV of BMP 2)

Example for WQ Zones A and C

A 1 acre drainage area with no impervious cover will be developed at 50% IC. Select and size a BMP system to meet the 3 applicable performance standards:

- *No increase in existing TP pollutant load*
- *Provide stream protection*
- *Maintain or enhance existing infiltration rate*

Steps:

- *Select BMP 1 as a Sand Filtration system with a 48 hour DDT; an impermeable liner is required in WQ Zone A. To ensure meeting the Edwards Aquifer Rules, size WQV for at least 0.52-inch (0.62 with 20% sediment accumulation added).*
- *The SPV for 50% IC is 0.65-inch, which exceeds the TCEQ WQV, so input this value, and note that the Stream Protection performance standard is met.*
- *Select BMP 2 as an infiltration system. Route treated effluent from BMP 1 to BMP 2, but not bypass flows (can be changed at User's discretion)*
- *Because the infiltration basin (BMP 2) will be shallow, it will have a large footprint. Minimize total footprint area by maximizing the WQV of BMP 1.*
- *By trial and error, an optimum design is derived: BMP 1 with 0.95-inch WQV, and BMP 2 with 0.29-inch WQV. Add 20% to the WQV of BMP 1 to account for sediment accumulation (=1.14 inches); this is not required for BMP 2 as the only inflow is the previously treated effluent from BMP 1.*

Alternatives:

- *If TSS is used as the pollutant constituent, BMP 1 WQV must be increased to 1.01 inches (= 1.22 with 20% sediment accumulation factor); BMP 2 WQV is reduced to 0.15-inch*
- *If BMP 1 is Biofiltration, with TP the pollutant constituent, the modeled WQV is 1.01 inches, and construction WQV 1.22 inches, with BMP 2 being an Infiltration Pond with 0.18-inch WQV*
- *If BMP 1 is Biofiltration, with TSS the pollutant constituent, the modeled WQV is 0.85-inch, and construction WQV 1.02 inches, with BMP 2 being an Infiltration Pond with 0.15-inch WQV*

[Note: Biofiltration, as proposed by the WQPP, may not be allowed by the current TCEQ Edwards Aquifer Rules technical manual]

Appendix H provides recommendations for simple BMP systems, and can be used instead of running the *WQ BMP Model*.

The User must select BMPs from a pull-down menu and input design variables:

- For all pond-type BMPs, Water Quality Volume (WQV) and Drawdown Time (DDT) must be entered (a standard DDT is 48 hours). Be aware the WQV is calculated based on inches for the drainage area and, if there are intervening drainage areas, these are included in the calculation. The spreadsheet will display the resulting WQV in ft^3, so the User should check this value.
- For Sedimentation, Batch Sedimentation, and Wet Pond BMPs, the User must also input pond area A. The effluent concentrations for these BMPs vary with design; this information is displayed at the bottom of the table for the User's information.

- For the Vegetative Filter Strip BMP, no WQV or DDT apply, but the User must input the size, infiltration rate (calculated as VFS area * soil hydraulic conductivity), and width (dimension perpendicular to the flow).
- For the Vegetated Swale BMP, the User must input the infiltration rate (calculated as area * soil hydraulic conductivity). It is assumed that a “standard” swale has no WQV but, if “swale blocks” or similar ponding devices are installed, then it will have a WQV, and be classified as a “Vegetated Swale (swale blocks).” The User must then input the WQV and DDT, the latter based on the soil hydraulic conductivity.
- For the Green Roof BMP, a WQV is input but no DDT applies (the only assumed “removal” mechanism is evaporation). If this BMP is selected, it is only allowed in Drainage Area 1 and, furthermore, the footprint area of the Green Roof is the same as the DEVELOPED condition Subarea 1A.
- For the Permeable Pavement BMP, the WQV is based on the subsurface storage reservoir volume, and DDT based on the underlying soil hydraulic conductivity. The footprint area of this BMP is the same as the DEVELOPED condition Subarea A (i.e., Subarea 1A, 2A, and/or 3A).
- If a non-standard or proprietary BMP is selected, it is assumed to be a pond-type BMP, thus the User must input WQV and DDT, and also the assumed average effluent concentration for the chosen pollutant constituent. If it is an infiltration BMP, then this must be input as well.

BMP routing rules (assuming a multiple BMP system):

- The User must define the disposition of the (1) Treated Effluent and (2) Bypass flows. By definition, bypass flows result when the WQV and/or treatment rate of the BMP are exceeded; bypass flows are assumed to be discharged without treatment, with the same concentration as the inflow. There is no Treated Effluent for the portion of runoff removed by infiltration, reuse, evaporation, or other “volume reduction” mechanisms (alternately, this “Treated Effluent” is discharged at a flowrate of 0).
- Treated Effluent from BMP 1 can be routed to BMP 2 or BMP 3 (but not both), or to neither.
- Bypasses from BMP 1 can be routed to BMP 2 or BMP 3 (but not both), or to neither.
- Treated Effluent and/or Bypasses from BMP 2 can be routed to BMP 3, or not.
- If there are intervening drainage areas then, by definition, Drainage Area 1 goes to BMP 1, Drainage Area 2 goes to BMP 2, and Drainage Area 3 goes to BMP 3.

Step 7. Evaluate Performance

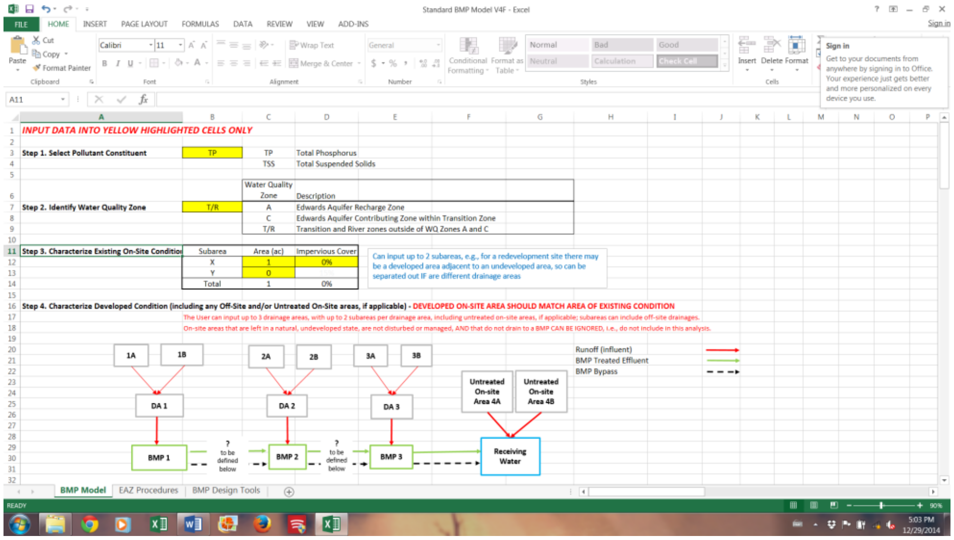
A “Performance Standards Status” table is embedded in the worksheet between the BMP design and routing cells; this allows the User to interactively determine if the performance standards are being achieved and, if not, the percent achievement provided by the proposed system.

Two summary tables are provided below the status table, the first displaying statistics for the overall system performance, the second more detailed information on the performance of individual BMPs; the latter can be useful for determining which BMPs to focus more attention on.

Step 8. Size BMP WQV to account for sediment accumulation

All storage-based BMPs will have 20% added to the “design” WQV to account for potential volume losses over time due to sedimentation or poor maintenance. The exception to this is when a BMP in series has no intervening drainage area, as most of the sediment will likely have been removed by the upstream BMP. A table is displayed showing the "modeled" vs. "construction" WQV values.

Screenshots of Spreadsheet Model



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INPUT DATA INTO YELLOW HIGHLIGHTED CELLS ONLY

Step 1. Select Pollutant Constituent TP

TP	Total Phosphorus
TSS	Total Suspended Solids

Step 2. Identify Water Quality Zone T/R

Water Quality Zone	Description
A	Edwards Aquifer Recharge Zone
C	Edwards Aquifer Contributing Zone within Transition Zone
T/R	Transition and River zones outside of WQ Zones A and C

Step 3. Characterize Existing On-Site Conditio

Subarea	Area (ac)	Impervious Cover
X	1	0%
Y	0	
Total	1	0%

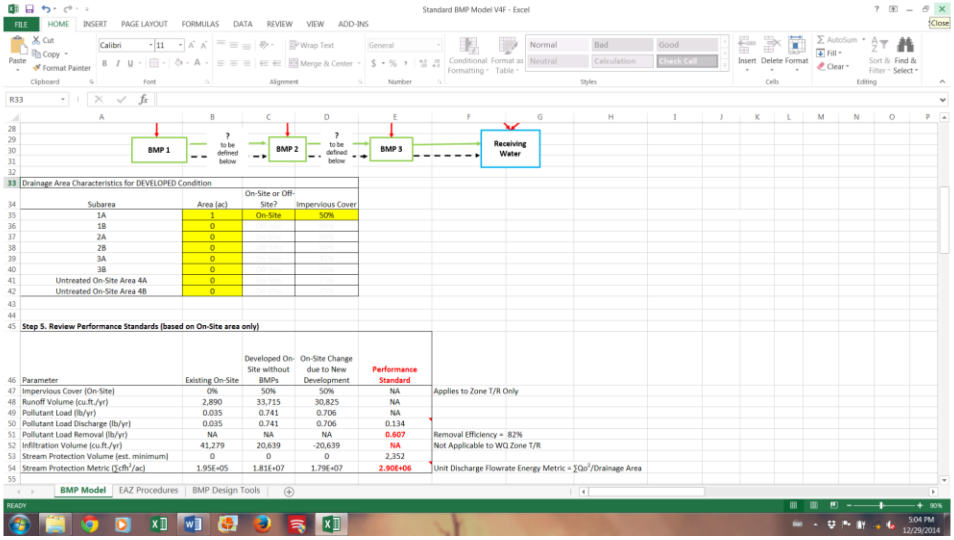
Can input up to 2 subareas, e.g., for a redevelopment site there may be a developed area adjacent to an undeveloped area, so can be separated out IF are different drainage areas

Step 4. Characterize Developed Condition (including any Off-Site and/or Untreated On-Site areas, if applicable) - DEVELOPED ON-SITE AREA SHOULD MATCH AREA OF EXISTING CONDITION

The User can input up to 3 drainage areas, with up to 2 subareas per drainage area, including untreated on-site areas, if applicable; subareas can include off-site drainages.

On-site areas that are left in a natural, undeveloped state, are not disturbed or managed, AND that do not drain to a BMP CAN BE IGNORED, i.e., do not include in this analysis.

Runoff (influent) →
BMP Treated Effluent →
BMP Bypass - - →

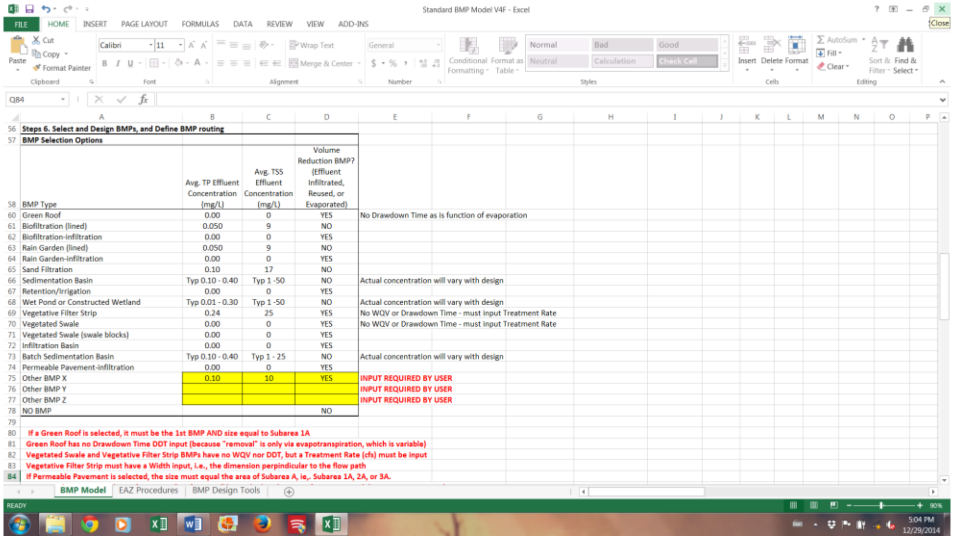


Drainage Area Characteristics for DEVELOPED Condition

Subarea	Area (ac)	On-Site or Off-Site?	Impervious Cover
1A	1	On-Site	50%
1B	0		
2A	0		
2B	0		
3A	0		
3B	0		
Untreated On-Site Area 4A	0		
Untreated On-Site Area 4B	0		

Step 5. Review Performance Standards (based on On-Site area only)

Parameter	Existing On-Site	Developed On-Site without BMPs	On-Site Change due to New Development	Performance Standard	
Impervious Cover (On-Site)	0%	50%	50%	NA	Applies to Zone T/R Only
Runoff Volume (cu.ft./yr)	2,890	33,715	30,825	NA	
Pollutant Load (lb/yr)	0.035	0.741	0.706	NA	
Pollutant Load Discharge (lb/yr)	0.035	0.741	0.706	0.134	
Pollutant Load Removal (lb/yr)	NA	NA	NA	0.607	Removal Efficiency = 82%
Infiltration Volume (cu.ft./yr)	41,279	20,639	-20,639	NA	Not Applicable to WQ Zone T/R
Stream Protection Volume (est. minimum)	0	0	0	2,352	
Stream Protection Metric (∑cfh^2/ac)	1.95E+05	1.81E+07	1.79E+07	2.90E+06	Unit Discharge Flowrate Energy Metric = ∑Qo^2/Drainage Area



	A	B	C	D	E
56	**Steps 6. Select and Design BMPs, and Define BMP routing**				
57	**BMP Selection Options**				
58	BMP Type	Avg. TP Effluent Concentration (mg/L)	Avg. TSS Effluent Concentration (mg/L)	Volume Reduction BMP? (Effluent Infiltrated, Reused, or Evaporated)	
60	Green Roof	0.00	0	YES	No Drawdown Time as is function of evaporation
61	Biofiltration (lined)	0.050	9	NO	
62	Biofiltration-infiltration	0.00	0	YES	
63	Rain Garden (lined)	0.050	9	NO	
64	Rain Garden-infiltration	0.00	0	YES	
65	Sand Filtration	0.10	17	NO	
66	Sedimentation Basin	Typ 0.10 - 0.40	Typ 1 -50	NO	Actual concentration will vary with design
67	Retention/Irrigation	0.00	0	YES	
68	Wet Pond or Constructed Wetland	Typ 0.01 - 0.30	Typ 1 -50	NO	Actual concentration will vary with design
69	Vegetative Filter Strip	0.24	25	YES	No WQV or Drawdown Time - must input Treatment Rate
70	Vegetated Swale	0.00	0	YES	No WQV or Drawdown Time - must input Treatment Rate
71	Vegetated Swale (swale blocks)	0.00	0	YES	
72	Infiltration Basin	0.00	0	YES	
73	Batch Sedimentation Basin	Typ 0.10 - 0.40	Typ 1 - 25	NO	Actual concentration will vary with design
74	Permeable Pavement-infiltration	0.00	0	YES	
75	Other BMP X	0.10	10	YES	**INPUT REQUIRED BY USER**
76	Other BMP Y				**INPUT REQUIRED BY USER**
77	Other BMP Z				**INPUT REQUIRED BY USER**
78	NO BMP			NO	
79					

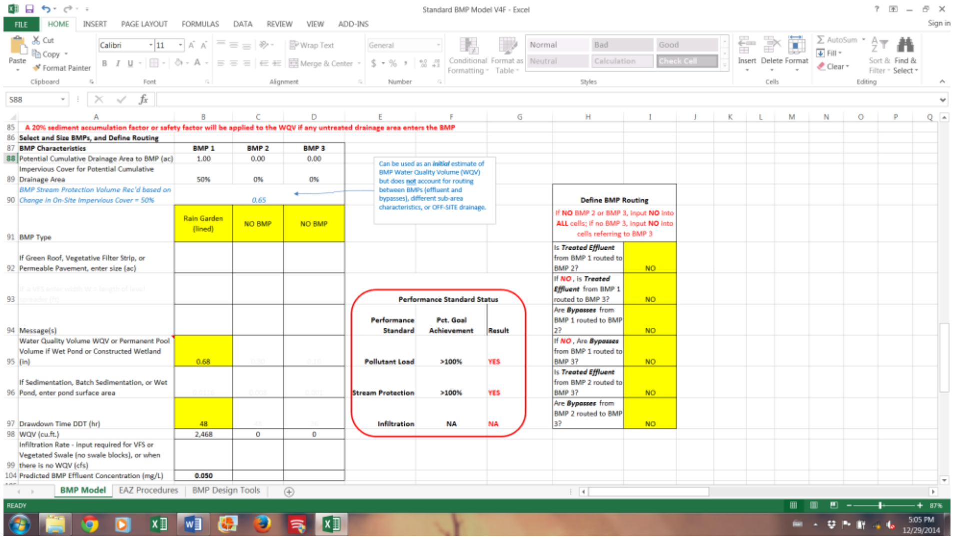
80 **If a Green Roof is selected, it must be the 1st BMP AND size equal to Subarea 1A**

81 **Green Roof has no Drawdown Time DDT input (because "removal" is only via evapotranspiration, which is variable)**

82 **Vegetated Swale and Vegetative Filter Strip BMPs have no WQV nor DDT, but a Treatment Rate (cfs) must be input**

83 **Vegetative Filter Strip must have a Width input, i.e., the dimension perpindicular to the flow path**

84 **If Permeable Pavement is selected, the size must equal the area of Subarea A, ie,. Subarea 1A, 2A, or 3A.**



85 **A 20% sediment accumulation factor or safety factor will be applied to the WQV if any untreated drainage area enters the BMP**

	A	B	C	D
86	**Select and Size BMPs, and Define Routing**			
87	**BMP Characteristics**	**BMP 1**	**BMP 2**	**BMP 3**
88	Potential Cumulative Drainage Area to BMP (ac)	1.00	0.00	0.00
89	Impervious Cover for Potential Cumulative Drainage Area	50%	0%	0%
90	*BMP Stream Protection Volume Rec'd based on Change in On-Site Impervious Cover = 50%*		*0.65*	
91	BMP Type	Rain Garden (lined)	NO BMP	NO BMP
92	If Green Roof, Vegetative Filter Strip, or Permeable Pavement, enter size (ac)			
93	If a VFS enter width W = length of level spreader (ft)			
94	Message(s)			
95	Water Quality Volume WQV or Permanent Pool Volume if Wet Pond or Constructed Wetland (in)	0.68	0.30	0.10
96	If Sedimentation, Batch Sedimentation, or Wet Pond, enter pond surface area	0.0116	0.008	0.001
97	Drawdown Time DDT (hr)	48	48	36
98	WQV (cu.ft.)	2,468	0	0
99	Infiltration Rate - input required for VFS or Vegetated Swale (no swale blocks), or when there is no WQV (cfs)			
104	Predicted BMP Effluent Concentration (mg/L)	**0.050**		

Can be used as an ***initial*** estimate of BMP Water Quality Volume (WQV) but does not account for routing between BMPs (effluent and bypasses), different sub-area characteristics, or OFF-SITE drainage.

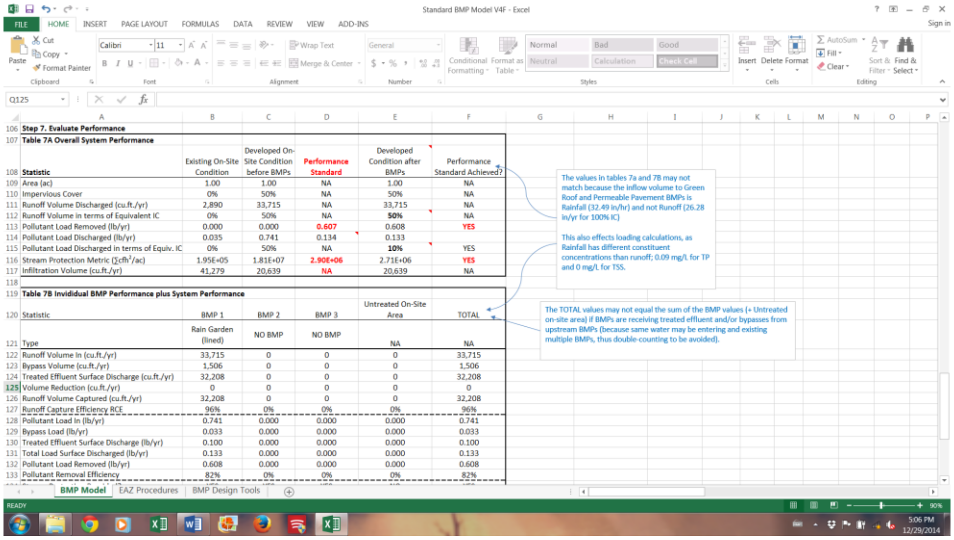
Performance Standard Status

Performance Standard	**Pct. Goal Achievement**	**Result**
Pollutant Load	**>100%**	**YES**
Stream Protection	**>100%**	**YES**
Infiltration	**NA**	**NA**

Define BMP Routing

If **NO** BMP 2 or BMP 3, input **NO** into **ALL** cells; if no BMP 3, input **NO** into cells referring to BMP 3

Is ***Treated Effluent*** from BMP 1 routed to BMP 2?	NO
If ***NO*** , is ***Treated Effluent*** from BMP 1 routed to BMP 3?	NO
Are ***Bypasses*** from BMP 1 routed to BMP 2?	NO
If ***NO*** , Are ***Bypasses*** from BMP 1 routed to BMP 3?	NO
Is ***Treated Effluent*** from BMP 2 routed to BMP 3?	NO
Are ***Bypasses*** from BMP 2 routed to BMP 3?	NO



Step 7. Evaluate Performance

Table 7A Overall System Performance

Statistic	Existing On-Site Condition	Developed On-Site Condition before BMPs	**Performance Standard**	Developed Condition after BMPs	Performance Standard Achieved?
Area (ac)	1.00	1.00	NA	1.00	NA
Impervious Cover	0%	50%	NA	50%	NA
Runoff Volume Discharged (cu.ft./yr)	2,890	33,715	NA	33,715	NA
Runoff Volume in terms of Equivalent IC	0%	50%	NA	**50%**	NA
Pollutant Load Removed (lb/yr)	0.000	0.000	**0.607**	0.608	**YES**
Pollutant Load Discharged (lb/yr)	0.035	0.741	0.134	0.133	
Pollutant Load Discharged in terms of Equiv. IC	0%	50%	NA	**10%**	YES
Stream Protection Metric (∑cfh²/ac)	1.95E+05	1.81E+07	**2.90E+06**	2.71E+06	**YES**
Infiltration Volume (cu.ft./yr)	41,279	20,639	**NA**	20,639	NA

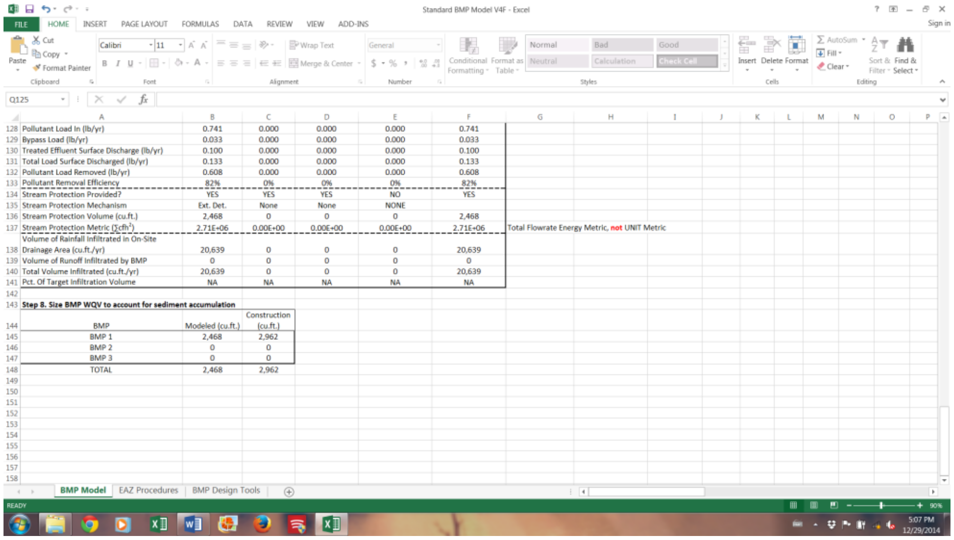
The values in tables 7a and 7B may not match because the inflow volume to Green Roof and Permeable Pavement BMPs is Rainfall (32.49 in/hr) and not Runoff (26.28 in/yr for 100% IC)

This also effects loading calculations, as Rainfall has different constituent concentrations than runoff; 0.09 mg/L for TP and 0 mg/L for TSS.

Table 7B Invididual BMP Performance plus System Performance

Statistic	BMP 1	BMP 2	BMP 3	Untreated On-Site Area	TOTAL
Type	Rain Garden (lined)	NO BMP	NO BMP	NA	NA
Runoff Volume In (cu.ft./yr)	33,715	0	0	0	33,715
Bypass Volume (cu.ft./yr)	1,506	0	0	0	1,506
Treated Effluent Surface Discharge (cu.ft./yr)	32,208	0	0	0	32,208
Volume Reduction (cu.ft./yr)	0	0	0	0	0
Runoff Volume Captured (cu.ft./yr)	32,208	0	0	0	32,208
Runoff Capture Efficiency RCE	96%	0%	0%	0%	96%
Pollutant Load In (lb/yr)	0.741	0.000	0.000	0.000	0.741
Bypass Load (lb/yr)	0.033	0.000	0.000	0.000	0.033
Treated Effluent Surface Discharge (lb/yr)	0.100	0.000	0.000	0.000	0.100
Total Load Surface Discharged (lb/yr)	0.133	0.000	0.000	0.000	0.133
Pollutant Load Removed (lb/yr)	0.608	0.000	0.000	0.000	0.608
Pollutant Removal Efficiency	82%	0%	0%	0%	82%

The TOTAL values may not equal the sum of the BMP values (+ Untreated on-site area) if BMPs are receiving treated effluent and/or bypasses from upstream BMPs (because same water may be entering and existing multiple BMPs, thus double-counting to be avoided).



Pollutant Load In (lb/yr)	0.741	0.000	0.000	0.000	0.741
Bypass Load (lb/yr)	0.033	0.000	0.000	0.000	0.033
Treated Effluent Surface Discharge (lb/yr)	0.100	0.000	0.000	0.000	0.100
Total Load Surface Discharged (lb/yr)	0.133	0.000	0.000	0.000	0.133
Pollutant Load Removed (lb/yr)	0.608	0.000	0.000	0.000	0.608
Pollutant Removal Efficiency	82%	0%	0%	0%	82%
Stream Protection Provided?	YES	YES	YES	NO	YES
Stream Protection Mechanism	Ext. Det.	None	None	NONE	
Stream Protection Volume (cu.ft.)	2,468	0	0	0	2,468
Stream Protection Metric (∑cfh²)	2.71E+06	0.00E+00	0.00E+00	0.00E+00	2.71E+06
Volume of Rainfall Infiltrated in On-Site Drainage Area (cu.ft./yr)	20,639	0	0	0	20,639
Volume of Runoff Infiltrated by BMP	0	0	0	0	0
Total Volume Infiltrated (cu.ft./yr)	20,639	0	0	0	20,639
Pct. Of Target Infiltration Volume	NA	NA	NA	NA	NA

Total Flowrate Energy Metric, **not** UNIT Metric

Step 8. Size BMP WQV to account for sediment accumulation

BMP	Modeled (cu.ft.)	Construction (cu.ft.)
BMP 1	2,468	2,962
BMP 2	0	0
BMP 3	0	0
TOTAL	2,468	2,962

APPENDIX H SIZING TABLES FOR WATER QUALITY BMPS

The following tables can be used to extrapolate the water quality volume (WQV) for a simple BMP system, in lieu of running the WQ BMP spreadsheet described in Appendix G. A 48 hour drawdown time is assumed, and Total Suspended Solids (TSS) is the pollutant constituent. The WQV includes a 20% sediment accumulation factor.

Table H-1A Biofiltration or Rain Garden BMP for Water Quality Zone T/R – TOTAL PHOSPHORUS
(with underdrain system; no infiltration assumed)

	Developed IC -------------->									
Existing IC	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0.10	0.27	0.45	0.62	0.82	1.42	NA*	NA*	NA*	NA*
10%	0	0.18	0.35	0.52	0.70	0.87	1.06	1.76	NA*	NA*
20%	0	0	0.18	0.35	0.52	0.70	0.87	1.08	1.68	2.78
30%	0	0	0	0.18	0.35	0.52	0.70	0.87	1.20	1.86
40%	0	0	0	0	0.18	0.35	0.52	0.70	0.89	1.41
50%	0	0	0	0	0	0.18	0.35	0.52	0.70	1.07
60%	0	0	0	0	0	0	0.18	0.35	0.52	0.77
70%	0	0	0	0	0	0	0	0.18	0.35	0.53
80%	0	0	0	0	0	0	0	0	0.18	0.35
90%	0	0	0	0	0	0	0	0	0	0.18
100%	0	0	0	0	0	0	0	0	0	0

* The TP load reduction goal cannot be achieved by this BMP alone at this IC level; a treatment train and/or volume reduction BMP system will be required.

Table H-1B Biofiltration or Rain Garden BMP for Water Quality Zone T/R – TOTAL SUSPENDED SOLIDS
(with underdrain system; no infiltration assumed)

	Developed IC ---------------->									
Existing IC	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0.10	0.27	0.45	0.62	0.78	0.96	1.13	1.30	1.48	2.08
10%	0	0.18	0.35	0.52	0.70	0.87	1.04	1.22	1.38	1.55
20%	0	0	0.18	0.35	0.52	0.70	0.87	1.04	1.22	1.38
30%	0	0	0	0.18	0.35	0.52	0.70	0.87	1.04	1.22
40%	0	0	0	0	0.18	0.35	0.52	0.70	0.87	1.04
50%	0	0	0	0	0	0.18	0.35	0.52	0.70	0.87
60%	0	0	0	0	0	0	0.18	0.35	0.52	0.70
70%	0	0	0	0	0	0	0	0.18	0.35	0.52
80%	0	0	0	0	0	0	0	0	0.18	0.35
90%	0	0	0	0	0	0	0	0	0	0.18
100%	0	0	0	0	0	0	0	0	0	0

*

Table H-2A Biofiltration or Rain Garden BMP with Infiltration Design for Water Quality Zone T/R – TOTAL PHOSPHORUS

(no underdrain system; no impermeable liner)

	Developed IC									
Existing IC	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0.09	0.22	0.33	0.44	0.54	0.65	0.88	1.20	1.61	2.15
10%	0	0.16	0.28	0.39	0.48	0.60	0.72	0.93	1.30	1.79
20%	0	0	0.16	0.29	0.41	0.53	0.66	0.80	1.05	1.48
30%	0	0	0	0.17	0.30	0.44	0.56	0.68	0.84	1.24
40%	0	0	0	0	0.17	0.30	0.46	0.59	0.74	1.01
50%	0	0	0	0	0	0.17	0.32	0.46	0.60	0.81
60%	0	0	0	0	0	0	0.17	0.33	0.47	0.62
70%	0	0	0	0	0	0	0	0.17	0.33	0.48
80%	0	0	0	0	0	0	0	0	0.17	0.33
90%	0	0	0	0	0	0	0	0	0	0.17
100%	0	0	0	0	0	0	0	0	0	0

Table H-2B Biofiltration or Rain Garden BMP with Infiltration Design for Water Quality Zone T/R – TOTAL SUSPENDED SOLIDS

(no underdrain system; no impermeable liner)

	Developed IC									
Existing IC	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0.09	0.22	0.33	0.44	0.54	0.65	0.77	0.89	1.17	1.60
10%	0	0.16	0.28	0.39	0.48	0.60	0.72	0.86	1.01	1.18
20%	0	0	0.16	0.29	0.41	0.53	0.66	0.80	0.93	1.07
30%	0	0	0	0.17	0.30	0.44	0.56	0.68	0.82	0.98
40%	0	0	0	0	0.17	0.30	0.46	0.60	0.74	0.88
50%	0	0	0	0	0	0.17	0.32	0.46	0.60	0.75
60%	0	0	0	0	0	0	0.17	0.33	0.47	0.62
70%	0	0	0	0	0	0	0	0.17	0.33	0.48
80%	0	0	0	0	0	0	0	0	0.17	0.33
90%	0	0	0	0	0	0	0	0	0	0.17
100%	0	0	0	0	0	0	0	0	0	0

Table H-3 Biofiltration or Rain Garden/Infiltration Treatment Train System for Water Quality Zones A and C – TOTAL PHOSPHORUS (Biofiltration BMP has impermeable liner and underdrain system)
Nomenclature: 0.15/0.03 means 0.15” WQV for Biofiltration and 0.03” WQV for Infiltration Basin; WQV for BMP 1 includes 20% sediment accumulation factor (not required for BMP 2)

General procedure:

- Goal is to meet all 3 performance standards with smallest infiltration basin (BMP 2) possible
- Input a WQV into BMP 1 such that little or no bypass occurs (could be similar to SPV)
- Input values for BMP 2 WQV until Pollutant Load and Infiltration performance standards are met
- Incrementally increase BMP 1 WQV while decreasing BMP 2 WQV, while still meeting all 3 performance standards
- Typically a “breakpoint” for BMP 2 WQV will occur where the WQV is a minimum that will still meet the 3 performance standards; at this point, reduce BMP 1 WQV until all performance standards are met.
- At this point, an optimum size has been determined for the 2 BMPs

	Developed IC									
Existing IC	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	.15/.03	.36/.06	.68/.09	.95/.13	1.22/.18	1.49/.25	1.79/.35	2.18/.48	2.67/.64	3.26/.85
10%	0	.16/.03	.29/.05	.42/.07	.53/.10	.81/.12	1.17/.15	1.86/.17	2.67/.20	3.27/.33
20%	0	0	.17/.02	.32/.04	.44/.07	.59/.09	.76/.11	1.16/.13	1.72/.15	2.73/.17
30%	0	0	0	.17/.02	.33/.04	.46/.06	.60/.08	.82/.10	1.25/.12	1.88/.14
40%	0	0	0	0	.17/.02	.33/.04	.48/.06	.63/.07	.95/.09	1.46/.11
50%	0	0	0	0	0	.17/.02	.33//.04	.48/05	.68/.07	1.12/.09
60%	0	0	0	0	0	0	.17/.02	.33/.04	.50/.05	.81/.07
70%	0	0	0	0	0	0	0	.17/.02	.34/.03	.57/.05
80%	0	0	0	0	0	0	0	0	.17/.02	.36/.03
90%	0	0	0	0	0	0	0	0	0	.17/.02
100%	0	0	0	0	0	0	0	0	0	0

Table H-4 Sand Filtration/Infiltration Treatment Train System for Water Quality Zones A and C – TOTAL PHOSPHORUS (Biofiltration BMP has impermeable liner and underdrain system)

Nomenclature: 0.15/0.03 means 0.15" WQV for Sand Filtration and 0.03" WQV for Infiltration Basin; WQV for BMP 1 includes 20% sediment accumulation factor (not required for BMP 2)

	Developed IC									
Existing IC	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	.14/.05	.42/.09	.71/.15	.88/.22	1.14/.29	1.47/.37	1.78/.48	2.18/.63	2.68/.82	3.26/1.07
10%	0	.16/.03	.29/.05	.48/.07	.78/.10	1.29/.14	1.77/.20	2.16/.30	2.65/.43	3.25/.61
20%	0	0	.17/.02	.32/.04	.44/.07	.63/.09	1.01/.12	2.00/.14	2.61/.23	3.24/.36
30%	0	0	0	.17/.02	.33/.04	.46/.06	.66/.08	1.12/.10	1.91/.13	3.26/.18
40%	0	0	0	0	.17/.02	.33/.04	.48/.06	.74/.08	1.24/.10	2.15/12
50%	0	0	0	0	0	.17/.02	.33//.04	.48/05	.88/.07	1.49/.09
60%	0	0	0	0	0	0	.17/.02	.34/.03	.57/.05	1.04/.07
70%	0	0	0	0	0	0	0	.17/.02	.34/.03	.66/.05
80%	0	0	0	0	0	0	0	0	.17/.02	.41/.03
90%	0	0	0	0	0	0	0	0	0	.18/.02
100%	0	0	0	0	0	0	0	0	0	0

Table H-5 Retention/Irrigation in Water Quality Zones A and C for Undeveloped Existing Condition

Retention/Irrigation Water Quality Volume (inches) [Note: volume includes 20% sediment accumulation factor]		
IC	TP	TSS
10%	0.14	0.20
20%	0.29	0.36
30%	0.47	0.53
40%	0.65	0.70
50%	0.87	0.90
60%	1.14	1.18
70%	1.50	1.50
80%	1.95	1.91
90%	2.48	2.42
100%	3.12	3.05

APPENDIX I DISCONNECTED AND EFFECTIVE IMPERVIOUS COVER CREDIT

Impervious cover is the single most important factor that affects the quantity and quality of stormwater. Impervious area that drains directly to the storm sewer system is most problematic, and is known as Directly Connected Impervious Area (DCIA). The effects of DCIA can be mitigated by "disconnecting" it, i.e., divert runoff to pervious areas such as vegetation, or to areas where it can be stored, reused, and/or infiltrated. At the site level, direct credit for disconnecting impervious areas, and/or retaining pervious areas, is typically given in the form of deriving an "effective" impervious cover (EIC) value that is less than the total impervious cover (TIC). EIC values can then be used instead of TIC when calculating runoff volumes and pollutant loads, thus reducing the size of stormwater treatment and stream protection BMPs.

Measures that are commonly used for impervious cover reduction credit generally fall into the following categories:

- Natural area conservation whereby natural areas are left undisturbed, and subtracted from the site "developed" area.
- Disconnection of impervious areas, e.g., roofs, parking lots, by routing runoff to pervious areas, such as vegetated filter strips and vegetated swales.
- Permeable pavement where rainfall infiltrates into the subsurface instead of running off paved areas.
- Rainwater harvesting where stormwater is captured for subsequent reuse, such as for landscape irrigation.
- Green roof where a rooftop is partially or fully covered with a rainfall-absorbing medium, thus preventing runoff from occurring.

The measures are discussed below, with recommendations provided. Source of information regarding these techniques include the EPA Low Impact Development Center, Lower Colorado River Authority Highland, Maryland Department of the Environment, North Central Texas Council of Governments (NCTCOG), San Antonio River Authority, City of San Antonio, Urban Drainage and Flood Control District (Denver, Colorado)

I-1 Credit for Natural Area Conservation

Areas that are left in a natural, undisturbed condition will generate much less stormwater than developed areas. A typical incentive is to calculate an "effective" drainage area by subtracting the natural area from the site drainage area. From a runoff modeling standpoint, this is not exactly correct, but may be a reasonable assumption as the contribution of runoff from natural areas will usually be negligible compared to that from developed areas. Some methods (e.g., LCRA) then have the user recalculate the impervious cover for the "effective" drainage area while others (e.g., NCTCOG, MDE) do not; the latter is not technically valid and will not be considered further. The proposed method is the following:

I-1.1 Procedure for Natural Area Credit:

1. Calculate "Effective" site drainage area as Total Site Drainage Area – Natural Area
2. Calculate impervious cover for the effective site drainage area
3. Use "Effective" area and impervious cover for BMP sizing purposes

I-1.2 Natural Area Credit Example:

A 1 acre with will be developed at 50% impervious cover. A 0.2-acre natural area has been set aside within that area. Calculate the effective drainage area and impervious cover.

- Site Drainage Area = 1 acre @ 50% IC, or 0.5 impervious acre.
- Effective Drainage Area = 1 – 0.2 = 0.8-acre
- Effective Impervious Cover = 0.5/0.8 = 62.5% IC

Natural areas must be undisturbed prior, during, and after site development. To receive credit, it is required* that the proposed natural areas:

- Shall not be disturbed during project construction (e.g., cleared or graded) except for temporary impacts associated with incidental utility construction or mitigation and revegetation projects,
- Shall be protected by having the limits of disturbance clearly shown on all construction drawings and delimited in the field except as provided for above,
- Shall be located within an acceptable conservation easement or other enforceable instrument that ensures perpetual protection of the proposed area. The easement must clearly specify how the natural area vegetation shall be managed and boundaries will be marked [Note: managed turf (e.g., playgrounds, regularly maintained open areas) is not an acceptable form of vegetation management],
- Shall be located on the development project and in the drainage area to a proposed BMP system (if a natural area is not in a drainage area to a BMP, then it can be ignored for BMP purposes), and
- Cannot be used for stormwater treatment

*Requirements modified from MDE, 2000

NOTE: In terms of BMP credit, it may be preferable to instead utilize a potential natural area as a Vegetative Filter Strip (VFS).

Commented [D61]: Added

I-2 Credit for Disconnection of Impervious Area

Disconnection refers to directing runoff from rooftops, parking lots, and other paved surfaces to vegetation or storage devices (e.g., rainwater harvesting) so that the runoff is slowed down, infiltrated, or stored for reuse. Disconnection credit is then usually given in terms of reduced impervious cover, or "effective" impervious cover.

Disconnection opportunities shall be identified early in the site planning process, and relatively simple procedures are proposed that are appropriate for that stage of the development process. In particular, the discharge of runoff from impervious areas to vegetation as overland sheet flow is of primary interest. Some entities include other practices in their disconnection procedures, including vegetated swales and subsurface storage devices (e.g., "dry wells"), but those generally require engineering knowledge to design and implement correctly, and will not be considered in this section. Another popular choice, especially for rooftop runoff, is to direct runoff to planter boxes. However, the size of planter box systems is highly site-specific, and no simple design assumptions can be made. Planter boxes are simply a variation of rain gardens, thus can be designed as such using the spreadsheet water quality model.

I-2.1 Procedures for Disconnection of Impervious Area Credit:

Commented [D62]: Edited – changed Non-Rooftop to Sheet Flow, which is more accurate and can allow roof tops to be used for this practice, if sheet flow can be achieved.

Two basic procedures will be presented:

A. Rooftop Disconnection (non-sheet flow)
B. Sheet Flow Disconnection

The technical basis for the procedures shall be based primarily on the volume of runoff lost to abstraction and infiltration, with the resulting runoff volume credited in terms of an “effective” impervious cover. This procedure clearly accounts for the area of vegetation, which is a fundamental hydrologic basis for losses. It does not assume highly permeable soils, which can overestimate runoff losses. Also, it requires a relatively moderate level of knowledge in order to run the procedure, in terms of site and soil conditions, and hydrologic variables.

A simplified procedure is recommended, using the general approach taken by MDE and LCRA, but with credit values derived from modeling and studies*. The spreadsheet model developed for the WQPP and described in Appendix I: Water Quality Model Description was used to derive disconnection credit. The credit values reflect the approximate volume of annual average runoff after disconnection, in terms of an equivalent impervious cover, from which the “effective” impervious cover is derived. See Sidebar: Avoiding Problematic Aspects of Other Procedures

Commented [D63]: Slight edit to following text box

Avoiding Problematic Aspects of Other Procedures

Some procedures that base credit on disconnection length are problematic, as they do not clearly account for the area of vegetation, which is a fundamental hydrologic basis for losses. Also, several of these procedures appear to assume highly permeable soils, which can overestimate runoff losses. For example, the Maryland and LCRA criteria give 100% credit if the disconnection length is 75 feet or greater, i.e., a 100% IC roof would be assumed to have an effective impervious cover (EIC) of 0%. This is not considered to be a reasonable assumption, as it would imply that ALL of the additional runoff applied to the vegetated area from the roof would be abstracted and infiltrated. The City of Austin studies on overland flow and vegetative filter strips can illuminate this issue further. Assuming a 500 sq. ft. roof area, the MDE/LCRA criteria would assume an EIC of 0% if the disconnection length is ≥ 75 feet; this implies that all of the roof runoff will be abstracted/infiltrated, as the vegetated area itself is already 0% IC and will generate its own runoff during larger storms. According to recent updates to the City of Austin Environmental Criteria Manual, if runoff from a 500 ft^2 impervious area is discharged as sheet flow for a distance of 75 feet, the flow width would have to be about 4 feet to infiltrate 65% (not 100%) of the annual average runoff in Type A, B, and amended C soils, and nearly 10 feet in Type C and amended D soils. Given that the average width of a roof downspout is much less than 1 foot, and given much greater widths than this would be needed to infiltrate just 65% of the runoff, the MDE/LCRA criteria cannot be recommended.

The Denver procedure is superior, as it accounts for multiple hydrologic areas (i.e., directly connected and disconnected impervious and pervious areas) and soil types, and uses a sophisticated hydrologic model to derive effective impervious cover values. Its primary drawback is that is requires a relatively high level of knowledge in order to run the procedure, in terms of site and soil conditions, and hydrologic variables.

I-2.1 A. Rooftop Disconnection (non-sheet flow)

For this procedure, it is assumed that runoff from a roof downspout is discharged to a splash pad and level spreader in order to create a sheet flow regime. A roof area of 500 ft^2 per downspout is assumed. Most downspouts have a width of 3-6 inches but this “flow width” is too concentrated for sheet flow, and an assumption is made that the flow will discharge runoff to the vegetation along a 12 inch wide splash pad and level spreader, thus a 1 foot wide flow width is assumed (which, multiplied times disconnection length, gives the abstraction/infiltration area). A simple Darcy’s Law approach is then applied, whereby runoff is lost to infiltration as the product of infiltration area and soil hydraulic conductivity. With these assumptions, and using the spreadsheet water quality model, the criteria in the following table was derived. No disconnection credit is proposed for poorly drained soils.

Procedure for Rooftop Disconnection Credit:

The values in the following table can be calculated using the equation:

Credit = 0.24*DL + 0.23

Table I-1: Percent Impervious Cover Reduction Credit for Rooftop Disconnection

Percent Impervious Cover Reduction Credit for Rooftop Disconnection		
Disconnection Length DL (ft)	Well-drained and Moderately Drained Soils[1]	Poorly-drained Soils[2]
<10	0%	0%
15	4%	0%
20	5%	0%
30	7%	0%
40	10%	0%
≥50	12%	0%

1. Hydrologic Soil Group A, B, or amended C, such as sand, sandy loam, loamy sand and Hydrologic Soil Group C or amended D, such as loam, sandy clay loam, clay loam
2. Hydrologic Soil Group D, such as clay, silty clay

Rooftop Disconnection Example:

The downspout from a 500 ft^2 rooftop is discharged to a level-spreading splash pad that is 12 inches wide, from which runoff flows across 42 feet of turf grass, underlain by moderately-drained soils.

Rooftop impervious cover = 100%

Calculated from equation, or linearly extrapolated from table above, the % reduction for a disconnection length of 41 feet is 10%, thus the Effective Impervious Cover (EIC) of the roof is calculated as:

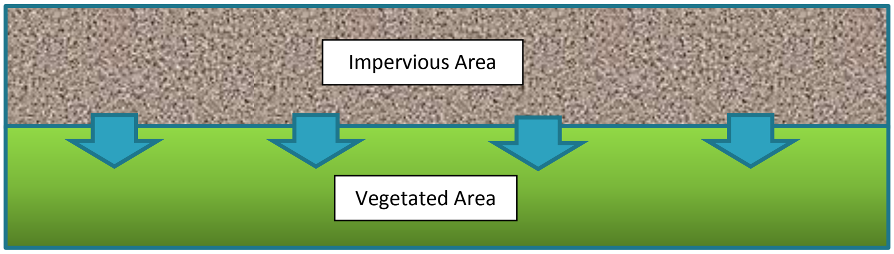
EIC = TIC * (1 - Credit) = 100 * (1 – 0.10) = 90%

Note: A primary reason the credit is low is because of the small overland flow area, assumed to be only 41 feet long by 12 inches wide, i.e., 41 ^{ft2} for a 500 ft^2 roof area. Increasing the flow width can substantially increase abstraction and infiltration. Recall from the City of Austin ECM, to infiltrate 65% of the rooftop runoff for a moderately drained soil would require an area of approximately 625 ft^2, or >15 times the size of the overland flow area in the example, and the resulting runoff volume would equate to that of a site with about 50% IC, thus 50% credit.

I-2.1 B. Sheet Flow Disconnection

For this measure, the drainage area can be a roof or other non-roof area, with an impervious cover of 100% or less (e.g., lower values may be a result of rainwater harvesting permeable pavement, or green roof). Runoff from the impervious area must be discharged as sheet flow to a vegetated area, as shown in the figure below, thus a level spreading device may be necessary. Flow lengths of 50 feet or more may require additional level spreaders. The slope of the vegetated area should not exceed 5%, otherwise sheet flow will likely not be maintained. An example of this technique is a ribbon curb along a roadway, as an alternative to curb and gutter designs. A key design variable is the ratio of impervious area to pervious area. The spreadsheet water quality model was used to derive the table below, applying a factor of safety to account for the difficulty of maintaining sheet flow. A maximum of 50% credit would be allowed.

Figure I-1: Plan View of Discharge as Sheet Flow to Vegetated Area



First (Simple) Procedure for Sheetflow Disconnection Credit:

Two procedures are described for Sheet Flow Disconnection Credit. This first procedure has the advantage being simple. A second (alternative) procedure for credit, more complex yet more flexible, is described thereafter.

The values in the following table can be derived as follows:

Calculate the Effective Impervious Cover EIC based on the impervious area IA and ½ of the pervious area PA, or:

EIC = 100 * [IA/(IA + PA/2)]

Credit = 100 - EIC

Table I-2 Percent Impervious Cover Reduction Credit for Sheet Flow Disconnection

Pervious Area to Impervious Area Ratio PA:IA	Well-drained and Moderately Drained Soils[1]	Poorly-drained Soils[2]
< 0.1	0	0
0.1	5	0
0.25	11	0
0.50	20	0
0.75	27	0
1.00	33	0
1.50	43	0
≥2.00	50	0

1. Hydrologic Soil Group A, B, or amended C, such as sand, sandy loam, loamy sand, and Hydrologic Soil Group C or amended D, such as loam, sandy clay loam, clay loam

2. Hydrologic Soil Group D, such as clay, silty clay

Sheet Flow Disconnection Example

A driveway 50 feet long by 15 feet wide is designed to drain as sheet flow to an adjacent vegetated area for 20 feet before leaving the site. Calculate the sheet flow credit for this system.

The driveway area is 50 feet x 15 feet = 750 ft^2 of impervious area

The pervious area is located along the length of the driveway, thus is 50 feet x 20 feet = 1000 ft^2

The ratio of pervious area to impervious area is thus 1000/750 = 1.33.

Using the credit procedure above:

EIC = 100 * [IA/(IA + PA/2)] = 100 * [750/(750 + 1000/2)] = 60%

Credit = 100 – EIC = 100 – 60 = 40%

Second (Alternative) Procedure for Sheet Flow Disconnection Credit:

A more rigorous technical procedure can be developed that reflects the basic approach taken in Denver's Impervious Reduction Factor (IRF) method, in which a model is run for three distinct hydrologic areas on a site:

- Directly Connected Impervious Area
- Impervious Area that discharges to Pervious Area
- Separate Pervious Area

This procedure would allow the designer more flexibility than the simplified ones presented earlier. A version appropriate for the San Marcos climate and geology can be developed.

I-3 Credit for Rainwater Harvesting

Rainwater harvesting is only eligible for Effective Impervious Cover (EIC) credit, and that credit is determined by running the landscape-irrigation-rainwater harvesting model described in Appendix K. A basic challenge with designing these systems is estimating the usage rate of the captured water, as this is an important variable when determining hydrologic performance. The spreadsheet model provides a landscape-irrigation procedure for this purpose, and also allows the user to input other "water demand" values. To be eligible for EIC credit, these systems will require professional operation, maintenance, and management to ensure on-going effective performance. In typical residential or private settings, rainwater harvesting systems may not be operated in a consistent manner, thus even roughly estimating performance can be difficult. But the use of RWH should be strongly encouraged and incentivized, even if regulatory credit is not a factor, e.g., for private homeowners, businesses, schools, and governmental facilities.

I-4 Credit for Permeable Pavement

For the purpose of disconnection credit, permeable pavement must be designed as an infiltration system that allows stored runoff to infiltrate into the underlying soil. Thus appropriate site conditions must exist for infiltration, in terms of soil permeability, depth to bedrock or water table, potential for groundwater pollution, etc. Due to current TCEQ rules, permeable pavement is not allowed in the recharge zone.

Commented [D64]: I wonder if this is true even for pedestrian walkways?

I-4.1 Procedure for Permeable Pavement Credit (presented as a Table)

The following table has been developed for disconnection credit. The water quality volume WQV is the storage volume of the subsurface reservoir system, and can be estimated as the reservoir depth multiplied times the porosity of the reservoir media. Note that the infiltration rate assumed for deriving these criteria is that of the underlying soil, not the permeable pavement itself (which should be high, e.g., ≥ 5 in/hr). Also note that no off-site runoff (aka run-on) can be allowed to enter the permeable pavement area.

Table I-3 Percent Impervious Cover Reduction Credit for Permeable Pavement		
Water Quality Volume (in)	**Well-drained and Moderately Drained Soils[1]**	**Poorly-drained Soils[2]**
< 1	0%	0%
≥ 1	75%	0%

1. Hydrologic Soil Group A, B, or amended C, such as sand, sandy loam, loamy sand and Hydrologic Soil Group C or amended D, such as loam, sandy clay loam, clay loam

2. Hydrologic Soil Group D, such as clay, silty clay

I-4.1 Example for Permeable Pavement

A 1 acre permeable pavement parking lot is proposed at a site located in the San Marcos River Corridor watershed. Soils are well-drained Seawillow clay loam. The site planner specifies that the permeable pavement must have a WQV > 1 inch; the subsequent subsurface reservoir depth will be 6 inches with porosity of 0.4. Determine the impervious cover credit.

Water Quality Volume WQV = 6 * 0.4 = 2.4 inches, which is > 1 inch, thus eligible for credit

From table above, the percent credit = 75%, or 0.75

EIC = TIC * (1 - Credit) = 100 * (1 – 0.75) = 25%

I-5 Credit for Green Roof

Green roofs have significant potential for reducing stormwater volumes and pollution, but their actual performance in Central Texas is still being studied and debated. Roofs that are irrigated and fertilized have significant potential to become pollutant sources rather than treatment BMPs, thus appropriate management is of critical importance, more so than other BMPs.

I-5.1 Procedure for Green Roof Credit (presented as a Table)

The following table shows the proposed disconnection credit, and applies only to systems that are not irrigated or fertilized. Green roofs that are irrigated and/or fertilized can still pursue regulatory credit for pollutant load reduction and stream protection criteria by designing them as stormwater BMPs, but would not be eligible for disconnection credit. Such systems would be required to be professionally designed, managed, and operated; monitoring may also be specified.

The Water Quality Volume WQV is calculated as the green roof media thickness multiplied by the media field capacity, a characteristic that should be provided by the media manufacturer. The WQV only applies to the portion of the roof that is covered; if an “intensive” green roof is used, only the areas covered by media or planters are to be considered.

Table I-4: Percent Impervious Cover Reduction Credit for Green Roof

Percent Impervious Cover Reduction Credit for Green Roof

Water Quality Volume (in)	No irrigation or fertilization[1]	With automatic irrigation and/or fertilization
1 – 2	50%	0%
>2– 3	75%	0%
> 3	90%	0%

Commented [D65]: Added > symbol to clarify how credit determined.

1. Hand watering is allowed but automatic irrigation systems are not eligible for credit

I-5.2 Example for Green Roof

A 0.5-acre green roof is proposed for a commercial development. The green roof media will be 3 inches thick, with a field capacity of 0.45. Determine the impervious cover credit for this system. The roof will not be irrigated or fertilized.

Water Quality Volume WQV = 3 * 0.45 = 1.35 inches

Based on the table above, the green roof is eligible for 50% credit.

Effective Impervious Cover EIC = TIC * (1 – Credit) = 100 (1 – 0.5) = 50%

I-6 Multiple Credits

Disconnection measures can be designed to complement each other to maximize disconnection credit. A simple procedure is proposed, as illustrated by the following example.

Example for Multiple Credits

The downspout from a 500 sq. ft. green roof is discharged to a splash pad and flow spreader (12 inches wide), whereby runoff travels 35 feet over a well-vegetated turf grass area before discharging to a street. The green roof will not be irrigated or fertilized, and will have 3 inches of media with a field capacity of 0.5. The on-site soils are moderately well-drained Lewisville silty clay. Calculate the effective impervious cover EIC for the roof.

Multiple Credit Element #1: Green Roof

- Total impervious cover (TIC) of roof = 100%
- No irrigation or fertilization
- WQV = 3 * 0.5 = 1.5-inch, or 1.2-inch with 20% factor of safety applied, so is eligible for 50% impervious cover reduction credit
- Effective Impervious Cover of Green Roof (EIC_{GR}) = TIC * (1 - Credit) = 100 * (1 – 0.50) = 50%

Commented [D66]: Corrected calculation to include 20% FOS

Multiple Credit Element #2: Rooftop Disconnection

- Soils are moderately well drained
- Disconnection Length DL = 35 feet
- Credit = 0.24*35 + 0.23 = 9% disconnection credit

Multiple Credit Elements Combined: Total System

- Effective Impervious Cover Total (EIC_{TOT}) = TIC * (1 - Credit)
- Use EIC_{GR} of the green roof instead of the roof TIC
- EIC_{TOT} = 50 * (1 – 0.09) = 45%

Thus the roof effective impervious cover can be assumed to be 45%

The same disconnection area cannot receive multiple credits. For example, an overland flow area cannot receive disconnection credit if runoff is discharged to it from both rooftop and sheet flow areas.

APPENDIX J RAINWATER HARVESTING/LANDSCAPE IRRIGATION TOOL

A flexible tool has been developed that has three primary purposes:

1) Assist in designing a water efficient landscape
2) Provide a sound technical basis for designing a rainwater harvesting system to meet landscape irrigation needs
3) Calculate an "Effective Impervious Cover" (EIC) for the drainage area to the RWH system, which can then be used for regulatory credit for meeting the TP and Stream Protection Volume performance measures.

The performance standard for this system is to "reduce water use (potable, groundwater, river diversion) for landscape irrigation by at least 50%." The basis for assessing the 50% reduction is a "baseline" condition, i.e., a typical landscape and irrigation system, and applied to a dry year condition, in this case the year 2011.

Similar to procedures in the EPA WaterSense Water Budget Tool (USEPA, 2009) and Sustainable Sites Initiative (SSI, 2009), this tool bases irrigation needs on evapotranspiration for a dry year. Unlike the EPA and SSI procedures, however, the spreadsheet estimates irrigation needs for an entire year instead of just for the driest month. This is necessary in order to link the irrigation results to design of a rainwater harvesting system, so that the design can be assessed for both reducing potable water demand and providing stormwater management benefits. It should be noted that the irrigation volumes calculated do not apply during the establishment period of the landscape, when more frequent irrigation may be needed.

In order to establish a basis for irrigation timing and volume (necessary for designing the rainwater harvesting system), procedures described in FAO 56 (Allen, et al., 1998) have been adopted, specifically as described in Chapter 8 "ETc under soil water stress conditions" but using a single crop coefficient. This procedure is fairly simple to apply, given adequate rainfall and evaporation data, and determines the irrigation volume needed in the plant root zone to avoid unacceptable stress. A daily time step is used in the spreadsheet.

A daily time step is used in the model. The starting point of the procedure is to estimate daily potential evapotranspiration ETo. The Texas A&M "Texas ET" website (http://texaset.tamu.edu/) provides average monthly and annual ETo for Austin, the nearest site to San Marcos, but *daily* ETo needs to be estimated. Daily pan evaporation (PAN) data is available for Austin from the National Climatic Data Center (http://ncdc.noaa.gov), and a simple procedure described in FAO 56 and other documents for estimating daily ETo is:

ETo = Kp * PAN

Where ETo is potential evapotranspiration , or reference crop evapotranspiration (in/day)

Kp = pan coefficient

PAN = pan evaporation (in/day)

As can be surmised, the pan coefficient Kp is simply the ratio of ETo to PAN. Based on analysis of the NCDC data, the average annual PAN value for Austin is about 80 inches. Based on the Texas ET website, the annual average ETo value for Austin is 57.51 inches. Thus:

Kp ≈ ETo/PAN = 57.51/80 = 0.72

An analysis of monthly ETo and PAN data was also conducted, but the results were similar to using the annual average Kp value of 0.72, thus that value will be assumed in the spreadsheet tool.

To estimate crop evapotranspiration ETc, the amount of water lost by the crop or plant, the FAO procedure used is:

ETc = Kc * ETo

Where ET is crop or plant evapotranspiration (in/day)

Kc = crop coefficient

Plant crop coefficients are available from FAO 56, the Texas ET website, and other sources. The following are used in the spreadsheet:

Plant	Kc	Source
Turfgrass – warm season	0.6	Texas ET website
Trees, shrubs, or groundcover – occasionally watered	0.5	Texas ET website
Drought tolerant turfgrass (e.g., buffalograss)	0.4	WQPP judgment
Drought tolerant trees, shrubs, or groundcover	0.4	WQPP judgment

Application of mulch can reduce Kc by 10-30% (FAO 56), so an option is the spreadsheet is to apply mulch for the trees, shrubs, or groundcover plant types; a reduction in Kc of 10% is assumed.

In order to determine the timing and volume of irrigation needed, a soil water balance in the plant root zone is conducted, based on FAO 56:

TAW = Zr * (Θ_{FC} - Θ_{WP})

TAW = Total Available Water in the plant root zone (in)

Zr = plant rooting zone depth (in)

Θ_{FC} = soil moisture content at Field Capacity (in/in)

Θ_{WP} = soil moisture content at Wilting Point (in/in)

Plant root zone depths are shown as 0.5-1.0 meter for warm season turf grasses (≈ 1.5 – 3 ft), and 0.6 – 2.0 meters for bushes, fruit and ornamental trees (≈ 2 – 6.5 ft). Assumptions in the spreadsheet are 1.5 feet for warm season turfgrasses, and 3 feet for shrubs, trees, and groundcover.

Plant water stress is negligible when soil moisture content equals TAW, but significant stress can occur when it is less, and the following equation is used:

RAW = p * TAW

RAW = Readily Available Water (in)

p = average fraction of TAW that can be depleted from the root zone before moisture stress occurs

Average values of p vary from 0.30 – 0.70, and a value of 0.50 is commonly used; 0.50 will be used in the spreadsheet.

When soil moisture conditions are less than TAW, the amount of evapotranspiration that can occur can reduced because there is less water to evapotranspire. This can be accounted for using the following equations:

ETc = Kc * Ks * ETo

Ks is the water stress coefficient, a value between 0 and 1; 0 when soil moisture is equal to TAW, and 1 when equal to RAW. Ks is calculated as:

Ks = (TAW – Dr)/(TAW – RAW)

Dr is the root zone depletion, and calculated in the spreadsheet as:

$Dr = Zr * (\Theta_{FC} - \Theta_i)$

Where Θ_i is the soil moisture content (in/in) at the time step (day).

The calculation sequence incorporates daily rainfall, using the continuity equation to conduct a daily water balance:

$S_i = S_{i-1} + I - O$

Where S_i = soil moisture at end of day (in)

S_{i-1} = soil moisture at start of day (in)

I = total water inputs = rainfall and/or irrigation (in)

O = total water outputs = evapotranspiration (in)

The soil moisture S is the rooting depth Zr multiplied times the soil moisture content Θ_i.

If daily rainfall is less than or equal to 20% of the daily ETo, it is assumed ineffective (i.e., assume P = 0). Thus effective rainfall P_{eff} is used.

Incorporating the relevant factors into the continuity equation gives:

$S_i = (Zr * \Theta_{i-1}) + P_{eff} - ETc$

If the calculated Si is less than RAW, then irrigation water is added until Si equals TAW (equates to restoring soil moisture to Field Capacity).

The actual amount of irrigation water applied accounts for the irrigation system efficiency:

$IRR_{applied} = IRR_{needed}/Eff_{irr}$

Where $IRR_{applied}$ = the volume of irrigation water applied, IRR_{needed} is the volume needed, and Eff_{irr} is the irrigation system efficiency.

Irrigation efficiency assumptions in the spreadsheet are based on information from the Texas A&M AgriLife program (Bubbler efficiency from Phocaides, 2000).

Irrigation System Efficiency (Woodson, 2012)	
System	Efficiency
Drip	90%
Bubbler	75%
Micro Drip	85%
Sprinkler – rotor	65%
Sprinkler - surface	50%

The dry year of 2011 is used as the basis for landscape irrigation design, using precipitation and pan evaporation data from a Canyon Dam site, the nearest to San Marcos that had adequate data. Rainfall data was complete but some days were missing evaporation data. Data gaps were filled by assuming the missing value was equal to the average value of the immediate preceding and following days.

A baseline landscape and irrigation design is first defined, which serves as the basis for achieving at least a 50% reduction in potable water use. The user can input their own baseline assumptions, but defaults are the following:

- Turfgrass – Kc = 0.6, irrigation system = Sprinkler–surface
- Trees, shrubs, or groundcover - Kc = 0.5, irrigation system = sprinkler-rotor, no mulch

Up to five hydrozones can be input into the spreadsheet.

The rainwater harvesting system is modeled using a daily time step, and applying the continuity equation:

$S_i = S_{i-1} + I - O$

S_i is the storage volume in the RWH system at the end of the day, S_{i-1} is the storage at the start of the day, I is the inflow volume from runoff, and O is the outflow = irrigation volume (all units are in ft_3). The maximum value of S is the design volume, which is input in gallons. The irrigation volume provided by the RWH system is lesser of the volume needed by the landscape or the volume available in the RWH system (thus, if the RWH system is empty, no irrigation water can be provided).

The spreadsheet calculates the annual runoff from the drainage area, and the runoff captured by the RWH system, from which the runoff volume discharged from the system is calculated. The runoff volume discharged from the system is then translated into an "Effective Impervious Cover" (EIC). While the landscape-irrigation-rainwater harvesting 50% performance standard is based on a dry year (2011), the EIC calculation is based on an annual average rainfall year (1985), so that the value can be input into the WQ BMP spreadsheet model. For example, if the system captures 5 inches/year from a 100% impervious cover roof, which generates 26.28 inches/year of runoff, the RWH system discharges 21.28 inches/year. Based on the impervious cover-runoff volume relationships described previously, a volume of 21.28 inches/year equates to an impervious cover of about 90%, thus an EIC value of 90% is assigned to the RWH drainage area.

The following pages show some of the spreadsheet input and outputs. Note that a message is displayed at the bottom when the 50% reduction goal is achieved (if the goal is not met, the message "Goal Not Met" is displayed). In the example, 41% of the goal is met by better landscape and irrigation design, and the remainder by rainwater harvesting (i.e., replacing potable water or groundwater with captured stormwater for landscape irrigation). The EIC for the system is calculated to be 97%.

STEP 1. DESIGN LANDSCAPE AND IRRIGATION SYSTEM

BASELINE CONDITION (Dry Year)

Hydrozone	Hydrozone Area (sq.ft.)	Plant Type	Mulched?	Irrigation System Type	Irrigation System Efficiency	Irrigation Volume Applied (gal/yr)
1	10,000	Turfgrass	No	Sprinkler - Surface	50%	429,785
2	10,000	Trees, Shrubs, or Groundcover	No	Sprinkler - Rotor	65%	250,408
3	0	Trees, Shrubs, or Groundcover	No	Sprinkler - Rotor	65%	0
4	0	Turfgrass	No	Sprinkler - Surface	50%	0
5	0	Turfgrass	No	Sprinkler - Surface	50%	0
TOTAL	20,000				56%	680,193

DESIGN CONDITION (Dry Year)

Hydrozone	Hydrozone Area (sq.ft.)	Plant Type	Mulched?	Irrigation System Type	Irrigation System Efficiency	Irrigation Volume Applied (gal/yr)
1	5,000	Turfgrass	No	Sprinkler - Rotor	65%	165,302
2	7,500	Trees, Shrubs, or Groundcover	No	Drip	90%	135,638
3	2,500	Drought Tolerant Trees, Shrubs, or Groundcover	Yes	Drip	90%	26,911
4	5,000	Drought Tolerant Turfgrass	No	Drip	90%	76,850
5	0	Trees, Shrubs, or Groundcover	Yes	Drip	90%	0
TOTAL	20,000				80%	404,700

Results for Irrigation Design (Dry Year)	**Irrigation Area (sq.ft.)**	**Irrigation Volume (gal/yr)**
Baseline Conditon	**20,000**	**680,193**
Design Condition	**20,000**	**404,700**
Pct. Reduction	**0%**	**41%**

STEP 2. INPUT DAILY NON-IRRIGATION WATER USE FOR THE RAINWATER HARVESING SYSTEM, IF APPLICABLE

Non-Irrigation Water Use		
Daily Non-Irrigation Water Demand (gallons per day)	0	e.g., indoor plumbing use

STEP 3. SIZE RAINWATER HARVESTING SYSTEM

Rainwater Harvesting System Design	
Catchment Area (ac)	1
Catchment Impervious Cover	100%
Runoff Coefficient Rv	0.892
Depression Storage Sd	0.036
Identify which Hydrozones to be irrigated from RWH System	
Hydrozone (Design Condition)	Irrigated from RWH?
1	Yes
2	Yes
3	Yes
4	Yes
5	Yes
RWH Volume (gallons)	12,000

STEP 4. ASSESS OVERALL SYSTEM PERFORMANCE AND GOAL ATTAINMENT

	Dry Year	Average Year	
Total Volume Needed for BASELINE Condition (gal/yr)	680,193	247,105	
Total Volume Needed for DESIGN Condition (gal/yr)	404,700	125,620	
Potable Water Volume Needed for DESIGN Condition (gal/yr)	338,098	70,514	
Reduction in Potable Water Use compared to BASELINE Condition (%)	**50%**	71%	**GOAL MET**

STEP 5. ESTIMATE EFFECTIVE IMPERVIOUS COVER OF ROOF FOR AVERAGE YEAR

97%

APPENDIX K ERОSION HAZARD ZONE GUIDANCE

Erosion Hazard Zone Guidance has been prepared by staff at the City of Austin Watershed Protection Department. A hyperlink to the online guidance is provided here with the intent to share information that others may find helpful. https://www.austintexas.gov/faq/erosion-hazard-zone-criteria

APPENDIX L BMP EXAMPLES

The following examples are provided to illustrate the BMP selecting and sizing procedures proposed by the WQPP, and to compare BMP designs with other procedures, in particular used for the City of San Marcos and the TCEQ Edwards Aquifer Rules.

- Example 1. Redevelopment Site in SmartCode Zone T5 and Water Quality Zone T/R
- Example 2. Residential Subdivision in Water Quality Zone A (Edwards Aquifer Recharge Zone)
- Example 3. Site in Water Quality Zone A (Edwards Aquifer Recharge Zone) with Treatment Train BMP Systems
- Example 4. New Development Site in Water Quality Zone T/R and Inside San Marcos River Corridor – High Impervious Cover
- Example 5. New Development Site in Water Quality Zone T/R and Inside San Marcos River Corridor – Low Impervious Cover

Example 1. Redevelopment Site in SmartCode Zone T5 (Urban Center) and Water Quality Zone T/R

Question 1: Is the total of new and redeveloped impervious cover 5000 ft^2 or greater?
Answer: Yes; the total is 1 acre * 43560 ft^2/ac * (0.90 – 0.70) = 8712 ft^2.

Question 2: Does the Existing impervious cover decrease, stay the same, or increase?
Answer: It increases, from 70% to 90%

From the table in 8.1.5.3, on-site BMPs are required, to the extent possible. Three performance standards apply:

- New development TP load to be no greater than a site with 10% IC
- Provide Stream Protection Volume or equivalent for the new development
- Reduce water use (potable, ground, river diversion) for landscape irrigation by at least 50%

There is one optional performance standard:

- Maintain or increase the existing infiltration rate

For this example, it is assumed that it is possible to fully meet the 3 required performance standards. For simplicity's sake, the water demand/reuse performance standard is not analyzed, is assumed to be met with landscape and irrigation design only, i.e., a RWH BMP is not utilized. Because the site is located is SmartCode Zone T/R, it would be eligible for cost recovery for implementing on-site BMPs.

<u>Pollutant Load Removal Performance Standard</u>
(Note: calculations are taken from the WQ BMP spreadsheet model, which does not round numeric values up or down)

Existing pollutant load:
Runoff volume for 75% IC site = 13.99 inches/year
Mean TP concentration in runoff = 0.318*IC + 0.194 = 0.318*0.70 + 0.194 = 0.417 mg/L
TP load $L_{existing}$ = Area * ROV * C * 0.226 = 1*13.99*0.417*0.226 = **1.317 lb/yr**

Target load:
The “10% IC equivalent” target load to be discharged is calculated by multiplying the drainage area times 0.099 lb/ac/yr, and adding the existing load:
TP load target $L_{target} = L_{existing} + A*0.099 = 1.317 + 1*0.099 =$ **1.416 lb/yr**

TP load after redevelopment:
Runoff volume for 90% IC site = 21.26 inches/year
Mean TP concentration in runoff = 0.318*IC + 0.194 = 0.318*0.90 + 0.194 = 0.480 mg/L
TP Load L_{redev} = Area ROV * C * 0.226 = 1*21.26*0.480*0.226 = **2.307 lb/yr**

Pollutant Load Removal Performance Standard

The performance standard is to remove, at a minimum, the difference between the developed condition load without BMPs and the target load, or:

Performance Standard = 2.307 – 1.416 = **0.891 lb/yr**

Assuming no off-site runoff, this equates to a Load Removal Efficiency of:

$RE = (L_{redev} - L_{target})/L_{redev} = (2.307 - 1.416)/2.307 = 0.386$ or **39%**

It off-site drainage is treated, the removal efficiency may be different because the inflow load would be different (higher), but the performance standard remains the same, i.e., remove at least 0.891 lb/yr.

Initial BMP Selection and Determine if Volume Reduction is Needed to Meet Pollutant Load Reduction
Given the site conditions, a Rain Garden system is selected, with an underdrain system, as underlying soils are marginal for infiltration. First determine if a Rain Garden BMP will provide adequate treatment alone, or if volume reduction is required. This requires solving the basic Removal Efficiency RE equation:

RE = RCE * ER
Where RE = load removal efficiency
RCE = Runoff Capture Efficiency, or the fraction of runoff that is captured by the BMP
ER = Efficiency Ratio, or the reduction in TP concentration provided by the BMP

Rearranging and solving for RCE:

RCE = RE/ER

If RCE > 1, then volume reduction is required.

$ER = (C_{dev} - C_{bmp})/C_{dev}$
Where C_{dev} = mean TP concentration of runoff for the developed condition, or 0.480 mg/L
The TP effluent concentration C_{bmp} for a Rain Garden BMP is 0.05 mg/L

ER = (0.480 – 0.05)/0.480 = 0.896 or 90%

Inserting ER into RCE equation:

RCE = 0.386/0.896 = 0.43 < 1

Therefore the BMP will meet the TP load goal without volume reduction.

The first step in sizing the BMP should be to meet the Stream Protection performance standard, as shown in the following

Stream Protection Performance Standard

The minimum SPV needed is the difference in SPV requirements for the redeveloped and existing conditions:

$SPV_{ex} = 1.4314*IC – 0.0677 = 1.4314*0.70 – 0.0677 = 0.934$, so round to 0.94 inch

$SPV_{redev} = 1.4314*0.90 – 0.0677 = 1.221$, so round up to 1.23 inches

Therefore SPV = 1.23 – 0.94 = 0.29 inch

The WQ BMP spreadsheet calculates the runoff volume captured and bypassed by a hypothetical extended detention basin for an average annual year, for the 90% IC condition, assuming a WQV of 0.29-inch and 48 hour drawdown time. The “flow energy” metric is calculated, as described in Appendix G.

Input 0.29-inch WQV into the WQ BMP spreadsheet, with a 48 hour drawdown time.

Pollutant Load Reduction Performance Standard

From the spreadsheet, it is shown that a 0.29-inch WQV is sufficient to meet the load reduction goal. It may be instructive to determine what WQV is necessary to meet just the pollutant load performance standard; it is found to be 0.22-inch.

To verify this finding, note that, from the calculations above, with a 90% Efficiency Ratio, and 39% Removal Efficiency, the BMP system must capture at least 43% of the annual average runoff. Input a WQV of 0.22-inch into the spreadsheet model; Table 7B displays the “Runoff Capture Efficiency (RCE) as 44%. With a WQV of 0.29-inch to meet the SPV performance standard, the actual RCE is 53%.

Finalize the Design

The SPV required is greater than the WQV, thus choice the larger of the two, which is 0.29-inch.

A WQV of 0.29-inch for the 1 acre drainage area equates to 1053 ft^3. Add 20% to this value to account for sediment accumulation, or:

$WQV_{final} = 1053 *1.2 = 1263\ ft^3$ (= 0.35-inch)

Assuming a 6 inch (= 0.5 feet) ponding depth for the Rain Garden, and vertical walls, the surface area of the Rain Garden system will be:

$A_{RG} = WQV/d = 1263/0.5 = 2526\ ft^2$

The WQV volumes before and after applying the sediment accumulation factor are also displayed at the bottom of the spreadsheet.

The 1 acre site will have 10% pervious area, or 4356 ft^2, so there is sufficient room to incorporate the Rain Garden system into the site.

Verify that this is sufficient surface area to meet the 48 hour drawdown time, using the Austin "Partial Sedimentation-Filtration" equation:

A = WQV/(4 + 1.33H) where H is the maximum ponding depth, in this case 6 inches, or 0.5 feet.

$$A = 1263/(4 + 1.33*0.5) = 271\ ft^2$$

The 2526 ft^2 provided is sufficient. An underdrain orifice must be installed for the Rain Garden, sized for a 48 hour drawdown time.

<u>Design Alternatives</u>

A Rainwater Harvesting System could be installed to provide irrigation water for landscaped areas, including the Rain Garden system. If 1600 ft^2 of turfgrass area is irrigated, with a catchment (roof) area of 10,000 ft^2, the optional performance standard of "50% reduction in potable or groundwater use for landscape irrigation" could be met with a 2000 gallon tank. This would also reduce the roof "Effective Impervious Cover" (EIC) from 100% to 98%.

The redeveloped site could also install 4000 ft^2 of permeable pavement for pedestrian walkways. Using the credit system described in Appendix I, that area could be assumed to have an EIC of 25%.

The net effect of the RWH and permeable pavement BMPs would be to reduce the site Effective Impervious Cover from 90% to 83%. Inputting this value into the WQ BMP spreadsheet reduces the WQV from 1263 ft^3 to 828 ft^3, and the Rain Garden area from 2526 ft^2 to 1656 ft^2, a 34% reduction.

<u>Cost Recovery</u>

Because the site is located in Water Quality Zone T/R, SmartCode Zone T5, and is implementing on-site BMPs, it would be eligible for 75% reimbursement for the cost of the BMPs, which is an incentive to redevelopment in the Urban Center.

Example 2 Residential Subdivision in Water Quality Zone A (Edwards Aquifer Recharge Zone)

An undeveloped 20 acre tract of land in the recharge zone will be developed as a residential subdivision. To comply with the 20% impervious cover limit, the development will be clustered, with 12 acres left undeveloped, and the remaining 8 acres developed at 50% impervious cover. The soils on the site are Rumple-Comfort; in-situ testing determined a soil hydraulic conductivity of 0.1 in/hr. Design a BMP system for this development.

NOTE: Calculations are provided below for instructional purposes, but using the *BMP Model* worksheet is recommended, as results and design variations can be evaluated much faster.

<u>Performance Standards</u>

Four performance standards apply:

- No increase in the existing TP load

- Provide Stream Protection Volume or equivalent for the new development
- Maintain or increase the existing infiltration rate
- Reduce potable or groundwater use for landscape irrigation by at least 50%

The last performance standard is not generally applicable to residential subdivisions, unless professional operation and maintenance can be provided. For this example, this is not assumed, thus the standard does not apply. Nonetheless, the intent of the performance measure should be encouraged, i.e., drought tolerant landscapes, efficient irrigation systems, and rainwater harvesting to reduce demand groundwater or potable water supplies.

Pollutant Load Removal Performance Standard
(Note: calculations are taken from the WQ BMP spreadsheet model, with numbers rounded)

Existing pollutant load:

- The 12 acres that will be left undeveloped can be excluded from the calculations. The existing impervious cover for the 8 acres to be developed is 0%.
- Runoff volume for 0% IC = 0.80 inches/year
- Mean TP concentration in runoff = 0.318*IC + 0.194 = 0.318*0 + 0.194 = 0.194 mg/L
- TP load $L_{existing}$ = Area * ROV * C * 0.226 = 8*0.80*0.194*0.226 = **0.279 lb/yr**

TP load after development:

- Based on 8 acres at 50% IC
- Runoff volume for 50% IC site = 9.29 inches/year
- Mean TP concentration in runoff = 0.318*IC + 0.194 = 0.318*0.50 + 0.194 = 0.353 mg/L
- TP Load L_{redev} = Area ROV * C * 0.226 = 8*9.29*0.353*0.226 = **5.928 lb/yr**

Pollutant Load Removal Performance Standard

The performance standard is to remove, at a minimum, the difference between the developed condition load without BMPs and the target load, or:

Performance Standard for pollutant load removal = 5.928 – 0.279 = **5.649 lb/yr**

Assuming no off-site runoff, this equates to a Load Removal Efficiency of:

$RE = (L_{redev} - L_{target})/L_{redev} = (5.928 - 0.279)/5.928 = 0.953$ or **95%**

If off-site drainage is treated, the removal efficiency may be different because the inflow load would be different (higher), but the performance standard remains the same, i.e., remove at least 5.649 lb/yr.

The BMP selection and sizing to meet this goal will be described below after the Stream Protection and Infiltration calculations are provided.

Stream Protection Performance Standard

- The SPV needed for a 50% IC site is SPV = 1.4314*IC – 0.0677 = 1.4314*0.50 – 0.0677 = 0.648 inch, so round to 0.65 inch
- The WQ BMP spreadsheet calculates the runoff volume captured and bypassed, on an average annual basis, by a hypothetical extended detention basin for the 50% IC condition, assuming a

WQV of 0.65-inch, and 48 hour drawdown time. The “flow energy” metric (see Appendix G) is calculated for this hypothetical condition, and also for the developed condition with the BMP system. The Stream Protection performance standard is met if the latter metric value is less than that for the site with the hypothetical SPV BMP.

Infiltration Performance Standard

The equation used to estimate the annual average infiltration is:

$VI_{ex} = A * P * FI_{ex} * 3630$

VI_{ex} = Annual average infiltration volume in ft^3/yr for the existing site condition
A = site area (acres)
P = annual average rainfall = 32.49 inches assumed in WQ BMP spreadsheet model
FI = Fraction of rainfall infiltrated, calculated as a function of IC:
$FI_{ex} = 0.35 - 0.35IC$
3630 = conversion factor

For the undeveloped condition, with 0% IC:

$FI = 0.35 - 0.35*0 = 0.35$

and

$VI = 8 * 32.49 * 0.35 * 3630 = 330{,}228\ ft^3/year$

As the performance standard is to maintain or enhance the existing rate of recharge, the numeric standard for this site is 330,228 ft^3/year.

For the 50% developed condition, the site itself will infiltrate (without BMPs):

$FI = 0.35 - 0.35*0.5 = 0.175$

and

$VI = 8 * 32.49 * 0.175 * 3630 = 165{,}114\ ft^3/year$

The difference between the performance standard and the developed site infiltration is 165,114 ft^3/year (= 330,228 – 165,114), thus the BMP system must infiltrate at least 116,114 ft^3/year.

The runoff volume from the 50% IC site is 9.29 in/yr, or 269,782 ft^3/yr, thus the BMP system will need to infiltrate at least 43% of the runoff.

BMP Selection and Design Approach

In order to meet the infiltration performance standard, a BMP treatment train is proposed:

- 1st BMP designed to comply with the Edwards Aquifer Rules (and an impermeable liner is required, unless a Vegetative Filter Strip, Vegetated Swale, Retention/Irrigation, or Green Roof).
- 2nd BMP designed for infiltration: Because the 1st BMP complies with the Edwards Aquifer Rules, it is presumed subsequent BMPs are not subject to the rules, thus an impermeable liner is not required.

Design 1st BMP to Comply or Exceed Edwards Aquifer Rules

The following provides step-by-step application of the Edwards Aquifer Rules technical manual RG-348 (TCEQ, 2005). The worksheet *EAZ Procedures* embedded in the *WQ BMP Model* spreadsheet can be used to more quickly derive a BMP system that meets the State rules.

Step 1. Required TSS Removal

Use RG-348 equation 3.3:

$L_M = 27.2 * (A_N * P)$

Where L_M = TSS load removal required, in lb/yr
A_N = net change in impervious acres = 8 * 0.5 = 4 acres
P = annual average rainfall; from RG-348 Table 3-3 for Hays County, P = 33 in/yr

LM = 27.2 * (4 * 33) = 3590 lb

Step 2*. Select an appropriate BMP*

A Biofiltration system is proposed, as it can provide a high level of treatment while also being incorporated into landscaping. Under the TCEQ technical manual RG-348 (TCEQ, 2005), Biofiltration Is not specifically identified, but it can be assumed to be equivalent to either the Bioretention or Sand Filter BMPs, which have a TSS % reduction value of 0.89, from Table 3-4.

Step 3*. Calculate (maximum) TSS Load Removed by BMP*

Using RG-348 equation 3.8:

L_R = (BMP Efficiency) * P * (A_I*34.6 + A_P*0.54)

Where L_R is the TSS load removed by the BMP (lb)
P = annual average rainfall, or 33 inches for Hays County
A_I = Impervious area in acres = 8 * 0.5 = 4 acres
A_P = Pervious area in acres = 8 - 4 = 4 acres

L_R = 0.89 * 33 * (4*34.6 + 4*0.54) = 4128 lbs

Step 4*. Calculate Fraction of Annual Runoff to be Treated*

Use RG-348 equation 3.9:

$F = L_M/L_R$

Where F = fraction of the annual rainfall treated by the BMP

F = 3590/4128 = 0.87

***Step 5**. Calculate Capture Volume*

From RG-348 Table 3-5, an F value of 0.87 equates to a rainfall depth of 1.44 inches.

Use RG-348 equation 3.10 to determine the WQV of the BMP:

WQV = Rainfall depth * runoff coefficient * Area

Use RG-348 equation 3.11 to calculate the runoff coefficient

$Rv = 1.72*IC^3 – 1.97*IC^2 + 1.23*IC + 0.02$
$= 1.72*0.5^3 – 1.97*0.5^2 + 1.23*0.5 + 0.02 = 0.36$

WQV = 1.44 * 0.36 * 8 acres * 3630 = 15,054 ft^3 = 0.52-inch

RG-348 applies a 20% sediment accumulation factor, thus the final WQV would be:

WQV_{tceq} = 15054 * 1.2 = 18,065 ft^3 = 0.62-inch

For the WQPP, always select a higher WQV then the minimum needed to comply with the TCEQ requirements, thus start with a WQV = 0.53-inch, and recall that a 20% sediment accumulation factor will be applied.

Size BMP Treatment Train

To size the BMP treatment train system, the WQ BMP spreadsheet model is run (as an option, a sizing table can be provided that does not require running the model). The 1st BMP is a Biofiltration system, with an impermeable liner. In order to meet the infiltration performance standard, the 2nd BMP is proposed to be an Infiltration Basin. Treated effluent from BMP 1 will be routed to BMP 2; bypass flows from BMP 1 will *not* be routed to BMP 2 (the User can change this at their discretion). For this example, there is no intervening drainage area between the two BMPs. Both BMPs will be sized for a 48 hour drawdown time.

There is no unique solution, but as a general rule, Infiltration Basins can require large areas when soils are slow draining, so attempt to minimize the area of BMP 2. As a general approach, set the initial WQV of BMP 1 to a value greater than the TCEQ-required volume, or the SPV, whichever is greater, and then input small WQV volumes for BMP 2. Incrementally increase one or both BMP WQVs until a solution is reached, i.e. all three performance standards are met. For this site the initial TCEQ-derived WQV for BMP 1 is 0.52-inch, but the SPV for a 50% IC site is 0.65, so input the latter to start. For this site the following design worked:

- Biofiltration system with WQV = 0.73-inch
- Infiltration Basin system with WQV = 0.30-inch

20% must be added to the Biofiltration WQV, or 0.73 * 1.2 = 0.88-inch, or 25,439 ft^3

Assuming a ponding depth of 2 feet in the Biofiltration system (in order to minimize excavation into the shallow soils), the minimum biofitration media surface area is (using City of Austin "Partial Sedimentation-Filtration" equation):

$$A_{biof} = WQV/(4 + 1.33H) = 25{,}439/(4 + 1.33*2) = 3{,}820 \text{ ft}^2$$

The footprint area of the entire biofiltration system, including the pretreatment "sediment chamber", assuming 3:1 side slopes and 2:1 length:width ratio, is approximately 14,000 ft^2, or about 0.32 acre. (Note: the worksheet *BMP Design Tools* can be used to estimate BMP footprint area.)

The volume of the Infiltration Basin is 0.30-inch or 8,712 ft^3. Because it is the 2nd BMP in a series, and has negligible intervening drainage area, no sediment accumulation factor is applied.

The area required to infiltrate 8,712 ft^3 in 48 hours, given a soil hydraulic conductivity of 0.10 in/hr (0083 ft/hr), is:

$$A_{inf} = WQV/(k * T) = 8712/(0.0083 * 48) = 21{,}780 \text{ ft}^2\text{, or about 0.50 acre; round to } 22{,}000 \text{ ft}^2$$

The ponding depth for the infiltration system (assumes vertical sides) is:

$$H_{inf} = WQV/A_{inf} = 8712/21780 = 0.40 \text{ ft} = 4.8 \text{ inches}$$

The following table summarizes the design.

	Water Quality Volume		Footprint Area
BMP	Inch	Ft^3	Ft^2
Biofiltration	0.88	25,439	14,000
Infiltration Basin	0.30	8,712	22,000
Total	1.18	34,151	36,000

The total footprint area is about 0.83-acre, or about 10% of the 8 acre drainage area.

Comparison with Current City of San Marcos Requirements

The City has established a treatment standard in the recharge zone of (LDC 5.2.4.1(b)):

> *The permanent BMPs must limit the increase in the total suspended solids load in drainage from the site that results from the development to no more than 20 percent above that which would occur from natural drainage from the site.*

The following provides step-by-step application of the Edwards Aquifer Rules technical manual RG-348 (TCEQ, 2005) and the City of San Marcos Stormwater Technical Manual, but the worksheet *EAZ Procedures*, embedded in the *WQ BMP Model* spreadsheet, can be used to more quickly derive a BMP system that meets the City's requirements.

Step 1. Required TSS Removal

Instead of RG-348 equation 3.3, the following equation is used to calculate the required TSS removal (from San Marcos Stormwater Technical Manual, 2014):

Equation 3.3r $L_M = 33 \times [(A_N \times 34.6) + (A_{P\_DEV} \times 0.54) – (A_{P\_EX} \times 0.65)]$.

Where L_M = Required TSS removal (pounds)
A_N = net increase in impervious area (acres) = 4 acres
A_{P_DEV} = pervious area for the developed condition = 4 acres
A_{P_EX} = pervious area for the existing condition = 8 acres

$L_M = 33 * [(4*34.6) + 4*0.54) – (8*0.65)] = 4467$ lbs

Recall from above that the TCEQ equation gives an L_M value is 3590 lbs.

Step 2*. Select an appropriate BMP*

Table 5-3 of the San Marcos stormwater manual provides TSS reduction values for BMPs, as shown below, ranging from 70-100%. Before selecting, it will be useful to determine the required load removal efficiency of the system:

$RE = L_M/L_{dev}$

The developed load Ldev is calculated using the TCEQ equation:

$L_{dev} = P * (34.6*A_N + 0.54*A_P) = 33 * (34.6*4 + 0.54*4) = 4638$ lbs

Thus RE = 4467/4638 = 0.96

San Marcos Stormwater Technical Manual Table 5.3: TSS Reduction of Selected BMPs (Modified from TCEQ Table 3-4 to add the Rain Garden BMP)

BMP	TSS Reduction %
Retention/Irrigation	100
Extended Detention Basin (aka Sedimentation)	75
Grassy Swale	70
Vegetated Filter Strip	85
Sand Filter	89
AquaLogicTM Cartridge Filter System	95
Wet Basin	93
Constructed Wetland	93
Bioretention (aka Biofiltration)*	89
Rain Garden*	89
Permeable Concrete with under-drain	93
Permeable Concrete without under-drain	100
Wet Vault Sizing Dependent	Sizing Dependent

*For design guidance and criteria, the San Marcos LID Manual should be used instead of the TCEQ RG-348 bioretention criteria, especially for the filtration media specifications

As can be seen only two BMPs can provide at least 96% TSS reduction, and one of those, the Permeable Concrete without under-drain, is not allowed in the recharge zone (an impermeable liner is required). Thus, the only standalone BMP that could be used is Retention/Irrigation. Another option is a treatment train, using the TCEQ RG-348 equation 3.6:

$$E_{tot} = [1 – ((1-E_1) * (1 – 0.5E_2) * (1-0.25E_3))] * 100$$

Where E_{Tot} = Total TSS removal efficiency of BMPs in series (%)
E_1 = Removal efficiency of first BMP (decimal fraction)
E_2 = Removal efficiency of second BMP (decimal fraction)
E_3 = Removal efficiency of third BMP (decimal fraction)

When applying this equation, the highest TSS reduction BMP should be the first, which limits options to the cartridge system, wet basin, or constructed wetland. The cartridge system requires high maintenance, and is prone to clogging (a distinct advantage of vegetated BMPs is their ability to continue functioning even with sediment loads), thus it is not considered a viable option. The wet basin and constructed wetland BMPs are not considered to be good options in the semi-arid Central Texas area, due to the need for makeup water (in direct conflict with the “reduce water use” goal), tendency to leak, and more difficult construction and maintenance requirements. This leaves a filtration system (Sand Filtration, Biofiltration, or Rain Garden) with 89% TSS reduction. No combination of the remaining BMPs can achieve the 96% reduction required, thus a Retention/Irrigation system is selected, with a 100% TSS reduction.

Step 3*. Calculate (maximum) TSS Load Removed by BMP*

Using RG-348 equation 3.8:

$$L_R = (\text{BMP Efficiency}) * P * (A_I*34.6 + A_P*0.54)$$

$$L_R = 1 * 33 * (4*34.6 + 4*0.54) = 4638 \text{ lbs}$$

Step 4*. Calculate Fraction of Annual Runoff to be Treated*

Use RG-348 equation 3.9:

$$F = L_M/L_R$$

Where F = fraction of the annual rainfall treated by the BMP

$$F = 4467/4638 = 0.96$$

Step 5*. Calculate Capture Volume*

From RG-348 Table 3-5, an F value of 0.96 equates to a rainfall depth of 2.80 inches.

Use RG-348 equation 3.10 to determine the WQV of the BMP:

$$WQV = \text{Rainfall depth} * \text{runoff coefficient} * \text{Area}$$

Use RG-348 equation 3.11 to calculate the runoff coefficient

$$Rv = 1.72*IC^3 – 1.97*IC^2 + 1.23*IC + 0.02$$
$$= 1.72*0.5^3 – 1.97*0.5^2 + 1.23*0.5 + 0.02 = 0.36$$

$$WQV = 2.80 * 0.36 * 8 \text{ acres} * 3630 = 29{,}272 \text{ ft}^3 = 1.01\text{-inch}$$

RG-348 applies a 20% sediment accumulation factor, thus the final WQV would be:

$$WQV_{tceq} = 29{,}272 * 1.2 = 35{,}126 \text{ ft}^3 = 1.21\text{-inch}$$

Step 6. *Calculate Retention and Irrigation Areas*

As water will be pumped out of the retention basin (i.e., does not rely on gravity flow), it can have a deeper ponding than other BMPs; 6 feet is assumed, with bottom excavated 2 feet and top of water column 4 feet above the surface, 3:1 side slopes, L:W ratio of 1, and a 4 foot wide berm. To hold a volume of 35,126 ft^3 will require a footprint of about 12,000 ft^2. (Note: the worksheet *BMP Design Tools* can be used to estimate BMP footprint area.)

Size the irrigation area using the TCEQ equation, with r = 0.1 in/hr, volume V = 29,272 (TCEQ does not apply the 20% sediment accumulation factor for the irrigation area sizing), and active irrigation time T = 30 hours:

$$A_{irr} = (12 * V)/(r * T) = (12 * 29272)/(0.1 * 30) = 117{,}088 \text{ ft}^2$$

Comparison of WQPP and City of San Marcos Systems

The following table compares the WQPP design to the City of San Marcos design.

Procedure	BMP System	WQV (ft^3)	Footprint Area (ft^2)
WQPP	Biofiltration/Infiltration Basin	34,151	36,000
City of San Marcos	Retention/Irrigation	35,126	129,088

Findings:

- The WQPP system provides a high level of protection, in terms of pollutant loads, stream protection, and infiltration, but is smaller than the City of San Marcos system, primarily because the shallow infiltration basin is much smaller than the City's irrigation area.

Example 3 Site in Water Quality Zone A (Edwards Aquifer Recharge Zone) with Treatment Train BMP Systems

This example will apply the WQPP and City of San Marcos procedures to a lower impervious cover site, so that a Retention/Irrigation system is not required for the latter.

Assume a site of 1.5 acres at 20% impervious cover (maximum allowed under WQPP), with developed portion of site equal to 1 acre at 30% impervious cover. Only the 1 acre portion requires BMP treatment. The dimensions of the developed portion are approximately 295' x 148' feet, sloped so that drainage is into the shorter dimension (i.e., flow is perpendicular to the 148' dimension). Design a treatment train system where the first BMP is a biofiltration system, and the second is a natural vegetative filter strip. The soil hydraulic conductivity is 0.1 in/hr. Evaluate two scenarios:

1. WQPP procedure
2. City of San Marcos procedure

Abbreviated steps will be shown. Note: the vegetative filter strip is sized per the TCEQ procedure, but the procedure may not correctly account for the VFS being the 2nd BMP in a series, in particular, the flow rate applied to the VFS is controlled by the 1st BMP, and the length of the VFS is actually controlled by the length of the flow spreader that the 1st BMP discharges to, which may be very different than the length of the contributing drainage area.

(Note: the worksheet *BMP Design Tools* can be used to estimate the BMP footprint areas shown below.)

1. WQPP Procedure

- Existing TP load = 0.035 lbs
- Developed TP load = 0.384 lbs
- Target load to discharge = Existing Load = 0.035 lbs
- TP load removal required = 0.384 – 0.035 = 0.349 lbs or 91%
- Biofiltration TP effluent concentration = 0.05 mg/L
- Infiltration TP effluent concentration = 0 mg/L
- SPV volume required = 0.36-inch = 1307 ft^3
- Existing annual average infiltration rate = 58,969 ft^3

Solution:

- Biofiltration BMP with WQV = 0.37-inch = 1343 ft^3
- With 20% sediment accumulation factor WQV = 0.444-inch = 1612 ft^3
- Minimum filtration area required, assuming 2 feet ponding depth = 242 ft^2
- Total pond footprint area, assuming 3:1 side slopes, 2:1 L:W ratio, is about 1300 ft^2
- VFS dimensions 148' x 50', or 7,400 ft^2
- The total footprint area of the treatment train system is about 8,700 ft^2

2. City of San Marcos

- The *EAZ Procedures* worksheet can be used for these calculations.
- L_M = 334 lbs TSS
- BMP treatment train of Bioretention/Biofiltration (TSS Reduction 0.89) discharging to a Vegetative Filter Strip (TSS Reduction 0.85) has a total TSS Reduction of 0.94.
- L_R = 334 lbs TSS
- F = 1.00
- P = 4.00
- Rv = 0.26

- WQV for the Bioretention/Biofiltration BMP is 4.00 * 0.26 = 1.04 inches = 3775 ft^3
- With 20% sediment accumulation factor applied, the WQV = 1.25 inches = 4530 ft^3
- The minimum surface area of the biofiltration media is 378 ft^2 (TCEQ procedure)
- Assuming a 2 feet ponding depth, 3:1 side slopes, and L:W ratio of 2, the total pond area required to hold 4530 ft^3 is about 3000 ft^2.
- The minimum dimensions of the VFS are 148' x 50' per the TCEQ technical manual, or 7400 ft^2
- The total footprint area for the treatment train system is about 10,400 ft^2

Comparison of WQPP and City of San Marcos Treatment Train Systems

Procedure	BMP System	WQV (ft^3)	Footprint Area (ft^2)
WQPP	Biofiltration/VFS	1,612	8,700
City of San Marcos	Biofiltration/VFS	4,530	10,400

Example 4. New Development Site in Water Quality Zone T/R and Inside San Marcos River Corridor – High Impervious Cover – TP and TSS

A 0.5 acre drainage area which currently has no development in it, will be developed at 60% impervious cover. Design a BMP system for each of the following scenarios:

1. WQPP procedure
3. City of San Marcos Land Development Code - Sedimentation-Filtration = Biofiltration
4. City of San Marcos Land Development Code - Sedimentation-Filtration = Sand Filtration

To make an apples-to-apples comparison, the WQ BMP spreadsheet model will be run for each scenario, and the load discharged expressed in terms of equivalent impervious cover.

WQPP Procedure

Total Phosphorus TP:

A Biofiltration BMP is assumed, with an underdrain system.

- Existing TP Load = 0.017 lb
- Developed TP Load = 0.496 lb
- Target TP Load to discharge = 0.017 + (0.5*0.099) = 0.067 lb
- TP Load removal required = 0.496 – 0.067 = 0.430, or 87%
- Stream Protection Volume required = 0.80-inch
- Biofiltration TP effluent concentration = 0.05 mg/L

Solution:

- WQV = 1.18 inches = 1652 ft^3
- With 20% sediment accumulation factor WQV = 1.42 inch = 2570 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for this BMP is about 1800 ft^2
- TP Load removed by BMP treatment = 0.429 lb
- TP Load discharged after BMP treatment = 0.067 lb

- TP Load discharged in terms of Equivalent Impervious Cover = 10% IC

Total Suspended Solids TSS:

A Biofiltration BMP is assumed, with an underdrain system.

- Existing TSS Load = 7 lb
- Developed TSS Load = 219 lb
- Target TSS Load to discharge = 7 + (0.5*86.2) = 50 lb
- TSS Load removal required = 219 – 50 = 169, or 77%
- Stream Protection Volume required = 0.80-inch
- Biofiltration TSS effluent concentration = 9 mg/L

Solution:

- WQV = 0.80 inches = 1452 ft^3
- With 20% sediment accumulation factor WQV = 0.96 inch = 1742 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for this BMP is about 1200 ft^2
- TSS Load removed by BMP treatment = 197 lb
- TSS Load discharged after BMP treatment = 22 lb
- TSS Load discharged in terms of Equivalent Impervious Cover = 2% IC

<u>City of San Marcos Land Development Code - Biofiltration</u>

The LDC requires a Sedimentation-Filtration BMP or equivalent, with ½" WQV for the entire contributing area, with a 48 hour drawdown time (though code states 24 hours, all sizing equations in TCEQ and City of Austin manuals are based on 40-48 hour drawdown times). A Biofiltration system is assumed.

- WQV = 0.5-inch = 908 ft^3
- There are no requirements for adding 20% for sediment accumulation, thus the assumed WQV for modeling purposes will be reduced to 0.5/1.2 = 0.42-inch = 756 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for the 908 ft^3 WQV BMP is about 750 ft^2
- Assumed Biofiltration effluent concentration = 0.05 mg/L for TP and 9 mg/L for TSS
- Existing and Developed TP and TSS loads are same as for WQPP above
- Load removed by BMP system = 0.347 lb TP and 167 lb TSS
- Loads Discharged after BMP treatment = 0.149 lb TP and 52 lb for TSS
- Load Discharged in terms of Equivalent Impervious Cover = 24% IC for TP and 11% for TSS

<u>City of San Marcos Land Development Code - Sand Filtration</u>

The LDC requires a Sedimentation-Filtration BMP or equivalent, with ½" WQV for the entire contributing area, with a 48 hour drawdown time (though code states 24 hours, all sizing equations in TCEQ and City of Austin manuals are based on 40-48 hour drawdown times). A Sand Filtration system is assumed.

- WQV = 0.5-inch = 908 ft^3

- There are no requirements for adding 20% for sediment accumulation, thus the assumed WQV for modeling purposes will be reduced to 0.5/1.2 = 0.42-inch = 756 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for this BMP is about 750 ft^2
- Assumed Sand Filtration effluent concentration = 0.10 mg/L for TP and 17 mg/L for TSS
- Existing and Developed TP and TSS loads are same as above
- Load removed by BMP system = 0.295 lb TP and 158 lb TSS
- Loads Discharged after BMP treatment = 0.201 lb TP and 61 lb for TSS
- Load Discharged in terms of Equivalent Impervious Cover = 31% IC for TP and 13% for TSS

<u>Comparison of WQPP and City of San Marcos Systems</u>

Procedure	BMP System	WQV (ft^3)	Footprint Area (ft^2)	Load Discharged in terms of Equiv. IC
WQPP – TP	Biofiltration	2570	1800	10% IC
WQPP - TSS	Biofiltration	1742	1200	2% IC
City of San Marcos LDC - TP	Biofiltration	908	750	24% IC
City of San Marcos LDC - TSS	Biofiltration	908	750	11% IC
City of San Marcos LDC - TP	Sand Filtration	908	750	31% IC
City of San Marcos LDC - TSS	Sand Filtration	908	750	13% IC

Findings:

- The WQPP system was the only one to provide sufficient Stream Protection.
- The WQPP system provides a higher level of pollution removal, especially in terms of equivalent impervious cover for the load discharged. None of the City of San Marcos BMPs could reduce loads sufficient to meet the “10% impervious cover equivalent” performance standard.
- The San Marcos Biofiltration BMP performed better than the Sand Filtration BMP, with loads discharged 15-26% lower.

Example 5. New Development Site in Water Quality Zone T/R and Inside San Marcos River Corridor – Low Impervious Cover – TP and TSS

A 1 acre drainage area which currently has no development in it, will be developed at 25% impervious cover. Design a BMP system for each of the following scenarios:

1. WQPP procedure
3. City of San Marcos Land Development Code - Sedimentation-Filtration = Biofiltration
4. City of San Marcos Land Development Code - Sedimentation-Filtration = Sand Filtration

To make an apples-to-apples comparison, the WQ BMP spreadsheet model will be run for each scenario, and the load discharged expressed in terms of equivalent impervious cover.

<u>WQPP Procedure</u>

Total Phosphorus TP:

A Biofiltration BMP is assumed, with an underdrain system.

- Existing TP Load = 0.035 lb
- Developed TP Load = 0.314 lb
- Target TP Load to discharge = 0.134 lb
- TP target load to remove = 0.180 lb
- Stream Protection Volume required = 0.30-inch
- Assumed Biofiltration TP effluent concentration = 0.05 mg/L

Solution:

- WQV = 0.30-inch = 1089 ft^3
- With 20% sediment accumulation factor WQV = 0.36-inch = 1307 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for this BMP is about 950 ft^2
- TP Load discharged after BMP treatment = 0.083 lb
- TP load removed after BMP treatment = 0.231 lb
- TP Load discharged in terms of Equivalent Impervious Cover = 5% IC

Total Suspended Solids TSS:

The exact same BMP is used to meet the TSS Stream Protection and Pollutant Load Removal performance standards.

- Existing TSS Load = 14 lb
- Developed TSS Load = 195 lb
- Target TSS Load to discharge = 101 lb
- TSS target load to remove = 94 lb
- TSS load removed by BMP system = 166 lb
- TSS Load discharged after BMP treatment = 29 lb
- TSS Load discharged in terms of Equivalent Impervious Cover = <1% IC

City of San Marcos Land Development Code - Biofiltration

The STRM requires a Sedimentation-Filtration BMP or equivalent, with ½" WQV for the entire contributing area, with a 24 hour drawdown time. A Biofiltration system is assumed.

- WQV = 0.5-inch = 1815 ft^3
- There are no requirements for adding 20% for sediment accumulation, thus the assumed WQV for modeling purposes will be reduced to 0.5/1.2 = 0.42-inch = 1513 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for the 1815 ft^3 is about 1200 ft^2
- Assumed Biofiltration effluent concentration = 0.05 mg/L for TP and 9 mg/L for TSS
- Existing and Developed TP and TSS loads are same as for WQPP above
- Target TP and TSS Loads to discharge = undefined

- Load removed by BMP system = 0.246 lb TP and 177 lb TSS
- Loads Discharged after BMP treatment = 0.068 lb TP and 18 lb for TSS
- Load Discharged in terms of Equivalent Impervious Cover = 4% IC for TP and <1% for TSS

City of San Marcos Land Development Code - Sand Filtration

The STRM requires a Sedimentation-Filtration BMP or equivalent, with ½" WQV for the entire contributing area, with a 24 hour drawdown time. A Sand Filtration system is assumed.

- WQV = 0.5-inch = 1815 ft^3
- There are no requirements for adding 20% for sediment accumulation, thus the assumed WQV for modeling purposes will be reduced to 0.5/1.2 = 0.42-inch = 1513 ft^3
- Assuming a 3 feet ponding depth, 3:1 side slopes, and 2:1 L:W ratio, the footprint area for the 1815 ft^3 is about 1200 ft^2
- Assumed Sand Filtration effluent concentration = 0.10 mg/L for TP and 17 mg/L for TSS
- Existing and Developed TP and TSS loads are same as for WQPP above
- Target TP and TSS Loads to discharge = undefined
- Load removed by BMP system = 0.191 lb TP and 168 lb TSS
- Loads Discharged after BMP treatment = 0.123 lb TP and 27 lb for TSS
- Load Discharged in terms of Equivalent Impervious Cover = 9% IC for TP and <1% for TSS

Comparison of WQPP and City of San Marcos Systems

Procedure	BMP System	WQV (ft^3)	Footprint Area (ft^2)	Load in terms of Equiv. IC
WQPP – TP	Biofiltration	1307	950	5%
WQPP – TSS	Biofiltration	1307	950	<1%
City of San Marcos LDC - TP	Biofiltration	1815	1200	4%
City of San Marcos LDC - TSS	Biofiltration	1815	1200	<1%
City of San Marcos LDC - TP	Sand Filtration	1815	1200	9%
City of San Marcos LDC - TSS	Sand Filtration	1815	1200	<1%

Findings:

- The WQPP system provides excellent pollutant reduction and stream protection, but is smaller than the BMP system required under the current City of Sand Marcos Stormwater Technical Manual.
- The San Marcos Biofiltration BMP performed better than the Sand Filtration BMP, with loads discharged 33-45% lower.

APPENDIX M TURFGRASS MANAGEMENT SYSTEMS (TMS) GUIDELINES

Guidelines for Turfgrass Management Systems

Development of a Turfgrass Management System Plan (TMS Plan) is recommended for all sport and athletic facilities that use irrigation, fertilizer, and pesticides. The TMS plan should be specific to the facility, reflecting its unique site characteristics. Some basic elements of a TMS plan are described below. Certain information applies more specifically to golf courses than athletic fields.

TMS Plan Goals

Some goals of a TMS Plan:

- Protect local and regional surface water and groundwater resources, and sensitive environmental features (SEFs) from detrimental effects of fertilizers and pesticides used on the turf
- Maintain desirable turfgrass quality

TMS Plan Elements

The critical elements of a TMS plan include:

- Developing a system using multiple control methods
- Setting turfgrass quality standards
- Making management decisions based on intensive use of information
- Reducing risk by constant reevaluation of the results of management selections
- Using cost effective and site specific management strategies
- Assessing the effects of management alternatives on water budgets, nutrient budgets, and pesticide fate and transport before and after implementing practices

Site Conditions

Site specific information regarding soils, geology, hydrology and vegetation is required for development of management and monitoring plans. State and county scale resource mapping is intended only for use in first level planning, not for site specific plans. For example, in-situ testing to verify soil and engineering properties given in the County Soil Survey is necessary, since the Soil Survey data tables are based on either (1) laboratory procedures, or (2) a specific area which cannot represent all the variants of a given soil series. Determine the location and characteristics of the following:

- Surface water upstream and downstream of the golf course, and on adjacent creeks, tributaries, and water features draining golf course property
- Springs and seeps in areas draining golf course property
- Shallow groundwater in wells, piezometer, or lysimeters at representative depths and locations
- Tile drains from greens, tees, and fairways
- Soils to the first impermeable layer or to 36-inches, which ever encountered first
- Effluent (if used) in irrigation pond to estimate nitrogen and phosphorus loads contributed by effluent
- Nutrients, conventional pollutants and pesticides used at the golf course

Water Quality Management Zones

Two types of management zones are used. Their purpose and recommendations for each are noted.

1. **Turfgrass Management Zones (TMZs)**

TMZs are management units designed to stratify potential water quality effects based on site conditions. TMZs integrate irrigation strategies with nutrient, pesticide, and sediment management plans in order to address site limitations and reduce the risk of environmental contamination. TMZs are differentiated by the following site conditions (risk factors):

- climate
- soils
- geology
- landscape position/hydrology
- subsurface/surface drainage
- proximity to surface water, ground-water, and SEFs

2. **Vegetated Buffer Zones (VBZs)**

VBZs are naturally vegetated buffers between waterways, SEFs, and any irrigated areas. They are typically a 50-foot minimum width, which may be increased based upon site conditions and SEF characteristics, but not decreased. VBZs are to remain in, or be restored to, native conditions. The use of irrigation, fertilizer, and pesticides is prohibited in these zones. VBZs function by attenuating sediment and mobile forms of nutrients and pesticides before transport to:

- waterways, via surface water runoff
- shallow groundwater, springs or waterways, via lateral subsurface soil-water flows in the vadose zone

Management Plans for each TMZ

Information for each major element of a TMZ is essential for a TMS Plan.

1. **Irrigation Management Plan**

The Irrigation Management Plan is to be integrated with nutrient, pest and cultural management strategies. To prepare the plan one must evaluate the site and establish a water budget.

- Site evaluation determines areas with similar site conditions affecting transport processes; water is primary mechanism for transport of contaminants
- Water budget balances all water inputs (including effluent, raw water, and rainfall) with the needs of the turf.

Irrigation Management Plan strategies address site limitations and mitigate transport of contaminants from the course.

- climate - application rates not to exceed turfgrass ET rates in both growing and dormant season
- soils - application rates not to exceed site specific soil permeability and infiltration rates
- soil moisture - soil moisture sensors in and below root zone indicate onset of soil saturation and provide signal for irrigation to cease.
- storage capacity (if effluent irrigation used) - volume indicated by the water budget; storage occurs primarily during wet weather or saturated soil conditions.

If effluent is used for irrigation, one must incorporate the site-specific TMS Plan elements for land application of effluent into the permits and authorizations required by the Texas Commission on Environmental Quality (TCEQ). These include:

- TCEQ-Texas Land Application Permit (TCEQ-TLAP)
- TCEQ Underground Injection Control (TCEQ-UIC) program registration and authorization for the effluent irrigated area.

2. Nutrient Management Plan

The Nutrient Management Plan is to be integrated with irrigation, pest and cultural management strategies for each TMZ. To complete the plan one must prepare a nutrient budget that matches nutrient input to the needs of the turf.

- Nutrient budget incorporates nutrient constituents in effluent (if used), fertilizers, raw water, and rainfall
- Vegetative tissue sampling results
- Soil analysis showing nutrients, organic matter and related characteristics
- Fertilizer (and effluent nutrient) additions must not exceed turfgrass uptake requirements during any season; slow release fertilizers, timing of applications, and multiple low rate applications address plant needs and reduce nutrient losses from the site.

3. Integrated Pest Management (IPM) Plan

The IPM Plan is to be integrated with irrigation, nutrient, and cultural management strategies. Determine action thresholds, list products used, application rates, and other pertinent information.

- Action thresholds indicate application rates, if any, and reduce pesticides use
- Pest specific products reduce hazards to beneficial organisms
- Minimized applications and/or alternate controls reduce hazards to beneficial organisms

APPENDIX N RETROFITS SITE VISITS: PHOTOS AND INFORMATION

This Appendix is reserved for retrofit site photos and information. Since this information is so data intensive the authors felt that it would best be provided as a separate file.

End