Final Technical Report

Habitat Restoration Workgroup

Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado

Strategies to Enhance Both Water Quality and Habitat

Deliverable 5 (Task 6)

January 18, 2006

A report of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058.
This paper is funded in part by a grant/cooperative agreement from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors' and do not necessarily reflect the views of NOAA or any of its sub-agencies.

Crespo Consulting Services, Inc.
Civil & Environmental Engineering

ALAN PLUMMER ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERS • DESIGNERS • SCIENTISTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE **DESCRIPTION**

ABBREVIATIONS

ACWP	**Arroyo Colorado Watershed Partnership**
APAI	**Alan Plummer Associates, Inc.**
BOD	**Biochemical Oxygen Demand**
DO	**Dissolved Oxygen**
ESA	**Endangered Species Act**
FWS	**Free Water Surface**
GIS	**Geographic Information Systems**
HSPF	**Hydrologic Simulation Program-Fortran**
IBWC	**International Boundary and Water Commission**
LUNKERS	**Little Underwater Neighborhood Keepers Encompassing Rheotactic Salmonids**
NEPA	**National Environmental Policy Act**
NHPA	**National Historic Preservation Act**
NOAA	**National Oceanic and Atmospheric Administration**
NOI	**Notice of Intent**
NPDES	**National Pollutant Discharge Elimination System**
TCEQ	**Texas Commission on Environmental Quality**
TCMP	**Texas Coastal Management Program**
TMDL	**Total Maximum Daily Load**
TN	**Total Nitrogen**
TP	**Total Phosphorus**
TPDES	**Texas Pollution Discharge Elimination System**
TPWD	**Texas Parks and Wildlife Department**
TRWD	**Tarrant Regional Water District**
VFS	**Vegetative Filter Strips**
WWTP	**Wastewater Treatment Plant**

EXECUTIVE SUMMARY

ES.1 Introduction

Due to historical modifications to the Arroyo Colorado and nutrient enrichment from both point and non-point source discharges, the dissolved oxygen (DO) concentrations within the Arroyo Colorado are sometimes lower than the criterion established to assure optimum conditions for aquatic life in the tidal segment (2201). The Texas Commission on Environmental Quality (TCEQ) completed the first phase of a Total Maximum Daily Load (TMDL) analysis in 2002, and has since assisted in the development of an Arroyo Watershed Protection Plan through the Arroyo Colorado Watershed Partnership. Six workgroups were formed to address the needs of the Watershed Protection Plan: wastewater infrastructure, agricultural issues, habitat restoration, refinement of TMDL analysis, outreach and education and landuse. Individually, the workgroups will address water quality issues related to its focus, and develop recommendations for improvement. Collectively, the goal of the workgroups is to address all water quality considerations including current loading of pollutants, enhancement of assimilative capacity, increased public awareness of the problems, and further study to improve understanding of the factors that cause low DO conditions in the Arroyo Colorado.

The Habitat Restoration Workgroup, under the leadership of the Texas Parks and Wildlife Department (TPWD), contracted with Alan Plummer Associates, Inc. (APAI) to perform a feasibility study to compile information regarding habitat restoration measures that will reduce non-point source pollution to the Arroyo Colorado and/or mitigate existing physical conditions that contribute to poor water quality conditions in the stream. Based on discussion during the kick-off meeting, criteria were determined for development of a comprehensive list of strategies that would be presented to the Habitat Restoration Workgroup for selection of ten strategies for which information including applications, limitations, cost, and effectiveness would be developed. The comprehensive list would not include strategies related to public outreach; regulatory zoning controls; or housekeeping, but would focus on structural strategies (those that require design and construction); and changes in management strategies (practices requiring designs) for the International Boundary and Water Commission (IBWC) and the Port of

Harlingen. The strategies to be included were those with multiple benefits, which include or affect habitat.

On October 18, 2005, Loretta Mokry and Tim Noack of APAI met with the Habitat Restoration Workgroup and presented a comprehensive list of 51 strategies. These strategies represented three major categories of source water (non-point source, point source, or collective) and one category identified as "management strategies." The four major categories were further divided into 19 sub-categories. After discussion, the Workgroup combined some similar strategies to form a list of 36 from which 10 would be selected for further information development. The ten strategies are as follows:

1. Ponds (micropool extended detention ponds, multiple pond systems, wet extended detention ponds)
2. Stormwater wetland systems using a series of wetland cells within small drainage and wetland swales.
3. Stormwater wetland systems using extended detention shallow wetlands, pocket wetlands and pond/wetland systems.
4. Blank/slope stabilization using bioengineering with vegetation for erosion control
5. Filtration using vegetated filter strips
6. Channels with wet swales or wetlands
7. Constructed wetlands for tertiary treatment following an individual wastewater treatment plant (mechanical or lagoon WWTP)
8. Regional constructed wetlands polishing flows from multiple wastewater treatment plants in close proximity.
9. Large-scale on-channel constructed wetland systems
10. Large-scale off-channel constructed wetland systems.

ES.2 Objectives and Goals

Numerous studies have been conducted for the Arroyo Colorado regarding water quality issues over the past 25 years. Water quality concerns that affect habitat within and along the Arroyo Colorado are presented in Chapter 2 of this report.

Analysis of data assembled for an 11 year period from January 1, 1989 through December 31, 1999 by the TCEQ through their HSPF (Hydrologic Simulations Program – Fortran) model was used to determine constituent loadings based on identified landuse categories within the watershed, permitted wastewater discharges, and other pollutant loading sources. Relative pollutant loadings per land use within the sub-basins as well as pollutant loadings by sub-basins for dry weather flows, storm flows (non-point sources), and wastewater treatment plants are depicted on Geographic Information System (GIS) maps.

ES.3 Variables/Factors Affecting Selection of Alternatives and Design

A comprehensive list of 51 strategies was developed all of which were considered to be feasible for application within the Arroyo Colorado watershed based on climate, identified land uses, and sources of water quality contaminants (non-point versus point source and collective treatment strategies). Further feasibility study and alternatives analysis will be required based on site specific requirements. Some major factors used in the selection of appropriate strategies for various water quality improvement needs for point and non-point sources include:

- Volume of water to be treated
- Flow regime
- Nutrient loading
- Sediment loading
- Location within the watershed
- Jurisdictional restrictions
- Habitat potential
- Water quality improvement potential
- Soils
- Topography

Review of GIS maps developed from the HSPF model data along with evaluation of the factors listed above should be performed for assessment of sites to determine appropriateness of potential application of technical strategies.

Although rules-of-thumb may be used during feasibility studies evaluating alternative strategies, using simplistic single-number approaches for final design may result in less than optimal treatment efficiency in a developed water quality improvement strategy. Kadlec and Knight (53) indicate that final design should consider multiple site-specific factors including:

- A set of pollution reduction targets
- Spatial variability of pollutant removal
- Hydraulic and meteorological constraints
- Internal depth and vegetation density patterns
- Internal water flow and mixing
- Baseline wetland concentration values
- Seasonality
- Interaction with other treatment system components
- Nature of the regulatory requirements
- Acceptable level of risk

ES.4 Technical Treatment Alternatives for Water Quality Improvement

Detailed information in reference to both water quality improvement and habitat potential was developed for the ten strategies selected by the Habitat Restoration Workgroup and is presented in chapter 4 (non-point source strategies), chapter 5 (point-source strategies), and chapter 6 (collective non-point and point source strategies). Tables ES-1, ES-2, and ES-3 present a summary of key information for each of the selected strategies within the three categories.

Table ES-1
Non-Point Source Strategies Site Selection Considerations

Characteristic	Strategy 1 Pond Systems	Strategy 2 Stormwater Wetlands Along & In Linear Drainages	Strategy 3 Stormwater Wetlands At Outfall of Drainage Area	Strategy 4 Bank/Slope Stabilization Using Bioengineering	Strategy 5 Vegetative Filter Strips	Strategy 6 Channels With Wet Swales
Flow Regime	Need base flow or positive water balance to maintain permanent pool	Need base flow, high water table or positive water balance to support aquatic vegetation	Need base flow, high water table or positive water balance to support aquatic vegetation	Intermittent or base flow with velocity less than 10 feet per second	Intermittent sheet flow, velocity less than 10 feet per second	Base flow or intermittent flow with high ground water table for wet swale
Native Soil Requirements	Clay (or clay lined)	Clay (or clay lined)	Clay (or clay lined)	None	Well drained soils	Well drained soils
Drainage Area (ac)	Rural: >25 ac Urban: >5 ac	Rural: >25 ac Urban: >5 ac	Rural: >25 ac Urban: >5 ac (10 ac max for pocket wetland)	N/A	Rural: 150 ft of contributing length of flow Urban: 25 to 50 ft of contributing length of flow	10 acres, but usually limited by footprint available for wet swale
Depth to Groundwater	>2 ft	>0 ft	>0 ft	N/A	>2 ft	>0 ft
Land Area Required	Rural: 1-2% of drainage area Urban: 2-3% of drainage area	Rural: 1-2% of drainage area Urban: 2-5% of drainage area	Rural: 1-3% of drainage area Urban: 2-5% of drainage area	N/A	<5 ac	Rural: 3-7% of drainage area Urban: 10-15% of drainage area
Elevation Drop Required	6 to 8 ft	2 to 5 ft	2 to 5 ft	N/A	2 to 6% slope with flat topography	2 to 6% slope
Habitat Improvement Potential	Moderate to Very Good	Good (with appropriate pre-treatment)	Good (with appropriate pre-treatment)	Low (Good if include riparian zone restoration)	Low	Low to Good
Water Quality Improvement Potential	Very Good	Very Good	Very Good	Good	Good to Very Good	Good to Very Good
Possible Site Locations - Rural	Drainage canals or natural drainages downstream of irrigated farmland or Colonias	Drainage canals or natural drainages downstream of irrigated farmland or Colonias	Outfall of drainage canals or natural drainages downstream of irrigated farmland or Colonias	Along channel of Arroyo Colorado or other natural or manmade drainages that exhibit bank or slope failures	Edge of fields; terrace zone along stream banks; along roadways; perimeter of Colonias prior to discharge into ditch	Natural or manmade drainage ditches downstream of irrigated farmland or roadside ditches near Colonias
Possible Site Locations - Urban	Natural or manmade drainages receiving residential irrigation runoff or runoff from large impervious area	Natural or manmade drainages receiving residential irrigation runoff	Outfall of natural or manmade drainages receiving residential irrigation runoff	Along channel fo Arroyo Colorado or other natural or manmade drainages that exhibit bank or slope failures	Near isolated impervious areas (rooftops, small parking lots)	Natural or manmade stormwater ditches

Table ES-2
Point Source Strategies Site Selection Considerations

Characteristic	Strategy 7	Strategy 8
	Constructed wetlands for polishing/tertiary treatment at individual WWTPs	Constructed wetland for polishing/tertiary treatment at multiple WWTPs in close proximity
Flow Regime	Continuous flow usually provided by gravity feed or pumping from WWTP but can handle variable flows from diurnal/seasonal effects	Continuous flow usually provided by gravity feed or pumping from WWTPs; can handle variable flows; flows from multiple plants can reduce diurnal/seasonal variation
Native Soil Requirements	Clay (or clay lined)	Clay (or clay lined)
"Rule-of-Thumb" Planning Level Sizing for Polishing/Tertiary Treatment*	25 wetted surface acres per MGD	25 wetted surface acres per MGD
Depth to Groundwater	>6 feet	>6 feet
Elevation Drop Required	2 to 5 feet	2 to 5 feet with flat topography
Habitat Improvement Potential	Very Good	Excellent
Water Quality Improvement Potential	Very Good	Very Good
Possible Site Locations	Adjacent to WWTP if land available; can pump to available site away from WWTP if necessary	Adjacent to one of multiple WWTPs providing flow or centrally located between WWTPs
Unit Construction Costs ($/acre)**	0-50 acres: $7,700-$79,221 (11) 51-100 acres: $1,774-$36,000 (4) 101-500 acres: $1,825 - $11,677 (3)	101-500 acres: $1,825 - $11,677 (3) >500 acres: $21,798 (1)

*Actual area requirements should be calculated based on design flows and loads during preliminary design.
** Unit cost ranges for construction based on data from several FWS constructed wetland systems across North America. If a constructed wetland polishing system will be downstream of the permitted discharge point and not considered part of the treatment train by TCEQ, it is possible that a compacted clay liner (as required under Section 317 rules) may not be required. If some seepage is allowable, clay lining sufficient to maintain wetland flows will be much less expensive to construct than the two foot deep, highly compacted clay lining required under the State regulations for a wastewater treatment unit.

Table ES-3
Collective Non-Point and Point Source Strategies Site Selection Considerations

Characteristic	Strategy 9	Strategy 10
	Regional on-channel constructed wetland system	Regional off-channel constructed wetland system
Flow Regime	Continuous flow without pumping but volume control difficult; potential for very high volume/high velocity flows during flood events	Continuous flow provided via pumping; limited potential for gravity feed; more control of flow
Water level control	Must be able to maintain water depths (under normal conditions) that will sustain growth of aquatic emergent vegetation	Must be able to regulate water depths to sustain aquatic emergent vegetation
Limitations	Structures and vegetation within floodway may not adversely impact flood flow conveyance	Structures and vegetation within floodway may not adversely impact flood flow conveyance
Native Soil Requirements	Sufficient to sustain growth of aquatic rooted vegetation	Sufficient to sustain growth of aquatic rooted vegetation
"Rule-of-Thumb" Planning Level Sizing for Polishing/Tertiary Treatment*	25 wetted surface acres per MGD	25 wetted surface acres per MGD
Elevation Drop Required	1 to 2 % slope	2 to 5% slope with flat topography
Habitat Improvement Potential	Excellent	Excellent
Water Quality Improvement Potential	Very Good	Excellent
Possible Site Locations	Llano Grande	Upstream of the zone of impairment; adjacent to the zone of impairment; Within the floodway or outside the floodway
Unit Construction Costs ($/acre)**		$4,031 - $18,744 (5)

*Actual area requirements should be calculated based on design flows and loads during preliminary design.
** Unit cost ranges for construction based on data from five FWS large-scale constructed wetland systems, three in Texas and two in Florida.

Chapter 1
Introduction

1.1 Background

The hydraulic conditions of the Arroyo Colorado have been significantly modified by dredging in the tidal segment (2201), and channelization and floodway construction in the non-tidal segment (2202). In combination, physical modifications such as channel deepening and widening, placement of dredge spoils, and loss of riparian habitat have the effect of exacerbating low dissolved oxygen (DO) concentrations in the tidal portion of the Arroyo Colorado by reducing circulation, lowering reaeration rates and increasing sediment oxygen demand (10). Nutrient enrichment from discharges of municipal and industrial raw wastewater and treated effluent, urban runoff and agricultural stormwater runoff from fields, and irrigation return flow from production of crops contribute to the production of algae and subsequent oxygen demand for this aquatic resource. As a consequence of the altered physical condition of these physical attributes as well as the loss of riparian habitat and anthropogenic contributions, the (DO) concentrations are sometimes lower than the criterion established to assure optimum conditions for aquatic life in the tidal segment. Accordingly, the tidal segment of the Arroyo Colorado is included on the 2002 Texas Clean Water Act Section 303(d) list.

The Texas Commission on Environmental Quality (TCEQ) completed the first phase of an attempt to determine Total Maximum Daily Load (TMDL) in 2002, and has since facilitated in the development of an Arroyo Watershed Protection Plan through the Arroyo Colorado Watershed Partnership (ACWP). The ACWP formed six workgroups to address the needs of the Watershed Protection Plan: wastewater infrastructure, agricultural issues, habitat restoration, refinement of TMDL analysis, outreach and education, and land use. Each workgroup will address water quality issues related to its focus, and develop recommendations for improvement. Collectively, the goal of the workgroups is to address all water quality considerations including current loading of pollutants, enhancement of assimilative capacity, increased public awareness of the problems, and further study to improve understanding of the factors that cause low DO conditions in the Arroyo Colorado.

The Habitat Restoration Workgroup, which is led by the Texas Parks and Wildlife Department (TPWD), is charged with investigating habitat restoration measures that will reduce non-point source pollution to the Arroyo Colorado and/or mitigate existing physical conditions that contribute to poor water quality conditions in the stream. To this end, the TPWD received a grant to perform a feasibility study on the Arroyo Colorado. Funded by NOAA through a Texas Coastal Coordination Council, Coastal Management Program grant administered by the Texas General Land Office, the goal of the feasibility study is to compile the information necessary to assist the Habitat Restoration Workgroup in developing recommendations for the Watershed Protection Plan.

Alan Plummer Associates, Inc. (APAI) was selected as the consulting firm to perform the feasibility study and develop the necessary information. The primary work product to be produced is a technical report (Draft Report, Deliverable No. 4 and Final Report, Deliverable No.5) that will include information on the applications, limitations, cost, and effectiveness of ten selected strategies (i.e., facilities and programs) that can enhance both water quality and habitat. A draft table of contents for the technical report was presented as Deliverable No. 1 at the kick-off meeting for the project. Based on discussion during the kick-off meeting, criteria were determined for development of a comprehensive list of strategies that would be presented to the Habitat Restoration Workgroup for the selection of ten strategies to be included in the technical report. The comprehensive list would not include strategies related to public outreach; regulatory; zoning controls; or housekeeping, but would focus on structural strategies (those that require design and construction); and changes in management strategies (practices requiring designs) for the International Boundary and Water Commission (IBWC) and the Port of Harlingen. The strategies to be included were those with multiple benefits, which include or affect habitat.

A technical memorandum was developed as Deliverable No. 2 to demonstrate APAI's understanding of the purpose of the project. The technical memorandum included a literature review, summary of compiled information and data, and identification of additional needed information. The data summary included a list of pertinent references, summary descriptions, and relevance of the data to the project. Since additional references continued to be discovered during preparation of Deliverable No. 3, the Discussion Document presenting a comprehensive list of strategies and a revised list of pertinent references was delivered to the Habitat Restoration Workgroup along with the Discussion Document. On October 18, 2005, Loretta Mokry and Tim Noack of APAI met with the Habitat Restoration Workgroup and presented a comprehensive list of 51 strategies from which the Workgroup would select 10 to be evaluated further by APAI and included in this technical report. One of the presentation documents for the meeting was a large table with the 51 strategies placed into either of four major categories. These strategies represented three major categories of source water for treatment (non-point source, point source, or collective) and one category identified as "management strategies." The four major categories were further divided into 19 sub-categories. After some discussion, the Workgroup combined some similar strategies to form a list of 36. These 36 strategies were then re-presented to the Workgroup for voting. The final list of the ten strategies selected by the Workgroup is shown in Table 1-1.

Table 1-1
Ten Selected Strategies

Selected Strategy	Votes Received by Workgroup	Major Category
1. Ponds (micropool extended detention ponds, multiple pond systems, wet extended detention ponds)	15	NPS
2. Stormwater wetland systems using a series of wetland cells within small drainage and wetland swales	13	NPS
3. Stormwater wetland systems using extended detention shallow wetlands, pocket wetlands and pond/wetland systems	12	NPS
4. Bank/slope stabilization using bioengineering with vegetation for erosion control	12	NPS
5. Filtration using vegetated filter strips	7	NPS
6. Channels with wet swales or wetlands	6	NPS
7. Constructed wetlands for tertiary treatment following an individual wastewater treatment plant (mechanical or lagoon WWTP)	6	PS
8. Regional constructed wetlands polishing flows from multiple wastewater treatment plants in close proximity	11	PS
9. Large-scale on-channel constructed wetland systems	12	Collective (NPS + PS)
10. Large-scale off-channel constructed wetland systems	11	Collective (NPS + PS)

Detailed information in reference to both water quality improvement and habitat potential has been developed by APAI for the ten selected strategies. Since other strategies from the comprehensive list will be applicable for consideration and further development by the various workgroups, the comprehensive list of strategies developed initially during the feasibility study is included as an appendix to this report.

To assist in the interpretation of terms and phrases used in this document and Glossary of Technical Terminology is provided after Chapter 6.

Chapter 2
Objectives and Goals

The objective of the final phase of the feasibility study was to further investigate ten strategies that the Habitat Restoration Workgroup selected to potentially be included in the Watershed Protection Plan for addressing habitat improvement and water quality in the Arroyo Colorado. Numerous studies have been conducted in the Arroyo Colorado regarding water quality issues over the past 25 years. The following information compiled from those studies was used to identify water quality concerns that affect habitat within and along the Arroyo Colorado and to develop data tables and maps. Tables 1 through 7, included in Appendix A, provide the results of calculations of constituent loadings from the TCEQ (HSPF) Hydrologic Simulations Program-Fortran model based on data collected for an 11 year period from January 1, 1989 through December 31, 1999. Maps developed from the HSPF model data analysis, also included in Appendix A, depict land use within the watershed; permitted wastewater discharges and other pollutant loading sources; relative pollutant loadings per land use within the sub-basins; and pollutant loadings by sub-basins for dry weather flows, storm flows (non-point sources), and wastewater treatment plants.

A TMDL analysis conducted by the TCEQ between 1998 and 2002 concluded that the physical setting in the Arroyo Colorado (in particular segment 2201, the tidally influenced portion of the Arroyo) contributes significantly to the observed DO impairment (51). One conclusion of the TMDL study was that even extreme reductions (up to 90 percent) in the loading of constituents of concern into the Arroyo Colorado will not achieve the TMDL endpoint target, which is defined as a 90 percent rate of compliance with the DO criteria currently applied (24-hr average DO of 4.0 mg/L and a 24-hr minimum DO of 3.0 mg/L) (51).

A second conclusion of the TMDL analysis, based primarily on self-reported data and available monitoring, is that a significant volume of poorly treated and essentially untreated wastewater enters the Arroyo Colorado between the cities of Mission and Rio Hondo along with nutrients, biochemical oxygen demand (BOD), and sediment from agricultural non-point sources. The TMDL analysis concluded that improvements in water quality and a potential reduction in the environmental stresses to aquatic life can be achieved through the reduction of nutrients, BOD and sediment loadings into the Arroyo Colorado (51).

2.1 Water Quality Improvement

2.1.1 Dissolved Oxygen

Elevated nutrient levels in the tidal region of the Arroyo Colorado (2201) contribute to periodic low DO levels. The depressed DO contributes to the poor benthic community structure and the history of fish kills in the river. Sources of nutrient loadings from the watershed include agricultural runoff and irrigation return flows, point source municipal and industrial discharges, urban runoff, and discharges from large aquaculture operations. The zone of impairment is located in the upper portion of the tidal segment (2201), a reach of the Arroyo Colorado known as the Gulf Intracoastal Waterway – Tributary Channel to Harlingen, Texas, which provides shipping access to the Port of Harlingen, where DO levels are frequently below 2.0 mg/L. Wide diurnal fluctuations in DO (from 0 mg/L to super-saturated DO concentrations) observed in the tidal segment (2201) indicate substantial impact on the DO regime due to the primary production of aquatic algae within the Arroyo Colorado channel. Extreme DO diurnal fluctuations are characteristic of an algal dominated water body due to the production of oxygen resulting from photosynthesis during the day and the consumption of oxygen by the algal biomass during the night. Low DO has been indicated as the primary cause for 19 documented fish kills from 1990 through 2004 resulting in the loss of approximately 26 million fish (10).

2.1.2 Total Suspended Solids

Sediment loads to the Arroyo Colorado are dominated by non-point source loadings from agricultural and urban land as a result of storm runoff; although significant sediment loading is contributed by municipal and industrial point-source discharges as well, maintaining suspended sediment loads to the Arroyo Colorado during dry weather flows. Sediment loading also results from in-channel erosion where steep banks of the modified channel have insufficient vegetative cover to promote slope stability.

In addition to suspended sediments, algal production within the Arroyo Colorado contributes to the suspended solids. Excessive algal growth is prevalent within the Arroyo Colorado as a result of the high nutrient levels. This primary production also contributes to the downstream organic and nutrient loadings as the algal biomass is cycled within the aquatic system.

2.1.3 Total Nitrogen

Based on the loadings calculated from the HSPF modeling conducted by the TCEQ, the average total nitrogen concentration at the downstream end of segment 2202 (just above the zone of impairment) is 5.4 mg/L for all flow data and 4.9 mg/L for dry weather flows during the critical period of May through October. This corresponds to a total nitrogen load of 9,694 lbs/day for all flow data and 6,312 lbs/day for dry weather flows during the critical period. Table A-1, included in Appendix A, presents the average loadings for all constituents based on the TCEQ HSPF modeling for the downstream end of segment 2202.

Although significant nitrogen loads are contributed by the municipal and industrial point-source discharges, the total nitrogen load to the Arroyo Colorado is dominated by non-point source loadings from urban and agricultural runoff and from irrigation return flows. Other significant sources include land application of permitted discharges, non-point source wastewater from colonias, and wastewater from septic systems. Table A-1a, included in Appendix A, presents the total nitrogen loadings by land use category per acre per year.

2.1.4 Total Phosphorus

Reported total phosphorus levels are highest in the non-tidal segment (2202), but average total phosphorus is a concern in all but the lowermost 11 miles of segment 2202. Based on the loadings calculated from the HSPF modeling conducted by the TCEQ for 11 years of data from 1989-1999, total phosphorus concentrations are 0.7 mg/L for all flow data and 0.8 mg/L for dry weather flows during May through October. This corresponds to loads of 1,259 lbs/day for all flow data and 992 lbs/day for dry weather flows during May through October (refer to Table A-1 in Appendix A). Significant contributions of total phosphorus loads are from both point-source discharges and non-point sources including urban areas (single family residential/recreational, non-residential urban, and low-density urban), land application of permitted discharges, non-point source wastewater from colonias, wastewater from septic systems, and agricultural cropland including row crop irrigated, citrus, citrus tile-drained, sugar cane, and sugar cane tile-drained. Total calculated load for total phosphorus at the downstream end of the non-tidal segment based on the HSPF model data for 1989-1999 was approximately 249,500 lbs/year.

2.1.5 Biochemical Oxygen Demand

Average concentration of BOD at the downstream end of the non-tidal segment (2202) for all flow data from the TCEQ HSPF model for 1989 through 1999 was 4.0 mg/L with dry weather flows from May through October averaging 2.6 mg/L. Municipal wastewater facilities accounted for 23 percent of the BOD entering the Arroyo Colorado. Significant loads of BOD are contributed by non-point sources including urban runoff, land application of permitted discharges, non-point source wastewater from colonias, wastewater from septic systems, runoff and irrigation return flows from agricultural lands.

Significant internal loading of BOD occurs within the Arroyo Colorado due to the excessive growth of aquatic algae and resulting cycling of algal biomass within the channel. The hydrology of the modified river channel also affects the assimilation capacity of the Arroyo Colorado since the low velocities typically found in the tidal segment of the Arroyo Colorado including the turning basin do not adequately facilitate reaeration. The modifications to the channel (straightening, widening and deepening, removal of sand and gravel bars and large woody debris) to facilitate ship traffic effectively reduces velocity of flow since the channel gradient in this system remains very low due to the flat topography of the area. Removal of obstructions (point bars and large woody debris) also removes potential areas of turbulence which would facilitate reaeration of the water column.

2.2 Habitat Restoration

Much of the eastern part of the Rio Grande Valley is drained by small coastal streams, the Arroyo Colorado, resacas, and drainage ditches that flow into the Laguna Madre. The Arroyo Colorado carries much of the natural drainage and irrigation return flows to the Laguna Madre. The four southernmost counties of Texas have one of the highest diversities of plants and animals in the continental United States. Seven of the eleven biotic communities in these counties is considered riparian or partially riparian. However, native areas within the Arroyo Colorado watershed have been impacted by a variety of human activities including agriculture;

urban development; channelization; construction of flood control levees; routine maintenance of floodways; and introduction of exotic species resulting in substantial loss of native habitat areas within the watershed, as well as within and along the channel. Potential water quality improvement strategies may provide multiple benefits such as redevelopment or restoration of native habitat areas for both plants and wildlife.

2.3 Erosion Control

Steep slopes subject to sloughing and slope failure characterize the modified channel of the Arroyo Colorado. Routine mowing of the floodway to maintain flood flow conveyance effectively controls woody riparian vegetation, further limiting vegetative stabilization of the banks. Bank erosion of the Arroyo Colorado occurs during periods of high flows when velocities and wet soils produce in-channel erosion. The unit weight of soil is increased when wet so that slopes that were stable when dry become unstable due to the weight of the water held in the soil profile. Plus the water acts a lubricant along shear planes. Erosion within the watershed also transports contaminants from agricultural fields and urban areas. Additionally, the primary path of legacy pollutant transport into the aquatic system is from erosion of contaminated soils (90, 91).

2.4 Other

Bacteria has been identified as an impairment in the entire above tidal segment (Segment 2202)(8)(31). Sediment samples from the Arroyo Colorado were reported as having high metals and pesticides assumed to reflect anthropogenic uses within the watershed(3). Other potential water quality concerns identified for the Arroyo Colorado include sulfate (Segments 2201 and 2202) and chloride (Segment 2201)(40).

Legacy pollutants including DDD, DDT, chlordane, dieldrin, endrin, heptachlor epoxide, heptachlor, hexachlorobenzene, lindane, and toxaphene in smallmouth buffalo and DDE in fish tissue were also listed as impairments in the 2002 Assessment. These organics continue to be monitored.

Chapter 3
Variables/Factors Affecting Selection of Alternatives and Design

Many variables are important to consider when evaluating strategies to deal with various water quality improvement needs for point and non-point sources. Several of these variables are also used during the design phase for a specific strategy that has been selected to achieve water quality improvement or other goals based on the needs within a watershed. Some of the major factors that are used in the selection of appropriate strategies for site specific situations are described in the following sections.

3.1 Volume of Water to Treat

The volume of water to be treated will typically dictate the physical size of a given strategy, and depending on the setting, may ultimately dictate which type (or types) of strategy is appropriate. For example, if a large volume of water is projected and land availability for location and construction is limited, then a more structural strategy may be required. Conversely, it may be appropriate to treat only a portion of the flow, such as the "first flush" of storm runoff, and provide a means to bypass the remaining volume. If the volume of flow is large and continuous, it may be possible to collect and route the flow to an area where sufficient land is available to develop a more land intensive strategy. Where continuous flows are large and land availability is small, a combination of controls and strategies in a treatment train approach may be employed to meet pollutant removal goals within the constraints of the site.

One of the techniques typically used to increase the pollutant removal performance of treatment systems is to increase the hydraulic residence time within the system. This may be accomplished by increasing the storage or treatment volume of the system. For systems that treat storm flows, the volume is usually associated with a rain event of a specified return frequency or probability of occurrence.

One rule-of-thumb used for stormwater treatment strategies is that the system should contain a treatment volume that is capable of capturing the runoff generated by 90 percent of the runoff-producing storms in the region on an annual basis (144). However, this should be considered a screening criterion. Comparison of sizing requirements using a variety of rules-of-thumb is provided in Table 3-1 as adapted from Schueler (144).

Table 3-1 (144)
Comparison of Treatment Volume (Vt) Requirements
under various BMP sizing criteria (watershed-inches of storage)

Imperviousness of Contributing Watershed	Rule 1 RFS	Rule 2 (1.0) (IA)	Rule 3 0.5 (A)	Rule 4 (0.5) (IA)	Rule 5 2.5(VB/VR)
10%	0.25	0.14	0.50	0.05	0.15
20%	0.29	0.23	0.50	0.10	0.24
30%	0.40	0.32	0.50	0.15	0.34
40%	0.51	0.41	0.50	0.20	0.43
50%	0.63	0.50	0.50	0.25	0.53
60%	0.74	0.59	0.50	0.30	0.62
70%	0.85	0.68	0.50	0.35	0.71
80%	0.96	0.77	0.50	0.40	0.81
90%	1.08	0.86	0.50	0.45	0.90
100%	1.19	0.95	0.50	0.50	1.00

Rule 1: Capture 90 percent of the Annual Runoff Volume (1.25)(Rv)(A)
Rule 2: Capture one inch of runoff times the site runoff coefficient
Rule 3: Capture on-half inch of runoff per acre
Rule 4: Capture one-half inch of runoff per impervious acre
Rule 5: Capture 2.5 times the runoff from the mean storm (0.42 inch)
Rv = storm runoff coefficient
A = contributing area
I = percent site imperviousness
RFS = Rainfall Frequency Spectrum

3.2 Flow Regime

Another important factor to consider in selecting the most appropriate strategy for a particular site is the flow regime (i.e., pulsed/intermittent or continuous/steady). Flows, whether municipal, industrial, or stormwater, are often seasonal in character. It is necessary to anticipate those patterns because the treatment system must function appropriately under variable hydraulic conditions. Monthly flow estimates will be required for most point source projects, but stormwater systems may require a definition of the frequencies of events and their magnitude and timing (53).

Storm flows and irrigation return flows (both agricultural and urban landscape irrigation) provide a pulsed or intermittent flow regime. The periodicity and volume of storm runoff can be projected from analysis of historical rainfall data and mapped land cover data. Irrigation return flows are based on irrigation practices for specific crops or routine landscape irrigation schedules. Where conveyances such as ditches, swales, or culverts carry flows from multiple sources, these multiple sources may provide complimenting flows to a treatment system that employs aquatic vegetation. However, the design of the strategy employed must also consider the varying volumes of flow to be treated within the overall system.

Flows from point source discharges are typically continuous so systems designed to polish either individual plant or multiple plant flows or collective flows should be based on the monthly flow estimates with capability to handle storage and conveyance of peak flows. Systems receiving flows directly from the Arroyo Colorado would also have continuous flow. Average flows in the Arroyo Colorado at the downstream end of the non-tidal segment (2202), based on the HPSF model data, were 230 MGD for all flows and 152 MGD for dry weather flows during the critical period of May through October (Refer to Table A-1 in Appendix A).

3.3 Nutrient Loading

Nutrient removal for treatment systems typically focuses on two macro-nutrients: nitrogen and phosphorus. Several aspects of nutrient loading should be considered during the selection and design of treatment strategies. For example, inflow nutrient loadings and the target outflow nutrient concentrations directly relate to the size and/or volume of a system required. If a system is designed to reuse treated water for land application or reuse irrigation, the system may require less removal of nutrients since these will be beneficially used by the plant life at the application site. However, the nitrogen to phosphorus ratio of plant uptake at the disposal site should be considered in order to minimize buildup of excess nutrients in the soil and subsequent release through runoff flows.

When evaluating strategies and designing treatment systems, consideration of nitrogen speciation in the inflows to the treatment system is also important. This affects the required detention time and the operational requirements for effective removal of total nitrogen. Due to the complexities and interactions of phosphorus cycling, total phosphorus is the desired parameter to use for evaluation of targeted removal rates and treatment efficiency.

Average concentrations and loads for total nitrogen within the Arroyo Colorado at the downstream end of the non-tidal segment (2202) were 5.4 mg/L and 9,694 lbs/day, respectively, for all flow data; and 4.9 mg/L and 6,312 lbs/day, respectively, for dry weather flows during the critical period of May through October (Refer to Table A-1 in Appendix A). Average concentrations and loads for total phosphorus within the Arroyo Colorado at the same location were 0.7 mg/L and 951 lbs/day, respectively, for all flow data; and 0.8 mg/L and 992 lbs/day, respectively, during the critical period of May through October (Refer to Table A-1 in Appendix A).

3.4 Sediment Loading

Consideration of sediment loading from various sources of flow is important in the selection and design of a treatment strategy since multiple options may be employed to reduce sediment loads to more sensitive elements of a treatment system. Strategies employed to capture sediment may be part of a treatment train approach or incorporated into the design of a complex strategy such as pond/wetland systems, micropool in an extended detention pond or wetland system, or sediment forebay within a stormwater wetland treatment system. Usually the component of a treatment system used to capture sediment will serve several useful purposes. As an example, a sediment forebay also acts to:

- Reduce the incoming runoff velocities to the wetland.
- Trap coarse sediments before they enter the wetland, thereby preserving the capacity and microtopography.
- Spread runoff to promote even distribution of flow across following treatment areas.
- Extend flow path and minimize short-circuiting of flows through the system.

Efficient capture of sediment improves removal efficiency for other contaminants that are typically adsorbed to sediment particles including phosphorus, pesticides, and other organics.

Regardless of the type of component used to remove sediment, it should be designed to facilitate the removal of accumulated solids through routine maintenance activities.

Average concentrations for total suspended solids (TSS), a parameter typically representative of the sediment load within the water column, within the Arroyo Colorado at the downstream end of segment 2202 were 142 mg/L for all flow data and 50 mg/L for dry weather flows during the critical period between May and October. TSS includes suspended organic material such as aquatic algae so evaluation of organic to inorganic portion of the TSS is needed for design calculations. Average loads for TSS at this location within the Arroyo Colorado were 370,622 lbs/day for all flow data and 66,423 lbs/day during dry weather flows during May through October indicating significant contribution of TSS from non-point sources during storm events (Refer to Table A-1 in Appendix A).

3.5 Location within the Watershed

Understanding the primary functional objective of a strategy should be used as the basis for recommending a treatment system or strategy in a given setting within the watershed. For example, smaller systems or strategies may be selected to provide water quality improvement for various land covers within a small drainage or sub-watershed, but these small systems should not be expected to provide flood storage capacity or significant wildlife habitat. Small sub-watersheds will likely have uneven fluctuations in flows, which may make it more difficult to maintain permanent water levels within ponds or wetland systems. Therefore, strategies utilizing ponds or wetlands may not be appropriate in small sub-watersheds or drainages with irregular flows. Where continuous or near-continous flows are available such as in the lower reaches of the watershed or within areas that have base flows from municipal or industrial sources, pond or wetland systems which provide more habitat features may be the most beneficial strategy.

3.5.1 Jurisdictional Restrictions

Wastewater treatment and disposal are regulated by a number of federal, state, and local laws, rules, ordinances, and standards. Regulations regarding stormwater runoff quality are also in effect. The federal law that most directly affects the permitting and implementation of water quality improvement systems is the Clean Water Act and its amendments. Section 404 of the

Clean Water Act requires a permit from the United States Army Corps of Engineers (USACE) for any dredge and fill activities within jurisdictional waters of the United States including adjacent wetlands. Section 401 water quality certification from the State of Texas promulgated through the TCEQ is also required with a Section 404 permit. Other federal regulations that may affect the siting and permitting of water quality treatment system permitting include the National Environmental Policy Act (NEPA), the Antiquities Act, and the Endangered Species Act. In addition to these acts of Congress, presidential executive orders and letters of interpretation from agency representatives shape the overall framework of federal regulations affecting the use of water treatment strategies.

Section 402 of the Clean Water Act created the National Pollutant Discharge Elimination System (NPDES) permitting program which is currently administered by the TCEQ. A TPDES permit is required for point source discharges of water or wastewater into or adjacent to waters of the state. Municipal, industrial, some agricultural and urban runoff all require TPDES stormwater discharge permits. TPDES permits specify allowable flows and chemical quality of discharges into waters of the United States based on established water quality standards for specific receiving waters.

Any construction or modification of existing conditions within the floodway under easement and managed by the IBWC would require either proof of land ownership or written letter from land owner giving permission to perform work as well as a license from the IBWC authorizing the work. The IBWC will evaluate the proposed work within the floodway to determine potential adverse impacts to flood conveyance capacity and/or flood protection.

3.5.2 Habitat Potential

Ponds and emergent wetland systems designed to provide water quality improvement can also function to provide or enhance wildlife habitat. In some cases, wetland systems have been designed to provide habitat for species of concern including threatened and endangered species. Constructed systems for water quality improvement such as ponds and emergent wetlands can provide incidental support of wildlife and waterfowl or the system designs can be enhanced by considering factors which encourage and support a wide range of wildlife communities. For example, research using pilot-scale wetland systems have shown that having 25 to 70 percent of the water surface dominated by submergent and floating macrophytes allows optimal water quality and habitat enhancement objectives to be met (93). Other design considerations include the inclusion of islands with low sloped sides that can be used by waterfowl and shorebirds for feeding, nesting, and rest areas. Shallow shoals of emergent vegetation surrounded by open water or beds of submerged vegetation also provide security for nesting and cover.

Filter strip buffer zones, especially in riparian areas, also have significant potential for habitat enhancement. Selection of plant species for buffer zones can enhance vegetation species diversity and provide habitat needs for species of concern within the local area. Buffer zones also provide sheltered corridors for wildlife movement when located to link fragmented habitat areas.

3.5.3 Water Quality Improvement Potential

Water quality improvement potential for treatment systems that depend on natural processes must consider irreducible background concentrations. Primary production of organic matter within natural treatment systems and the associated biogeochemical cycling of dissolved and particulate matter (C, N, and P) results in production of BOD and nutrients. This means that effluents from natural treatment systems will typically have some level of BOD, TSS, TN and TP that cannot be effectively reduced further within the system. Net carbon production in emergent wetlands tends to be high compared to ponds because of the much greater primary production of plant carbon. However, the retention of the produced carbon within the plant biomass is much higher for emergent wetland systems than for pond systems. High production of plant carbon and the resistance of plant carbon to degradation combined with a low organic carbon decomposition rate found in wetland environments means that emergent wetland systems provide more effective removal and retention of organic matter and nutrients than pond systems (93).

Comparisons of the performance of treatment systems receiving different influent concentrations, mass loads, and constituent characteristics can be misinterpreted because of the importance of inflow quality, loading rate, and climatic factors on removal efficiencies, outflow concentrations, and mass removal rates (53). Therefore, comparison of treatment system categories or strategies as well as individual treatment systems and configurations should be based on multiple indices. Selection of appropriate treatment strategies should be based on site specific data regarding constituents of concern, desired treatment goals, as well as physical constraints.

3.5.4 Soils

Treatment strategies that characteristically are designed to hold water typically use compacted clay soils to line the water-holding components (e.g., ponds, pools, forebay, wetland cells). Although alternatives such as geotextile liners or imported clays are available, these alternatives dramatically increase construction costs, can create operational complications, and decrease other natural amenities associated with the system such as public access, wildlife habitat, and aesthetics. Therefore, the characteristics of the soils located at the project site are of great importance.

3.5.5 Topography

Site topography will determine the amount of earth moving required for construction of the treatment system components and thus will influence the project cost. Topography also determines the opportunity for a gravity-flow system or will dictate the need for pumping, again an important cost consideration, both in terms of capital cost and operation and maintenance cost. For large-scale systems, topographic relief may be a factor that limits the capability to convey the desired peak flow through a system without producing water depths that are detrimental to emergent plant growth.

3.6 Watershed Mapping of Sources and Loads

The TCEQ conducted model runs for data collected for the Arroyo Colorado watershed over an 11-year period from January 1, 1989 through December 31, 1999. Data included land use, wastewater treatment plant locations and discharges, and water quality data for both non-point source and point-source discharges and within the Arroyo Colorado. Model runs were initially conducted for the watershed upstream of the zone of impairment (located in the upper portion of the tidal segment) and then by sub-basin. The data developed from the HPSF model runs was used to prepare GIS maps which are included as Figures 3-1 through 3-7. Figure 3-1 maps the all the landuse categories identified within the HSPF model data. For Figure 3-2, the landuse categories were aggregated into eight major categories of associated landuse to facilitate distinction of mapped land uses. Figure 3-3 identifies the locations of existing, upgraded, and proposed wastewater treatment plants (WWTPs) as well as location of concentrations of colonias, permitted land application discharges, and septic systems. Figure 3-4 illustrates the projection of total nitrogen loadings in lbs/acre/year from the watershed based on the analysis of the data. Figure 3-5 shows pollutant loadings by sub-basin for nitrate and ammonia loads, phosphate loads, and total suspended solids loads for dry weather non-point source, storm flow non-point source, and WWTP discharges. Figures 3-6 and 3-7 illustrate the projection of total suspended solids loadings and total phosphorus loadings, respectively, from the watershed. The GIS maps were developed to facilitate focusing water quality improvement efforts to areas within the watershed where the greatest potential for substantial improvement could be realized based on the historical data. The GIS maps are also included in large-scale format in Appendix A along with the data tables produced based on calculation of constituent loadings from the Texas Commission on Environmental Quality (TCEQ) HSPF model.

Figure 3-1

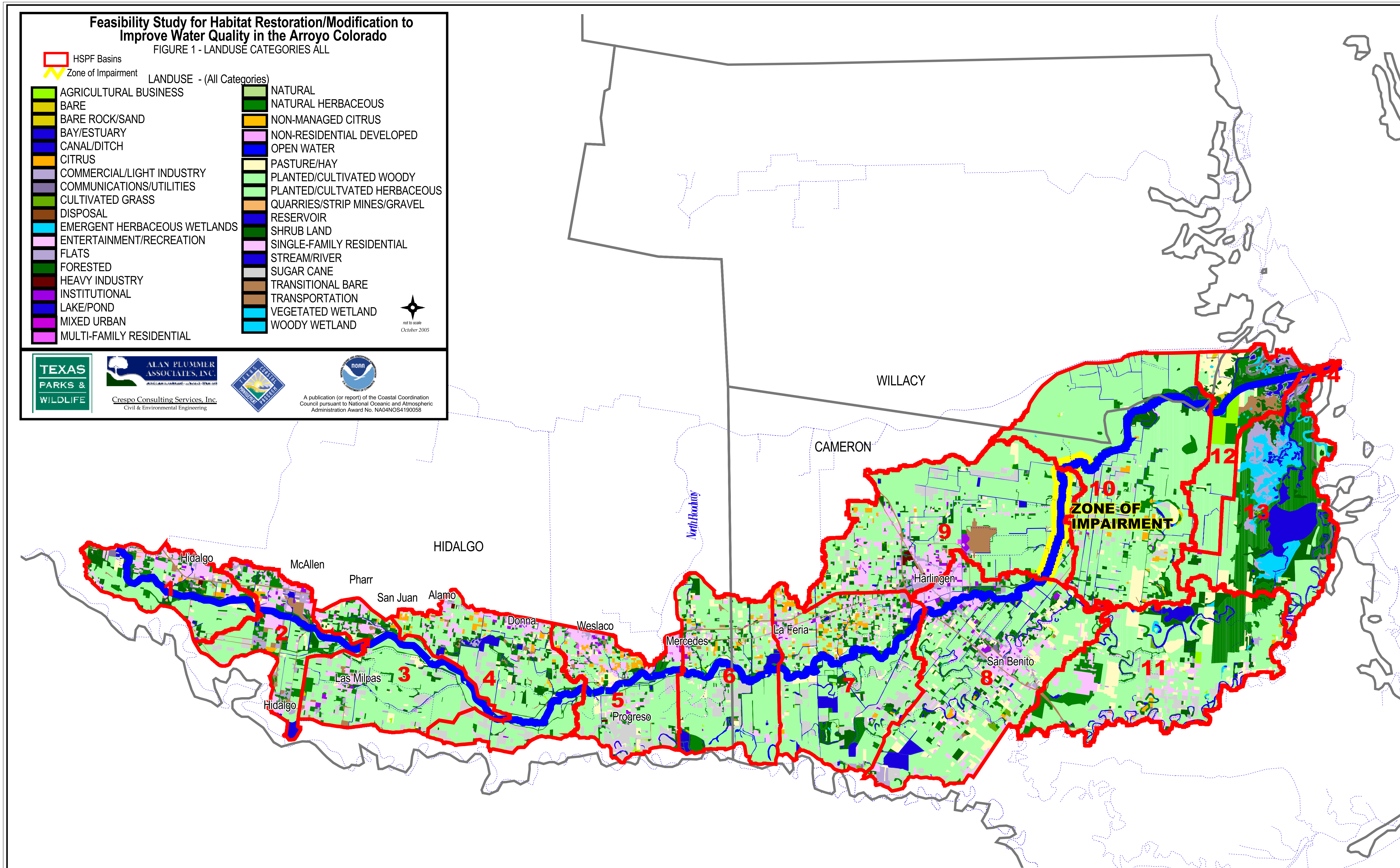
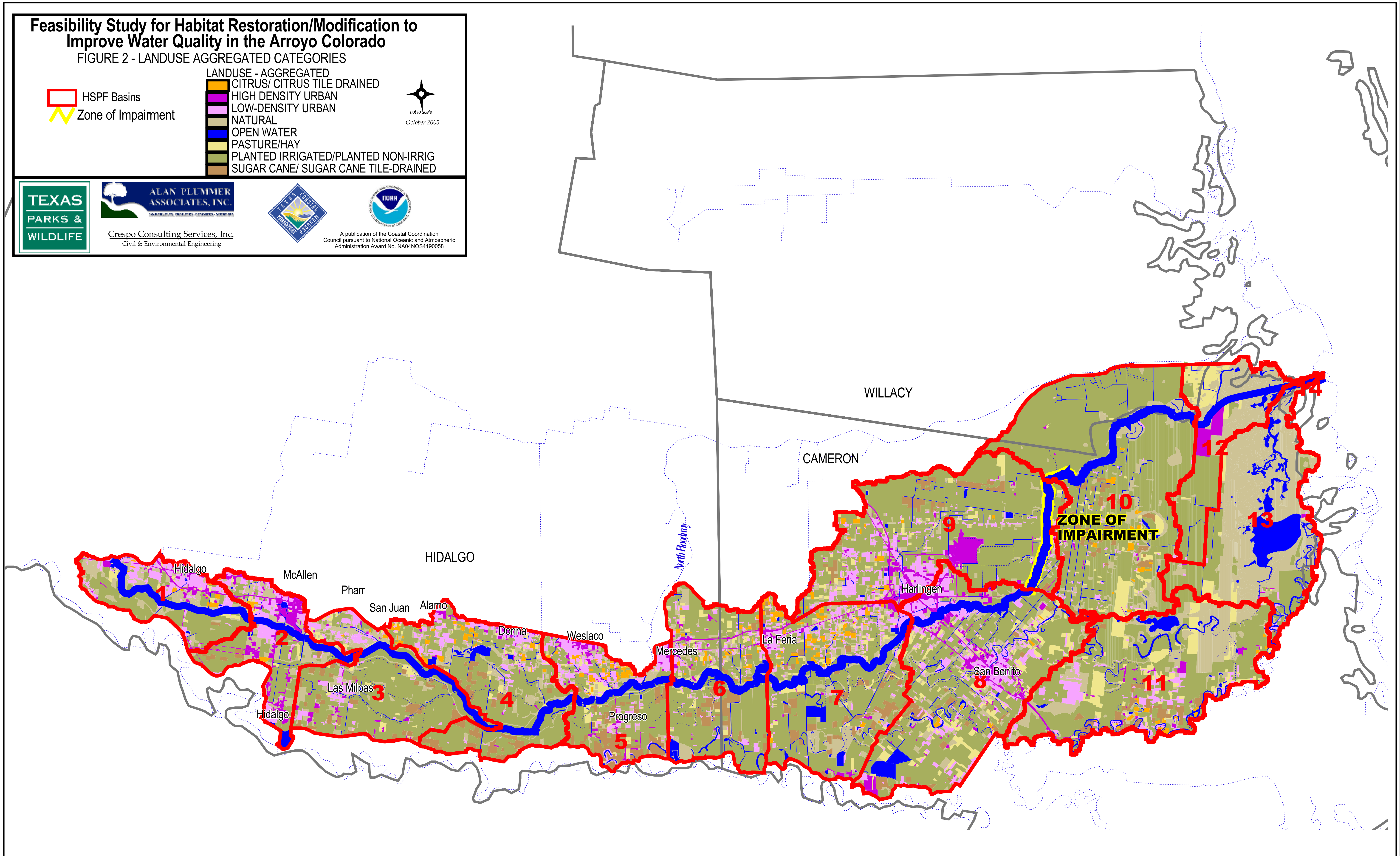

Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado
FIGURE 1 - LANDUSE CATEGORIES ALL
HSPF Basins
Zone of Impairment
LANDUSE - (All Categories)
AGRICULTURAL BUSINESS
BARE
BARE ROCK/SAND
BAY/ESTUARY
CANAL/DITCH
CITRUS
COMMERCIAL/LIGHT INDUSTRY
COMMUNICATIONS/UTILITIES
CULTIVATED GRASS
DISPOSAL
EMERGENT HERBACEOUS WETLANDS
ENTERTAINMENT/RECREATION
FLATS
FORESTED
HEAVY INDUSTRY
INSTITUTIONAL
LAKE/POND
MIXED URBAN
MULTI-FAMILY RESIDENTIAL
NATURAL
NATURAL HERBACEOUS
NON-MANAGED CITRUS
NON-RESIDENTIAL DEVELOPED
OPEN WATER
PASTURE/HAY
PLANTED/CULTIVATED WOODY
PLANTED/CULTVATED HERBACEOUS
QUARRIES/STRIP MINES/GRAVEL
RESERVOIR
SHRUB LAND
SINGLE-FAMILY RESIDENTIAL
STREAM/RIVER
SUGAR CANE
TRANSITIONAL BARE
TRANSPORTATION
VEGETATED WETLAND
WOODY WETLAND
not to scale
October 2005
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
A publication (or report) of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
WILLACY
CAMERON
HIDALGO
North Floodway
ZONE OF IMPAIRMENT
Hidalgo
McAllen
Pharr
San Juan
Alamo
Donna
Weslaco
Mercedes
La Feria
Harlingen
San Benito
Las Milpas
Progreso
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 3-2



Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado
FIGURE 2 - LANDUSE AGGREGATED CATEGORIES
HSPF Basins
Zone of Impairment
LANDUSE - AGGREGATED
CITRUS/ CITRUS TILE DRAINED
HIGH DENSITY URBAN
LOW-DENSITY URBAN
NATURAL
OPEN WATER
PASTURE/HAY
PLANTED IRRIGATED/PLANTED NON-IRRIG
SUGAR CANE/ SUGAR CANE TILE-DRAINED
not to scale
October 2005
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
WILLACY
CAMERON
HIDALGO
North Floodway
ZONE OF IMPAIRMENT
Hidalgo
McAllen
Pharr
San Juan
Alamo
Donna
Weslaco
Mercedes
La Feria
Harlingen
San Benito
Las Milpas
Hidalgo
Progreso
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 3-3

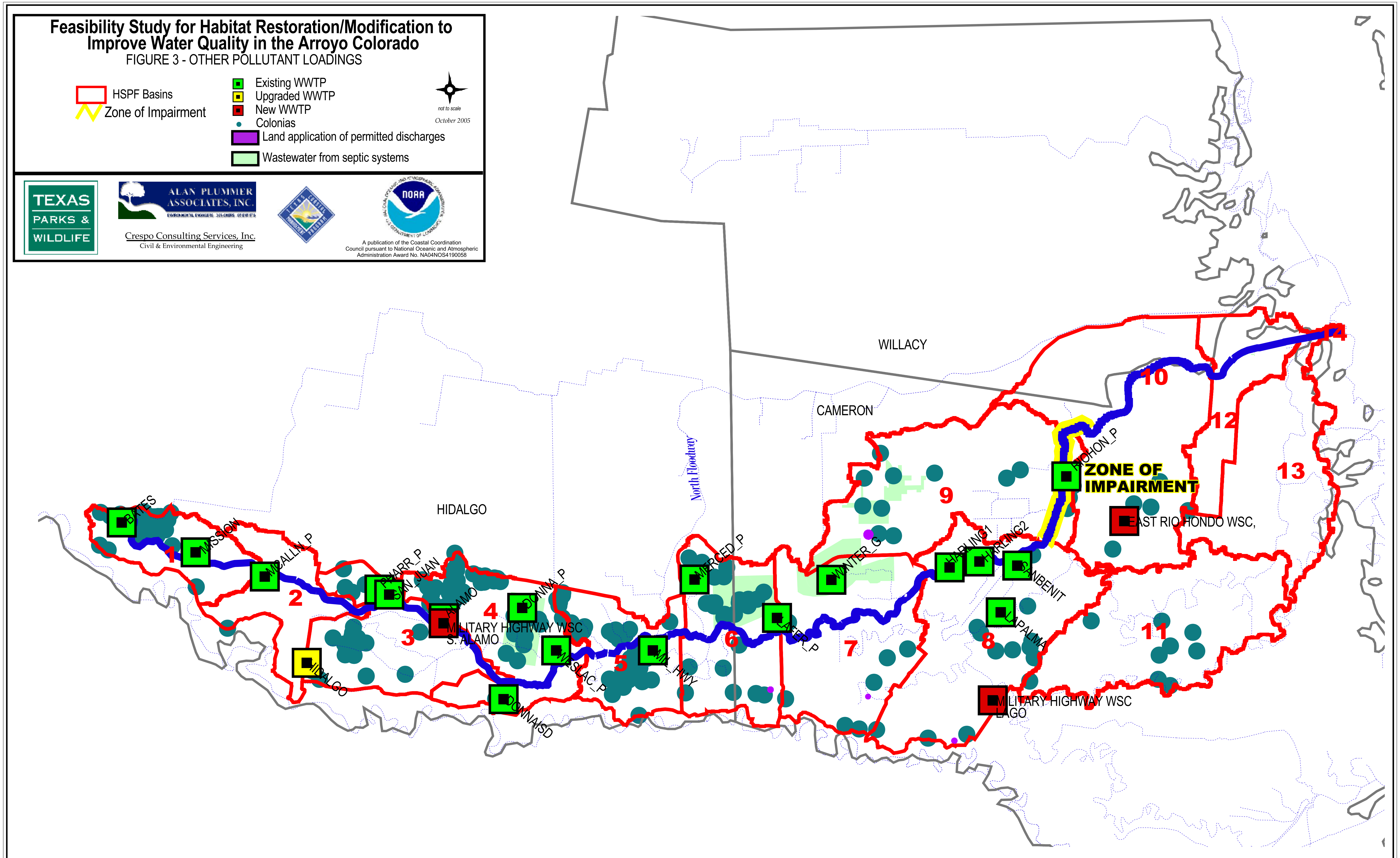

Feasibility Study for Habitat Restoration/Modification to
Improve Water Quality in the Arroyo Colorado
FIGURE 3 - OTHER POLLUTANT LOADINGS
HSPF Basins
Zone of Impairment
Existing WWTP
Upgraded WWTP
New WWTP
Colonias
Land application of permitted discharges
Wastewater from septic systems
not to scale
October 2005
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
NOAA
A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
WILLACY
CAMERON
HIDALGO
North Floodway
ZONE OF IMPAIRMENT
EAST RIO HONDO WSC,
MILITARY HIGHWAY WSC
S. ALAMO
MILITARY HIGHWAY WSC
LAGO
BATES
MISSION
MCALLIN_P
PHARR_P
SAN JUAN
ALAMO
DONNA_P
HIDALGO
DONNAISD
WESLAC_P
MERCED_P
WINTER_G
HARLING1
HARLING2
SANBENIT
LAPALMA
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 3-4

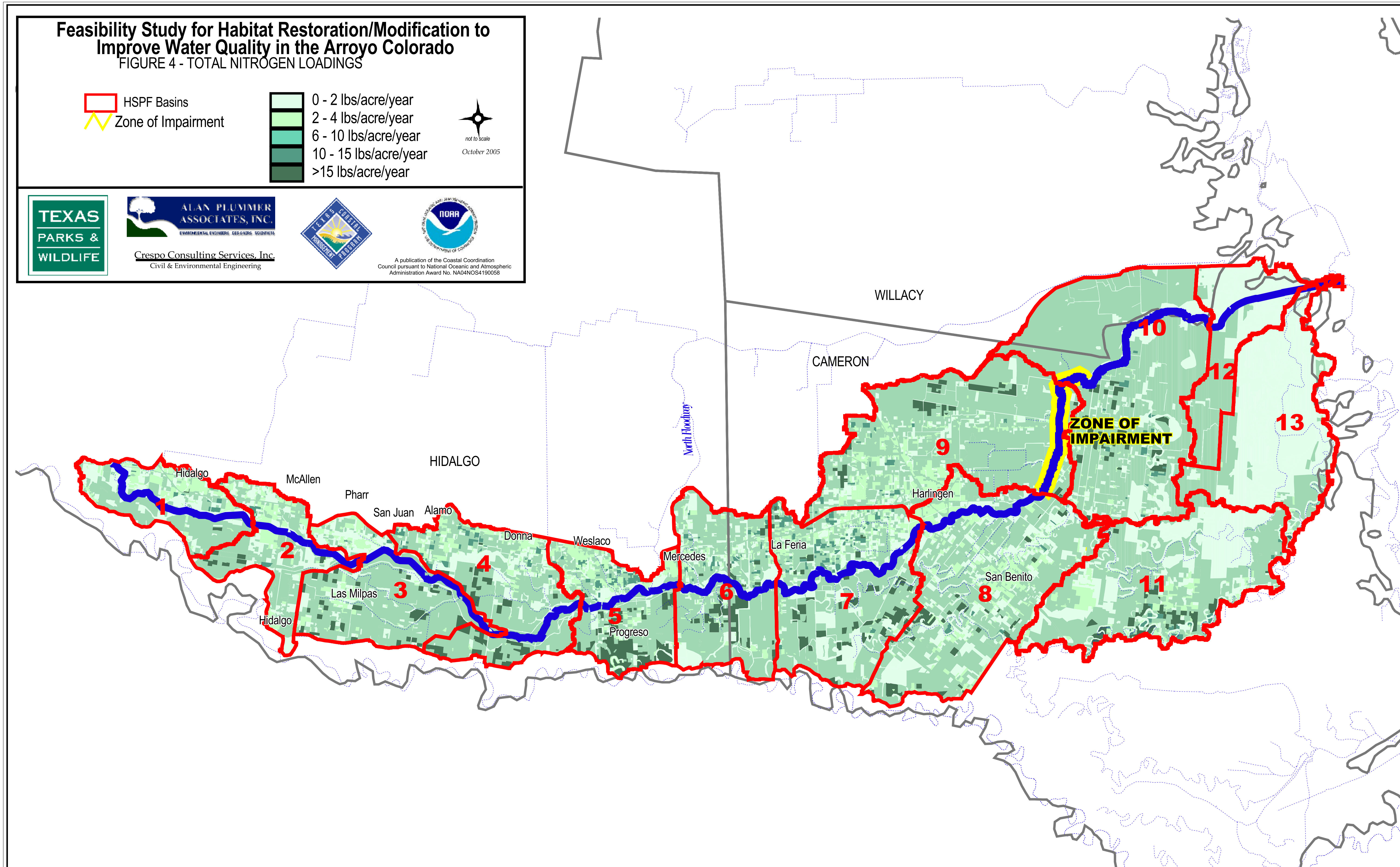
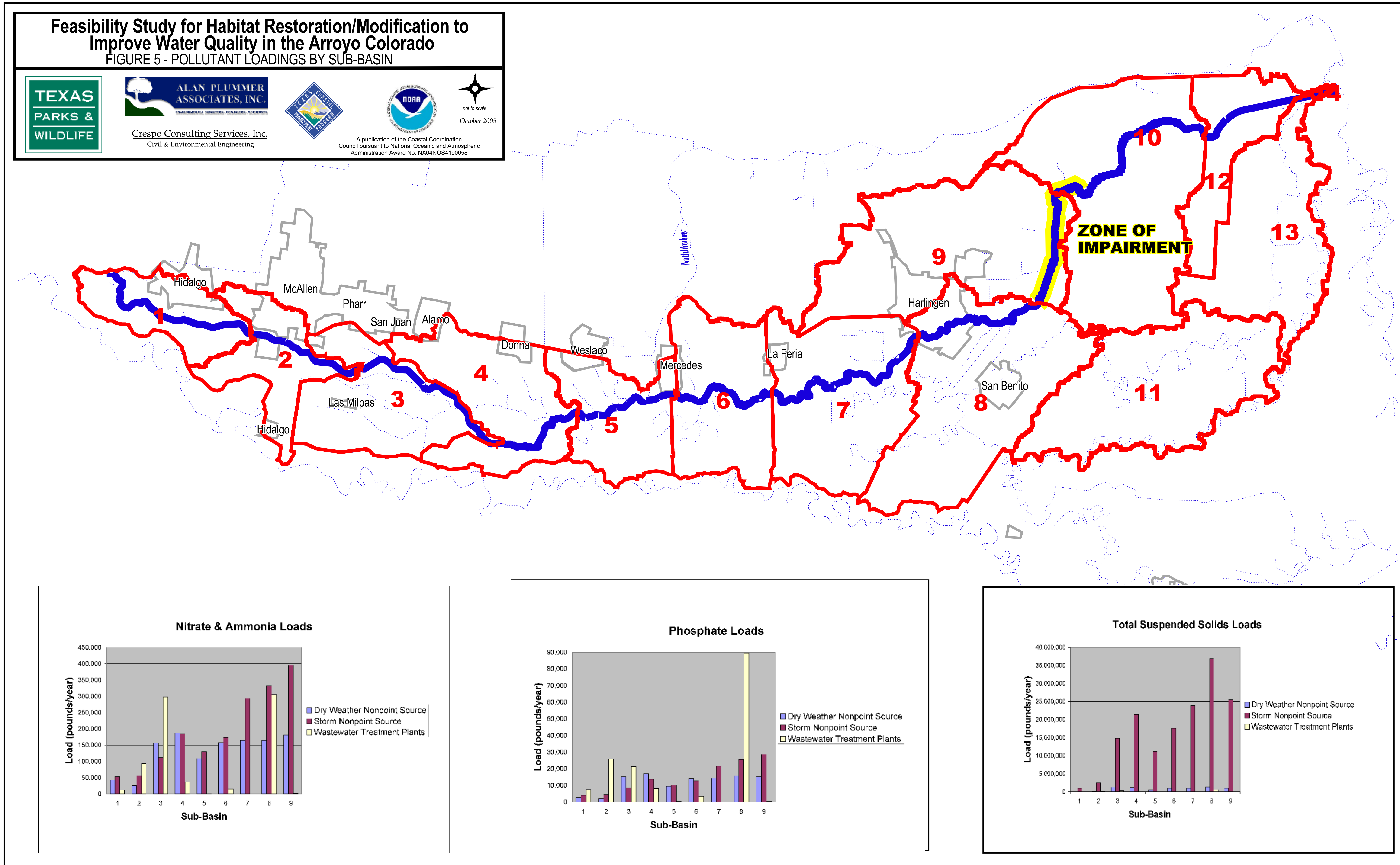
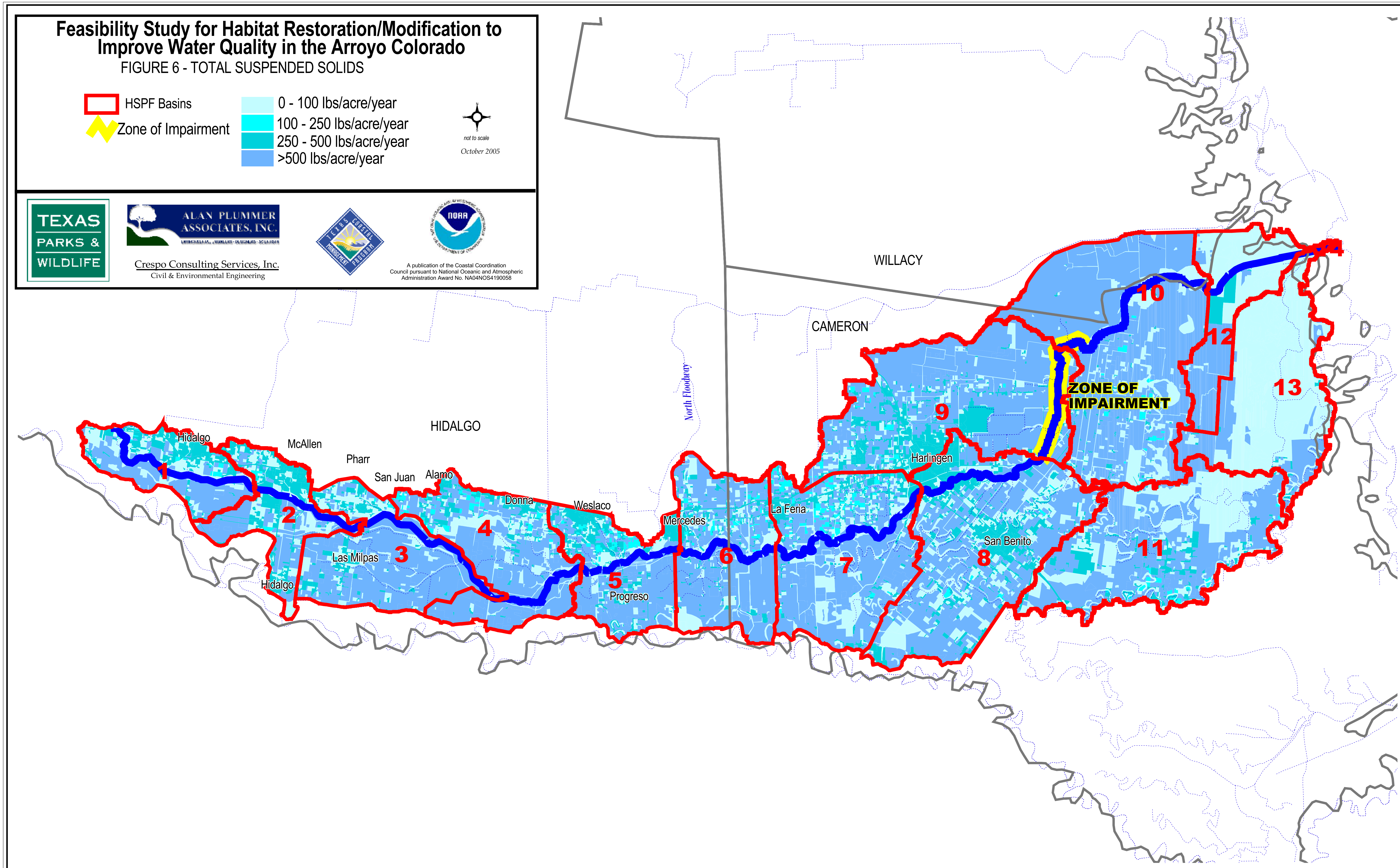

Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado
FIGURE 4 - TOTAL NITROGEN LOADINGS
HSPF Basins
Zone of Impairment
0 - 2 lbs/acre/year
2 - 4 lbs/acre/year
6 - 10 lbs/acre/year
10 - 15 lbs/acre/year
>15 lbs/acre/year
not to scale
October 2005
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
WILLACY
CAMERON
HIDALGO
North Floodway
ZONE OF IMPAIRMENT
Hidalgo
McAllen
Pharr
San Juan
Alamo
Donna
Weslaco
Mercedes
La Feria
Harlingen
San Benito
Las Milpas
Progreso
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 3-5



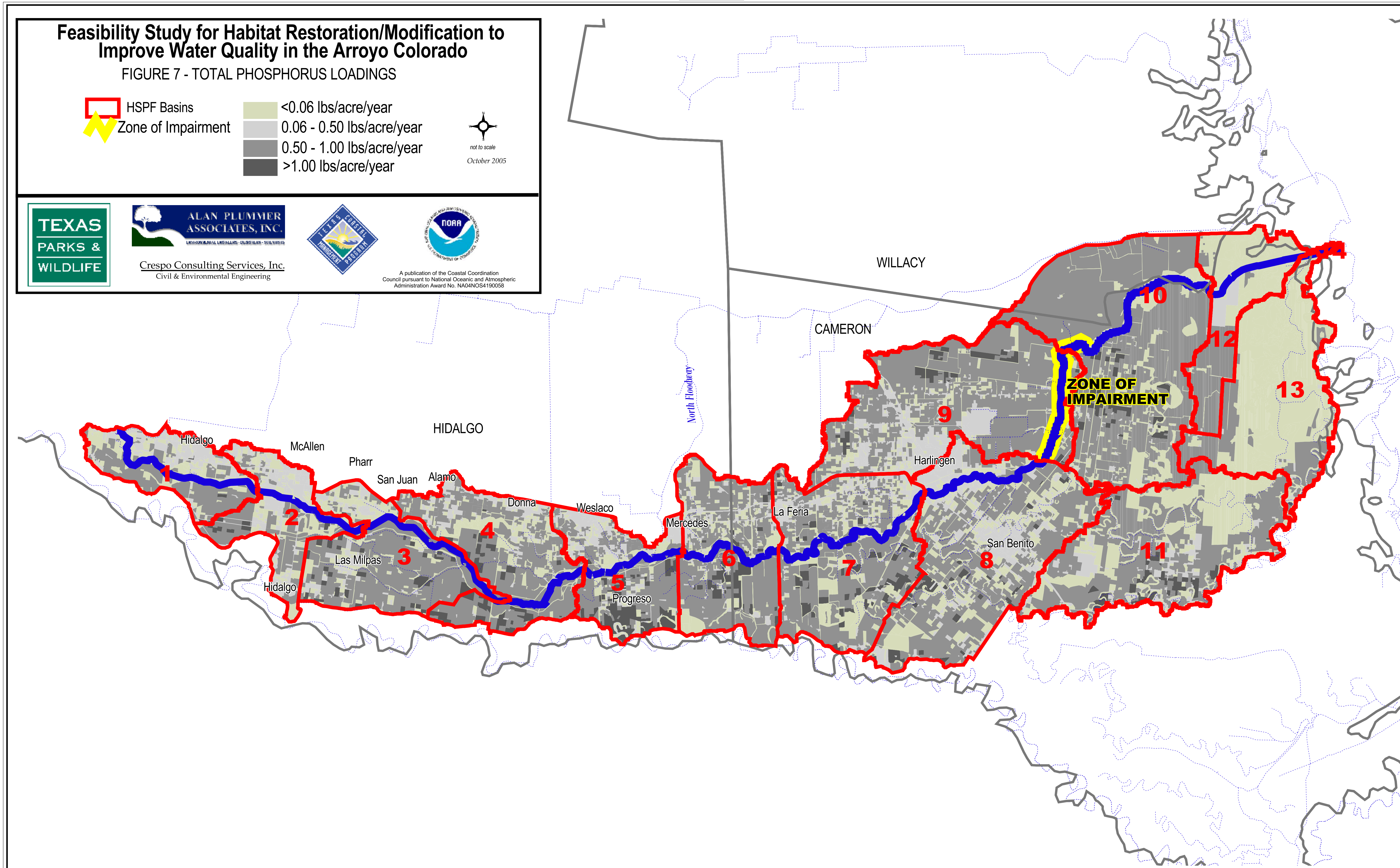
Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado
FIGURE 5 - POLLUTANT LOADINGS BY SUB-BASIN
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
not to scale
October 2005
A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
ZONE OF IMPAIRMENT
Hidalgo
McAllen
Pharr
San Juan
Alamo
Donna
Weslaco
Mercedes
La Feria
Harlingen
San Benito
Las Milpas
Hidalgo
1
2
3
4
5
6
7
8
9
10
11
12
13
Nitrate & Ammonia Loads
Load (pounds/year)
Sub-Basin
Phosphate Loads
Load (pounds/year)
Sub-Basin
Total Suspended Solids Loads
Load (pounds/year)
Sub-Basin
Dry Weather Nonpoint Source
Storm Nonpoint Source
Wastewater Treatment Plants

Figure 3-6



Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado
FIGURE 6 - TOTAL SUSPENDED SOLIDS
HSPF Basins
Zone of Impairment
0 - 100 lbs/acre/year
100 - 250 lbs/acre/year
250 - 500 lbs/acre/year
>500 lbs/acre/year
not to scale
October 2005
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
WILLACY
CAMERON
HIDALGO
North Floodway
ZONE OF IMPAIRMENT
Hidalgo
McAllen
Pharr
San Juan
Alamo
Donna
Weslaco
Mercedes
La Feria
Harlingen
San Benito
Las Milpas
Progreso
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 3-7


Feasibility Study for Habitat Restoration/Modification to Improve Water Quality in the Arroyo Colorado
FIGURE 7 - TOTAL PHOSPHORUS LOADINGS
HSPF Basins
Zone of Impairment
<0.06 lbs/acre/year
0.06 - 0.50 lbs/acre/year
0.50 - 1.00 lbs/acre/year
>1.00 lbs/acre/year
not to scale
October 2005
TEXAS PARKS & WILDLIFE
ALAN PLUMMER ASSOCIATES, INC.
Crespo Consulting Services, Inc.
Civil & Environmental Engineering
A publication of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA04NOS4190058
WILLACY
CAMERON
HIDALGO
North Floodway
ZONE OF IMPAIRMENT
Hidalgo
McAllen
Pharr
San Juan
Alamo
Donna
Weslaco
Mercedes
La Feria
Harlingen
San Benito
Las Milpas
Progreso
1
2
3
4
5
6
7
8
9
10
11
12
13

3.7 Other Considerations

Kadlec and Knight (53) caution that using a simplistic single-number approach for final design may result in less than optimal treatment efficiency since the simplistic design approach tends to result in systems that trend toward the central tendencies of treatment efficiency (53). While simplistic approaches may be useful for initial screening and selection of appropriate alternatives in general areas or regions, final design should consider the following additional items:

- A set of pollution reduction targets
- Spatial variability of pollutant removal
- Hydraulic and meteorological constraints
- Internal depth and vegetation density patterns
- Internal water flow and mixing
- Baseline wetland concentration values
- Seasonality
- Interaction with other treatment system components
- Nature of the regulatory requirements
- Acceptable level of risk

Chapter 4
Technical Treatment Alternatives for Water Quality Improvement – Non-Point Source Treatment Systems

4.1 Ponds (Strategy 1)

Stormwater ponds are constructed stormwater retention basins that have a permanent pool of water throughout the year. Runoff from each rain event is detained and treated in the pool through settling and biological activity until it is displaced by runoff from the next storm event. The permanent pool also serves to protect deposited sediments from resuspension. Above the permanent pool level, additional temporary storage is provided for runoff quantity control. The upper stages of a stormwater pond are designed to provide extended detention of the 1-year storm for downstream channel protection, as well as normal detention of larger storm events.

Stormwater ponds are among the most cost-effective and commonly used stormwater management techniques. When properly designed, they can provide multiple benefits including habitat and aesthetics.

There are a variety of stormwater pond designs to accommodate specific circumstances. The most common include the wet pond, the wet extended detention pond, and the micropool extended detention pond. In addition, multiple stormwater ponds can be placed in series or parallel to increase performance or meet site design constraints. Each of these design variants are described below and collectively make up Strategy 1, ponds.

Wet Ponds

Wet ponds are stormwater basins that have a permanent wet pool equal to the water quality volume. Stormwater runoff displaces the water already present in the pool. Temporary storage can be provided above the permanent pool elevation to temporarily detain larger flows. Wet ponds are suitable devices for a variety of watershed sizes and consist of two components: a forebay and a permanent wet pool. The forebay serves as a pretreatment device for substantial removal of sediment loads where they are accessible for maintenance removal with minimal disturbance to the system. The wet pool is the primary treatment component and contains most of the retention capacity. A conceptual plan and profile of a Wet Pond is shown in Figure 4-1.

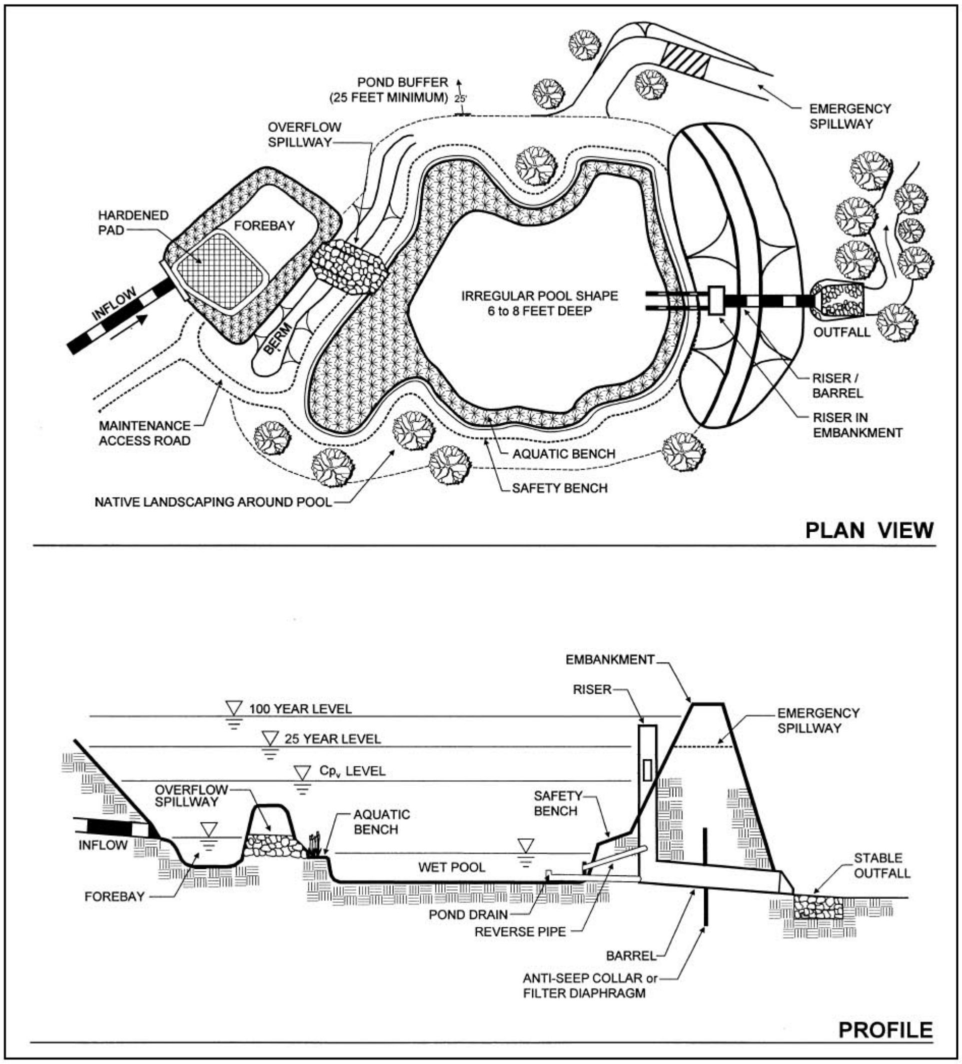


Figure 4-1. Wet Pond (30)

Wet Extended Detention (ED) Pond

A wet extended detention pond is a wet pond where the water quality volume is split evenly between the permanent pool and extended detention (ED) storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 24 hours. This design has similar pollutant removal to a traditional wet pond, but consumes less space. A conceptual plan and profile of a Wet Extended Detention Pond is shown in Figure 4-2.

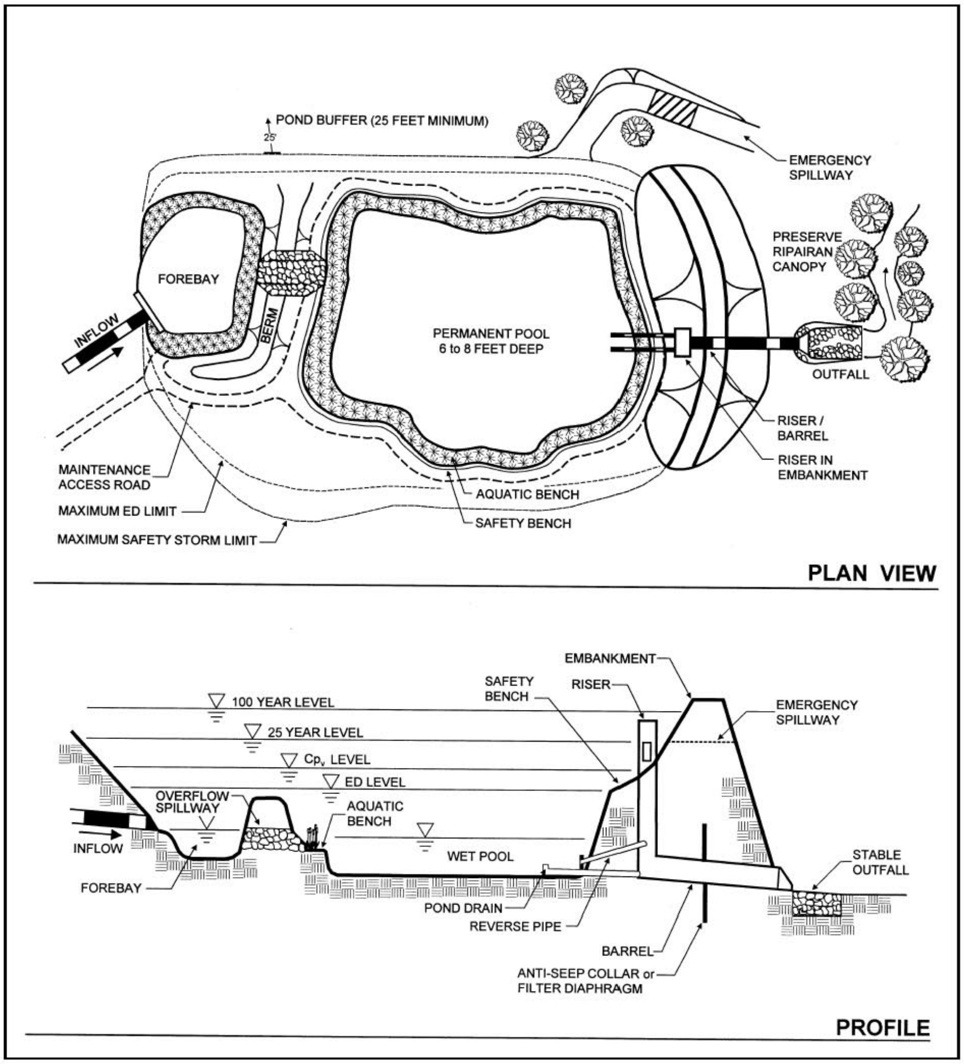


Figure 4-2. Wet Extended Detention Pond (30)

Micropool Extended Detention (ED) Pond

The micropool ED pond is a variation of the wet ED pond where only a small "micropool" is maintained at the outlet to the pond. The outlet structure is sized to detain the water quality volume for 24 hours. The micropool prevents resuspension of previously settled sediments and also prevents clogging of the low flow orifice. Very little monitoring data are available to assess the pollutant removal performance of the micropool ED pond. This practice is a modification of the dry ED pond with the major difference being the incorporation of a small micropool at the outlet and a wet forebay. It is assumed in the various stormwater BMP manuals that this practice performs similarly to wet ponds. A conceptual plan and profile of a Micropool Extended Detention Pond is shown in Figure 4-**3.**

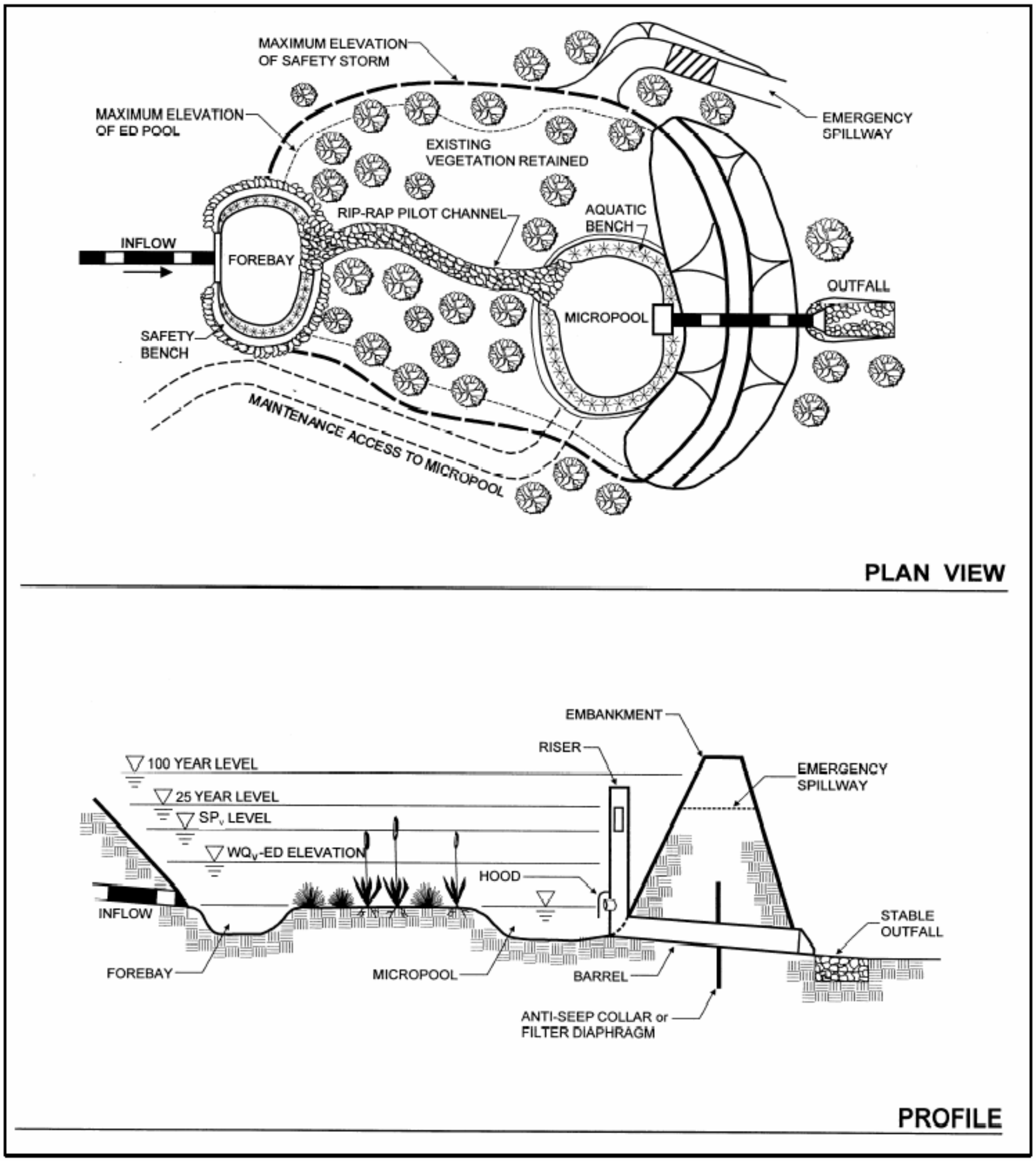


Figure 4-3. Micropool Extended Detention Pond (30)

Multiple Pond Systems

Multiple pond systems consist of constructed facilities that provide water quality and quantity volume storage in two or more cells. The additional cells can create longer pollutant removal pathways and improved downstream protection. The multiple cell design also allows more flexibility to meet site constraints. A conceptual plan and profile of a Multiple Pond System is shown in Figure 4-4.

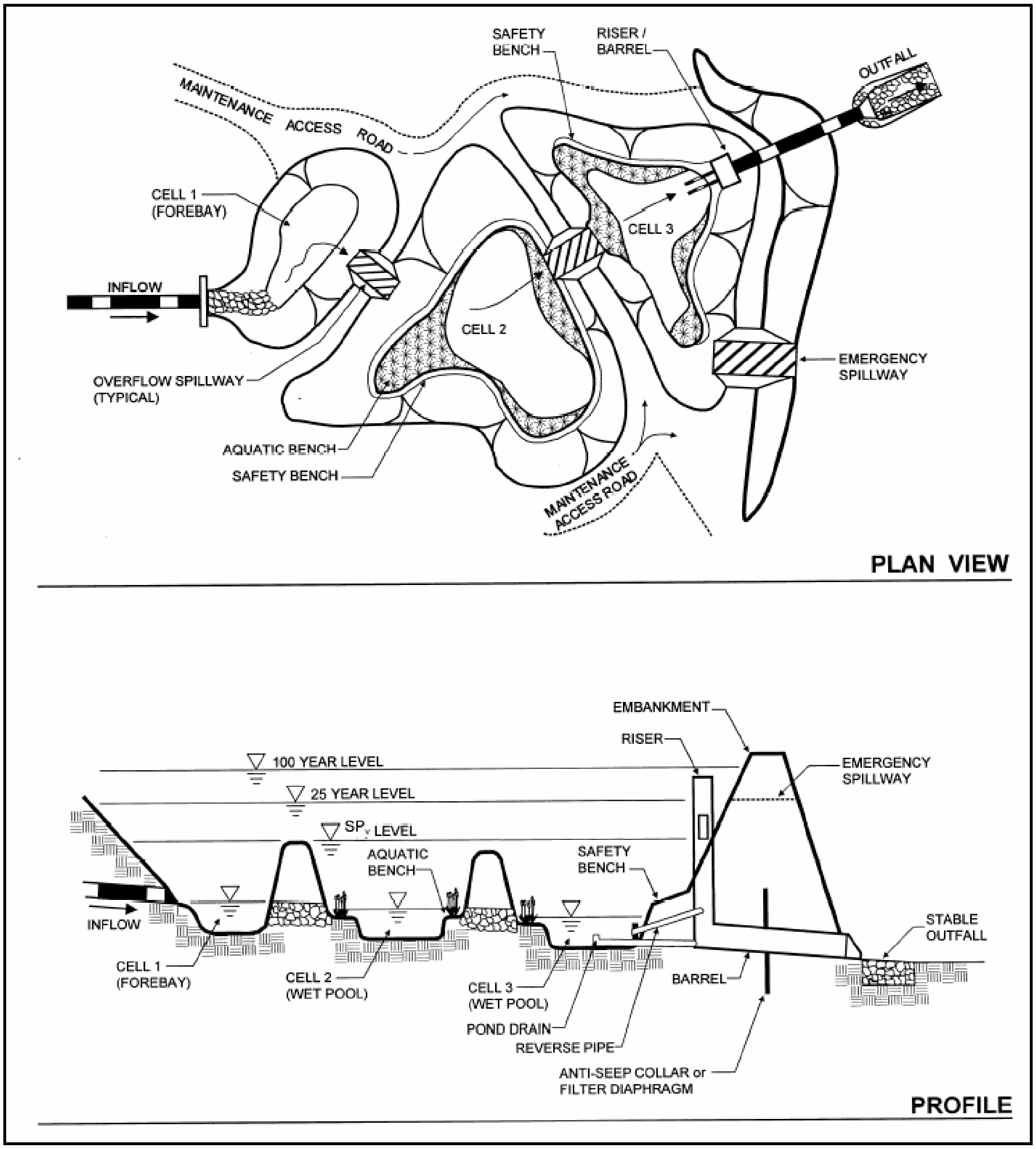


Figure 4-4. Multiple Pond Systems (30)

4.1.1 Applications

Stormwater ponds are generally applicable within a variety of landscapes. They can be used within new development and redevelopment, residential and nonresidential urban and rural agricultural areas. The main constraints for determining suitability are the land requirements and sufficient drainage area to sustain a permanent pool of water.

4.1.2 Limitations

Typically, a minimum of 25 acres is needed for a wet pond and wet ED pond to maintain a permanent pool; 10 acres minimum for micropool ED pond. A smaller drainage area may be acceptable with an adequate water balance with flows from sources other than just rainfall. In arid climates, supplemental sources of flow may be required to maintain a permanent pool. A study conducted in Austin, Texas found that 2.6 acre-feet per year of supplemental water was needed to maintain a permanent pool of only 0.29 acre-feet (45). An appropriate anti-clogging device should be provided for the pond outlet.

Wet ponds have the potential to impact groundwater if not properly designed. Also, potential thermal impacts should be evaluated for downstream receiving waters.

Physical site constraints include drainage area, space required, site slope, minimum head, minimum depth to water table, and soils. Size of a wet pond area should be approximately 2 to 3 percent of the drainage area being treated. At least 15 percent site slope is recommended across the pond site and the elevational difference needed at the site from the inflow to the outflow should be 6 to 8 feet to provide minimum head. In areas of low relief, the maximum normal pool depth may be limited and draining ponds for maintenance can be problematic.

A separation distance of 2 feet is recommended between the bottom of the pond and the elevation of the seasonally high water table if a wet pond system is to be used on a site with an underlying water supply aquifer or when treating a hotspot in an urban area (187). The underlying soils at a site should be evaluated to determine if they are adequate to minimize seepage and maintain a permanent pool.

Pond siting should also take into consideration the location and use of other site features such as buffers and undisturbed natural areas and should attempt to “fit” within the landscape so that minimal disturbance to these features occur as a result of construction of the pond system.

4.1.3 Effectiveness

There is considerable variation in the reported efficiencies of wet ponds resulting from differences in design, maintenance, and loadings from the drainage basin based on land use. Designs that effectively retain sediments and prevent or minimize resuspension of sediments are also more effective in the removal and retention of phosphorus since phosphorus is mostly adsorbed to the sediments carried in runoff. Table 4-1 provides the range of removal efficiencies of stormwater wet ponds for various pollutants of concern**.**

Table 4-1
Pollutant Removal Efficiency Wet Ponds (45)

Pollutant	Pollutant Removal Efficiency (%)
TSS	80 ± 27[1]
TP	51 ± 21
TN	33 ± 20
Metals	29 ± 73
Bacteria	70 ± 32
NOx	43 ± 38

[1] Note the ± symbol denotes one standard deviation**.**

4.1.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

Elements of stormwater pond design including permanent pool areas, shallow, vegetated littoral zone (aquatic bench that may double as a safety bench) along the edge of the permanent pool, pond buffer, and native landscaping around the stormwater pond system provide both water quality benefits and complementary habitat areas.

4.1.5 Conceptual Designs

Stormwater ponds are unique for each site and application. However, there are general criteria for geometric ratios and limiting depths for pond design that must be observed for adequate pollutant removal, ease of maintenance, and improved safety. Proper geometric design is essential to prevent hydraulic short-circuiting (unequal distribution of inflow), which results in the failure of the pond to achieve adequate levels of pollutant removal. The minimum length-to-width ratio for the permanent pool shape is 1.5:1 and should ideally be greater than 3:1 to avoid short-circuiting. In addition, ponds should be wedge-shaped when possible so that flow enters the pond and gradually spreads out, improving the sedimentation process. Baffles, pond shaping, or islands can be added within the permanent pool to increase the flow path.

Maximum depth of the permanent pool should generally not exceed 8 feet to avoid stratification and anoxic conditions. Minimum depth for the pond bottom should be 3 to 4 feet. Deeper depths near the outlet will yield cooler bottom water discharges that may mitigate downstream thermal effects.

Side slopes to the pond should not usually exceed 3:1 (H:V) and flatter slopes just above and below the water level increase safety as well as provide areas for aquatic vegetation. The contours and shape of the permanent pool should be irregular to provide a more natural landscaping effect and improve habitat quality. Aquatic vegetation plays an important role in pollutant removal in stormwater ponds, stabilizes side slopes, as well as provides enhanced wildlife habitat and aesthetics.

Each pond should have a sediment forebay or equivalent upstream pretreatment. A sediment forebay is designed to remove incoming sediment from the stormwater flow prior to dispersal in a larger permanent pool. The forebay should consist of a separate cell, formed by an acceptable barrier. A forebay is sized to contain 0.1 inches per impervious acre of contributing drainage and should be 4 to 6 feet deep. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.

Erosion control measures should be employed at inflow channels and outflow areas. Inlet pipes to the pond can be partially submerged to utilize the permanent pool of water for energy dispersion. Exit velocities from the forebay must also be non-erosive.

A number of outlets at varying depths in the outflow riser provide internal flow control for routing of the water quality, channel protection, and overbank flood protection for runoff volumes. Riprap, plunge pools or pads, or other energy dissipaters should be placed at the outflow to prevent scouring and erosion.

4.1.6 Unit Cost

Capital

Capital costs for pond systems can vary significantly by site. The spectrum of possible projects can include simple modifications to a naturally occurring depression or pond so that it will function as a stormwater pond treatment system (low capital cost) to elaborate designs that may include relocation of existing utilities, significant earthwork in difficult soils, numerous water control appurtenances, wetland plantings and expansive landscaping (high capital cost). For example, two pond projects constructed for water quality improvement in Austin with similar storage volumes ranged from approximately $92,000 to $263,000 per acre-foot of storage. EPA developed a relationship between storage volume and capital cost for both detention ponds and wet ponds (182). Using the EPA methodology, the unit capital cost for detention ponds and wet ponds is $41,600 and $48,200 per acre-foot, respectively. When a potential project site is identified, it must be evaluated using the selection criteria previously discussed in this document and weighed against the overall project objectives to determine the feasibility of the project at that site.

Operation and Maintenance

Operation and maintenance (O&M) costs for pond systems are associated with periodic removal and disposal of collected sediment; mowing of embankments or other public areas; possible restoration of wetland plantings; and restabilizing banks or channels that may have eroded. EPA provided guidance for estimating O&M costs for detention ponds and wet ponds based on a percent of construction cost (182). For detention ponds, EPA estimates an annual O&M cost of less than 1 percent of the construction cost per year. For wet ponds, EPA estimates an O&M cost of 3 to 6 percent of the construction cost per year. Kadlec and Knight (53) provide an estimate for wet ponds of $0.07 to $0.13 per cubic meter ($86 to $161 per acre-foot).

4.2 Stormwater Runoff Wetland Treatment Systems (Strategies 2 and 3)

There are several variations of stormwater runoff wetland treatment systems that can be used in a wide array of applications. The specific wetland systems included in Strategy 2 are generally applicable to linear drainages, such as channels or swales. Those included in Strategy 3 are not necessarily limited to linear-drainage applications, and these generally include some sort of a pond or pool. Because there are many commonalities between the various types of stormwater wetland systems, Strategies 2 and 3 are combined into this section. Individualized descriptions of the stormwater wetland design variations are also included in this section; with the applicable strategy notated by the variation.

Wetland treatment systems have some properties in common with ponds, but also have many important structural and functional differences. Physical, chemical, and biological processes of the water column of open water zones within wetland systems are nearly identical to similar zones within ponds. However, large areas of shallow water and emergent vegetation in wetland treatment systems provide an ideal matrix for many processes important for water quality improvement. Wetland plants both control the pollutant removal processes and act as sources and sinks of certain dissolved and particulate water quality constituents. Many of the biochemical transformations that occur in treatment wetlands are mediated by a variety of microbial species residing on surfaces provided by plants such as leaves, stems, and litter. Examples of these processes include the decomposition of organic matter, periphyton fixation, nitrification-denitrification, and sulfate reduction.

Wetland plants also affect the hydraulic characteristics of the wetland, which directly influences water quality constituent removal processes. Wetland vegetation can:

- Increase water losses through plant transpiration.
- Decrease evaporation water losses by shading water surfaces and cooling water temperatures.
- Create friction on the flowing water and, thereby, creating headloss and flocculation of colloids.

- Provide wind blocks, thus promoting quiescent water conditions and protection for floating plants such as duckweed.
- Provide complex water column flow pathways and occupy a portion of the water column, thus decreasing volume of water capacity.

Stormwater wetlands are among the most effective management practices in terms of pollutant removal and also offer aesthetic value and wildlife habitat. Constructed wetlands typically have less biodiversity than natural wetland both in terms of plant and animal life since they are designed and maintained primarily for water quality improvement. However, depending on the location of the system within the landscape, enhancement of habitat functions is possible.

Stormwater wetlands require either sufficient base flow or a high water table to be able to support aquatic vegetation. Multiple wetland-based systems are available that employ the water quality improvement functions of wetland vegetation. These include a series of wetland cells within small drainages, wetland swales, extended detention shallow wetland, pond/wetland systems, and pocket wetland. Information for each wetland system is provided below.

Series of wetland cells within small drainage (Strategy 2)

Small weirs constructed across drainage channels can be used to create a series of wetland cells. Conveyance capacity requirements for storm runoff or other drainage needs should be assessed since some channel volume will be lost to the volume of the retained water and vegetative biomass established within the wetland cells. Drainage channels in general, as well as channels developed into wetland cells, should be protected from high sediment loads. This can be accomplished through use of vegetative filter strips, buffer zones, or sediment forebays or basins.

Wetland Swales (Strategy 2)

Wetland swales are similar to a series of wetland cells within a small drainage channel; however, this design does not involve the construction of weirs. Small check dams may be employed along swales with steeper gradients if necessary to provide hydrology sufficient to promote wetland vegetation. If elevation grade along the channel is low, moist soils resulting from frequent urban or agricultural drainage will sustain growth of aquatic macrophytes including grasses, rushes, sedges, and spikerushes which all produce a dense sod with vigorous, upright growth.

Extended detention shallow wetland (Strategy 3)

Extended detention shallow wetland design includes relatively high (i.e., shallow water) and low (i.e., deeper water) marsh depths with a sediment forebay in front of the wetland and a micropool at the outflow. Low volume storm runoff events result in a meandering flow through the low marsh areas while larger flows flow across both high and low marsh areas. This design provides more treatment for "first flush" flows as well. This design requires the most land of the wetland stormwater treatment systems. The extended detention (ED) shallow wetland includes a shallow wetland with part of the water quality treatment volume provided as extended detention above the surface of the marsh and released over a period of 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. However, plants that can tolerate both wet and dry periods need to be employed in the ED zone. A conceptual plan and profile of a extended detention shallow wetland is shown in Figure 4-5.

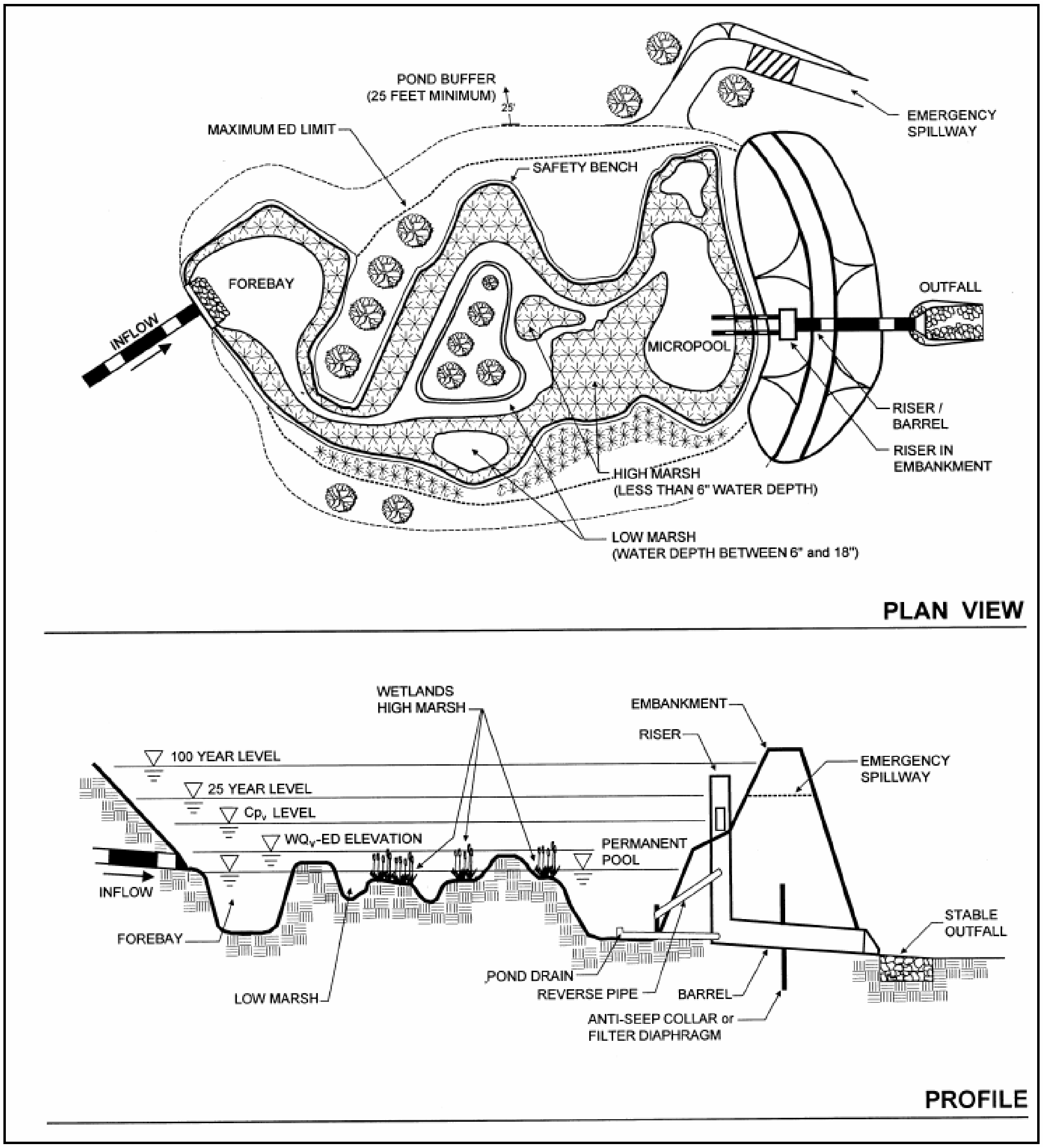


Figure 4-5. Extended Detention Shallow Wetland (30)

Pond/Wetland Systems (Strategy 3)

The pond/wetland system has two cells, a wet pond and a shallow marsh. The sediment forebay or other sediment trapping technique should still be employed before the wet pond in areas producing high sediment loads to facilitate maintenance and reduce disturbance to the treatment system. The wet pond further reduces sediments and provides treatment through settling and biological activity within the water column prior to entry into the wetland which then provides polishing treatment for solids as well as nutrient removal. Less land is required for a pond/wetland system than for the shallow wetland or the ED shallow wetland systems. A conceptual plan and profile of a pond/wetland system is shown in Figure 4-6.

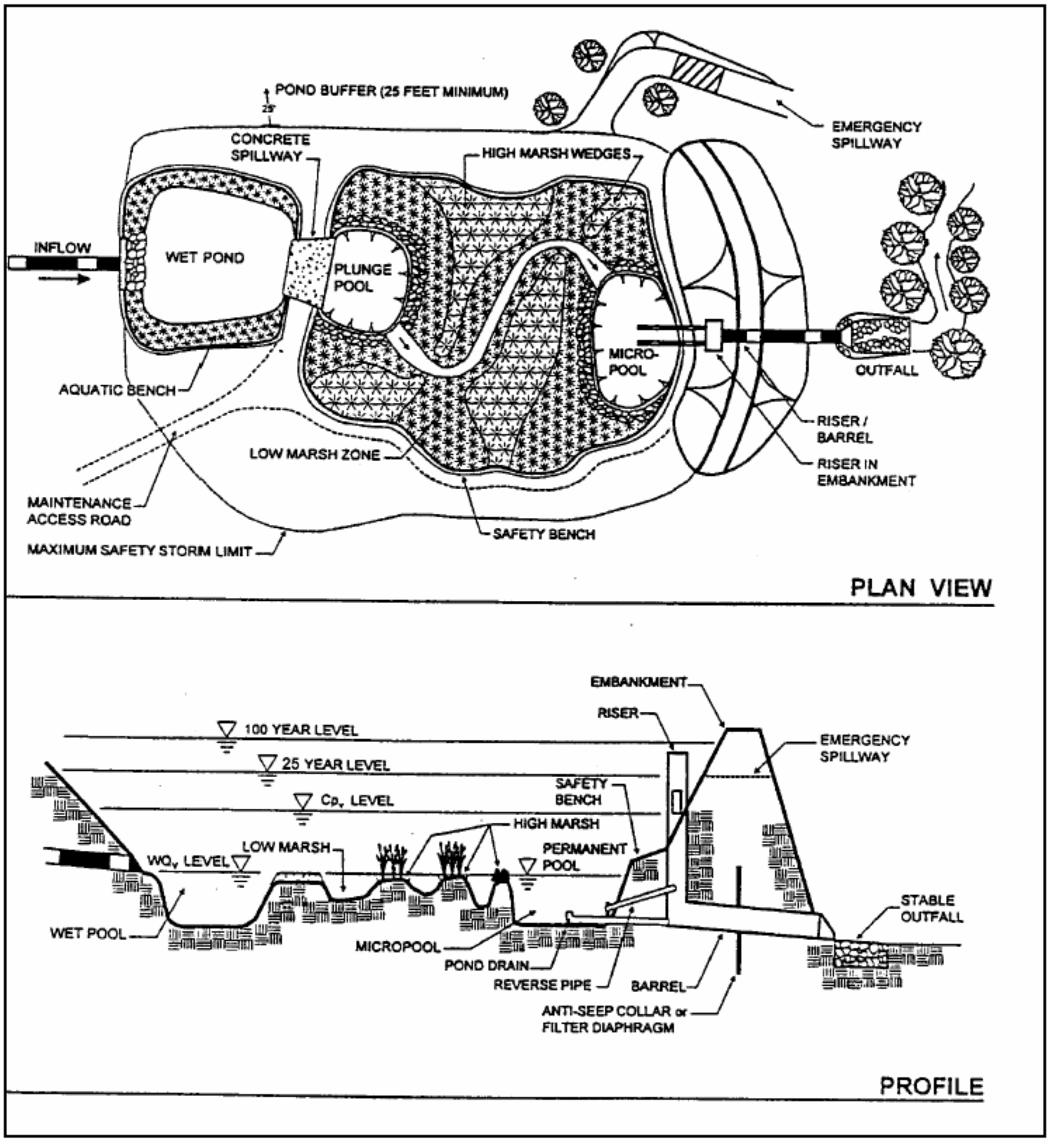


Figure 4-6. Pond/Wetland System (30)

Pocket Wetland (Strategy 3)

A pocket wetland is intended for smaller drainage areas of 5 to 10 acres and typically requires excavation down to the water table for a reliable water source to support the wetland system. However, supplemental water sources such as irrigation runoff or well water may also be used to maintain sufficient hydrology to support the wetland plants. A conceptual plan and profile of a pocket wetland is shown in Figure 4-7.

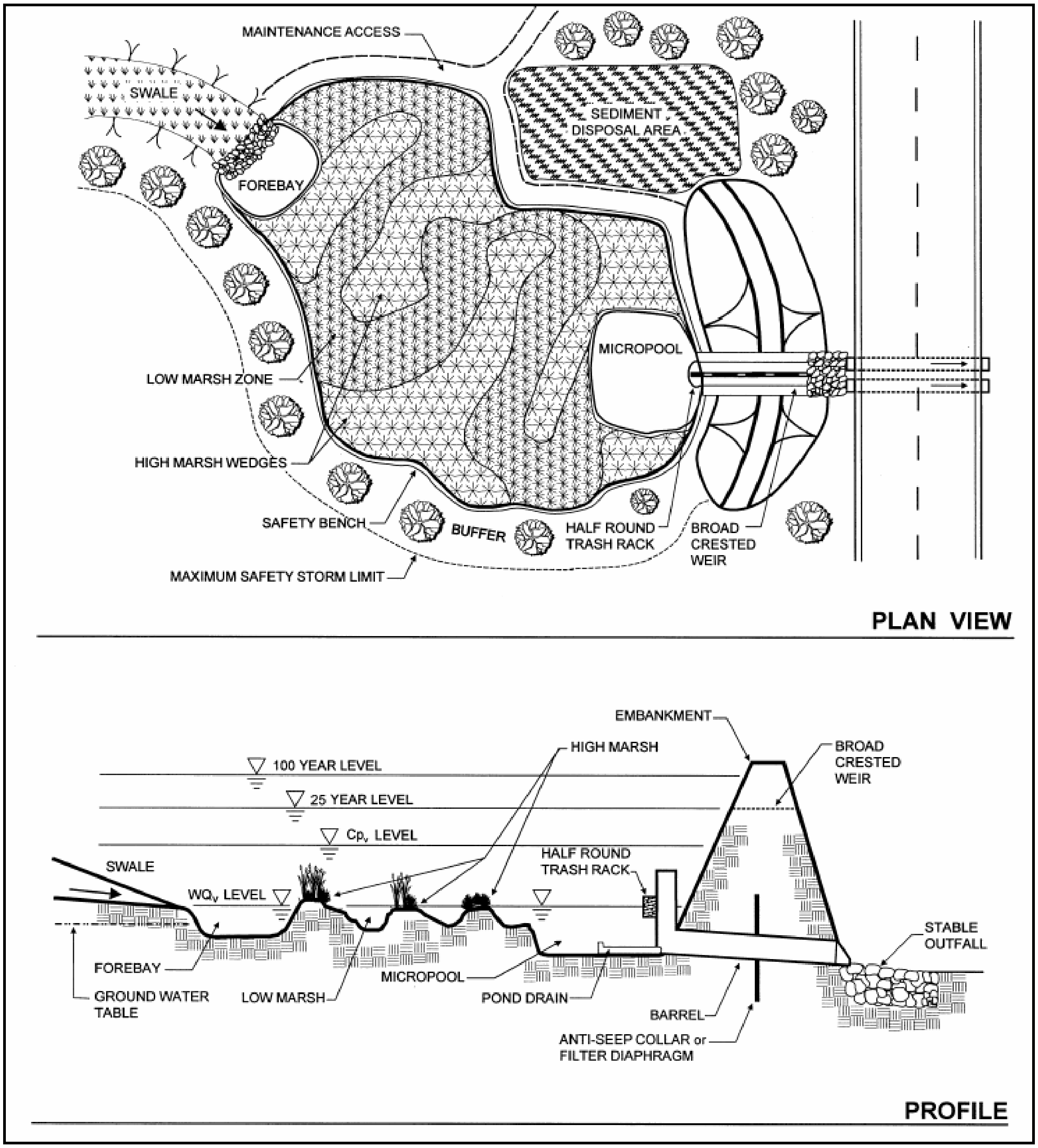


Figure 4-7. Pocket Wetland (30)

4.2.1 Applications

Stormwater wetlands are widely applicable stormwater treatment devices, and with the exception of highly urbanized areas and arid climates, few restrictions exist. Some advantages of stormwater wetlands include: relatively low maintenance costs (with the exception of pocket wetlands), creation of natural wildlife habitat, and good nutrient removal. Stormwater wetlands are also good devices for hotspots, as long as an significant separation from the groundwater is observed.

A series of wetland cells can be created within existing and proposed drainage channels wherever flow balances indicate sufficient hydrology is available to sustain wetland plants and modification of flow carrying capacity does not adversely affect surrounding property.

Wetland swales can be employed where sufficient land is available for construction of broad open channels for flow conveyance and periodicity and quantity of flows to the channel are sufficient to support wetland vegetation.

Stormwater wetlands are generally applicable to most types of new development and redevelopment, and can be used in both residential and nonresidential areas. However, due to large land requirements, wetlands may not be practical in higher density areas. Stormwater wetlands are also suitable for regional stormwater control.

Recommendations for drainage area requirements for stormwater wetlands are a minimum of 25 acres with determination of a positive water balance; 5 acres for a pocket wetland.

The amount of area designated for wetlands should equal approximately 3 to 5 percent of the area to be drained. Additional area should be provided as upland buffers around the wetlands.

Although there should not be more than 8 percent slope across a proposed wetland site, an elevation difference of 3 to 5 feet (2 to 3 feet for pocket wetland) is needed from the inflow to the outflow to allow water level control.

Permeable soils are not well suited for a constructed stormwater wetland without a high water table. Although liners can be constructed for sites with permeable soils, this adds considerable cost and maintenance requirements.

4.2.2 Limitations

Stormwater treatment wetlands require large areas of land with a fairly continuous baseflow to sustain a viable wetland ecosystem. Sediment regulation is critical to sustain appropriate elevations within the wetland system. Wetland treatment systems for runoff from agricultural cropland where herbicides are frequently used should also include a grass buffer strip before the inlet to the wetland to provide an early warning and safeguard against herbicide damage to the wetland.

4.2.3 Effectiveness

Wetlands are among the most effective practices for removing stormwater pollutants, but there is considerable variation in the reported efficiencies of stormwater wetland treatment systems resulting from differences in design, maintenance, and loadings from the drainage basin based on land use. Designs that effectively retain sediments and prevent or minimize resuspension of sediments are also more effective in the removal and retention of phosphorus since phosphorus is mostly adsorbed to the sediments carried in runoff. Table 4-2 provides pollutant removal data dervived from the Center for Watershed Protection's National Pollutant Removal Database for Stormwater Treatment Practices (45).

Table 4-2
Typical Pollutant Removal Rates of Wetlands (45)

Pollutant	Pollutant Removal Efficiency (%)		
	Shallow Marsh	ED Shallow Wetland	Pond/Wetland System
TSS	83 ± 51	69	71 ± 35
TP	43 ± 40	39	56 ± 35
TN	26 ± 49	56	19 ± 29
Metals	36 to 85	(-80)-63	0 - 57
NOx	73 ± 49	35	40 ± 68
Bacteria	76[1]	N/A	N/A

[1] Data based on fewer than five points.

4.2.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

Wetlands designed primarily to control non-point source pollution contained in agricultural runoff should not also have secondary objectives such as long term wildlife habitat or recreational values. However, if those secondary design objectives are desired, employment of pollutant-specific vegetated buffer zones or other pretreatment techniques above the inlet to the wetland may reduce potential adverse impacts to the habitat areas.

Design strategies that incorporate multiple water depths within a wetland system, buffer zones planted with native vegetation, and preservation of other natural areas adjacent to the system will provide a diverse ecosystem with a variety of habitats.

4.2.5 Conceptual Designs

General ecologically sound principles for designing wetlands into a landscape are suggested by Mitsch and expounded by De Laney (186):

- Design the system for minimal maintenance. The system of plants, animal, microbes, substrate and water flows should be developed for self-maintenance and self-design to the extent practicable.
- Design a system that utilizes natural energies, such as potential energy of streams, as natural subsidies to the system. Pulsing streams of water from rainfall events or irrigation return flows transport great quantities of nutrients in relatively short periods.
- Design the system with the landscape, not against it. Floods and droughts are to be expected, not feared. Incorporate existing drainage features into the design to the extent practicable. Outbreak of plant diseases and invasion of alien species are often symptomatic of other stresses and may indicate faulty design rather than ecosystem failure.
- Design the system with multiple objectives, but identify at least one major objective and several secondary objectives.

- Design the system as an ecotone. This means including a buffer strip around the site, but it also means that the wetland site itself is often a buffer system between upland and aquatic systems.
- Give the system time. Wetlands do not become functional overnight – several years may elapse before nutrient retention or wildlife enhancement is optimal. Strategies that try to short-circuit ecological succession or over-manage are doomed to failure.
- Design the system for function, not for form. If initial plantings and animal introductions fail, but the overall function of the wetland – based on the initial objective is intact, then the wetland has not failed. Expect the unexpected.
- Do not over-engineer wetlands with rectangular basin, rigid structures and channels, and regular morphology. Ecological engineering recognizes that natural systems should be mimicked to accommodate biological systems.

4.2.6 Unit Cost

Capital

Due to the great number of construction variables (e.g., excavation, planting, pretreatment or erosion control devices and land acquisition), wetland treatment systems vary significantly in cost. On the low end, Delaney reports costs for constructed wetland systems treating sediment and nutrients averaging about $800 per acre (186). Hammer suggests that a farmer should be able to construct an effective wetland, including planting of limited vegetation, for a little less than $3,000 per acre (186). Kadlec and Knight report unit costs for constructed wetlands treating stormwater runoff ranging from $4,000 per acre to $61,700 per acre (53). EPA provides a methodology for estimating capital cost for a constructed wetland based on storage volume (182). Using an assumed water depth, the EPA method can be converted to a "per acre" unit cost. For an average water depth of 6 to 12 inches, the EPA method yields an estimated capital cost of approximately $49,000 per acre.

Operation and Maintenance

O&M costs for wetland systems are associated with periodic removal and disposal of collected sediment; possible reestablishment of emergent wetland vegetation (if damaged by wildlife, such as feral hogs or nutria); mowing of embankments; and restabilizing banks or channels that may have eroded. EPA estimates the annual O&M cost for constructed wetlands range from 2 to 6 percent of the construction cost (182). Knight reports that for small wetlands (less than 8 acres), O&M costs average about $1,100 per year (102).

4.3 Bank/Slope Stablization/Erosion Control (Strategy 4)

Stream bank erosion is a natural process that occurs in streams. However, man-induced alteration of stream channels and land use changes within a drainage basin can result in significantly increased rates of erosion. The major factors accounting for stream bank erosion are the velocity of the flowing water and the local soils. Velocity is affected by the stream cross-section, streambed gradient, bank cover, depth of flow, and degree of meander. There are numerous methods of controlling stream bank erosion including both non-structural and structural or a combination of these two strategies. Strategy 4 focuses on techniques that employ vegetation in bioengineering applications. Based on the definition from the USACE Waterways Experiment Station reports (98 and 185), soil bioengineering is the use of live and dead plant materials, in combination with natural and synthetic support materials, for slope stabilization, erosion reduction, and vegetative establishment.

Bank stabilization practices that rely on vegetation to protect stream banks are much more sensitive to the effects of urbanization than more structural practices. While the effects of increasing imperviousness are less noticeable with structural practices, bank stabilization practices in drainage basins with a high percent of impervious surfaces tend to be less successful. Therefore, in more urban watersheds, bank stabilization practices based on vegetative stability are often used in combination with structural bank protection practices. The combined practices enable the stream bank to withstand elevated storm flows, high stream velocities, and rapid water level fluctuations (characteristics of urban streams) during the time appropriate vegetation is being established.

The riparian zone of a river, stream, or other water body is the land adjacent to that body of water that is, at least periodically, influenced by flooding. Riparian ecosystems usually occur as an ecotone between aquatic and upland ecosystems but have distinct vegetation and soil characteristics (103). Most commonly recognized riparian ecosystems include bottomland hardwoods and floodplain forests, typical of the eastern and central United States and bosque or streambank thickets in more arid regions in the west. Riparian ecosystems are uniquely characterized by the combination of high species diversity, high species densities and high productivity. These characteristics develop as a result of the large fluxes of energy and materials from upstream systems. The plant communities of riparian ecosystems are generally very productive and diverse due to the periodic flooding (103).

Primary productivity in riparian areas is generally higher than that in uplands from the same region. The riparian ecosystem acts as a nutrient sink as regards to its effect on lateral runoff from uplands but as a nutrient transformer as regards to the entire export of the watershed (103).

Bioengineering designs should address factors contributing to the bank or slope erosion and provide remediation to the extent possible within the local constraints. Other design components to consider include climatological data, physical constraints, hydrodynamic aspects, geomorphic features, and soil characteristics. The biological component of the bioengineering design is very important and plant selection should be based on availability of plant materials, adaptations to the ecological conditions of the site, as well as tolerance to the various hydroperiods resulting from fluctuations in water levels and position on the bank slope. Native plants suitable for providing the structural stability of erosion control may also provide habitat needs for local wildlife.

When designing a bank stabilization project with soil bioengineering some additional parameters need to be considered (159):

- Compaction of the backfill needs slight modification to allow for root system development.
- Slight modification in the backfill to provide both a well-drained environment and moisture to the vegetation.

- Preplanning for suitable planting times and/or availability of plant materials is required.

Bioengineering designs typically addresses multiple zones along the stream bank. Based on design guidelines developed at the USACE Waterways Experiment Station (185), these zones are referred to as the toe zone, splash zone, bank zone, and terrace zone. Figure 4-8 illustrates the location of the identified zones. Appropriate plant selection should be made for each zone.

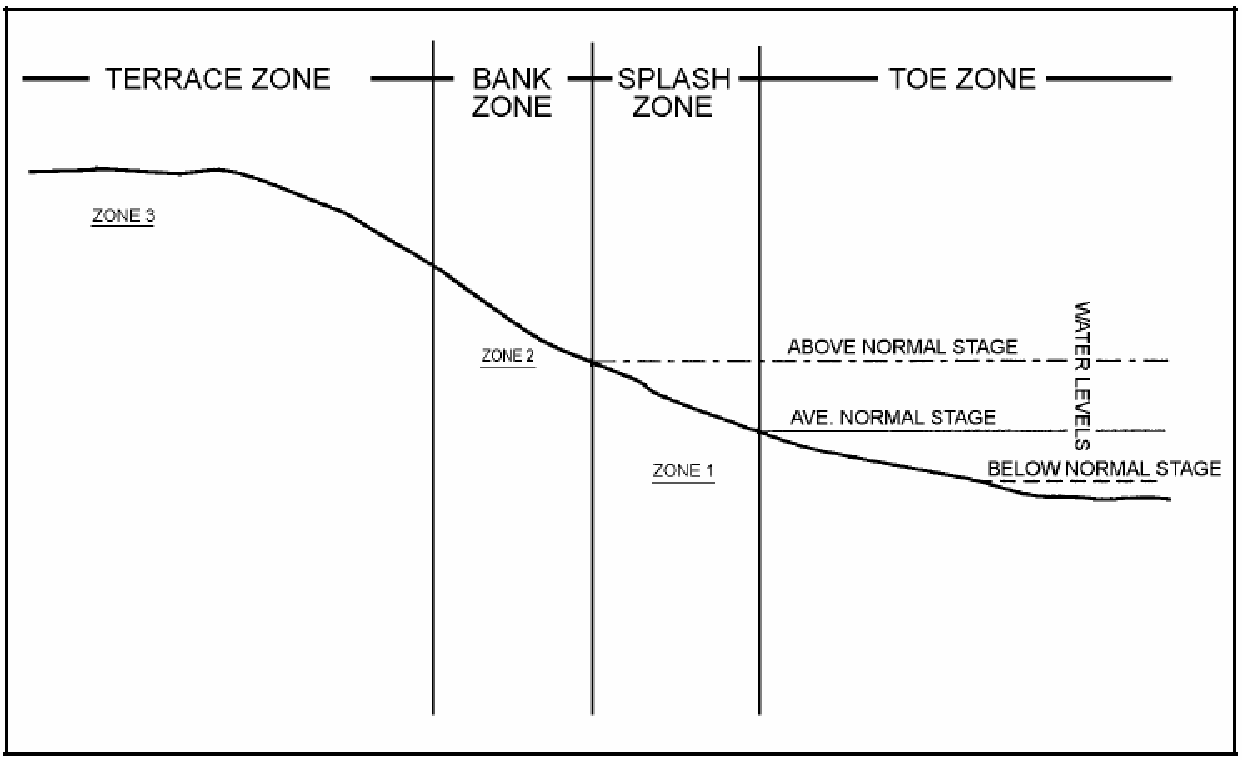


Figure 4-8. Elevation Zones of a Streambank Riparian Ecosystem(185)

To check the stability of soil bioengineering techniques, the ability of the vegetation to resist shear stress needs to be considered as well as the ability of the vegetation to adapt to the existing conditions of the site.

Natural structural components utilized in bioengineering include coir logs, coir mats, brush mattresses, rock toe revetments, rock rolls, gabion baskets, geotextile fabric and mats, LUNKERS, bank cribs, root wads, log revetments, wattling bundles, brush layering, vegetative geogrid (fabric encapsulated soil), dormant posts (living posts of woody vegetation), and live stakes (smaller live cuttings of woody vegetation). Discussions of the use of and design incorporating these materials can be found in the USACE Waterways Experiment Station Bioengineering Design Manual (185).

4.3.1 Applications

Bioengineering designs are generally suitable for stream slopes where velocities are less than 10 feet per second (fps), although literature regarding some newer design geotextile mats indicate that they are applicable up to 25 fps (SIGeosolutions, Pyrmat High Performance Reinforcement Mats). Most of the velocity data from the literature developed for turf grass cover designed for erosion control ditches or waterways indicate use of grasses on bank areas where velocities are not expected to exceed 6 to 8 fps. Maximum flow velocities suggested by Hoag (1993, as cited in Reference 185) were less than 3 fps for herbaceous plantings, 3-5 fps for woody and herbaceous mixed plantings, 5-8 fps for woody planting alone, and that maximum flows above 8 fps require soil-bioengineering approaches. For the case studies monitored by the USACE Waterways Experiment Station during the development of their Bioengineering Design Manual, measured velocities for local flow conditions around the bioengineering treatment never exceeded 10 fps.

In order to evaluate velocities, the IBWC existing HEC-RAS model of the Arroyo Colorado Floodway was utilized to simulate the design floodway flow for 21,000 cfs and the median (non-flood) flow of 285 cfs. For flood conditions, the average channel velocity is approximately 6 fps, and typically ranges between 4 and 8 fps. For low-flow conditions, the channel velocities are typically between 1 and 2 fps. Estimated velocities in the Arroyo Colorado are provided in Table 4-3. Site specific conditions may vary.

Table 4-3
Arroyo Colorado Channel Velocities

	Design	**Median**
Flow (cfs)	21,000	285
Channel Velocity (fps)		
Average	6.09	1.50
Median	6.02	1.50
Maximum	12.01	5.67
Minimum	2.74	0.29
25% Percent Exceedance	4.80	1.16
75% Percent Exceedance	7.11	1.65

Properly keying in structures for toe and end protection as well as monitoring, and possible maintenance early in the life of a bioengineering project are important for long-term success.

4.3.2 Limitations

Using planted vegetation for stream bank and slope erosion control has its limitations. These may include the occasional failure of the growth of the planted vegetation, the vegetation may be subject to undermining; it may be uprooted by high wind or water; wildlife (or livestock) may feed upon and depredate it; and it may require some maintenance. Most of these limitations, such as undermining or uprooting may be lessened or prevented by the use of bioengineering measures (185).

Other limitations include poor plant growth as a result of infertile soils and impacts from high wave action.

4.3.3 Effectiveness

Bank and slope stabilization primarily address instream loadings of sediment. However, bioengineering techniques which address multiple zones along the stream bank also in effect help restore riparian buffers. Riparian buffers are generally also very effective at trapping sediment and nutrients in surface runoff from the drainage basin. Effectiveness of removal of contaminants is directly linked to width of buffer and slope (96). The tables included in Figure

4-9 report effective removal of TSS, TP and TN based on width and slope of buffer (Wenger 1999) (as cited in 96).

Author	Width (m)	% Slope	% Removal of TSS
Dillaha et al (1988)	4.6	11	87
Dillaha et al (1988)	4.6	16	76
Dillaha et al (1988)	9.1	11	95
Dillaha et al (1988)	9.1	16	88
Dillaha et al (1989)	4.6	11	86
Dillaha et al (1989)	4.6	16	53
Dillaha et al (1989)	9.1	11	98
Dillaha et al (1989)	9.1	16	70
Magette et al (1989)	4.6	3.5	66
Magette et al (1989)	9.1	3.5	82
Peterjohn & Correll (1984)	19	5	90
Peterjohn & Correll (1984)	60	5	94
Young et al (1980)	21.3	4	75-81
Young et al (1980)	27.4	4	66-93

Study	Total P Removal	
	4.6 m buffer	9.1 m buffer
Dillaha et al 1988	71.5%	57.5%
Dillaha et al 1989	61%	79%
Magette et al 1987	41%	53%
Magette et al 1989	18%	46%

Study	Total N Removal	
	4.6 m buffer	9.1 m buffer
Dillaha et al 1988	67%	74%
Dillaha et al 1989	54%	73%
Magette et al 1987	17%	51%
Magette et al 1989	0%	48%

Figure 4-9 Data Tables with reported removal efficiencies for riparian buffers (96).

4.3.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

Although riparian zones typically are a small component of the landscape, they provide essential habitat for many species of birds, mammals, and herpetofauna (97). The riparian zone is also valuable for many animals that seek its refuge, diversity of habitat, and abundant water or that use it as a corridor for migration. The preservation and/or creation of habitat corridors and landscape linkages with reestablishment of riparian zones is an important aspect of wildlife conservation strategy as it serves to reconnect fragmented habitats. These habitat corridors can be comprised of native tall grass prairies with limited woody vegetation that would be amenable to current IBWC maintenance regimes so that impacts to floodway capacity would be minimal. (Manning's n values used in HEC-RAS model runs of hydraulic modeling for the Arroyo Colorado Floodway conducted by IBWC ranged from 0.065 to 0.07 for the bank areas upstream of State Highway 448 in Harlingen. Downstream of State Highway 448, Manning's n values used for bank areas of the Arroyo Colorado were 0.2. The 0.065 to 0.07 n values used are characterized as representing vegetative growth where the average depth of flow is less than half the height of vegetation as characterized by bushy willow trees about 1 year old intergrown with weeds along side slopes with all vegetation in full foliage, or dense cattails growing along the channel bottom, or trees intergrown with weeds and brush and all vegetation in full foliage. The 0.2 n value used represents fully vegetated banks with dense understory and all vegetation in full foliage.) Although establishment of native tall prairie grasses and shrubs within the floodway would need to be approved by the IBWC and verification that the roughness created by the proposed vegetation would be within acceptable constraints, the physical characteristics of a tall prairie grass community should provide less resistance to flow than the bushy willow trees or dense cattails described above. Annual mowing of a tall prairie grass community interspersed with some woody shrubs as conducted during routine maintenance activities by the IBWC would not adversely impact the survival of the vegetation, especially if vegetation was mown to a height of 8 inches.

4.3.5 Conceptual Designs

Figures 4-10 through 4-16 provide conceptual designs for various types of bioengineering techniques.

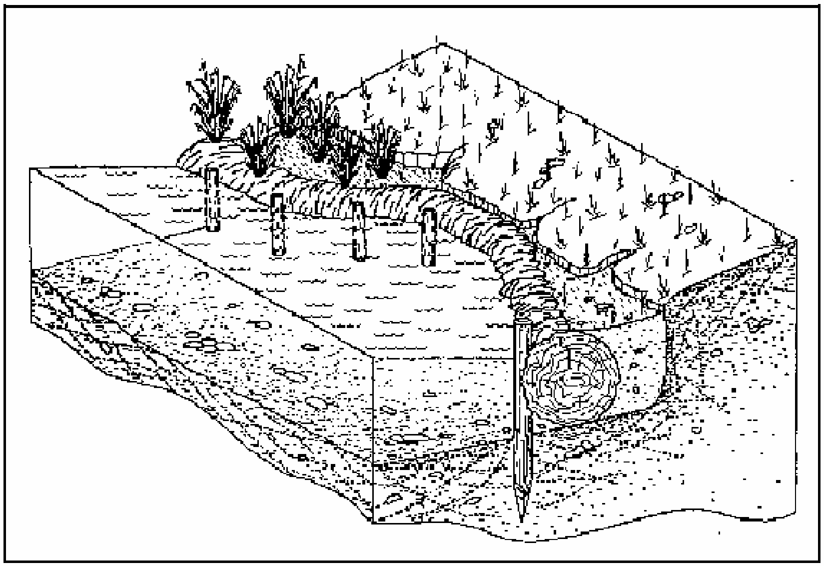
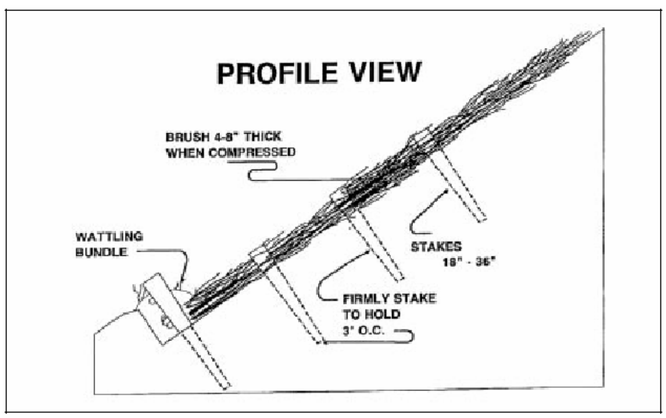
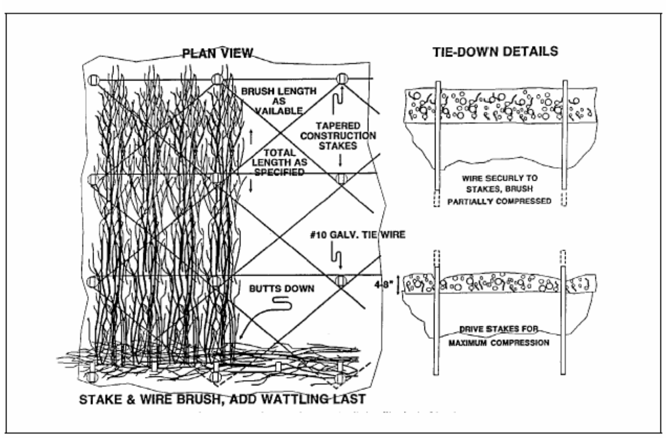


Figure 4-10. Coir geotextile rolls are used to stabilize streambanks and permit planting of wetland vegetation within them (185)



a. Profile view



b. Plan view

Figure 4-11. Schematics of brushmattress and wattling combination used to provide erosion protection and establish shrub vegetation along stream bank at and above water line.(185)

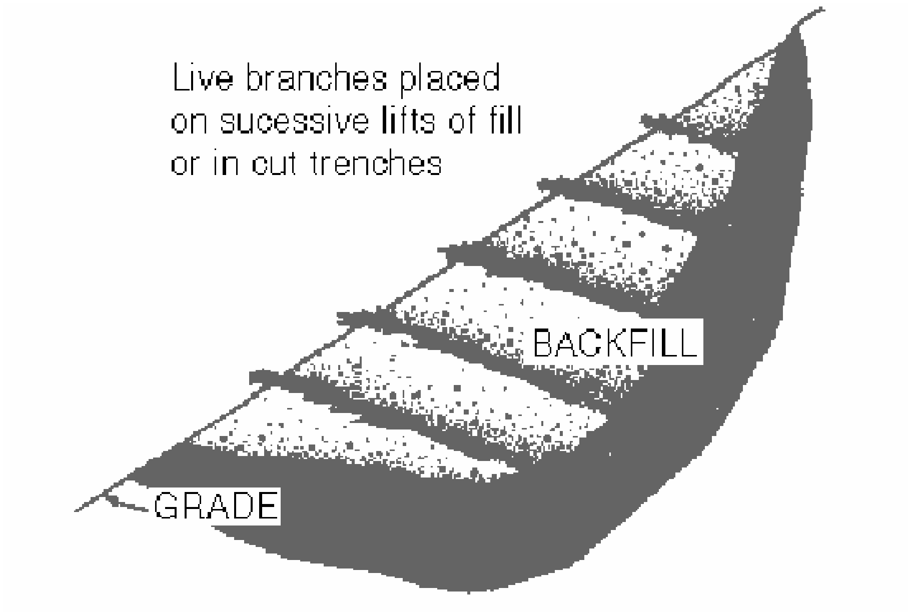


Figure 4-12. Cross-section of brush layering to provide erosion protection of stream bank above water line (185)

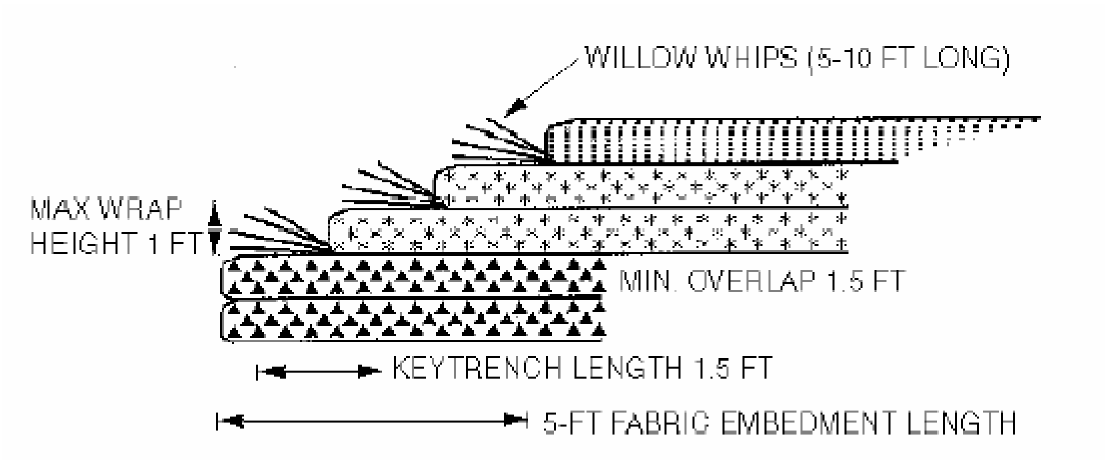


Figure 4-13. Cross section of vegetative geogrid, also called fabric encapsulated soil with vegetation for reinforcement of stream bank (185)

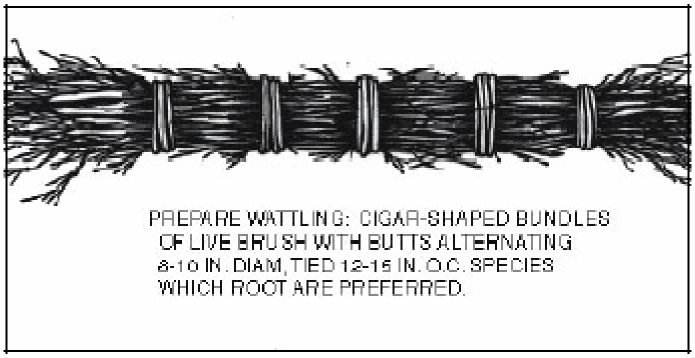


Figure 4-14. Schematic of wattling bundle with preparation specifications (185)

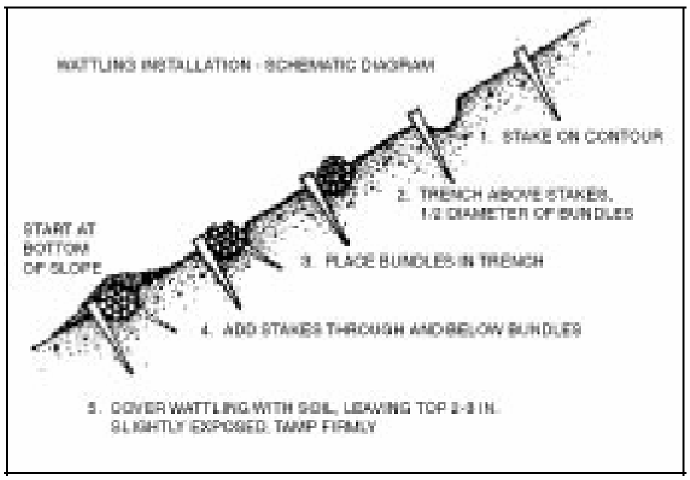


Figure 4-15. Procedures for installing wattling bundles on slope in bank zone (185)

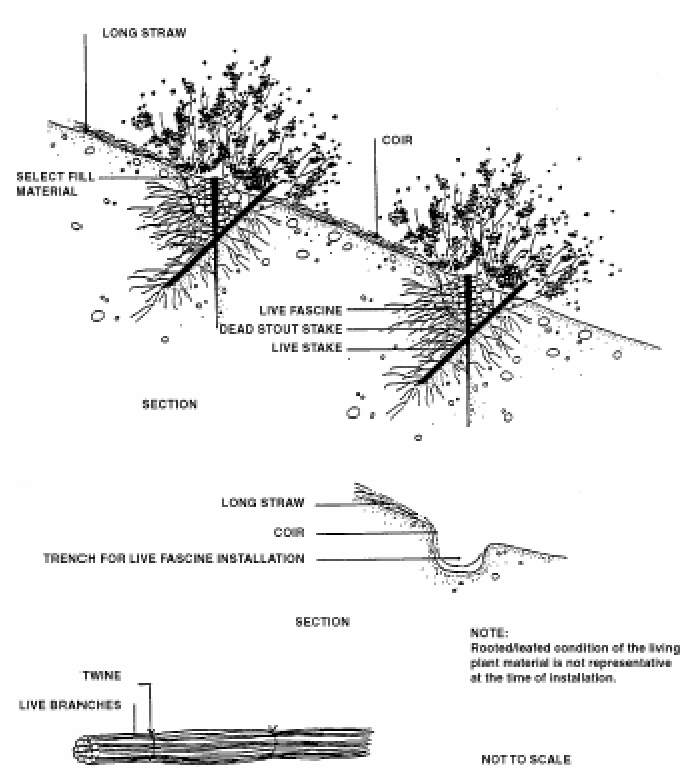


Figure 4-16. Schematic illustration of live fascine bundles with coir rope mesh fabric and long straw installed between bundles (185).

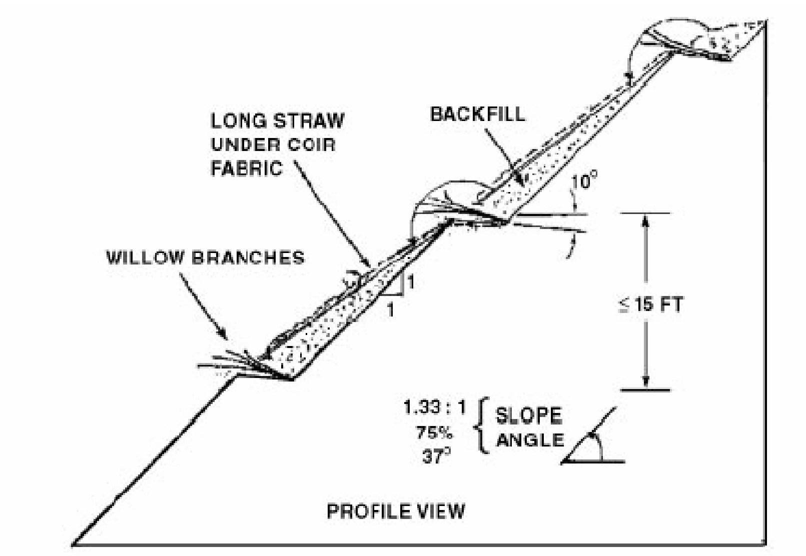


Figure 4-17. Brush layering with coir woven fabric and long straw under fabric (Coir fabric and straw help control rillying and gullying between layers) (185).

4.3.6 Unit Cost

Capital

The use of bioengineering solutions for stabilizing shorelines is a low cost, highly effective means of solving erosion problems. Bioengineering techniques are typically lower cost than traditional "hard-scaping" erosion control techniques. For typical installations, the cost for a bioengineering solution can range from $10 to $80 per foot of shoreline (191). Traditional approaches can cost from $100 to $1000+ per foot. Table 4-3 provides budgetary installation costs for some commonly used bioengineering techniques.

TABLE 4-4
Unit Capital Costs for Various Bioengineering Techniques (191)

Bioengineering Technique	Installation Cost ($ per linear foot of shoreline)
Vegetative Stabilization	$10 - $20
Live Stakes ("willow post" method)	$10 - $20
Fiber rolls	$25 - $35
A-jacks	$30 - $75
Live cribwall	$90 - $100

Operation and Maintenance

Maintenance costs for a bioengineered site should be low or not required, once the site becomes well established. Some long-term maintenance may include annual or biennial controlled burns (or mowing) to control non-native plants and prevent invasion of undesirable woody plants. Selective use of a herbicide also may be helpful in controlling invasive weed species until the native vegetation is fully established.

4.4 Filtration (Strategy 5)

Vegetative filter strips (VFS) are zones of vegetation through which sediment and pollutant-laden flows are directed before being discharged to a concentrated flow channel. Engineered filter strip buffer zones are designed to mimic natural ecological communities such as grassy meadows or riparian areas. Both naturally occurring and preserved vegetation zones, as well as constructed vegetation zones, are considered filter strips. Strategy 5 focuses on various forms and applications of VFS.

Dense vegetation facilitates conventional pollutant removal through detention, filtration by vegetation, sediment deposition, and infiltration and adsorption in the soil as well as uptake by the vegetation and associated microbes. VFS are often used in conjunction with other management strategies to reduce sediment and pollutant loading to downstream treatment strategies, to reduce maintenance costs and to enhance overall pollutant removal capabilities. However, filter strips are effective only for sheet flow and provide little treatment for concentrated flows (168).

More recent and developing use for the filter strip include: the use of filter strips to reduce the impact of development on the hydrologic regime alterations of a site; addressing groundwater recharge concerns; reducing impacts to stream channel erosion; and controlling peak discharges for the 2, 10, and 100-year storms (168).

Factors that affect VFS performance include: flow rate, drainage area, development conditions, soils, infiltration rate, topography, depth of water table, vegetation, climate, sediment characteristics, and characteristics of chemicals being trapped.

The effectiveness of a VFS is inversely related to flow rate (168). As runoff travels across surfaces (whether pervious or impervious), it begins to collect into channels of more concentrated flow. Concentrated flow channels across a VFS tend to decrease the effectiveness of contaminant removal. A more significant problem is that deeper flow channels can start erosion and form incised channels, causing VFS failure (168). Therefore, recommended values of overland flow are reduced to 150 feet over pervious surfaces and 75 feet over impervious surfaces (168). A level spreader may be used to convert shallow concentrated flow from larger areas back to sheet flow before it enters the filter strip. In any event, the contributing drainage area should be kept relatively small and a maximum of 5 acres is suggested (168).

Figures 4-18 through 4-21 provide illustration of a variety of vegetative filter strip applications and designs**.**

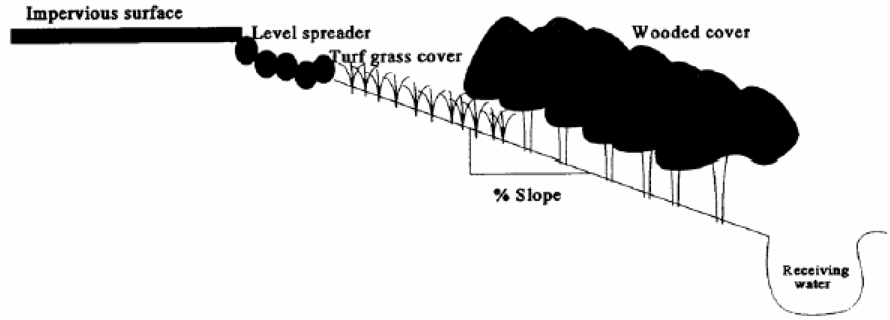


Figure 4-18. Filter Strip (168)

Figure 4-19. Filter Strip (168)

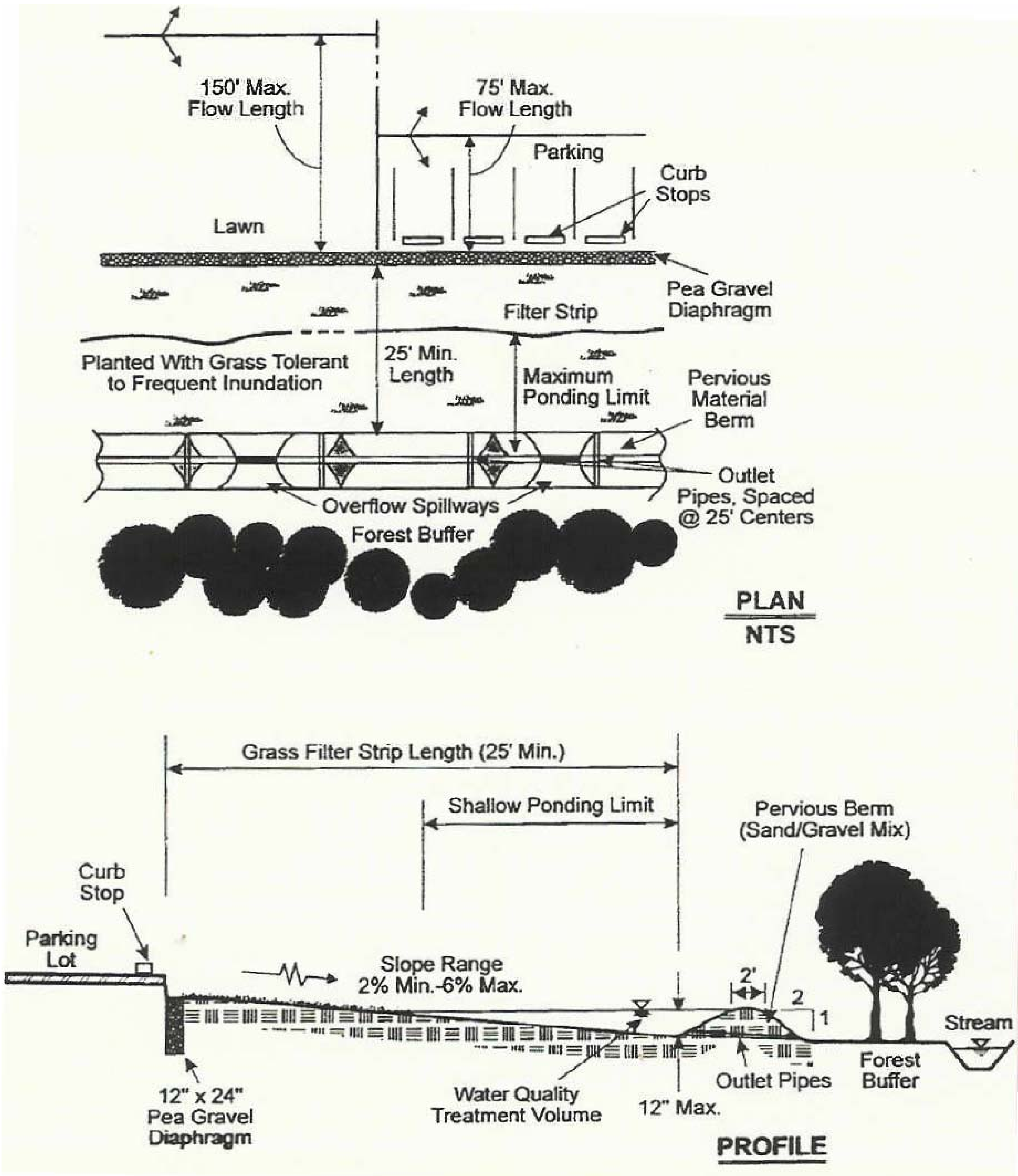


Figure 4-20. Vegetative Filter Strip (CRC, 1996 used with permission) (from EPA/600/R-04/121A) (168)

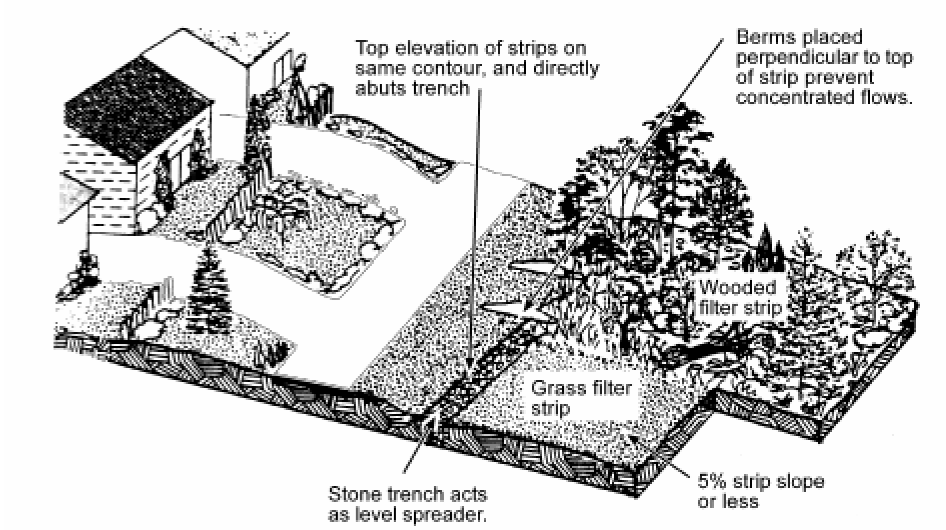


Figure 4-21. Schematic of a Grassed and Wooded Filter Strip, Schueler, 1987, (from Protecting Water Quality in Urban Areas Manual)

4.4.1 Applications

Engineered filter strips are applicable to most regions of the country, but are restricted in some watersheds where land is not available to install them. Filter strips are best suited for treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. Filter strips are also ideal components of the "outer zone" of a stream buffer or as pretreatment to another stormwater treatment practice.

VFS have historically been used and proven successful on agricultural lands, primarily due to their low runoff volumes. In urban areas, filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, small parking areas and other small impervious areas. Filter strips should not be used to control large impervious areas (168).

VFS may be incorporated into buffer zones along drainages to physically protect and separate a stream from disturbance or encroachment, provide stormwater management, and act as a right-of-way during floods, sustaining the integrity of stream ecosystems and habitats (45). The three zone buffer system is an effective technique for establishing a buffer, consisting of an inner, middle, and outer zones. The zones are distinguished by function, width, vegetative target, and allowable uses. The buffer should be composed of three lateral zones, a stormwater depression area that leads to a grass filter strip that in turn leads to a forested buffer. The stormwater depression is designed to capture and store stormwater during smaller storm events, and bypass larger stormflows directly into a channel. The captured runoff within the stormwater depression can then be spread across a grass filter designed for sheetflow conditions for the water quality storm. The grass filter then discharges into a wider forest buffer designed to have zero discharge of surface runoff to the stream (i.e., full infiltration of sheetflow) (45). The three-zone buffer system is illustrated in Figure 4-18 above.

The limiting design factor for filter strips is not the drainage area the filter strip treats but rather the length of flow contributing to it (45).

Filter strips should be designed on slopes between 2 and 6 percent. Topography needs to be relatively flat to maintain sheet flow conditions. Although, some designs have been successful in steeper slopes ranging from 15 to 20 percent (168). Filter strips should not be used on soils with high clay content because they require some infiltration for proper treatment.

4.4.2 Limitations

Filter strips should not be used to control runoff from large impervious areas or to treat concentrated flows. Poor soils that cannot sustain vegetative cover may be a limiting factor. A high water table, either sustained or seasonal, will inhibit opportunity for infiltration. Therefore, filter strips should be at least 2 feet above the mean high water table. If the soil's permeability and/or depth to water table are unsuitable for infiltration, the filter strip's primary function becomes the filtering and settling of pollutants. A modified design may be provided to allow ponding of the water quality volume at the filter's downstream end.

Filter strips require a large amount of space, typically equal to the impervious area they treat, making them often infeasible in urban environments where land prices are high.

If improperly designed, filter strips can become a mosquito breeding ground.

Slight problems in the design or construction, such as improper grading, can render the practice ineffective in terms of pollutant removal.

For the three-zone buffer system, there are several perceived impediments associated with implementation. These may include the following:

- Potential loss of developable land;
- Private landowners may be required to provide public access to privately held stream buffers;
- Excessive nuisance species will be present due to the natural buffer area; and buffer programs will place additional demand on scarce local government resources.

Three-zone buffer systems have also been suggested for agricultural areas to allow some limited use of riparian land while preserving buffer functionality (96).

4.4.3 Effectiveness

The pollutant removal mechanisms utilized in filter strips are similar to those employed in grassed swales and provide modest pollutant removal. Under low to moderate velocity, filter strips effectively reduce particulate pollutant levels such as sediment, organic materials, and trace metals (168). Research in Florida demonstrated removal rates of 70 percent for TSS, 40 percent for phosphorus (particulate) and zinc, 25 percent for lead, and 10 percent for nitrate/nitrite. Removal of soluble pollutants is accomplished when pollutants infiltrate into the soil, some of which are subsequently taken up by rooted vegetation. Therefore, removal of solubles depends on the infiltration rates. However, this mechanism is minor in most filter strips since only a modest portion of the incoming runoff is infiltrated, resulting in low removal rates for solubles (168).

Studies from agricultural settings suggest that a fifteen foot wide grass buffer can achieve a 50 percent removal rate of nitrogen, phosphorus, and sediment, and that a 100-foot buffer can reach closer to 70 percent removal of these constituents (45). Pollutant removal varied depending on the length of flow in the filter strip. Other factors affecting the rate of removal in filter strips include slope, soil permeability, size of contributing runoff area, particle size and settling velocity, and runoff velocity (168). In design, the variables that can be effectively manipulated include length and slope of the strip, soil characteristics, and vegetative cover.

Depending on design and width of multi-zone buffer systems, some improvement in removal efficiencies over vegetated filter strips may be achieved. Pollutant removal rates up to 89 percent for TSS, 88 percent for TP, and 87 percent for TN have been reported (45).

4.4.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

Although water quality is usually given a higher priority for design of VFS and buffer zones, aquatic habitat functions as well as terrestrial wildlife habitat, floodwater storage functions, recreation, and aesthetic value can also be achieved**.**

4.4.5 Unit Cost

Capital

The costs of establishing a VFS are relatively low. Costs are negligible when an existing grass or meadow area is reserved at a site before development begins. Further savings are realized if the VFS is used as an on-site erosion control practice during the construction phase of the development. Table 4-5 provides comparative costs for VFS establishment**.**

Table 4-5
Comparative Unit Costs for Vegetated Filter Strips (168)

Establishment Method	**Cost**		
Hydroseeding	***< 2 acre***	***2 to 5 acre***	***> 5 acre***
Temporary	$1,050 - $1,750	$875 - $1,550	$725 - $1,300
Permanent	$1,650 - $2,200	$1,350 - $2,025	$1,050 - $1,750
Conventional Seeding	***< 2 acre***	***2 to 5 acre***	***> 5 acre***
Temporary	$1,050 - $1,750	$875 - $1,550	$725 - $1,300
Permanent	$1,450 - $2,200	$1,200 - $1,975	$1,050 - $1,750
Sodding	$7,260 - $19,360 per acre		
Fertilization	$300 - $400 per acre		

Other sources cite potential installation costs ranging from $13,000 to $30,000 per acre, but state that if the site was to be seeded or sodded anyway, the designer should only include the net cost increase caused by the additional improvements needed for treatment; such as a berm and gravel diaphragm (182).

Operation and Maintenance

Maintenance costs for a VFS will depend on its length, vegetation type and frequency of mowing, but costs, relative to other strategies, are low. One source states that typical maintenance costs are about $350 per acre per year (182).

4.5 Channels (Strategy 6)

Strategy 6 relates to modifications made to drainage channels to create a strategy called a wet swale. A wet swale is a grassed open channel consisting of a broad open channel capable of temporarily storing water (88). Unlike the dry swale, a wet swale does not have an underlying filtering bed. The wet swale is constructed directly within existing soils and may or may not intersect the water table (88). The wet swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and microbial breakdown of pollutants. Wet swales also reduce the flow velocity of stormwater runoff and may promote infiltration. Wetland vegetation can be planted or allowed to naturally colonize these systems (88). Wet swales are designed to retain the water quality volume for 24 hours. The wet swale essentially acts as a very long and linear shallow wetland treatment system.

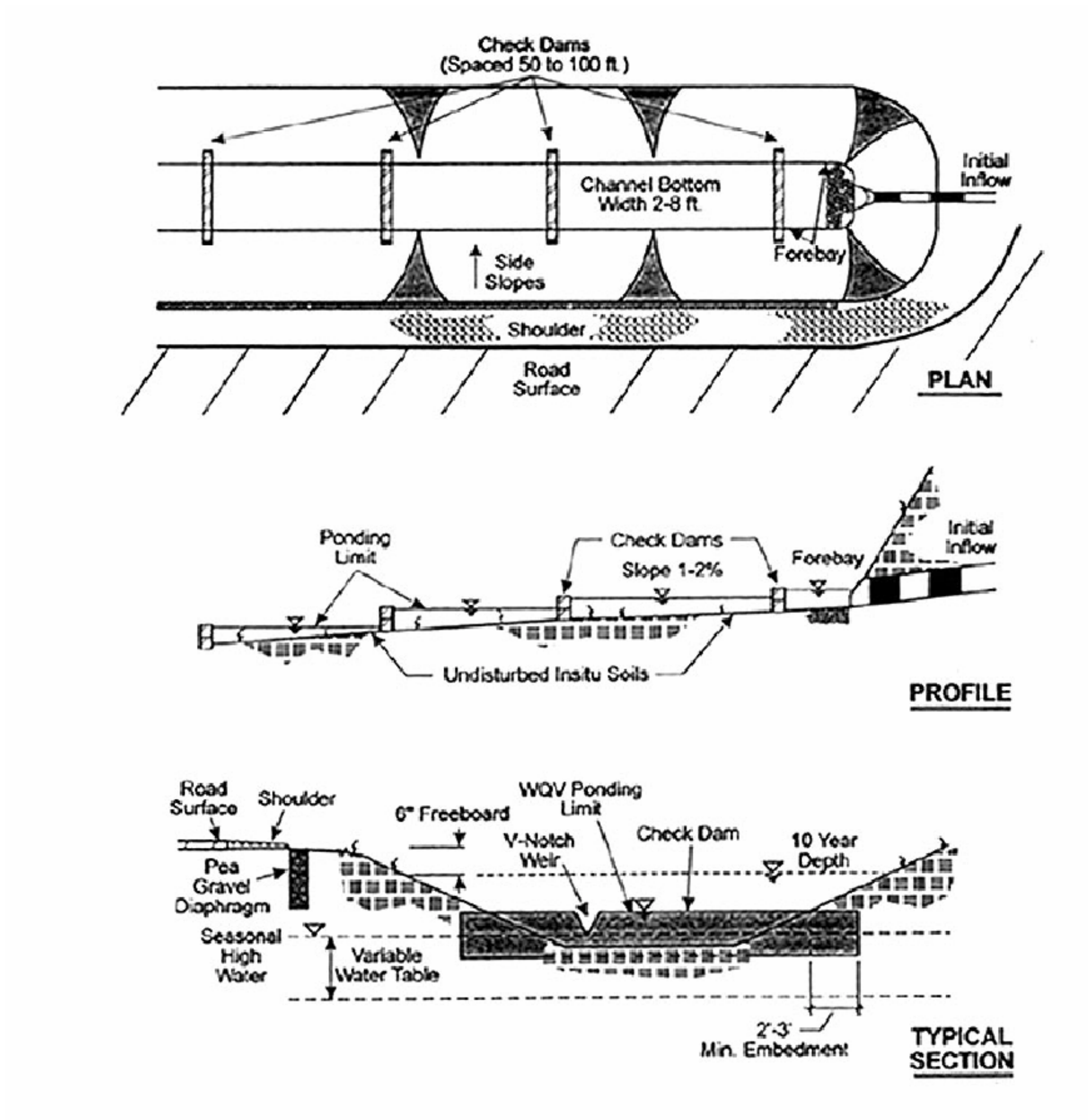


Figure 4-22. Wet Swale (88)

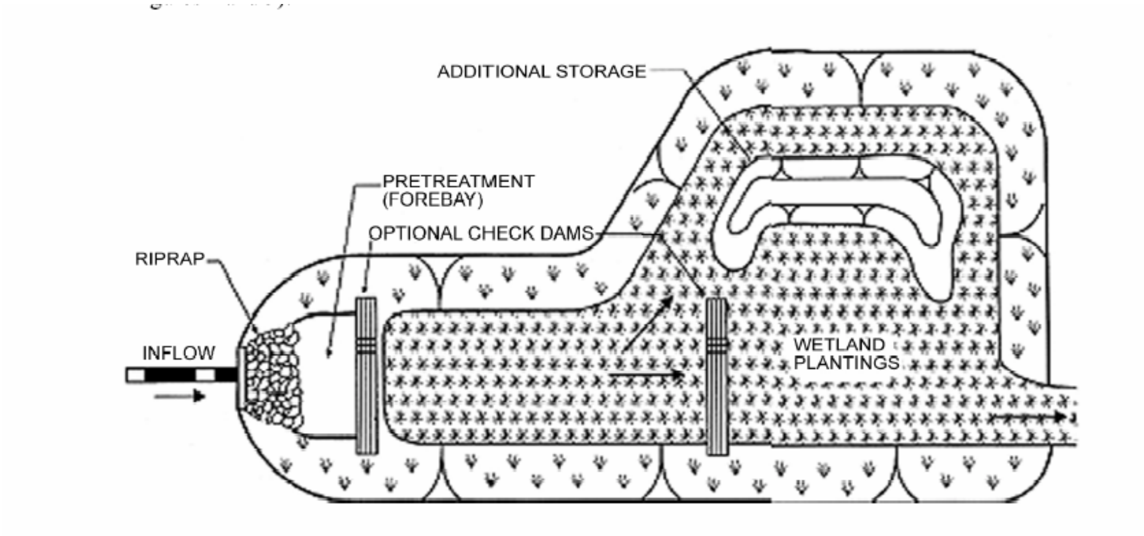


Figure 4-23. Wet Swale (88)

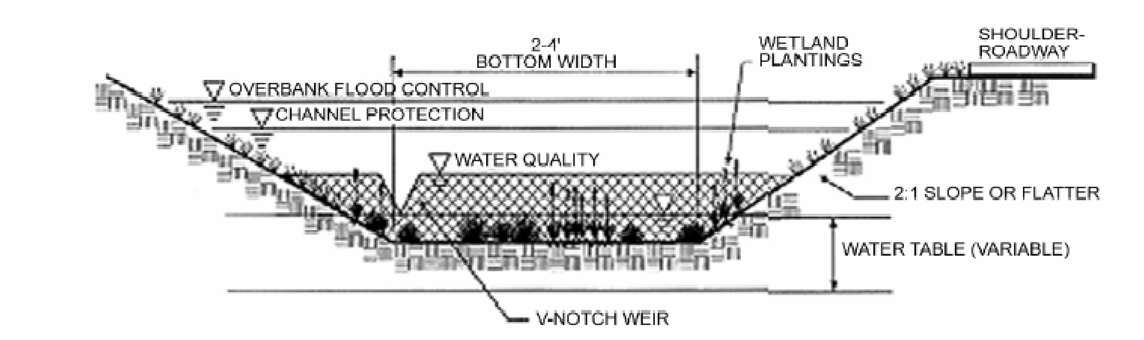


Figure 4-24. Wet Swale Cross Section (88)

4.5.1 Applications

Wet swales are typically located along property boundaries along a natural grade or they can serve as part of a stormwater drainage system replacing curbs, gutters, and storm sewer systems (88).

4.5.2 Limitations

- Wet swales may be impractical in areas with very flat grades, steep topography, or wet or poorly drained soils.
- Erosion may be a problem when flow volumes and/or velocities are high during storm events.
- Area requirements can be excessive for highly developed sites.

- Roadside swales become less feasible as the number of driveway entrances requiring culverts increases**.**

4.5.3 Effectiveness

Wet swales are considered very effective for sediment control with high removal rate for TSS. They are moderately effective for reduction of nutrient loading with mid-range removals of total phosphorus and nitrogen. They also provide moderately effective removal of heavy metals, fecal coliform, and BOD (88).

4.5.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

Wet swales may enhance biological diversity and create beneficial habitat between upland areas and surface waters (88). However, this habitat benefit would be limited by the size, location, and minimal diversity of vegetation within the swale.

4.5.5 Conceptual Designs

Wet swale design criteria are provided in Figure 4-25.

Parameter	Swale Design Criteria
Pretreatment volume	.05" per impervious acre, at initial inflow point.
Preferred shape	Trapezoidal or parabolic.
Bottom width	2 feet minimum, 8 feet maximum widths up to 16 feet are allowable if a dividing berm or structure is used.
Side slopes	2:1 maximum, 3:1, or flatter preferred.
Longitudinal slope	1.0% to 2.0% without, check dams.
Sizing criteria	Length, width, depth, and slope needed to provide surface storage for WQV. Outlet structures sized to release WQV over 24 hours.
Underlying soil bed	Equal to swale width Dry Swale: Moderately permeable soils (USCS ML, SM, or SC) 30" deep with gravel/pipe underdrain system Wet Swale: Undisturbed soils, No underdrain system
Depth and capacity	▸ Surface storage of WQV with a maximum ▸ depth of 18 inches for water quality treatment (12" average depth). ▸ Safely convey 2 year storm with non-erosive velocity (≤ 4.0 to 5.0 ft/s) ▸ Adequate capacity for 10 year storm with 6" of freeboard

Figure 4-25. Swale Design Summary (88)

4.5.6 Unit Cost

Capital

As with most other stormwater management practices, channels or swales will be designed and constructed to meet site-specific conditions. As such, there is much variability in cost between site-specific applications. Little data are available that provides a generalized unit cost for constructing various swale configurations. A 1991 study estimated the construction cost of grassed channels at approximately $0.25 per square foot (192). A study conducted within the past 5 years states that a more realistic estimate is about $0.50 per square foot (45).

Operation and Maintenance

Again, very little data are available on O&M costs for channels Most of the maintenance activities will include maintenance of the grass or wetland plant cover. Table 4-6 identifies some of the maintenance activities associated with channels/swales.

Table 4-6
Typical Maintenance Activities for Channels and Swales

Activity	Schedule
• Inspect pea gravel diaphragm for clogging and correct if needed • Inspect grass along side slopes for erosion and formation of rills or gullies and correct if needed • Remove trash and debris accumulated in forebay area • Inspect and correct erosion problems in the sand bed area of dry swales • Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established • Replant wetland species (for wet swales) if not sufficiently established	Annual (semi-annual the first year)
• Rototill or cultivate the surface of the sand/soil bed for dry swales if the swale does not draw down in 48 hours • Remove sediment build-up within the bottom of the swale once it has accumulated 25% of the original design volume	As needed (infrequent)
• Mow grass to maintain a height of 3 to 4 inches	As needed (frequent seasonally)

4.6 Regulatory Requirements

Depending on specific project location for all of the non-point source treatment strategies described in this chapter, pertinent regulatory requirements include:

- Section 404 of Clean Water Act (dredge and fill activities)
- Section 401 Water Quality Certification (Clean Water Act) for 404 permit
- Endangered Species Act – evaluation of potential impacts to protected species and/or critical habitat areas
- National Historic Preservation Act – evaluation of potential impacts to cultural resources
- License from IBWC for activities within the floodway easement

All construction sites disturbing more than one acre will require submittal of a NOI to the TCEQ for authorization under the General Stormwater Permit for Construction for Section 402 (Clean Water Act). This will require development of a Stormwater Pollution Prevention Plan.

Requirements for Stormwater Discharge Permits for municipalities under Section 402 of the Clean Water Act may also trigger review of stormwater management strategies employed within municipal jurisdictions.

Any construction or modification of existing conditions within the floodway under easement and managed by the IBWC would require either proof of land ownership or a written letter from the land owner giving permission to perform the work as well as a license from the IBWC authorizing the work. The IBWC will evaluate the proposed work within the floodway to determine if potential adverse impacts to flood conveyance capacity and/or flood protection would exist.

Chapter 5
Technical Treatment Alternatives for Water Quality Improvement – Point Source Treatment Systems

5.1 Constructed Wetlands for Tertiary Treatment Following Mechanical or Lagoon Treatment Plants (Strategies 7 and 8)

Strategies 7 and 8 relate to constructed wetlands used for treatment of point source waste streams, particularly tertiary treatment following a mechanical or lagoon wastewater treatment plant. Specifically, Strategy 7 relates to placing the constructed wetland system after an individual wastewater treatment plant; Strategy 8 applies to treating effluent from multiple plants in close proximity. This section addresses the characteristics of constructed wetlands for both applications.

The EPA defines constructed wetlands as wastewater treatment systems composed of one or more treatment cells in a built and partially controlled environment designed and constructed to provide wastewater treatment (188). Free water surface (FWS) constructed wetlands closely resemble natural wetlands in appearance and function, with combination of open-water areas, emergent vegetation, sometimes submergent vegetation as well, varying water depths, and other typical wetland features (188). Similar treatment mechanisms for removal of contaminants occur in wastewater treatment wetland systems that are found in stormwater wetlands. However, the steady flow regime found in a wastewater treatment wetland provides an environment that can be optimized for removal of certain pollutants including nutrients and metals.

Wastewater polishing wetland systems have proven to be very reliable (93). FWS wetlands have been engineered for water quality treatment in the United States since the early 1970s and the accumulated design information and operational performance data for these FWS treatment wetlands have been summarized and assessed to provide improved design and operational practice guidance. Wetland aquatic plants, through their canopy, biomass, and rhizosphere, create an environment that supports a wide range of physical, chemical, and biological processes. These processes separately and in combination remove total suspended solids, reduce the influent BOD, transform nitrogen forms, provide storage for metals, cycle phosphorus, and attenuate organisms of public health significance. The biogeochemical cycling of macro and micronutrients within the wetland is the framework for the treatment capacity of a wetland system. This treatment capacity is driven by natural solar radiation; kinetic wind energy; the chemical-free energy of rainwater, surface water, and groundwater; and storage of potential energy in biomass and soils, rather than the nonrenewable, fossil-fuel energies used in conventional wastewater treatment systems. However, FWS treatment wetlands are much more land-intensive wastewater treatment systems.

It is the vegetation, specifically the emergent and submergent vegetation, that gives a FWS constructed wetland its capability to treat wastewater effectively in a passive manner. FWS constructed wetlands are unique in that they grow their own physical substrate for periphytic microorganisms, resulting in capture of incoming solar energy while minimizing the effects of solar radiation to the water column. Many of the biochemical transformations that occur in treatment wetlands are mediated by the variety of microbes living on the surface area provided by the plant litter as well as the living plant leaves, stems, and roots. A diversity of vegetative species is recommended to provide both a robust treatment facility and a high quality habitat.

5.1.1 Applications

Constructed wetlands may be used to provide secondary treatment in a community's wastewater treatment system as well as be used in combination with other secondary treatment technologies (188). They are also frequently used to provide enhancement for tertiary treatment of municipal wastewaters, or for treatment of industrial and agricultural wastewaters.

Site specific factors that need to be considered in the design of wetland treatment systems include topography, soil type, climate (growing season, temperature variation, evapotranspiration and precipitation), wastewater characteristics, flows and loads, and wildlife activity. Design variables include total area, the number, size, depth, and shape of wetland cells, hydraulic retention time, vegetation types and coverage, inlet and outlet type and location, and internal flow patterns (188).

Although constructed wetland systems are typically developed down gradient of a municipal wastewater treatment plant to limit pumping needs to the polishing system, land availability issues sometimes require pumping to an appropriate wetland site. Larger wastewater effluent flows requiring more land for development of a constructed wetland may especially find it difficult to locate a constructed wetland for wastewater polishing in the immediate vicinity of the wastewater treatment plant. Large-scale wetland treatment systems at Beaumont, Texas and Orlando, Florida both receive pumped flows from the treatment plant. Where multiple wastewater treatment plants lie in relatively close proximity, and effluent flows can be pumped to a common location, some economy of construction cost may be achieved by developing a larger scale regional wetland system.

5.1.2 Limitations

Wetland treatment systems are land intensive. Typically they are constructed out of the 100-year floodplain or protected from floods via levees or berms. However, if not considered by the State as part of the treatment train (i.e., discharge permit compliance is upstream of the wetland system), protection from floods should not be necessary.

Natural treatment systems including wetlands result in primary production of organic matter and corresponding cycling of nutrients as well as carbon. As a result, parameters including TSS, BOD, TN, and TP have background concentrations, which must be taken into consideration during design.

Wetland treatment systems must be operated in a manner that maintains normal operating water depths that will support the growth of emergent vegetation in order for the treatment mechanisms providing removal of contaminants to function properly.

5.1.3 Effectiveness

The removal efficiency of a constructed wetland treatment system is greatly dependent upon the loadings to the system as well as individual system design and operation.

Constructed wetland systems are effective in the reduction of BOD, as long as incoming BOD exceeds the natural level at which the wetland operates (53). Based upon conservative analysis of data available from municipal wastewater wetland treatment systems, open water FWS systems loaded below 45-50 kg BOD/ha-d (40.2-44.6 lb BOD/ac-d) can be expected to attain effluent BODs of 20 mg/L or less (188). Wetland systems used for polishing treatment that receive low loadings of BOD should approach background concentrations of 5-7 mg/L in outflows.

Constructed wetland treatment systems are very effective for removal of TSS. Under a fairly wide range of solids loadings, relatively low effluent TSS concentrations can be attained (93). However, wetlands generally will not reduce TSS concentrations below 3 mg/L (93). The TSS effluent concentrations rates from the Arcata Enhancement Wetland are consistently low, less than 5 mg/L, 90 percent of the time, with an annual average loading of 16 TSS kg/ha-d. The Arcata enhancement marsh has continued to remove TSS at a constant rate of approximately 90 percent for the last six years (93). The Tarrant Regional Water District's (TRWD's) pilot-scale wetland achieved greater than 95 percent mass removal of TSS over the eight years of operation with average inflow concentration of 224 mg/L and average outflow concentration of 11 mg/L (95).

Outflow concentration data for nitrogen species show considerable variation in response to the nitrogen loading (93). Total nitrogen and total Kjeldahl nitrogen effluent concentrations are generally correlated to their respective loadings (93). Distribution of various species of nitrogen within a wetland indicates that the nitrogen dynamics are affected by the influent loading, the degree of plant coverage and maturity of emergent vegetation (93). Wetland systems have demonstrated long-term removal efficiency of ammonia nitrogen approaching 90 percent. Given the transformability of individual nitrogen components between each other based on the conditions existing at different locations in the FWS wetland, designs should provide passive controls (e.g. depth and vegetation patterns) for effective removal of the incoming nitrogen load (188). Over an eight year period of operation, the TRWD's pilot-scale wetland system effectively removed about 82 percent of the mass load of TN with average outflow concentrations less than 1.5 mg/L TN (95).

Treatment wetlands are capable of phosphorus removal from wastewaters on both short-term and long-term bases (53). However, the cycling of total phosphorus (TP) as a result of plant and microbe uptake and plant senescence confounds short-term studies of phosphorus transformations and removal (188). Adsorption to soils and accretion of new soils within wetland soils provide long-term storage of TP. The TRWD's pilot-scale wetland system provided about 65 percent TP mass removal over 8 years of operation with average inflow concentrations of 1.10 mg/L and average outflow concentrations of 0.40 mg/L (95). Large-scale wetland treatment systems have been used extensively in Florida for providing additional polishing of tertiary-treated municipal wastewater and removal of TP from stormwater runoff of agricultural areas (106, 108). The municipal wastewater polishing wetland systems have consistently produced effluent with TP concentrations less than 0.2 mg/L since the late 1980s. For more than 5 years, the wetland stormwater treatment areas have consistently exceeded performance goals of TP outflow concentration of <50 ug P/L and a 75 percent TP load reduction (108). New targets of 10 ug/L TP are proposed to protect Florida's receiving waters, including the Everglades. The technology proposed to achieve these levels is wetland stormwater treatment systems (106).

Limited data is available regarding fecal coliform removal within wetland treatment systems. The Arcata Pilot Project reported a consistent 2 to 3 log removal with a 6 day hydraulic residence time and fecal coliform removal was also found to be correlated with TSS removal in this system (93).

Information from FWS treatment wetlands indicates that a fraction of the incoming metal load will be trapped and effectively removed through sequestration with settleable suspended solids and soils. For many metals, the limited data indicate that concentration reduction efficiency and mass reduction efficiency correlate with TSS reduction (188).

5.1.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

A FWS constructed wetland utilized for treating municipal wastewater can also function as wildlife habitat, and in some cases constructed wetlands are being designed with wildlife habitat creation as a secondary or primary goal. Constructed FWS wetlands can provide incidental support of wildlife, or it can be enhanced by considering certain factors, which encourage and support a wide range of wildlife communities (93). Modifying open water areas used to facilitate flow distribution to increase open water areas with inclusions of islands and shallow shoal areas provide protected feeding, resting, and nesting areas for waterfowl and shorebirds. Studies have shown that having 25 to 70 percent of the water surface dominated by submergent and floating macrophytes allows optimal water quality and habitat enhancement objectives to be met (93). The design of a wetland system should take into account the desired mixture of open water and emergent marsh areas for calculation of projected removal efficiencies.

Wetland treatment systems present an excellent focus and facility for implementing community wide environmental education dealing with water conservation, pollution prevention, wastewater treatment, water reclamation, wetland ecology, watershed management, and energy conservation. The wetland site should be designed to incorporate public access (limited or full), aesthetically pleasing viewsheds, riparian and upland fringe areas, and physical structures for interpretative purposes (93).

5.1.5 Conceptual Designs

Design of constructed wetlands are controlled by several factors, some related to the characteristics of the wastewater inflows and some related to the site selected. Preliminary sizing calculations should be conducted to obtain a rough idea of the size of wetland required, or whether the target water quality goals can be achieved with the land available. Wetland size may be limited by geography, a lack of suitable construction sites, or regulatory limitations such as areas that cannot be altered (53).

Site topography must be considered during conceptual design as this influences volume of earth moving that may be required and thus the project cost. Topography also determines the need for pumps to move water to and from the site, another important cost consideration. To the extent possible, designs should accommodate the site topography to maximize the use of gravity flow for movement of water to and through the system, and minimize earth moving.

The number of wetland cells within a system is based on consideration of redundancy, maintenance, and topography. It is desirable for a constructed wetland system to have at least two cells that can operate in parallel to allow for operational flexibility (cell resting, rotation of flows, or maintenance) (53). Multiple cells operated in series (e.g. a treatment train) provide more control over flow distribution and more closely approximate plug flow conditions. For very small systems, one treatment train of multiple wetland cells can still be designed for operational flexibility of isolating an individual cell for maintenance purposed through the use of piping.

Preparation of even grades across the width of a wetland cell is critical to minimize flow channeling and thus short-circuiting of flows through a cell. Short-circuiting substantially reduces the gross areal efficiency of a wetland cell, reducing contaminant removal effectiveness. In addition to even grades, multiple inlets, deep water zones (i.e., open water areas) oriented perpendicular to flow surrounded by dense emergent vegetation within the marsh areas, and multiple outlets are also incorporated into designs to facilitate even flow across the wetland cells.

General ideas guiding wetland cell design from Kadlec and Knight (53) include:

- Avoid blind spots in corners.
- Provide flow straightener berms interior to an individual wetland cell.
- Reestablish flow distribution at intermediate points in a flow path.
- Maintain good bottom uniformity during construction and startup: minimize formation of topographic channels parallel to flow path.

Wetland system designs are often tailored to “fit” the available land. Even multiple tracts of land can be used if flows can be transferred efficiently.

A conceptual design developed for the Town of Flower Mound, (Town) Texas to provide wastewater treatment for two residential communities that relied solely on septic systems is shown as Figure 5.1. The septic systems in these two areas were constructed more than 25 years ago, prior to more stringent requirements for on-site sewage disposal and the advent of improved technologies. Concerns by the Town regarding health issues and the potential water quality impacts these systems could have on Grapevine Lake, a water supply lake, and its tributaries motivated the initial feasibility study and the further evaluation of treatment options that would be in character with the rural nature of this part of the Town. Design flows were based on the current number of residences in the study area plus 25 percent, which represents full build-out of undeveloped lots and open spaces already existing within the study area. Design loadings for development of unit sizes were based on typical wastewater concentrations for raw wastewater since several options were still being considered for solids handling and sewage collection. Specific project criteria included development of a treatment system that could produce a high quality effluent with maximum beneficial reuse of the treated effluent. The Town had also requested an assessment of environmental factors and the potential development of educational opportunities in conjunction with the natural treatment system. The recommended conceptual design for the natural treatment system to treat the liquid wastewater included three components: an integrated facultative pond (IFP), two parallel deep marsh wetland cells operated in parallel, and a free-water surface constructed wetland consisting of two parallel shallow marsh wetland cells, then one shallow marsh wetland cell with habitat features. The proposed natural treatment system would optimize treatment and operation flexibility, providing multiple levels of treatment processes for production of a high quality effluent with minimal odor production potential. Although maximum beneficial reuse was a design criteria, due to limitations of available land within the area for construction of storage capacity required by State regulations it was recommended that a Texas Pollutant Discharge Elimination System (TPDES) permit from the TCEQ be acquired for the facility and that the treatment system be designed to produce effluent of sufficient quality to meet the stringent discharge permit criteria that would be required for the receiving waters.

The conceptual plan for the natural treatment system developed for the Town incorporated opportunities for beneficial reuse of the treated effluent within the required buffer zone around the treatment units and development and enhancement of ecological areas that could be incorporated with proposed educational facilities to maximize public benefit of this area. These included the development of a nursery area for propagation of native trees and shrubs that could be utilized for planting mitigation areas required by Section 404 permits associated with municipal construction projects. Since woody vegetation can use irrigation water year-round, substantial beneficial utilization of the treated effluent would be realized within the nursery area. Restoration and enhancement of native oak/savannah areas characteristic of the local Cross

Timbers ecoregion including wetland pools and ponds to provide a diversity of habitat would be achieved with the remaining treated effluent not utilized in the nursery area and return flows from the nursery area. This natural area and the associated water features would also provide some storage capacity for treated effluent during wet periods when less irrigation water is utilized in the nursery area. This natural area would also provide significant study area in addition to the constructed wetland for science-oriented classroom activities planned for the proposed on-site educational facilities. The proposed facilities included an interpretive center/classroom and parking area to accommodate school buses and other vehicles. The buffer zone provided sufficient area to incorporate a diversity of natural ecosystems including native prairie, forested areas, ponds, and wetland pools in addition to the constructed wetland treatment cells. A proposed boardwalk and sampling pier would provide controlled access to the constructed wetland habitat for observations and sample collection. A trail system would provide access from the parking area to the interpretive center and to the perimeter of the constructed wetland as well as other developed ecosystems within the buffer zone. The proposed facilities would provide an accessible educational resource to the student population within the local area.

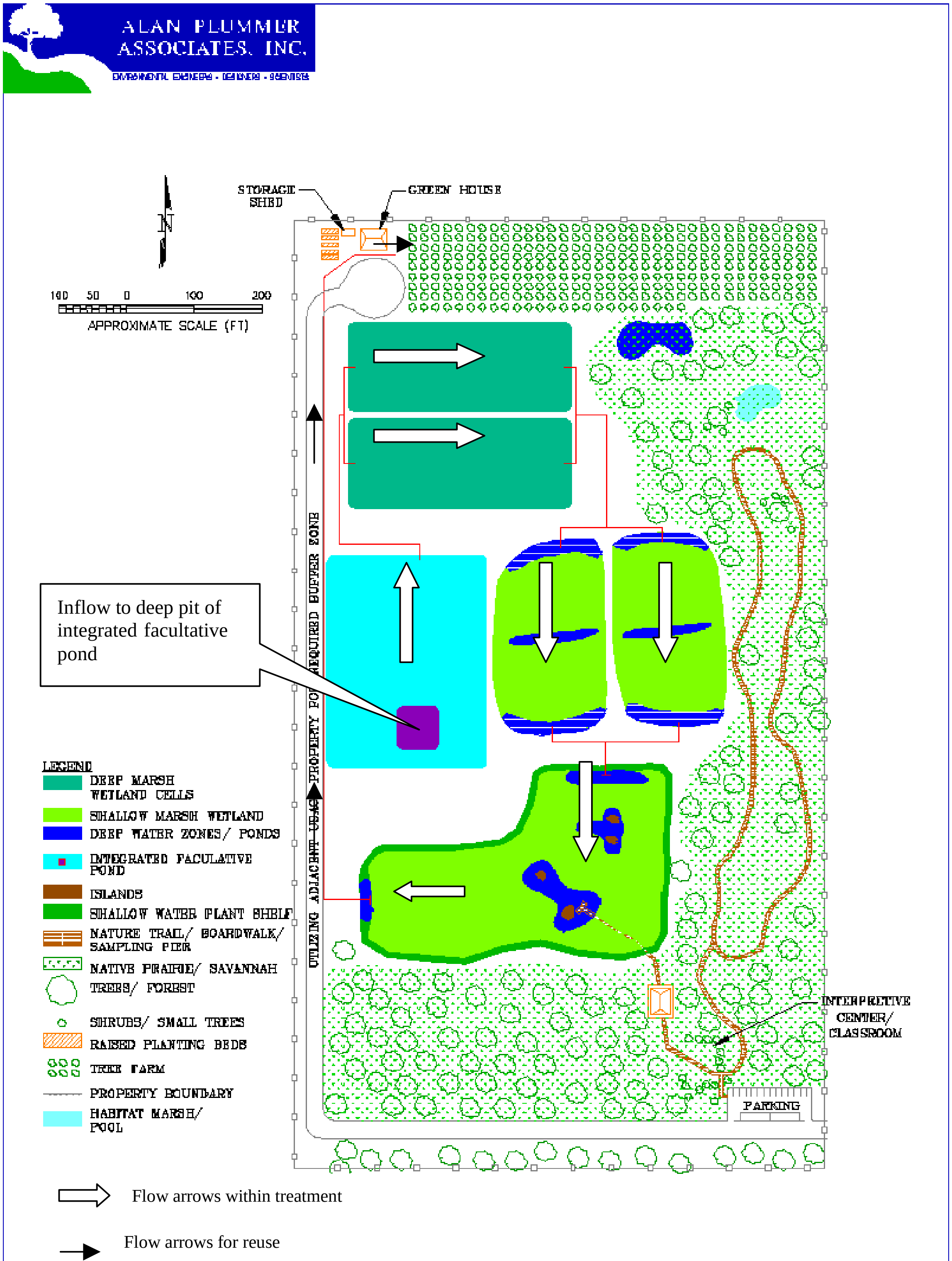


FIGURE 5-1. Conceptual Plan for Natural Treatment System for Western Flower Mound, TX with Proposed Facilities/Amenities Within Buffer Zone

5.1.6 Unit Cost

Capital

No two FWS constructed wetland systems are alike, and consequently, unit capital costs will range widely and will be dependant upon a number of project-specific factors. For example, the site may require significant or minimal earthwork; soil conditions may be such that clay will need to be imported for a liner; wastewater characteristics may require special plant needs; land may or may not be available at a reasonable price; etc. However, given equal conditions, there is a generalized economy of scale whereby smaller constructed wetlands will cost more per acre than larger wetlands. Table 5-1 provides capital costs for several FWS constructed wetland systems used for polishing effluent discharged from municipal and industrial wastewater treatment plants. Land costs are not included in the capital cost figures.

Table 5-1 (53, 121, 138)
Representative Capital Costs of Selected Surface Flow Constructed Wetland Systems

FWS Wetland Size (acres)	Capital Cost ($/acre)		Number of Facilities Surveyed
	Typical Range	Total Range	
0 – 50	$20,000-$40,000	$7,700 - $79,221	11
51 – 100	$10,000-$25,000	$1,774 - $36,000	4
101 – 500	$6,000-$15,000	$1,825 - $11,677	3
> 500		$21,798	1

Operation and Maintenance

The O&M costs for a FWS wetland facility are associated with pumping energy, compliance monitoring, levee maintenance, nuisance control, and equipment repairs and replacement. Levee (or berm) maintenance consists of mowing and preservation of structural integrity. Mowing may be a matter of aesthetics (or safety, to expose snakes or alligators). Equipment repairs and replacement pertain to piping and pipe supports, structures and pumps. Nuisance control may be required, and could include mosquito control or removal of rodents, bottom-stirring fish or damaging wildlife (feral hogs, etc).

Annual costs can range from $5,000 to $50,000 per year for small systems (53). Note that a sizeable portion of the operational costs can be caused by permit-required monitoring efforts.

5.1.7 Regulatory Requirements

If a wetland treatment system is constructed as part of the treatment train of a municipal wastewater treatment plant, it must be built outside of the 100-year floodplain or protected by levees or berms as required for other components of the treatment system. The treatment system must also comply with the requirements of 30 TAC 317.15, relating to constructed wetland units used for treatment of municipal wastewater. This regulation addresses minimum standards for types of vegetation, seepage protection (liners), hydraulic design, and other criteria. A TPDES discharge permit is required from the TCEQ with compliance to permit criteria monitored at the outfall of the plant. A constructed wetland within a permitted treatment train is not considered jurisdictional waters of the United States under the Clean Water Act.

If a wetland treatment system is constructed as a polishing system that is not considered part of the wastewater treatment train, it does not have to be built outside the 100-year floodplain or protected from the 100-year flood. It can be constructed within a floodway, if not otherwise restricted. The TPDES discharge permit for the WWTP would not include the constructed wetland as a treatment component and effluent monitoring for permit compliance would be located upstream of the wetland system. However, depending on the specific circumstances of a site chosen for construction of the wetland polishing system, after development the wetland might be considered jurisdictional waters of the United States under the Clean Water Act. If considered jurisdictional waters of the United States, maintenance activities involving dredge or fill would require a Section 404 permit. Under current permitting requirements, it is anticipated that any routine maintenance activities would be authorized by the general permit (Nationwide Permit 3 – Maintenance).

Construction of a wetland polishing system in an area where existing jurisdictional waters of the United States (i.e., stream channels, natural wetlands) are located would require a Section 404 permit under the Clean Water Act, either a general or individual 404 permit depending on the proposed impacts. Section 401 water quality certification requirements must also be met for authorization under Section 404. If existing jurisdictional areas are impacted or incorporated into a constructed wetland, it is more likely that the constructed wetland system will be considered jurisdictional under the Clean Water Act in the future.

Wetland systems constructed to provide polishing treatment downstream of the permitted discharge might be constructed within the IBWC floodway easement. This would require either proof of land ownership or written letter from the landowner giving permission to perform work, as well as a license from the IBWC authorizing the work. The IBWC will evaluate the proposed work within the floodway to determine potential adverse impacts to flood conveyance capacity and/or flood protection.

Submittal to the TCEQ of a Notice of Intent for authorization under the TPDES general stormwater discharge permit for construction activities would also be required for all construction activities disturbing more than 1 acre. This would involve preparation of a Stormwater Pollution Prevention Plan.

Chapter 6
Technical Treatment Alternatives for Water Quality Improvement – Collective (Non-Point Source and Point Source Treatment Systems)

6.1 Large-Scale Constructed Wetland Treatment System (Strategies 9 and 10)

Strategies 9 and 10 relate to large-scale constructed wetland systems that are located such that they could receive flow from collective drainages conveying both point and non-point source discharges. Strategy 9 specifically relates to a system constructed "on-channel", and Strategy 10 to a system constructed "off-channel". Construction of an on-channel wetland system is typically not considered feasible due to a number of factors including inappropriate water depths for establishment of emergent vegetation, very high potential for short-circuiting of flows through the system and resulting ineffective contaminant removals, substantial deposition of sediments, impedance of storm flow flows within the floodway, and frequency of significant damage to plant community from high velocity flows from storm events. However, at the request of the Habitat Restoration Workgroup, this strategy was included in the comprehensive list due to consideration of one potential site for an on-channel wetland system. Llano Grande is an on-channel lake formed by flow control structures within the branched Arroyo Colorado where flood flows are divided between the Arroyo Colorado and the North Floodway. Since Llano Grande is located within a Texas Parks and Wildlife Department State Park, possible water quality improvement associated with habitat enhancement within this on-channel segment is desired.

Potentially, an off-channel regional constructed wetland system (Strategy 10) could either receive collective flows prior to their reaching the Arroyo Colorado or water could be diverted from the Arroyo Colorado to a large-scale wetland polishing system, either within or outside the floodway levees. Although it is feasible that some locations may be able to receive diverted water from drainage channels or the Arroyo Colorado, diversion flows would most probably require pumping. Pumping would also enable more control of inflows to the wetland treatment system.

6.1.1 Applications

Collective wetland treatment systems may be located upstream within the watershed to provide treatment for combined flows from municipal WWTPs, urban runoff, and agricultural runoff and irrigation return flows. Potential sites for an off-channel collective wetland treatment system within the watershed would be wherever there are drainage ditches or channels that convey multiple flows from municipal discharges, agricultural irrigation return flows and/or storm runoff from agricultural fields or urban area to the Arroyo Colorado and these flows can be rerouted to an appropriate site for development of a wetland system. An off-channel polishing wetland system to polish flows diverted directly from the Arroyo Colorado may be located outside the floodway, but may also be potentially located within the floodway of the Arroyo Colorado between the flood levees and receive flows diverted from the river channel.

The only site considered potentially feasible for location of an on-channel collective wetland treatment system is the Llano Grande. Further evaluation of the modifications required within the Llano Grande to develop suitable conditions for establishment of emergent wetland vegetation and potential impacts to flood flow conveyance is needed to determine feasibility.

6.1.2 Limitations

Location of a diversion pump station within the floodway would require a design that would not adversely impact flood flow conveyance.

Design of a constructed wetland within a flood area will require incorporation of elements to protect and minimize damage to structures from flood events. Growth of dense emergent vegetation associated with a constructed wetland treatment system within the floodway, whether in-channel or off-channel, would have to be evaluated to determine impacts to flood flow conveyance.

Wetland treatment systems must be operated in a manner that maintains normal operating water depths that are appropriate to maintain the growth of emergent vegetation in order for the treatment mechanisms providing removal of contaminants to function properly. Typically, water depths within wetland cells are 12 inches plus or minus 6 inches. Limited species of emergent wetland plants can survive extended periods of water depths from 18 to 24 inches, with most emergent wetland plant species requiring normal water depths of less than 12 inches. Water depth across land with minimal grade is primarily controlled by the hydraulic loading rate (i.e. the volume of water applied to a specified acreage) to achieve the desired hydraulic detention time (typically 7 to 10 days) rather than water level control structures places at outfall locations. Wetland designs for sites with very flat topography should consider hydraulic gradients required for water movement and the impacts to water depths within the wetland cells.

Wetland treatment systems with substantial inflow of nutrients result in high rates of primary production of organic matter and corresponding cycling of nutrients as well as carbon. As a result, parameters including TSS, BOD, TN, and TP have background concentrations, which must be taken into consideration during design. Wetland treatment systems also attract abundant wildlife which contribute to the loadings of nutrients and bacteria. Wildlife induced bioturbation will result in resuspension of settled solids.

Design of any wetland system for water quality improvement must consider loss of water through the system from evapotranspiration. Flow balances for constructed wetland systems in a wide variety of climate areas indicate that loss of water through evaporation from open water areas and transpiration from the emergent vegetation on an annual basis is very similar to that from reservoirs or lakes. Although the presence of wetland vegetation retards evaporation, transpiration losses from the vegetation can make up the difference and more. There is a seasonal effect on evapotranspiration as a result of both radiation patterns and vegetation patterns. The result is a growing-season enhancement followed by winter reductions.

6.1.3 Effectiveness

Effectiveness of constructed wetland systems is directly related to several design factors including constituent loadings, hydraulic retention time, flow distribution, and vegetative community. Based on eight years of operation of the TRWD's 2.5 acre pilot-scale wetland system, removals of TSS, TN, and TP based on mass balance calculations were greater than 95 percent, 80 percent, and 65 percent, respectively (95). Sediments and nutrients were the primary constituents of concern for the TRWD's constructed wetland systems, as the treated water will be used to supplement the yield of two existing drinking water supply reservoirs. However, additional studies were conducted during the 8-year operation of the pilot-scale wetland system and continue at the field-scale level. These additional studies include flow balances and monitoring for potential accumulation of heavy metals and toxic organics within the sediments and vegetation. These studies concluded that no detectable level of bioaccumulation of pesticides or other toxic organics was observed in the collected sediments and/or biomass and the levels of heavy metals accumulated within the aquatic vegetation were found to be within levels reported for comparable wetland plants from systems around the world. No evidence of phytotoxicity from metals accumulated within plant tissues was observed and the levels of metals detected do not exceed the maximum levels chronically tolerated by representative animals.

Initial operation of the 243 acre TRWD field-scale wetland system (prior to modifications in design to address short-circuiting within the cells) resulted in removals of TSS, TN, and TP based on mass balance calculations greater than 99 percent, 63 percent, and 54 percent, respectively. However, concentrations of these parameters at the outflow of the field-scale wetland system are comparable or lower than the average outflow concentrations for these parameters that were from the pilot-scale wetland. The average outflow concentrations reported for TSS and TN for both TRWD's pilot-scale and field-scale wetland systems are less than the wetland background concentration limits presented in *Treatment Wetlands* (53) for design calculations. Although, the TP concentrations are above the reported background concentration limits, both TRWD's pilot-scale and field-scale operations have been able to meet the goal of reduction of TP concentrations below those flowing into Richland-Chambers Reservoir in tributary inflows.

6.1.4 Ability to Provide Multiple Benefits in Reference to Water Quality Improvement and Habitat

Large-scale regional wetland treatment systems can be developed with multiple objectives including water quality improvement and habitat areas for both local and migratory wildlife. Downstream wetlands are perhaps most effective at creating wildlife habitat due to their size, regular hydrology, and longevity (186). The wetland ecology, multiple benefits, and public access for wildlife viewing and interpretation aspects of FWS constructed wetlands are one of the strongest endorsements for the use of this treatment process (93). The advantages of a multiple benefit investment in landuse can be a positive aspect of any FWS constructed wetland project. These landuse types could include (1) parkland, (2) wildlife habitat, (3) environmental education, (4) open space, (5) greenways, (6) water reclamation storage, and (7) landuse set aside for future public use and treatment. Public access is essential for communication and maintaining the multiple benefits of a FWS constructed wetlands project (93).

6.1.5 Conceptual Designs

Design of large-scale constructed wetlands for collective treatment must consider factors relevant to both sources of flow, stormwater runoff and WWTP effluent. If the wetland system is designed to receive flows routed directly to the system, it may receive either pumped or gravity flows or both. If flows to the wetland system will be diverted from the Arroyo Colorado, location of the wetland system will control the need for pumping. Design of an on-channel wetland system within the Llano Grande Channel may be able to receive all or most inflows via gravity flow. Substantial modifications to the Llano Grande Channel would be necessary to provide water depths appropriate for establishment of emergent vegetation. Control of the flow split between the Llano Grande and the Arroyo Colorado Channel may be problematic and the emergent wetland system would be subject to high velocities from large storm events, which could result in periodic damage to the wetland vegetation. However, potential opportunities for wetland development do exist within the Llano Grande itself and within the drainages that transport both WWTP effluent and storm runoff to this shallow channel.

Due to the lack of topographic relief within the overall watershed and immediate vicinity of the Arroyo Colorado and considering the modified channel of the Arroyo Colorado, a large-scale off-channel constructed wetland will probably require construction of a pump station to divert flows to the wetland system. The size of the wetland will be based on the amount of flow to be diverted, which will be dictated by available water for appropriation through a water rights permit from the TCEQ and water quality modeling of various scenarios to project potential water quality improvement for the Arroyo Colorado. Availability of land for potential constructed wetland sites will also be a factor in how much water can be treated.

Since the solids loading to a treatment system receiving inflows from the Arroyo Colorado will potentially be substantially higher than that from WWTP effluent, inclusion of a sedimentation basin before the wetland cells is recommended. As with smaller scale wetland treatment systems, it is desirable to develop parallel treatment paths within the overall system to facilitate operational flexibility. The site topography will influence the number of cells within a treatment train. Sites with minimal elevation drop from inflow to outflow points should not be divided into so many cells that insufficient head is available to adequately employ flow control structures. Fewer cells also reduce fill material and earth moving required for construction of berms. However, design of large wetland cells requires close attention to flow distribution and optimization of wetland area utilization.

A large-scale wetland system can make use of multiple tracts of land to develop a mosaic of interspersed habitat zones within an area if flows can be transferred efficiently from one tract to another.

The conceptual design of the TRWD Richland-Chambers wetland included a diversion pump station on the Trinity River, six settling ponds, four trains of multiple wetland cells, and a relift pump station to transfer the treated water to Richland-Chambers Reservoir. The full-scale system of about 2,000 acres will provide treatment for approximately 100 MGD diverted from the Trinity River. The field-scale wetland demonstration project, designed to treat the initial 15 MGD diversion, was constructed with one settling pond followed by a series of four wetland cells with a distribution canal to route flows around any one wetland cell, if needed. The field-scale system is the first treatment train of the full-scale system. Future development will not require additional distribution canals since design of additional trains will enable flows to be routed to other wetland cells instead.

The goal of the TRWD Richland-Chambers wetland system is to provide polishing treatment for water diverted from the Trinity River, which is dominated by treated discharges from regional WWTPs within the Dallas-Fort Worth metroplex. After treatment through the wetland system, the diverted water will be used to supplement the yield of Richland-Chambers Reservoir, which provides drinking water supply for the western half of the Dallas-Fort Worth metroplex. Treatment of the diverted river water is needed to protect water quality of the drinking water supply with the primary pollutants of concern being sediment and nutrients (nitrogen and phosphorus). In addition, potential impacts or bioaccumulation of heavy metals and organic compounds have been investigated in special studies.

An aerial photograph with overlay showing the TRWD Richland-Chambers full-scale wetland is included as Figure 6-1.

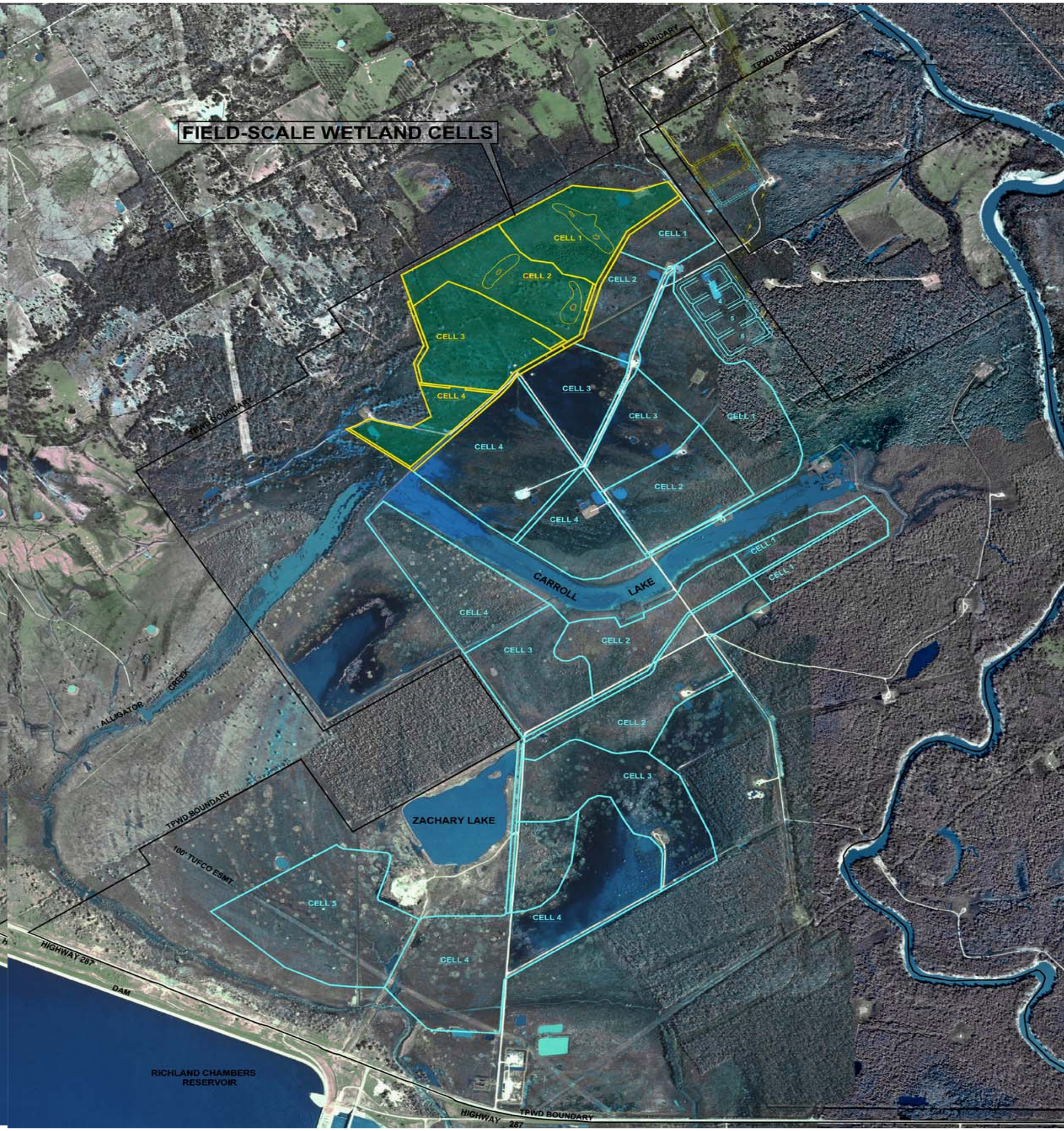


Figure 6-1. TRWD Richland-Chambers wetland system conceptual design

ALAN PLUMMER ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERS • DESIGNERS • SCIENTISTS

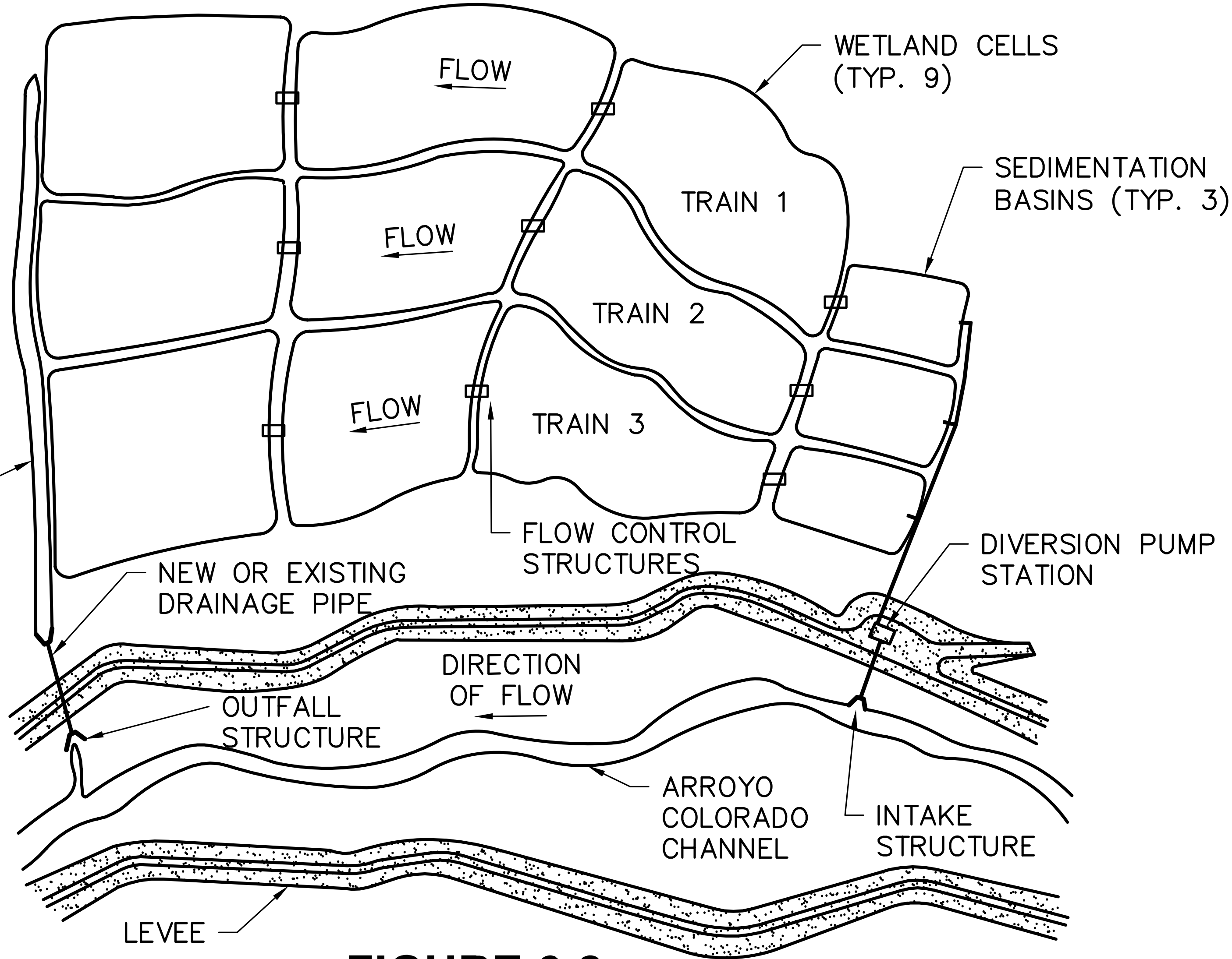


FIGURE 6-2
CONCEPTUAL DESIGN OF REGIONAL OFF-CHANNEL CONSTRUCTED WETLAND OUTSIDE FLOODWAY LEVEES

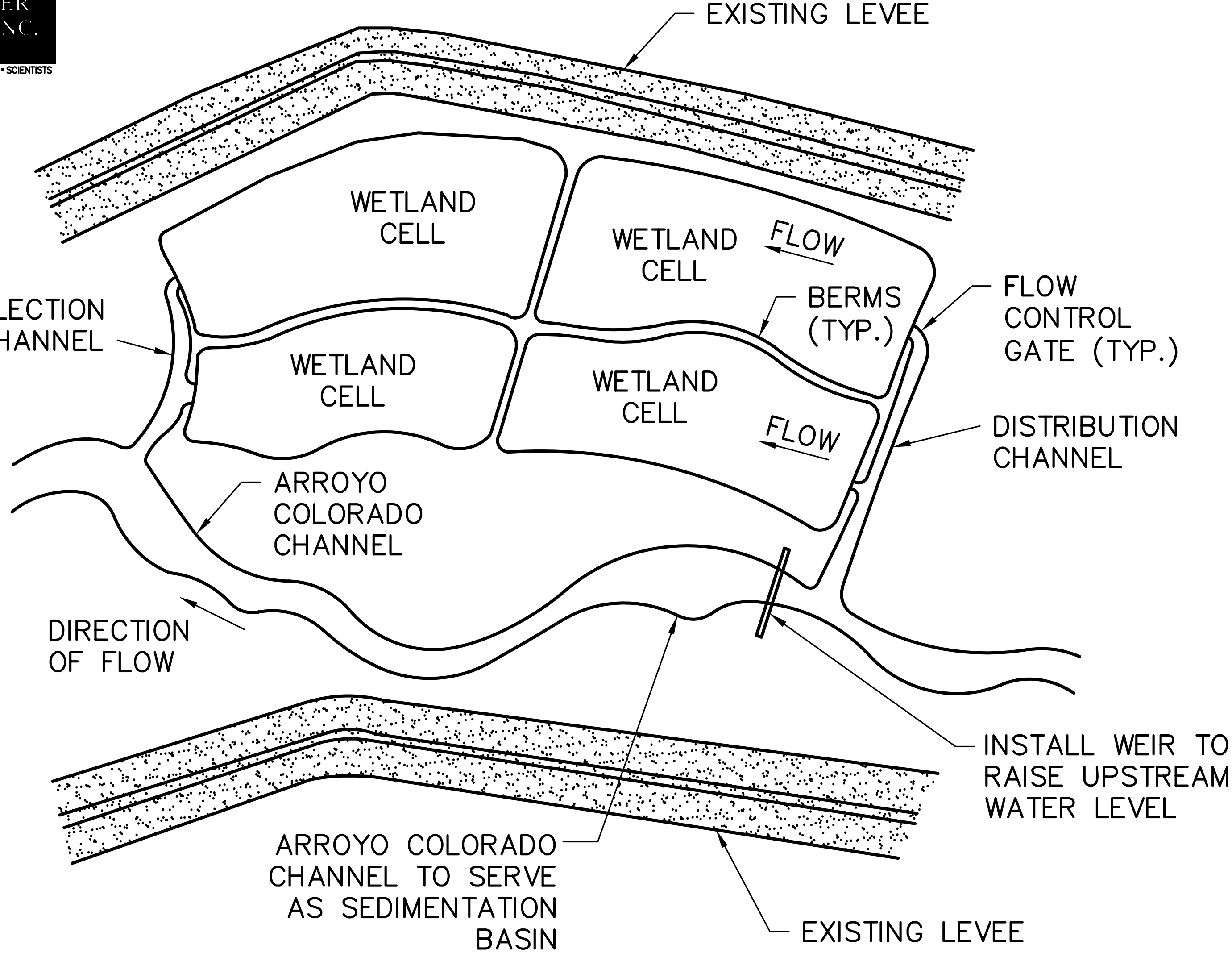


FIGURE 6-3
CONCEPTUAL DESIGN OF REGIONAL OFF-CHANNEL CONSTRUCTED WETLAND WITHIN FLOODWAY LEVEES

Conceptual design sketches showing plan views of a regional off-channel constructed wetland systems outside of the floodway levees along the Arroyo Colorado and within the floodway levees are included as Figures 6-2 and 6-3, respectively. Appropriate sites for potential regional wetland systems will need to be located and evaluated for feasibility.

6.1.6 Unit Cost

Capital

Large scale regional wetlands will typically have an economy of scale associated with the construction of the wetland itself. However, there are usually other costs associated with items needed for large-scale regional wetland projects that may not be necessary for smaller treatment wetlands following wastewater treatment plants. For example, a significant cost can be added to the project for constructing a pump station and pipeline to divert water to the wetland. In addition, a pump station and pipeline may also be needed to pump treated water from the wetland to the desired point of delivery. Since FWS wetlands are land intensive, land costs can significantly increase the unit cost of a project.

Construction costs for some regional scale FWS constructed wetland systems are provided in Table 6-1.

Table 6-1
Representative Capital Costs for Selected Large Scale Regional FWS Constructed Wetland Projects

Location	Area (acres)	Capital Cost (excluding land cost) ($/acre)	Year	Ref.
Everglades ENR (FL)	3,474	$4,031	1993	53
Everglades ECP (seven STAs) (FL)	41,418	$18,639	1997-2006	190
NTMWD East Fork Reuse Project (TX)	1,860	$18,744 (engineer's estimate)	2005	126
NTMWD East Fork Reuse Project Phase II Nursery (TX)	194	$9,943	2005	127
TRWD Richland-Chambers Field Scale Wetland (TX)	243	$7,936	2002	95

Operation and Maintenance

O&M costs incurred for a large scale FWS treatment wetland will include many of the same items as a smaller treatment wetland system. These primarily include pumping energy, compliance monitoring, levee maintenance, nuisance control and equipment repairs and replacement. Of these, it is likely that pumping costs will be the dominant expenditure, and it would be very site-specific. Depending on the project, there may be other O&M costs for a large-scale wetland. For example, if there is an emphasis on public education at the project, there may be repairs of public access/educational amenities (signage, trails, boardwalks) or salaries for outdoor educators.

In 1993, O&M costs for the 390-acre Incline Village (NV) constructed wetland were estimated at $85,500 per year ($219/ac/year) (53). In a 2004 study, Knight found the average O&M costs for a number of large stormwater treatment areas (STAs) in south Florida were $430 per acre per year (184). However, because each project is unique, O&M costs should be evaluated on a site-specific basis.

6.1.7 Regulatory Requirements

In addition to the regulatory requirements presented in Section 5.1.7 for collective wetland treatment systems including requirements resulting from impacts to jurisdictional waters of the United States under the Clean Water Act under Section 404 (dredge and fill activities), Section 401 (water quality certification), and Section 402 (stormwater discharge from construction sites), and licensing from the IBWC, a diversion of water from waters of the State (e.g., Arroyo Colorado and/or jurisdictional tributaries) would require a water rights permit from the TCEQ. Evapotranspiration losses from a wetland treatment system, even if outflow from the wetland system were discharged back to the Arroyo Colorado, would be considered a consumptive use.

GLOSSARY OF TECHNICAL TERMINOLOGY

Agricultural runoff: Stormwater runoff from agricultural fields

Best Management Practice (BMP): Structural devices that temporarily store or treat stormwater runoff to reduce flooding, remove pollutants, and provide other amenities.

Biofiltration: The use of a series of vegetated swales to provide filtering treatment for stormwater as it is conveyed through the channel. The swales can be grassed, or contain emergent wetlands, or high marsh plants.

Design storm: A rainfall event of specified size and return frequency (e.g., a storm that occurs only once every 2 years) that is used to calculate the runoff volume and peak discharge rate to a BMP.

Detention time: The theoretical time required to displace the contents of a water treatment facility at a given rate of discharge (volume divided by rate of discharge).

Emergent plant: An aquatic plant that is rooted in the sediment but whose leaves are at or above the water surface. Such wetland plants provide habitat for wildlife and waterfowl in addition to removing pollutants.

Forebay: An extra storage area provided near an inlet of a stormwater wetland to trap incoming sediments before they accumulate within the wetland or downstream pond.

Fringe wetland: Narrow emergent wetland areas that are created by the use of shallow underwater benches along the perimeter of a wet pond. The benches are usually 15 feet wide, and are zero to 12 inches deep. The fringe wetlands enhance pond pollutant removal, conceal trash and water level changes, reduce safety hazard and create a more natural appearance.

High Marsh: A pondscaping zone within a stormwater wetland that exists from the surface of the normal pool to a six-inch depth and typically contains the greatest density and diversity of emergent wetland plants.

Impervious Surface/Cover: A hard surface area that either prevents or retards the entry of water into the soil. Common impervious surfaces include roof tops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled surfaces.

Irrigation return flow: Flows resulting from excess irrigation water applied to agricultural fields, sometimes appeared to minimize accumulation of minerals and salts within the soils. Flows are typically surface flows, but may have subsurface flow components.

Level spreader: A temporary BMP used to spread stormwater runoff uniformly over the ground surface as sheet flow. The purpose of level spreaders is to prevent concentrated, erosive flows from occurring. Level spreaders will commonly be used at the upstream end of wider biofilters to ensure sheet flow into the biofilter.

Low marsh: A pondscaping zone within a stormwater wetland that exists from 6 to 18 inches below the normal pool. The low marsh zone is suitable for the growth of several emergent wetland plant species that can tolerate sustained periods of deeper water than those found in the high marsh zone.

Mass wasting: The movement of large volumes of earth material downslope.

Micropool: A smaller permanent pool used in a stormwater pond due to extenuating circumstances, i.e. concern over the thermal impacts of larger ponds, impacts on existing wetlands, or lack of topographic relief.

Nutrient sink: If the export of nutrients from a wetland is lower than the incoming nutrient load, the wetland is considered a net sink for nutrients.

Nutrient source: If the export of nutrients from a wetland is greater than the nutrient inflow, the wetland is a net source of nutrients. Net export of nutrients may occur as a result of high nutrient loading rate to a wetland followed by a reduced loading rate. In some case, some of the nutrient that accumulated under high loading rates continue to be exported from the wetland.

Nutrient transformer: Transformation of nutrients from inorganic to organic forms. Nutrients entering wetlands are predominantly in dissolved inorganic form (e.g., nitrate, ammonium, phosphate). In contrast, nutrients exported from wetlands are predominantly in organic form, a consequence of abundant primary production within a wetland. The nutrient transformation function of wetlands, coupled with their ability to buffer pulses of nutrients in the watershed by storing and slowly releasing nutrients to downstream waters, provides a significant measure of ecological stability to contiguous aquatic systems.

Overland flow: Movement of thin film of water in sheet flow over the land surface prior to concenttation of flows within rivulets, channels, or streams. Occurs when the infiltration capacity of an area's soil has been exceeded.

Plug flow conditions: In wastewater treatment design, plug flow conditions refer to high constituent loading at the influent end of the unit with loading reduced over the length of the unit as organic material in wastewater is assimilated.

Plunge pool: A small permanent pool located at either the inlet to a BMP or at the outfall from a BMP. The primary purpose of the pool is to dissipate the velocity of stormwater runoff, but it also can provide some pre-treatment, as well.

Pocket wetlands: A stormwater wetland design adapted for small drainage areas with no reliable source of baseflow. The surface area of pocket wetlands is usually less than a tenth of an acre. The pocket wetland usually has no deepwater cells, and is intended to provide some pollutant removal for very small development sites.

Pond/wetland system: A two-cell stormwater wetland design that utilizes a wet pond in combination with a shallow marsh. The pond/wetland design saves space, and has been shown to be very effective at removing urban pollutants.

Pondscaping: A technique that utilizes native trees, shrubs, herbaceous plants and wetland species to meet specific functional design objectives within a stormwater wetland. Species are selected for up to six zones in the pond and its buffer, based on their relative tolerance for inundation and/or soil saturation.

Primary productivity: The production of organic carbon compounds from inorganic nutrients. The energy source for this production is generally sunlight for chlorophyll-containing plants, but in some cases can be derived from reduced chemicals (chemoautotrophs).

Reverse slope pipe: A pipe that extends downwards from the riser into the permanent pool that sets the water surface elevation of pool. The lower end of the pipe is located up to 1 foot below the water surface. Very useful technique for regulating ED times in a stormwater wetland, and it seldom clogs.

Riser: A vertical pipe or weir within the embankment of a stormwater wetland that is used to regulate the stormwater discharge from the structure for specified design storm(s).

Runoff Frequency Spectrum (RFS): The frequency distribution of unit area runoff volumes generated by a long, term continuous time-series of rainfall events. Used to develop stormwater sizing rules for stormwater wetlands.

Sediment forebay: Stormwater design feature that employs the use of a small, separate cell pool to settle out incoming sediments before they are delivered to a stormwater wetland. The forebay is typically 10 percent of the total treatment volume of a BMP.

Water quality volume or water quality treatment volume: The volume of stormwater runoff that is treated within a BMP. The volume needed to capture and treat 90 percent of the average annual stormwater runoff volume equal to 1 inch (0.9 inch in Western Rainfall Zone) times the volumetric runoff coefficient (Rv) times the site area.

Weir: A structure that extends across the width of a channel and is intended to impound, delay or in some way alter the flow of water through a channel. A ported weir is a wall or dam that contains openings through which water may pass. Ported weirs slow the velocity of flow and theirfore, can assist in the removal of pollutants in runoff by providing opportunities for pollutants to settle, infiltrate or be adsorbed.

WWAR (Watershed Wetland Area Ratio): Defined as the ratio of wetland surface area to contributing watershed surface area. Good pollutant removal performance is often achieved when the ratio is greater than 1 percent.

APPENDIX A: HSPF MODEL DATA TABLES/GIS MAPS

TABLE A-1 - ARROYO COLORADO AVERAGE LOADINGS FROM TCEQ HSPF SIMULATION RESULTS **9-22-2005**

AVERAGE CONCENTRATION (mg/L) BY PARAMETER AT DOWNSTREAM END OF SEGMENT 2202												
Period	FLOW cfs	FLOW MGD	TSS mg/L	DO mg/L	BOD mg/L	NO3 mg/L	NH3 mg/L	TOTAL_N mg/L	PO4 mg/L	TOTAL_P mg/L	TOC mg/L	CHL-A mg/L
All Flow Data	355	230	142	5.6	4.0	4.3	0.5	5.4	0.6	0.7	2.8	10.5
Dry Flows Critical Period MAY - OCT	236	152	50	4.8	2.6	3.7	0.4	4.9	0.6	0.8	3.3	25.9

AVERAGE LOADS (lbs/day) BY PARAMETER AT DOWNSTREAM END OF SEGMENT 2202												
Period	FLOW cfs	FLOW MGD	TSS lbs/day	DO lbs/day	BOD lbs/day	NO3 lbs/day	NH3 lbs/day	TOTAL_N lbs/day	PO4 lbs/day	TOTAL_P lbs/day	TOC lbs/day	CHL-A lbs/day
All Flow Data	355	230	370,622	10,881	7,999	7,549	886	9,694	951	1,259	5,388	16,628
Dry Flows Critical Period MAY - OCT	236	152	66,423	6,162	3,342	4,785	511	6,312	801	992	4,100	31,294

The HSPF simulation results from TCEQ were analyzed for 2 cases:

1) Average of daily simulated values over the entire 11-year period
2) Average of daily flow values during the critical period (May-October) for dry-weather flows (all flows less than the median flow of 285 cfs).

TABLE A-2 - FLOW STATISTICS BASED ON TCEQ HSPF SIMULATED DAILY FLOWS AT THE DOWNSTREAM END OF SEGMENT 2202

	SEG2202 FLOW PERCENTILES BY MONTH IN CFS												
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ALL**
1 percentile	178	176	173	165	218	200	156	147	164	189	164	174	162
5 percentile	197	194	195	198	229	203	171	154	188	203	181	181	190
10 percentile	211	210	218	225	234	218	204	202	204	213	198	186	205
20 percentile	235	228	244	236	249	258	230	216	231	238	214	197	229
25 percentile	243	236	251	240	254	267	244	231	246	245	223	203	238
30 percentile	250	242	260	246	265	280	249	253	253	250	230	208	247
40 percentile	263	260	282	259	289	301	267	282	277	258	241	219	264
50 percentile	280	282	295	277	315	340	294	297	296	270	257	235	285
60 percentile	307	303	316	295	340	380	317	321	333	294	274	256	310
70 percentile	336	327	339	323	372	413	345	349	382	338	301	277	345
75 percentile	357	343	358	354	402	442	356	379	423	371	324	299	368
80 percentile	371	358	376	399	440	481	380	397	473	453	357	346	397
90 percentile	415	410	494	529	584	649	476	541	684	649	445	405	505
95 percentile	474	578	610	822	833	814	548	789	1060	925	521	440	701
99 percentile	593	1030	1368	4221	1512	1597	811	1392	1912	2150	839	716	1517

The daily simulated flows from the entire 11-year period of the TCEQ HSPF model were divided into percentiles based on the month in which the flow occurred.

Figure A-2a Flow Statistics for Segment 2202

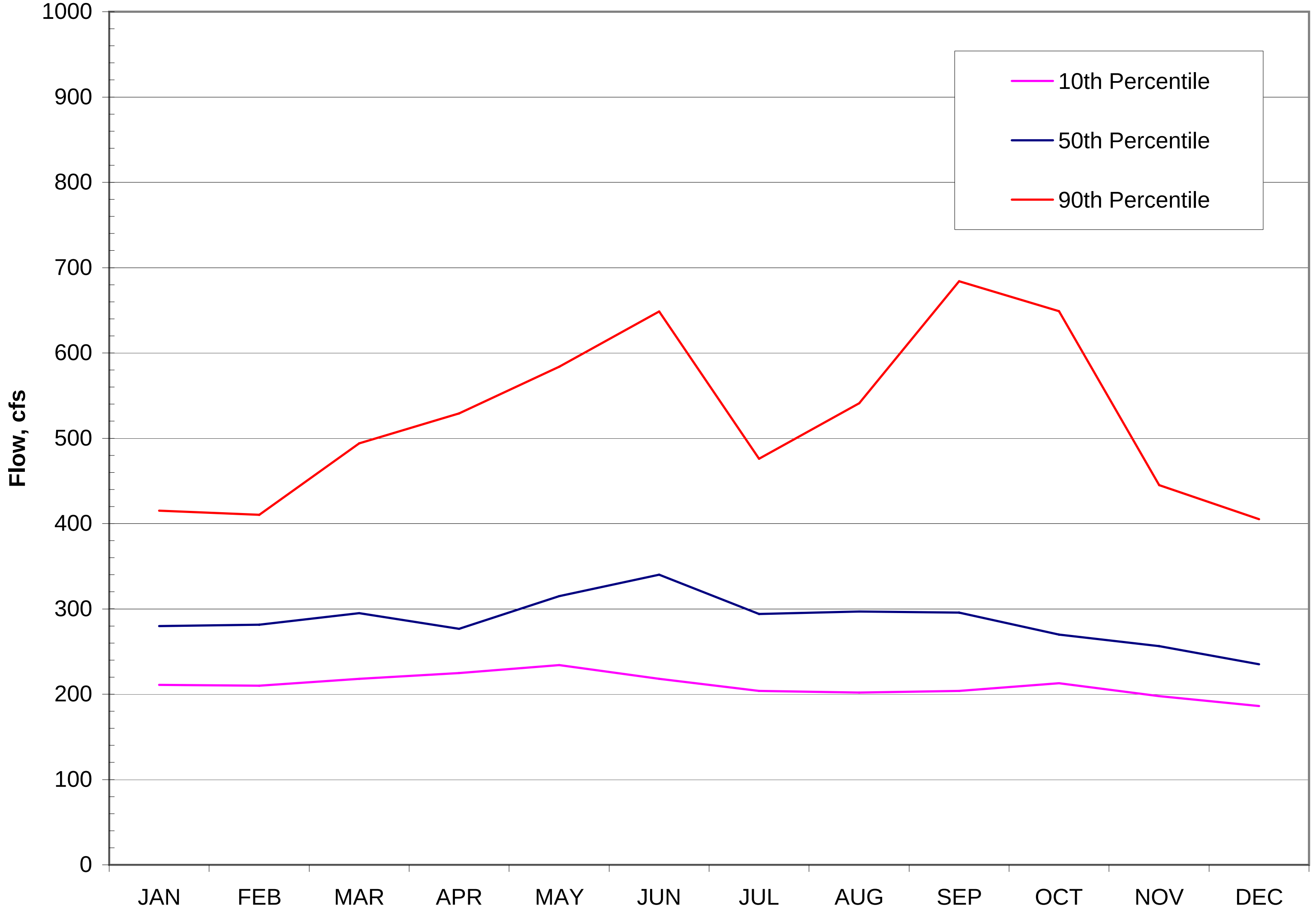


Figure A-2b Flow Statistics for Segment 2202

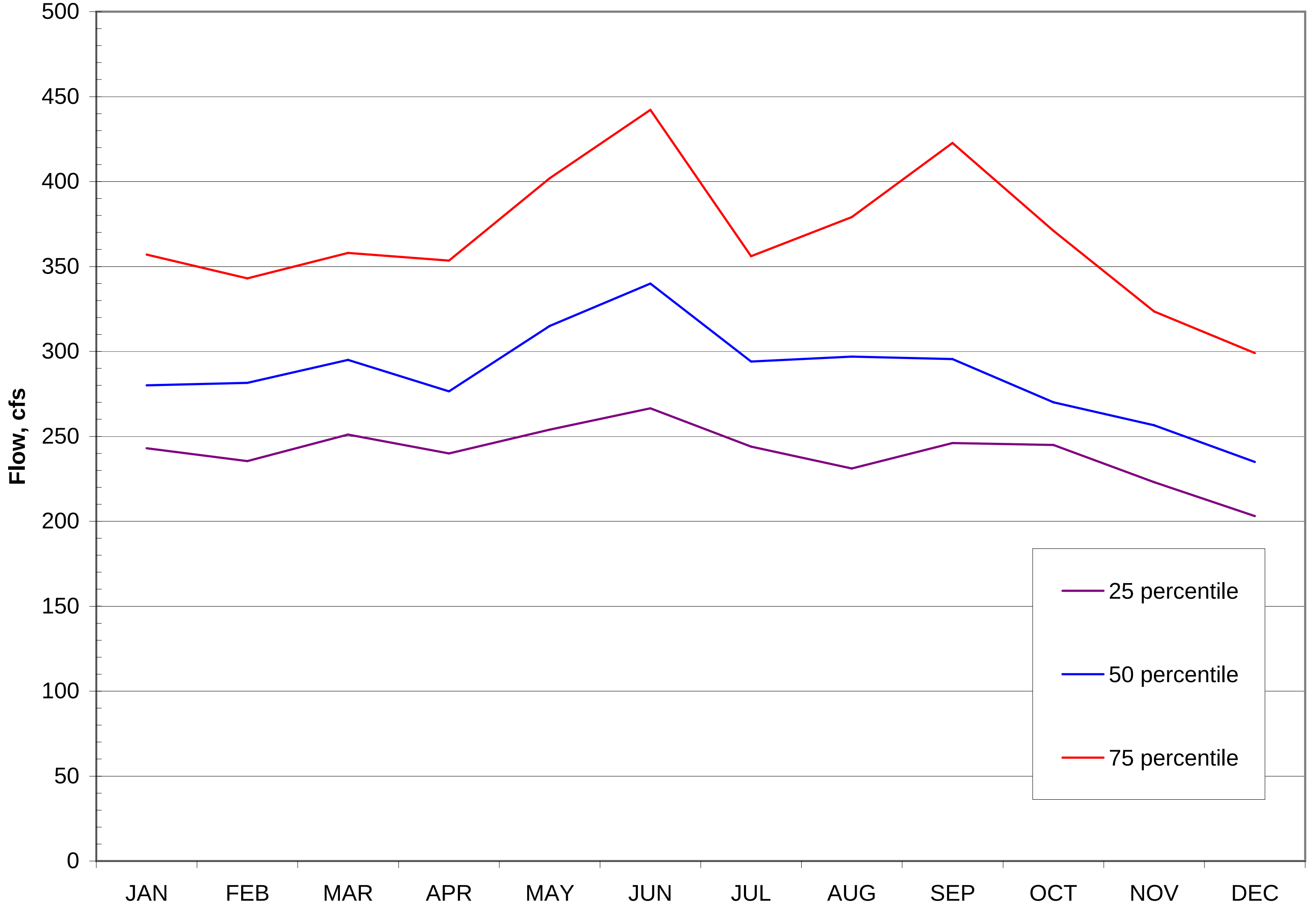


TABLE A-3 - ARROYO COLORADO PERMITTED LOADINGS FROM UPGRADED, NEW AND PROPOSED WWTP's **9-26-2005**

			AVERAGE CONCENTRATION (mg/L) BY PARAMETER						
WWTP	PERMIT NO.	STATUS	FLOW cfs	FLOW MGD	TSS mg/L	DO mg/L	BOD mg/L	CBOD mg/L	NH3 mg/L
Cityof Hidalgo	WQ0011080-001	Upgraded	1.9	1.2	15.0	4.0	n/a	10.0	3.0
Military Highway WSC, S. Alamo	WQ0013462-006	New	0.8	0.51	20.0	4.0	20.0	-	n/a
Military Highway WSC, Lago	WQ0013462-008	New	0.8	0.51	20.0	4.0	-	20.0	3.0
East Rio Hondo	WQ0014558-001	Proposed	0.2	0.16	15.0	4.0	-	10.0	3.0

			AVERAGE LOAD (lbs/day) BY PARAMETER						
WWTP	PERMIT NO.	STATUS	FLOW cfs	FLOW MGD	TSS lbs/day	DO lbs/day	BOD lbs/day	CBOD lbs/day	NH3 lbs/day
Cityof Hidalgo	WQ0011080-001	Upgraded	1.9	1.2	150.1	40.0	n/a	100.1	30.0
Military Highway WSC, S. Alamo	WQ0013462-006	New	0.8	0.51	85.1	17.0	85.1	-	n/a
Military Highway WSC, Lago	WQ0013462-008	New	0.8	0.51	85.1	17.0	-	85.1	12.8
East Rio Hondo	WQ0014558-001	Proposed	0.2	0.16	20.0	5.3	-	13.3	4.0

Crespo took data from TCEQ draft report "Wastewater Infrastructure Plan to Reduce Nutrients, Biochemical Oxygen Demand, Fecal Pathogens, and Suspended Solids Loading into the Arroyo Colorado", and reported the permitted amounts for the upgraded, new and proposed WWTP's that have occurred since the TCEQ HSPF model simulation.

Table A-4

Point source loadings derived from HSPF Arroyo Colorado watershed simulation 1/1/89-12/31/99 (Simulation was performed in 7/2001)
Loadings represent total loads over the 11 year simulation period

Name of Facility	Permit Number	Total Flow Volume (ac-ft)	Total Unit Load Flow (lbs-L/mg)	Total Suspended Solids (lbs)	Nitrate (lbs)	Ammonia (lbs)	Organic Nitrogen (lbs)	Total Nitrogen (lbs)	Phosphate (lbs)	Organic Phosphorus (lbs)	Total Phosphorus (lbs)	BOD Ultimate (lbs)	Comments
CPL Bates Plant	WQ0001254-000	6,395.38	17,392.83	372,400.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CPL La Palma	WQ0001256-000	5,404.16	14,697.11	304,600.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
City of Mercedes	WQ0010347-001	13,892.46	37,781.84	256,500.00	132,236.45	28,714.20	9,445.46	170,396.12	37,781.84	7,556.37	45,338.21	255,760.00	
City of San Benito	WQ0010473-002	19,723.18	53,639.04	1,579,122.00	2,145.56	364,209.05	472,559.90	838,914.51	74,558.26	57,393.77	131,952.03	3,105,264.50	
City of Rio Hondo	WQ0010475-002	1,898.05	5,161.93	102,300.00	15,485.80	7,123.47	1,548.58	24,157.85	3,613.35	619.43	4,232.79	196,075.00	
City of Mission Plant No. 1	WQ0010484-001	30,052.76	81,731.30	643,400.00	55,577.28	78,462.05	400,483.37	534,522.71	81,731.30	24,519.39	106,250.69	654,350.00	
City of Harlingen Plant No. 1	WQ0010490-002	24,087.01	65,506.89	373,100.00	386,490.65	704,199.07	131,013.78	1,221,703.51	153,286.12	52,405.51	0.00	1,106,070.00	
City of Harlingen Plant No. 2	WQ0010490-003	50,757.95	138,041.02	4,179,765.00	773,029.72	1,121,981.70	513,512.60	2,408,524.01	756,464.79	136,660.61	893,125.40	4,912,974.80	
City of Donna	WQ0010504-001	13,435.21	36,538.31	529,800.00	358,075.40	58,461.29	29,230.65	445,767.34	87,691.94	10,961.49	98,653.43	1,318,590.00	
City of Pharr	WQ0010596-001	34,646.75	94,225.10	955,200.00	2,591,190.20	265,714.78	20,729.52	2,877,634.50	143,222.15	220,486.73	363,708.88	1,668,650.00	
City of McAllen Plant No. 2	WQ0010633-003	85,957.09	233,768.38	733,400.00	839,228.48	95,845.04	140,261.03	1,075,334.54	261,820.58	25,714.52	287,535.11	1,555,950.00	
City of La Feria	WQ0010697-001	2,468.54	6,713.43	583,300.00	1,879.76	6,109.22	67,738.55	75,727.53	671.34	671.34	1,342.69	381,800.00	
City of Hidalgo	WQ0011080-001	3,928.06	10,682.74	942,000.00	747.79	95,076.38	115,373.58	211,197.75	21,365.48	19,228.93	40,594.41	923,910.00	
City of San Juan	WQ0011512-001	9,890.74	26,898.80	543,400.00	129,114.26	43,038.09	21,519.04	193,671.38	37,658.32	8,069.64	45,727.97	1,004,410.00	
Winter Garden Park	WQ0011628-001	38.85	105.66	1,127.00	25.36	145.81	35.92	207.09	11.62	35.92	47.55	2,725.50	
Military Hwy Water Supply Corp. Progreso	WQ0013462-001	599.03	1,629.12	215,200.00	32.58	3,030.16	1,954.94	5,017.68	1,743.16	97.75	1,840.90	154,905.00	
City of Alamo	WQ0013633-001	13,849.49	37,665.00	2,374,698.30	180,792.01	60,264.00	30,132.00	271,188.01	52,731.00	11,299.50	64,030.50	3,692,344.10	
Donna ISD	WQ0013680-001	19.95	54.25	798.40	54.25	54.25	43.40	151.90	54.25	16.27	70.52	191.73	
Total		**317,044.66**	**862,232.76**	**14,690,110.70**	**5,466,105.56**	**2,932,428.55**	**4,224,940.51**	**10,354,116.43**	**1,714,405.52**	**258,669.83**	**2,084,451.07**	**20,933,970.63**	

Total Flow Volume (MGD)	Total Flow Volume (Ac-ft)	Total Unit Load Flow (lbs-L/mg)	Total BOD5 (lbs)	Total Ultimate BOD (lbs)

TABLE A-4a - POINT SOURCE LOADINGS PER YEAR
Loadings represent loads per year*
Prepared by Crespo

Name of Facility	Permit Number	Total Flow Volume (ac-ft/yr)	Total Unit Load Flow (lbs-L/mg)**	Total Suspended Solids (lbs/year)	Nitrate (lbs/year)	Ammonia (lbs/year)	Organic Nitrogen (lbs/year)	Total Nitrogen (lbs/year)	Phosphate (lbs/year)	Organic Phosphorus (lbs/year)	Total Phosphorus (lbs/year)	BOD Ultimate (lbs/year)	Comments
CPL Bates Plant	WQ0001254-000	581.40	17,392.83	33,854.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CPL La Palma	WQ0001256-000	491.29	14,697.11	27,690.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
City of Mercedes	WQ0010347-001	1,262.95	37,781.84	23,318.18	12,021.50	2,610.38	858.68	15,490.56	3,434.71	686.94	4,121.66	23,250.91	
City of San Benito	WQ0010473-002	1,793.02	53,639.04	143,556.55	195.05	33,109.91	42,959.99	76,264.96	6,778.02	5,217.62	11,995.64	282,296.77	
City of Rio Hondo	WQ0010475-002	172.55	5,161.93	9,300.00	1,407.80	647.59	140.78	2,196.17	328.49	56.31	384.80	17,825.00	
City of Mission Plant No. 1	WQ0010484-001	2,732.07	81,731.30	58,490.91	5,052.48	7,132.91	36,407.58	48,592.97	7,430.12	2,229.04	9,659.15	59,486.36	
City of Harlingen Plant No. 1	WQ0010490-002	2,189.73	65,506.89	33,918.18	35,135.51	64,018.10	11,910.34	111,063.96	13,935.10	4,764.14	0.00	100,551.82	
City of Harlingen Plant No. 2	WQ0010490-003	4,614.36	138,041.02	379,978.64	70,275.43	101,998.34	46,682.96	218,956.73	68,769.53	12,423.69	81,193.22	446,634.07	
City of Donna	WQ0010504-001	1,221.38	36,538.31	48,163.64	32,552.31	5,314.66	2,657.33	40,524.30	7,971.99	996.50	8,968.49	119,871.82	
City of Pharr	WQ0010596-001	3,149.70	94,225.10	86,836.36	235,562.75	24,155.89	1,884.50	261,603.14	13,020.20	20,044.25	33,064.44	151,695.45	
City of McAllen Plant No. 2	WQ0010633-003	7,814.28	233,768.38	66,672.73	76,293.50	8,713.19	12,751.00	97,757.69	23,801.87	2,337.68	26,139.56	141,450.00	
City of La Feria	WQ0010697-001	224.41	6,713.43	53,027.27	170.89	555.38	6,158.05	6,884.32	61.03	61.03	122.06	34,709.09	
City of Hidalgo	WQ0011080-001	357.10	10,682.74	85,636.36	67.98	8,643.31	10,488.51	19,199.80	1,942.32	1,748.08	3,690.40	83,991.82	
City of San Juan	WQ0011512-001	899.16	26,898.80	49,400.00	11,737.66	3,912.55	1,956.28	17,606.49	3,423.48	733.60	4,157.09	91,310.00	
Winter Garden Park	WQ0011628-001	3.53	105.66	102.45	2.31	13.26	3.27	18.83	1.06	3.27	4.32	247.77	
Military Hwy Water Supply Corp. Progreso	WQ0013462-001	54.46	1,629.12	19,563.64	2.96	275.47	177.72	456.15	158.47	8.89	167.35	14,082.27	
City of Alamo	WQ0013633-001	1,259.04	37,665.00	215,881.66	16,435.64	5,478.55	2,739.27	24,653.46	4,793.73	1,027.23	5,820.95	335,667.65	
Donna ISD	WQ0013680-001	1.81	54.25	72.58	4.93	4.93	3.95	13.81	4.93	1.48	6.41	17.43	
Total		**28,822.24**	**862,232.76**	**1,335,464.61**	**496,918.69**	**266,584.41**	**177,780.21**	**941,283.31**	**155,855.05**	**52,339.74**	**189,495.55**	**1,903,088.24**	

*Point source loadings derived from HSPF Arroyo Colorado watershed simulation 1/1/89-12/31/99 (Simulation was performed in 7/2001)
**From original TCEQ data set

TABLE A-4b - AVERAGE ANNUAL FLOWS AND CONCENTRATIONS*

Prepared by Crespo

Name of Facility	Permit Number	Total Flow Volume (MGD)	Total Unit Load Flow (lbs-L/mg)**	Total Suspended Solids (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Organic Nitrogen (mg/L)	Total Nitrogen (mg/L)	Phosphate (mg/L)	Organic Phosphorus (mg/L)	Total Phosphorus (mg/L)	BOD Ultimate (mg/L)	Comments
CPL Bates Plant	WQ0001254-000	0.52	17,392.83	21.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CPL La Palma	WQ0001256-000	0.44	14,697.11	20.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
City of Mercedes	WQ0010347-001	1.13	37,781.84	6.79	3.50	0.76	0.25	4.51	1.00	0.20	1.20	6.77	
City of San Benito	WQ0010473-002	1.60	53,639.04	29.46	0.04	6.80	8.82	15.65	1.39	1.07	2.46	57.94	
City of Rio Hondo	WQ0010475-002	0.15	5,161.93	19.83	3.00	1.38	0.30	4.68	0.70	0.12	0.82	38.02	
City of Mission Plant No. 1	WQ0010484-001	2.44	81,731.30	7.88	0.68	0.96	4.90	6.55	1.00	0.30	1.30	8.01	
City of Harlingen Plant No. 1	WQ0010490-002	1.96	65,506.89	5.70	5.90	10.76	2.00	18.67	2.34	0.80	0.00	16.90	
City of Harlingen Plant No. 2	WQ0010490-003	4.12	138,041.02	30.30	5.60	8.13	3.72	17.46	5.48	0.99	6.48	35.62	
City of Donna	WQ0010504-001	1.09	36,538.31	14.51	9.81	1.60	0.80	12.21	2.40	0.30	2.70	36.12	
City of Pharr	WQ0010596-001	2.81	94,225.10	10.15	27.52	2.82	0.22	30.56	1.52	2.34	3.86	17.72	
City of McAllen Plant No. 2	WQ0010633-003	6.98	233,768.38	3.14	3.59	0.41	0.60	4.60	1.12	0.11	1.23	6.66	
City of La Feria	WQ0010697-001	0.20	6,713.43	86.96	0.28	0.91	10.10	11.29	0.10	0.10	0.20	56.92	
City of Hidalgo	WQ0011080-001	0.32	10,682.74	88.25	0.07	8.91	10.81	19.79	2.00	1.80	3.80	86.56	
City of San Juan	WQ0011512-001	0.80	26,898.80	20.22	4.80	1.60	0.80	7.21	1.40	0.30	1.70	37.37	
Winter Garden Park	WQ0011628-001	0.00	105.66	10.68	0.24	1.38	0.34	1.96	0.11	0.34	0.45	25.82	
Military Hwy Water Supply Corp. Progreso	WQ0013462-001	0.05	1,629.12	132.20	0.02	1.86	1.20	3.08	1.07	0.06	1.13	95.16	
City of Alamo	WQ0013633-001	1.12	37,665.00	63.10	4.80	1.60	0.80	7.21	1.40	0.30	1.70	98.11	
Donna ISD	WQ0013680-001	0.00	54.25	14.73	1.00	1.00	0.80	2.80	1.00	0.30	1.30	3.54	
Total		**25.73**	**862,232.76**										

*Point source loadings derived from HSPF Arroyo Colorado watershed simulation 1/1/89-12/31/99 (Simulation was performed in 7/2001)

**From original TCEQ data set (HSPF OUT worksheet in this document)

Table A-5

NPS Loadings derived from HSPF Arroyo Colorado watershed simulation 1/1/89-12/31/99 (Simulation was performed in 7/2001)
Loadings represent total loads over the 11 year simulation period

Land Use	Surface Runoff (ac-ft)	Interflow (ac-ft)	Active Groundwater Flow (ac-ft)	Total Runoff (ac-ft)	Total Suspended Solids (lbs)	Nitrate (lbs)	Ammonia (lbs)	Organic Nitrogen (lbs)	Total Nitrogen (lbs)	Phosphate (lbs)	Organic Phosphorus (lbs)	Total Phosphorus (lbs)	BOD (lbs)
Impermeable Land - Single Family Residential/Recreational	173,709.70	0.00	0.00	173,709.70	39,143,954.40	311,199.70	207,971.80	359,948.71	879,120.21	54,732.90	17,247.54	71,980.44	7,498,931.40
Impermeable Land - Non-residential Urban	247,458.40	0.00	0.00	247,458.40	54,597,742.90	423,363.10	276,045.40	472,311.51	1,171,720.01	58,522.50	22,631.59	81,154.09	9,839,823.20
Permeable Land - Low Density Urban	4,680.50	15,257.70	92,950.90	112,889.10	61,365,739.90	128,468.70	84,969.60	199,245.31	412,683.61	84,954.80	9,547.17	94,501.97	4,150,944.00
Permeable Land - High Density Urban	955.50	2,824.60	15,235.90	19,016.00	14,356,091.60	21,756.50	14,530.00	33,395.26	69,681.76	3,252.60	1,600.19	4,852.79	695,734.50
Permeable Land - Land application of permitted discharges	62.35	520.20	8,021.60	8,604.15	427,737.60	233,987.00	116,498.20	22,576.39	373,061.59	23,268.20	1,081.79	24,349.99	470,341.50
Permeable Land - Non-point source wastewater from colonias	34.26	45,080.00	1,368.50	46,482.76	362,965.20	1,269,880.00	631,345.00	121,351.20	2,022,576.20	126,251.00	5,814.75	132,065.75	2,528,150.00
Permeable Land - wastewater from septic systems	74.46	23,451.50	1,060.63	24,586.59	1,069,853.50	670,309.00	333,420.00	64,206.10	1,067,935.10	66,653.80	3,076.54	69,730.34	1,337,627.00
Permeable Land - natural	2,421.70	22,466.10	131,069.30	155,957.10	38,977,463.30	208,443.20	89,723.60	257,930.30	556,097.10	26,604.80	12,359.16	38,963.96	5,373,548.00
Permeable Land - pasture	902.20	7,725.40	39,541.30	48,168.90	24,486,014.50	52,305.60	28,892.50	79,379.42	160,577.52	8,323.10	3,803.60	12,126.70	1,653,738.00
Permeable Land - row crop non-irrigated	86.58	1,803.40	11,555.60	13,445.58	835,446.40	130,918.20	30,999.40	10,046.99	171,964.59	11,177.30	481.42	11,658.72	209,312.30
Permeable Land - row crop irrigated	101,726.10	388,318.20	889,733.00	1,379,777.30	1,357,902,673.70	14,931,320.00	6,604,300.00	1,350,756.96	22,886,376.96	1,679,654.00	64,723.77	1,744,377.77	28,140,770.00
Permeable Land - citrus	373.78	10,090.80	29,221.40	39,685.98	7,130,651.40	463,725.80	169,070.10	28,067.34	660,863.24	35,383.90	1,344.89	36,728.79	584,736.20
Permeable Land - citrus tile drained	449.52	8,262.20	13,925.20	22,636.92	6,952,231.10	272,349.50	82,325.30	20,506.23	375,181.03	22,930.90	982.59	23,913.49	427,213.20
Permeable Land - sugar cane	6,839.00	87,583.20	122,978.00	217,400.20	114,142,133.10	1,737,191.00	1,156,556.00	162,058.80	3,055,805.80	252,442.70	7,765.32	260,208.02	3,376,225.00
Permeable Land - sugar cane - tile drained	4,621.10	54,523.50	48,984.10	108,128.70	59,633,787.30	882,310.00	535,505.00	109,656.10	1,527,471.10	132,537.10	5,254.35	137,791.45	2,284,502.00
Total	**544,395.15**	**667,906.80**	**1,405,645.43**	**2,617,947.38**	**1,781,384,485.90**	**21,737,527.30**	**10,362,151.90**	**3,291,436.62**	**35,391,115.82**	**2,586,689.60**	**157,714.67**	**2,744,404.27**	**68,571,596.30**

Table A-4

Table A-4

TABLE A-5a - LANDUSE LOADINGS PER YEAR
Loadings represent loads per year*
Prepared by Crespo

Land Use	Surface Runoff (ac-ft/yr)	Interflow (ac-ft/yr)	Active Groundwater Flow (ac-ft/yr)	Total Runoff (ac-ft/yr)	Total Suspended Solids (lbs/year)	Nitrate (lbs/year)	Ammonia (lbs/year)	Organic Nitrogen (lbs/year)	Total Nitrogen (lbs/year)	Phosphate (lbs/year)	Organic Phosphorus (lbs/year)	Total Phosphorus (lbs/year)	BOD (lbs/year)
Impermeable Land - Single Family Residential/Recreational	15,791.79	0.00	0.00	15,791.79	3,558,541.31	28,290.88	18,906.53	32,722.61	79,920.02	4,975.72	1,567.96	6,543.68	681,721.04
Impermeable Land - Non-residential Urban	22,496.22	0.00	0.00	22,496.22	4,963,431.17	38,487.55	25,095.04	42,937.41	106,520.00	5,320.23	2,057.42	7,377.64	894,529.38
Permeable Land - Low Density Urban	425.50	1,387.06	8,450.08	10,262.65	5,578,703.63	11,678.97	7,724.51	18,113.21	37,516.69	7,723.16	867.92	8,591.09	377,358.55
Permeable Land - High Density Urban	86.86	256.78	1,385.08	1,728.73	1,305,099.24	1,977.86	1,320.91	3,035.93	6,334.71	295.69	145.47	441.16	63,248.59
Permeable Land - Land application of permitted discharges	5.67	47.29	729.24	782.20	38,885.24	21,271.55	10,590.75	2,052.40	33,914.69	2,115.29	98.34	2,213.64	42,758.32
Permeable Land - Non-point source wastewater from colonias	3.11	4,098.18	124.41	4,225.71	32,996.84	115,443.64	57,395.00	11,031.93	183,870.56	11,477.36	528.61	12,005.98	229,831.82
Permeable Land - wastewater from septic systems	6.77	2,131.95	96.42	2,235.14	97,259.41	60,937.18	30,310.91	5,836.92	97,085.01	6,059.44	279.69	6,339.12	121,602.45
Permeable Land - natural	220.15	2,042.37	11,915.39	14,177.92	3,543,405.75	18,949.38	8,156.69	23,448.21	50,554.28	2,418.62	1,123.56	3,542.18	488,504.36
Permeable Land - pasture	82.02	702.31	3,594.66	4,378.99	2,226,001.32	4,755.05	2,626.59	7,216.31	14,597.96	756.65	345.78	1,102.43	150,339.82
Permeable Land - row crop non-irrigated	7.87	163.95	1,050.51	1,222.33	75,949.67	11,901.65	2,818.13	913.36	15,633.14	1,016.12	43.77	1,059.88	19,028.39
Permeable Land - row crop irrigated	9,247.83	35,301.65	80,884.82	125,434.30	123,445,697.61	1,357,392.73	600,390.91	122,796.09	2,080,579.72	152,695.82	5,883.98	158,579.80	2,558,251.82
Permeable Land - citrus	33.98	917.35	2,656.49	3,607.82	648,241.04	42,156.89	15,370.01	2,551.58	60,078.48	3,216.72	122.26	3,338.98	53,157.84
Permeable Land - citrus tile-drained	40.87	751.11	1,265.93	2,057.90	632,021.01	24,759.05	7,484.12	1,864.20	34,107.37	2,084.63	89.33	2,173.95	38,837.56
Permeable Land - sugar cane	621.73	7,962.11	11,179.82	19,763.65	10,376,557.55	157,926.45	105,141.45	14,732.62	277,800.53	22,949.34	705.94	23,655.27	306,929.55
Permeable Land - sugar cane - tile drained	420.10	4,956.68	4,453.10	9,829.88	5,421,253.39	80,210.00	48,682.27	9,968.74	138,861.01	12,048.83	477.67	12,526.50	207,682.00
Total	**49,490.47**	**60,718.80**	**127,785.95**	**237,995.22**	**161,944,044.17**	**1,976,138.85**	**942,013.81**	**299,221.51**	**3,217,374.17**	**235,153.60**	**14,337.70**	**249,491.30**	**6,233,781.48**

TABLE A-5b - AVERAGE ANNUAL FLOWS AND CONCENTRATIONS*

Prepared by Crespo

Land Use	Surface Runoff (MGD)	Interflow (MGD)	Active Groundwater Flow (MGD)	Total Runoff (MGD)	Total Suspended Solids (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Organic Nitrogen (mg/L)	Total Nitrogen (mg/L)	Phosphate (mg/L)	Organic Phosphorus (mg/L)	Total Phosphorus (mg/L)	BOD (mg/L)
Impermeable Land - Single Family Residential/Recreational	14.10	0.00	0.00	14.10	82.93	0.66	0.44	0.76	1.86	0.12	0.04	0.15	15.89
Impermeable Land - Non-residential Urban	20.09	0.00	0.00	20.09	81.19	0.63	0.41	0.70	1.74	0.09	0.03	0.12	14.63
Permeable Land - Low Density Urban	0.38	1.24	7.54	9.16	200.04	0.42	0.28	0.65	1.35	0.28	0.03	0.31	13.53
Permeable Land - High Density Urban	0.08	0.23	1.24	1.54	277.82	0.42	0.28	0.65	1.35	0.06	0.03	0.09	13.46
Permeable Land - Land application of permitted discharges	0.01	0.04	0.65	0.70	18.29	10.01	4.98	0.97	15.96	1.00	0.05	1.04	20.12
Permeable Land - Non-point source wastewater from colonias	0.00	3.66	0.11	3.77	2.87	10.05	5.00	0.96	16.01	1.00	0.05	1.05	20.02
Permeable Land - wastewater from septic systems	0.01	1.90	0.09	2.00	16.01	10.03	4.99	0.96	15.98	1.00	0.05	1.04	20.02
Permeable Land - natural	0.20	1.82	10.64	12.66	91.97	0.49	0.21	0.61	1.31	0.06	0.03	0.09	12.68
Permeable Land - pasture	0.07	0.63	3.21	3.91	187.07	0.40	0.22	0.61	1.23	0.06	0.03	0.09	12.63
Permeable Land - row crop non-irrigated	0.01	0.15	0.94	1.09	22.87	3.58	0.85	0.27	4.71	0.31	0.01	0.32	5.73
Permeable Land - row crop irrigated	8.26	31.52	72.22	111.99	362.17	3.98	1.76	0.36	6.10	0.45	0.02	0.47	7.51
Permeable Land - citrus	0.03	0.82	2.37	3.22	66.12	4.30	1.57	0.26	6.13	0.33	0.01	0.34	5.42
Permeable Land - citrus tile-drained	0.04	0.67	1.13	1.84	113.02	4.43	1.34	0.33	6.10	0.37	0.02	0.39	6.95
Permeable Land - sugar cane	0.56	7.11	9.98	17.65	193.21	2.94	1.96	0.27	5.17	0.43	0.01	0.44	5.72
Permeable Land - sugar cane - tile drained	0.38	4.43	3.98	8.78	202.95	3.00	1.82	0.37	5.20	0.45	0.02	0.47	7.77
Total	**44.19**	**54.21**	**114.09**	**212.50**									

*NPS Loadings derived from HSPF Arroyo Colorado watershed simulation 1/1/89-12/31/99 (Simulation was performed in 7/2001)

TABLE A-5c - LANDUSE LOADINGS PER ACRE PER YEAR*

Prepared by Crespo (Rev. 10/14/05; 10:30am)

Land Use	acres**	Total Suspended Solids (lbs/acre/year)	Nitrate (lbs/acre/year)	Ammonia (lbs/acre/year)	Organic Nitrogen (lbs/acre/year)	Total Nitrogen (lbs/acre/year)	Phosphate (lbs/acre/year)	Organic Phosphorus (lbs/acre/year)	Total Phosphorus (lbs/acre/year)	BOD (lbs/acre/year)
Impermeable Land - Single Family Residential/Recreational	12,625	281.9	2.2	1.5	2.6	6.3	0.4	0.1	0.5	54.0
Impermeable Land - Non-residential Urban	12,352	401.8	3.1	2.0	3.5	8.6	0.4	0.2	0.6	72.4
Permeable Land - Low Density Urban	23,447	237.9	0.5	0.3	0.8	1.6	0.3	0.0	0.4	16.1
Permeable Land - High Density Urban	8,235	158.5	0.2	0.2	0.4	0.8	0.0	0.0	0.1	7.7
Permeable Land - Land application of permitted discharges	301	129.2	70.7	35.2	6.8	112.7	7.0	0.3	7.4	142.1
Permeable Land - Non-point source wastewater from colonias	406	81.3	284.3	141.4	27.2	452.9	28.3	1.3	29.6	566.1
Permeable Land - wastewater from septic systems	248	392.2	245.7	122.2	23.5	391.5	24.4	1.1	25.6	490.3
Permeable Land - natural	79,727	44.4	0.2	0.1	0.3	0.6	0.0	0.0	0.0	6.1
Permeable Land - pasture	22,376	99.5	0.2	0.1	0.3	0.7	0.0	0.0	0.0	6.7
Permeable Land - row crop non-irrigated	43,234	1.8	0.3	0.1	0.0	0.4	0.0	0.0	0.0	0.4
Permeable Land - row crop irrigated	194,206	635.6	7.0	3.1	0.6	10.7	0.8	0.0	0.8	13.2
Permeable Land - citrus	4,682	138.5	9.0	3.3	0.5	12.8	0.7	0.0	0.7	11.4
Permeable Land - citrus tile-drained	2,509	251.9	9.9	3.0	0.7	13.6	0.8	0.0	0.9	15.5
Permeable Land - sugar cane	14,518	714.7	10.9	7.2	1.0	19.1	1.6	0.0	1.6	21.1
Permeable Land - sugar cane - tile drained	5,727	946.6	14.0	8.5	1.7	24.2	2.1	0.1	2.2	36.3
Total	**367,934**									

*NPS Loadings derived from HSPF Arroyo Colorado watershed simulation 1/1/89-12/31/99 (Simulation was performed in 7/2001)

**TCEQ data; Area (in acres) of land use classifications used to model non-point source contributions of pollutants to each HSPF watershed model Sub-basin in the Arroyo Colorado; Land Use Layer is based on Orthophotography 1995 and ancillary data collected in 1998; The HSPF watershed model simulates pollutant loading from 1989-1999 and was completed in 2002

TABLE 5-3b - URBAN LANDUSE LOADINGS PER ACRE PER YEAR***

Prepared by Crespo

Urban Land Use	acres***	Total Suspended Solids (lbs/acre/year)	Nitrate (lbs/acre/year)	Ammonia (lbs/acre/year)	Organic Nitrogen (lbs/acre/year)	Total Nitrogen (lbs/acre/year)	Phosphate (lbs/acre/year)	Organic Phosphorus (lbs/acre/year)	Total Phosphorus (lbs/acre/year)	BOD (lbs/acre/year)
All - Single Family Residential/Recreational	36,072	253.31	1.11	0.74	1.41	3.26	0.35	0.07	0.42	29.36
All - Non-residential Urban	20,587	304.49	1.97	1.28	2.23	5.48	0.27	0.11	0.38	46.52
TOTAL	**56,659**									

***estimated from GIS

Table A-5d

Area (in acres) of land use classifications used to model non-point source contributions of pollutants to each HSPF watershed model Sub-basin in the Arroyo Colorado
Land Use Layer is based on Orthophotography 1995 and ancillary data collected in 1998
The HSPF watershed model simulates pollutant loading from 1989-1999 and was completed in 2002

Land Use	**Sub-Basin 1**	**Sub-Basin 2**	**Sub-Basin 3**	**Sub-Basin 4**	**Sub-Basin 5**	**Sub-Basin 6**	**Sub-Basin 7**	**Sub-Basin 8**	**Sub-Basin 9**	**Sub-Basin 10**	**Sub-Basin 11**	**Sub-Basin 12**	**Sub-basin 13**	**Sub-Basin 14**
Low Density Urban	3134.3	2633.3	2272.7	2622.1	3304.6	1806	3446.4	7464.5	4990.6	840.8	3102.2	198.4	256.3	0
Land Application *	1.4	0	0	0	0	60	29	59	151.7	0	0	0	0	0
Colonia **	55.2	2.4	54	84.3	63.1	34.7	8.9	22.1	51.8	9.3	20.6	0	0	0
Septic**	0	0	0	51.3	0	68.4	74.4	0	47.1	5.1	0	0	2.1	0
High Density Urban	1118.9	2810.9	530.6	594.7	1109.8	712.6	1126.3	3566.4	3831.9	96.9	517.7	12.7	88.5	0
Natural	4443.9	4042.8	4392.7	3900.7	2394.7	4306	6734.7	6274.7	4020.5	6350.8	9370.2	6889	16401.4	204.7
Pasture/Hay	602	378.2	980.2	615.9	956.6	1393.5	1721.6	4371.1	1306.6	2083.7	4474.3	2274.5	1217.9	0
Planted Non-irrigated	0	0	0	0	0	0	0	0	3305.1	21721.1	5600.6	5983.8	6623.7	0
Planted Irrigated	7066.4	6358.5	17482.5	17218.2	8782	16636	20408.2	25965.2	29741.9	26360	16804	680.4	702.6	0
Citrus	274.8	220.5	75.6	974.4	759	570.9	570.9	67.5	187.2	323.1	657.6	0	0	0
Citrus Tile-drained	117	0	0	0	0	706.8	1060.2	125.7	318.9	180	0	0	0	0
Sugar Cane	0	478.5	1797.3	2412.6	3187.8	1274.4	948.6	390.9	692.4	1282.2	1989.6	0	64.1	0
Sugar Cane Tile-drained	0	0	0	0	0	665.7	1900.2	1268.7	1179	713.4	0	0	0	0
Open Water	396.2	1027.7	453.4	1039.2	572.1	1366	1888.4	2871.7	1472.4	2183.2	2960.7	1346.4	11119.7	78.6

* values represent total area of disposal sites
** values represent total area of leach fields

TABLE A-6 - APPROXIMATE NPS LOADINGS BY BASIN FOR DRY AND STORM CONDITIONS

Prepared by Crespo 10/17/2005

	SUB-BAS 1	SUB-BAS 2	SUB-BAS 3	SUB-BAS 4	SUB-BAS 5	SUB-BAS 6	SUB-BAS 7	SUB-BAS 8	SUB-BAS 9	SUB-BAS 10	SUB-BAS 11	SUB-BAS 12	SUB-BAS 13	SUB-BAS 14
Acreage	**17,210**	**17,953**	**28,039**	**29,513**	**21,130**	**29,601**	**39,918**	**52,448**	**51,297**	**62,150**	**45,498**	**17,385**	**36,476**	**283**
NO3 Total NPS														
1989-1999 Total (lb)	712,152	603,219	2,016,694	2,779,944	1,731,291	2,465,092	3,414,077	3,703,705	4,312,524	4,121,114	2,708,502	483,083	555,163	1,459
Average Annual (lb/yr)	64,741	54,838	183,336	252,722	157,390	224,099	310,371	336,700	392,048	374,647	246,227	43,917	50,469	133
NO3 Dry Weather NPS														
1989-1999 Total (lb)	320,025	197,324	1,193,637	1,415,263	808,186	1,183,880	1,245,254	1,264,118	1,375,531	870,881	768,357	48,043	49,328	22
Average Annual (lb/yr)	29,093	17,939	108,512	128,660	73,471	107,625	113,205	114,920	125,048	79,171	69,851	4,368	4,484	2
NO3 Storm NPS														
1989-1999 Total (lb)	392,127	405,895	823,058	1,364,681	923,105	1,281,212	2,168,823	2,439,587	2,936,993	3,250,233	1,940,145	435,039	505,835	1,437
Average Annual (lb/yr)	35,648	36,900	74,823	124,062	83,919	116,474	197,166	221,781	266,999	295,476	176,377	39,549	45,985	131
NH3 Total NPS														
1989-1999 Total (lb)	342,453	297,502	927,981	1,318,154	895,212	1,163,703	1,626,343	1,760,039	2,032,481	1,746,542	1,256,846	151,465	185,435	638
Average Annual (lb/yr)	31,132	27,046	84,362	119,832	81,383	105,791	147,849	160,004	184,771	158,777	114,259	13,770	16,858	58
NH3 Dry Weather NPS														
1989-1999 Total (lb)	152,469	90,277	526,696	646,828	390,413	540,846	569,812	543,258	621,393	392,772	347,333	16,191	19,084	8
Average Annual (lb/yr)	13,861	8,207	47,881	58,803	35,492	49,168	51,801	49,387	56,490	35,707	31,576	1,472	1,735	1
NH3 Storm NPS														
1989-1999 Total (lb)	189,984	207,226	401,285	671,326	504,799	622,857	1,056,531	1,216,781	1,411,088	1,353,770	909,513	135,274	166,351	630
Average Annual (lb/yr)	17,271	18,839	36,480	61,030	45,891	56,623	96,048	110,616	128,281	123,070	82,683	12,298	15,123	57
PO4 Total NPS														
1989-1999 Total (lb)	73,958	70,490	262,235	340,476	213,672	295,164	394,485	455,655	480,780	414,510	304,839	51,521	59,007	181
Average Annual (lb/yr)	6,723	6,408	23,840	30,952	19,425	26,833	35,862	41,423	43,707	37,683	27,713	4,684	5,364	16
PO4 Dry Weather NPS														
1989-1999 Total (lb)	28,806	21,710	168,794	188,357	103,710	154,786	157,711	173,731	166,344	98,019	96,550	5,585	5,493	2
Average Annual (lb/yr)	2,619	1,974	15,345	17,123	9,428	14,071	14,337	15,794	15,122	8,911	8,777	508	499	0
PO4 Storm NPS														
1989-1999 Total (lb)	45,152	48,780	93,441	152,118	109,962	140,378	236,774	281,924	314,436	316,491	208,289	45,937	53,514	178
Average Annual (lb/yr)	4,105	4,435	8,495	13,829	9,997	12,762	21,525	25,629	28,585	28,772	18,935	4,176	4,865	16
BOD Total NPS														
1989-1999 Total (lb)	2,966,364	3,636,734	5,438,920	7,173,750	5,506,444	6,601,331	9,937,576	14,080,722	13,230,527	8,751,786	8,610,715	2,619,997	4,133,916	36,648
Average Annual (lb/yr)	269,669	330,612	494,447	652,159	500,586	600,121	903,416	1,280,066	1,202,775	795,617	782,792	238,182	375,811	3,332
BOD Dry Weather NPS														
1989-1999 Total (lb)	581,652	383,032	2,693,281	3,020,972	1,700,661	0	2,715,406	2,888,291	2,890,999	1,689,006	1,613,551	116,283	141,229	587
Average Annual (lb/yr)	52,877	34,821	244,844	274,634	154,606	0	246,855	262,572	262,818	153,546	146,686	10,571	12,839	53
BOD Storm NPS														
1989-1999 Total (lb)	2,384,712	3,253,701	2,745,639	4,152,778	3,805,783	6,601,331	7,222,170	11,192,431	10,339,528	7,062,780	6,997,164	2,503,714	3,992,687	36,061
Average Annual (lb/yr)	216,792	295,791	249,604	377,525	345,980	600,121	656,561	1,017,494	939,957	642,071	636,106	227,610	362,972	3,278
Sediment Total NPS														
1989-1999 Total (ton)	5,544	14,046	88,657	124,090	64,375	101,842	136,207	210,430	145,345	97,726	113,124	49,410	46,300	235
Average Annual (ton/yr)	504	1,277	8,060	11,281	5,852	9,258	12,382	19,130	13,213	8,884	10,284	4,492	4,209	21
Sediment Dry Weather NPS														
1989-1999 Total (ton)	9	566	6,905	6,263	3,027	5,181	5,230	7,524	5,241	2,857	3,328	242	169	0
Average Annual (ton/yr)	1	51	628	569	275	471	475	684	476	260	303	22	15	0
Sediment Storm NPS														
1989-1999 Total (ton)	5,535	13,479	81,752	117,827	61,348	96,660	130,977	202,907	140,104	94,868	109,796	49,168	46,131	235
Average Annual (ton/yr)	503	1,225	7,432	10,712	5,577	8,787	11,907	18,446	12,737	8,624	9,981	4,470	4,194	21

The HSPF software was used for the simulation and the period simulated is 1/1/1989 - 12/31/1999

Basins 12, 13, and 14 were sub-divided by TCEQ from original HSPF Model Basin 12 (as shown on GIS maps).

TABLE A-7a - APPROXIMATE POLLUTANT LOADINGS BY BASIN FOR DRY AND STORM CONDITIONS, WITH WWTP DISCHARGES

Prepared by Crespo

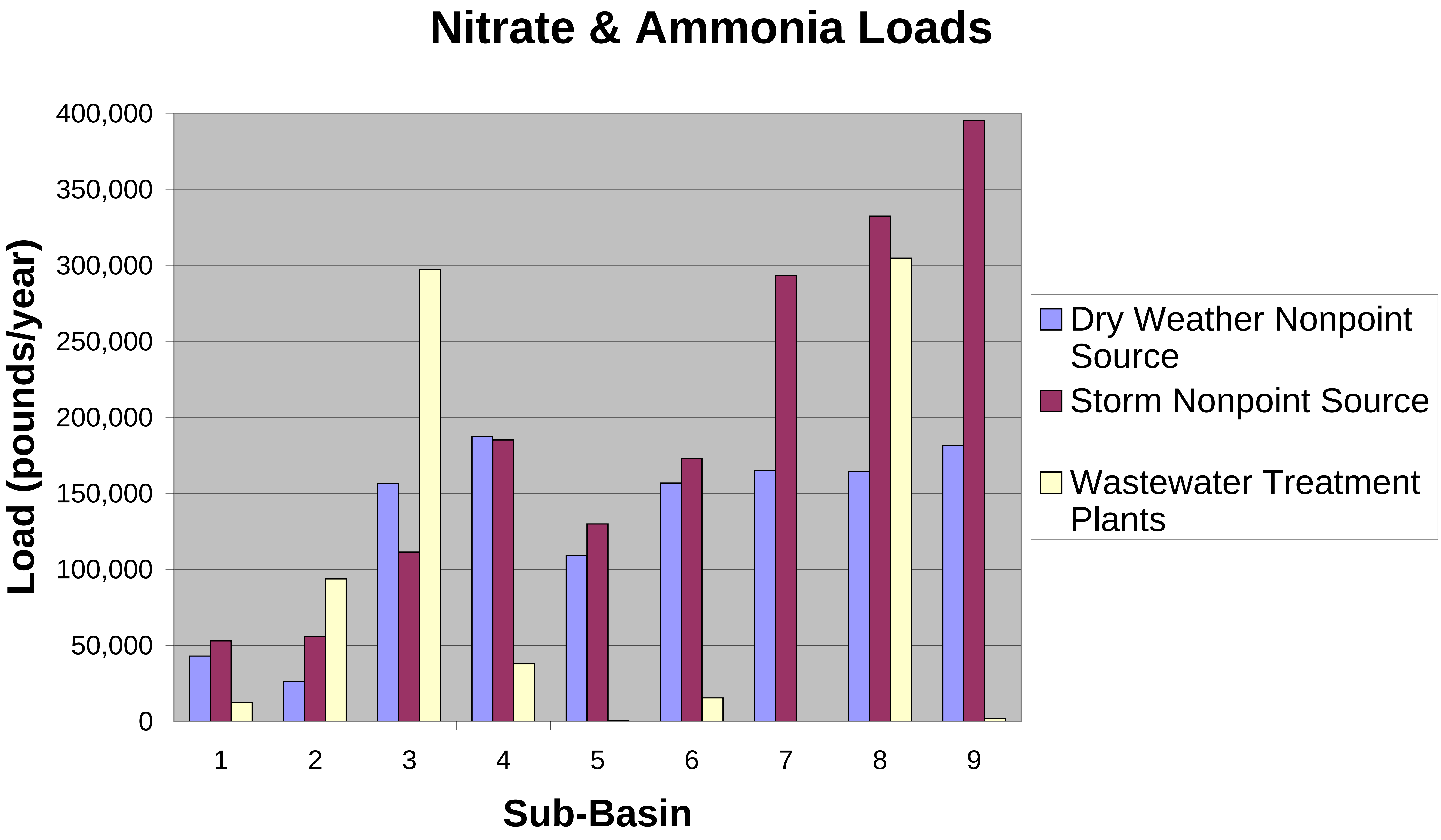
	1	2	3	4	5	6	7	8	9
NO3 Dry Weather NPS									
1989-1999 Total (lb)	320,025	197,324	1,193,637	1,415,263	808,186	1,183,880	1,245,254	1,264,118	1,375,531
Average Annual (lb/yr)	29,093	17,939	108,512	128,660	73,471	107,625	113,205	114,920	125,048
NO3 Storm NPS									
1989-1999 Total (lb)	392,127	405,895	823,058	1,364,681	923,105	1,281,212	2,168,823	2,439,587	2,936,993
Average Annual (lb/yr)	35,648	36,900	74,823	124,062	83,919	116,474	197,166	221,781	266,999
NO3 from WWTPs									
1989-1999 Total (lb)	55,577	839,976	2,901,096	358,130	33	134,116	25	1,161,666	15,486
Average Annual (lb/yr)	5,052	76,361	263,736	32,557	3	12,192	2	105,606	1,408
NH3 Dry Weather NPS									
1989-1999 Total (lb)	152,469	90,277	526,696	646,828	390,413	540,846	569,812	543,258	621,393
Average Annual (lb/yr)	13,861	8,207	47,881	58,803	35,492	49,168	51,801	49,387	56,490
NH3 Storm NPS									
1989-1999 Total (lb)	189,984	207,226	401,285	671,326	504,799	622,857	1,056,531	1,216,781	1,411,088
Average Annual (lb/yr)	17,271	18,839	36,480	61,030	45,891	56,623	96,048	110,616	128,281
NH3 from WWTPs									
1989-1999 Total (lb)	78,462	190,921	369,017	58,516	3,030	34,823	146	2,190,390	7,123
Average Annual (lb/yr)	7,133	17,356	33,547	5,320	275	3,166	13	199,126	648
PO4 Dry Weather NPS									
1989-1999 Total (lb)	28,806	21,710	168,794	188,357	103,710	154,786	157,711	173,731	166,344
Average Annual (lb/yr)	2,619	1,974	15,345	17,123	9,428	14,071	14,337	15,794	15,122
PO4 Storm NPS									
1989-1999 Total (lb)	45,152	48,780	93,441	152,118	109,962	140,378	236,774	281,924	314,436
Average Annual (lb/yr)	4,105	4,435	8,495	13,829	9,997	12,762	21,525	25,629	28,585
PO4 from WWTPs									
1989-1999 Total (lb)	81,731	283,186	233,611	87,746	1,743	38,453	12	984,309	3,613
Average Annual (lb/yr)	7,430	25,744	21,237	7,977	158	3,496	1	89,483	328
BOD Dry Weather NPS									
1989-1999 Total (lb)	581,652	383,032	2,693,281	3,020,972	1,700,661	0	2,715,406	2,888,291	2,890,999
Average Annual (lb/yr)	52,877	34,821	244,844	274,634	154,606	0	246,855	262,572	262,818
BOD Storm NPS									
1989-1999 Total (lb)	2,384,712	3,253,701	2,745,639	4,152,778	3,805,783	6,601,331	7,222,170	11,192,431	10,339,528
Average Annual (lb/yr)	216,792	295,791	249,604	377,525	345,980	600,121	656,561	1,017,494	939,957
BOD from WWTPs									
1989-1999 Total (lb)	654,350	2,479,860	6,365,404	1,318,782	154,905	637,560	2,726	9,124,309	196,075
Average Annual (lb/yr)	59,486	225,442	578,673	119,889	14,082	57,960	248	829,483	17,825
Sediment Dry Weather NPS									
1989-1999 Total (ton)	9	566	6,905	6,263	3,027	5,181	5,230	7,524	5,241
Average Annual (ton/yr)	1	51	628	569	275	471	475	684	476
Sediment Storm NPS									
1989-1999 Total (ton)	5,535	13,479	81,752	117,827	61,348	96,660	130,977	202,907	140,104
Average Annual (ton/yr)	503	1,225	7,432	10,712	5,577	8,787	11,907	18,446	12,737
Sediment from WWTPs									
1989-1999 Total (ton)	508	838	1,937	265	108	420	1	3,218	51
Average Annual (ton/yr)	46	76	176	24	10	38	0	293	5

TABLE A-7b - SUMMARY OF ESTIMATED POLLUTANT LOADINGS BY BASIN FOR DRY AND STORM CONDITIONS, INCLUDING WWTP DISCHARGES

Prepared by Crespo 10/14/2005

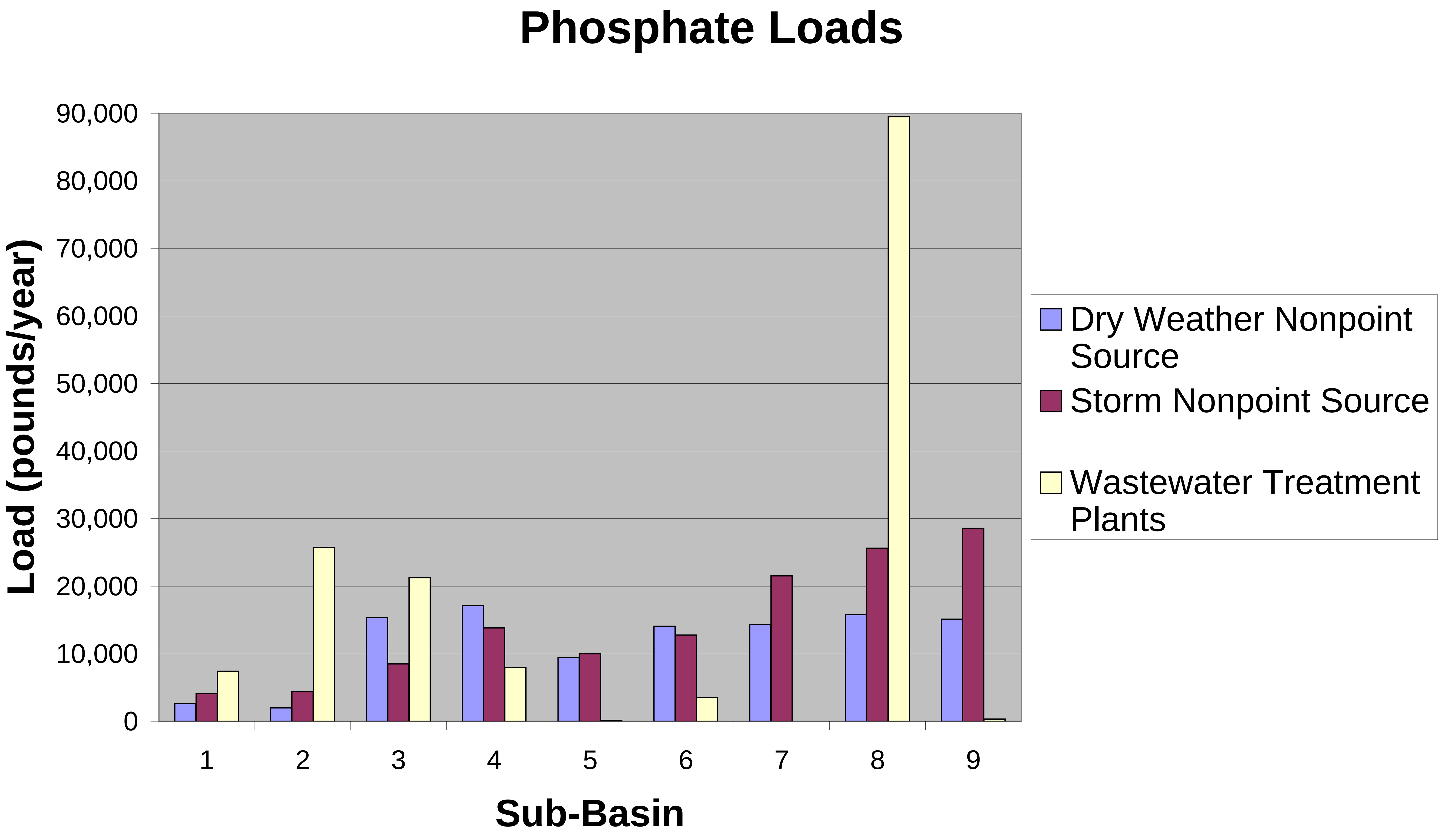
		Sub-basin number	1	2	3	4	5	6	7	8	9
Nitrate & Ammonia	**lbs/yr**	**Dry Weather Nonpoint Source**	42,954	26,145	156,394	187,463	108,964	156,793	165,006	164,307	181,539
Nitrate & Ammonia	**lbs/yr**	**Storm Nonpoint Source**	52,919	55,738	111,304	185,092	129,809	173,097	293,214	332,397	395,280
Nitrate & Ammonia	**lbs/yr**	**Wastewater Treatment Plants**	12,185	93,718	297,283	37,877	278	15,358	16	304,732	2,055
PO4	**lbs/yr**	**Dry Weather Nonpoint Source**	2,619	1,974	15,345	17,123	9,428	14,071	14,337	15,794	15,122
PO4	**lbs/yr**	**Storm Nonpoint Source**	4,105	4,435	8,495	13,829	9,997	12,762	21,525	25,629	28,585
PO4	**lbs/yr**	**Wastewater Treatment Plants**	7,430	25,744	21,237	7,977	158	3,496	1	89,483	328
Sediment	**lbs/yr**	**Dry Weather Nonpoint Source**	1,586	102,982	1,255,382	1,138,673	550,382	942,073	950,982	1,367,909	952,855
Sediment	**lbs/yr**	**Storm Nonpoint Source**	1,006,414	2,450,800	14,864,018	21,423,109	11,154,200	17,574,600	23,813,927	36,892,109	25,473,491
Sediment	**lbs/yr**	**Wastewater Treatment Plants**	92,345	152,309	352,118	48,236	19,564	76,345	102	585,144	9,300
NO3	**lbs/yr**	**Dry Weather Nonpoint Source**	29,093	17,939	108,512	128,660	73,471	107,625	113,205	114,920	125,048
NO3	**lbs/yr**	**Storm Nonpoint Source**	35,648	36,900	74,823	124,062	83,919	116,474	197,166	221,781	266,999
NO3	**lbs/yr**	**Wastewater Treatment Plants**	5,052	76,361	263,736	32,557	3	12,192	2	105,606	1,408
NH3	**lbs/yr**	**Dry Weather Nonpoint Source**	13,861	8,207	47,881	58,803	35,492	49,168	51,801	49,387	56,490
NH3	**lbs/yr**	**Storm Nonpoint Source**	17,271	18,839	36,480	61,030	45,891	56,623	96,048	110,616	128,281
NH3	**lbs/yr**	**Wastewater Treatment Plants**	7,133	17,356	33,547	5,320	275	3,166	13	199,126	648
Sediment	**tons**	**Dry Weather Nonpoint Source**	1	51	628	569	275	471	475	684	476
Sediment	**tons**	**Storm Nonpoint Source**	503	1,225	7,432	10,712	5,577	8,787	11,907	18,446	12,737
Sediment	**tons**	**Wastewater Treatment Plants**	46	76	176	24	10	38	0	293	5
Total number of WWTP per basin			2	2	3	3	1	2	1	4	1

Figure A-07a



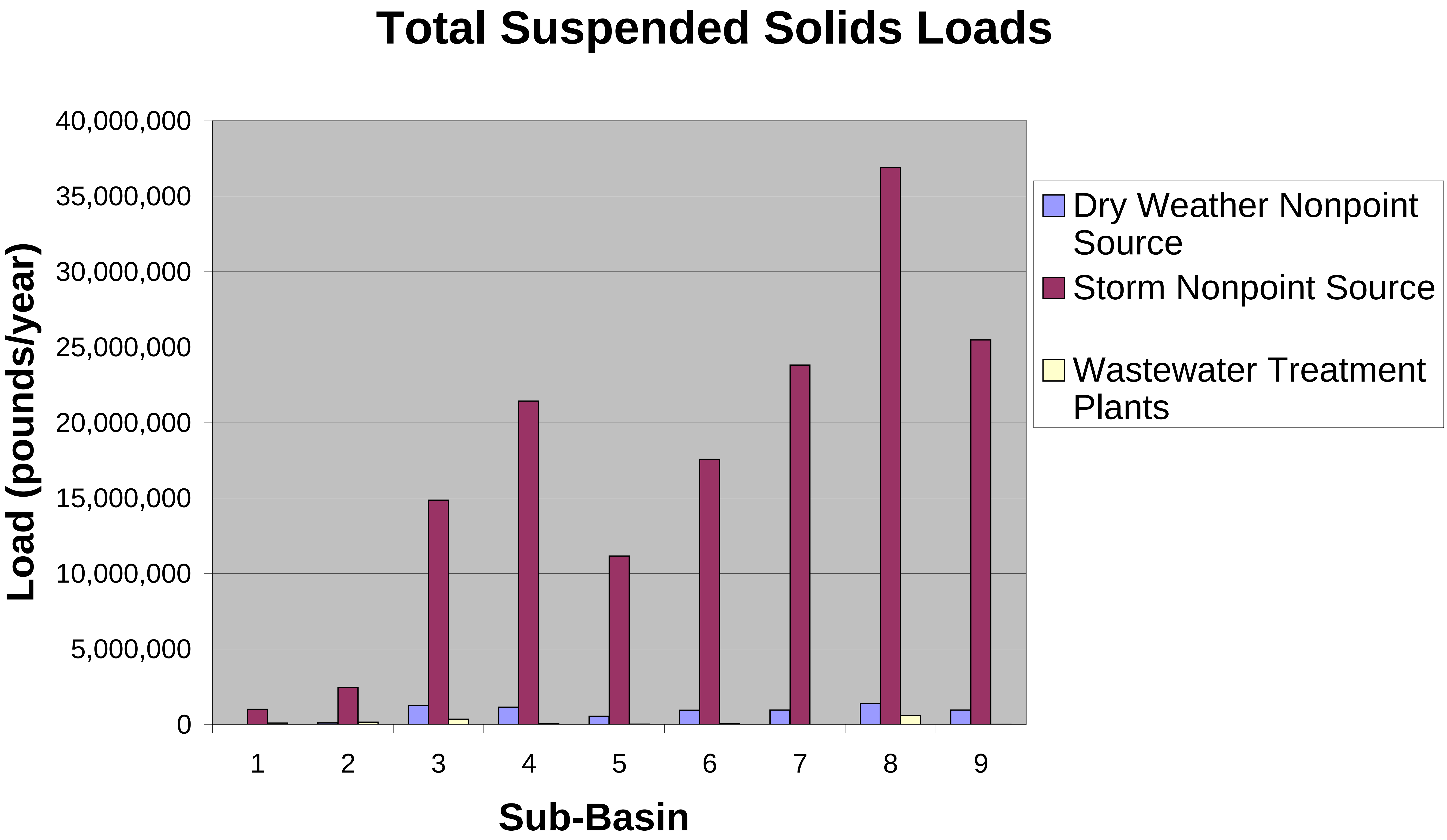
Nitrate & Ammonia Loads
Load (pounds/year)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1
2
3
4
5
6
7
8
9
Sub-Basin
Dry Weather Nonpoint Source
Storm Nonpoint Source
Wastewater Treatment Plants

Figure A-07b



Phosphate Loads
Load (pounds/year)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1
2
3
4
5
6
7
8
9
Sub-Basin
Dry Weather Nonpoint Source
Storm Nonpoint Source
Wastewater Treatment Plants

Figure A-07c


Total Suspended Solids Loads
Load (pounds/year)
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1
2
3
4
5
6
7
8
9
Sub-Basin
Dry Weather Nonpoint Source
Storm Nonpoint Source
Wastewater Treatment Plants

APPENDIX B: DISCUSSION DOCUMENT ON ALL STRATEGIES

ATTACHMENT C
STRATEGIES AND REFERENCE MATRIX

Description			Applicable Reference Number
NPS Treatment Systems	Stormwater Runoff Wetland Treatment Systems	Extended Detention Shallow Wetland	17, 30a, 30c, 30d, 58, 53, 59, 62, 63, 64, 65, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 80, 82, 83, 84, 87, 92, 103, 104, 105, 106, 107, 108, 112, 113, 118, 119, 132, 134, 142, 143, 144, 178, 179, 181, 182, 183, 186, 187, 189
		Pocket Wetland	
		Pond/Wetland Systems	
		Submerged Gravel Wetland Systems (subsurface flow systems)	30a, 66, 92, 107
		Series of wetland cells within small drainage	30a, 87, 92
		Wetland swales	30a, 87, 88, 92
	Bioretention	Low Impact Development Strategies - Rain Gardens	24, 30a, 30e, 41, 42, 43, 44, 50, 92, 168
	Channels	Dry Swale	30a, 92, 168, 192
		Grass Channel (biofilter)	30a, 86, 92, 168
		open conveyance channel	30a, 92
		Wet Swale/wetland channel	30a, 87, 88, 92, 168, 192
	Detention	dry detention/dry extended detention basins	30a, 30b, 92, 119
		Multipurpose detention areas	30a, 92, 119
		Underground detention	30a, 92, 119
	Filtration	Filter strips buffer zones	30a, 92, 96, 97, 112, 168, 178, 179, 181, 182, 183, 187, 189
		Organic Filter	30a, 92
		Sand Filters	30a, 92
	Hydrodynamic Devices	Gravity (oil/grit) separator	30a, 92
	Infiltration	Infiltration Trench	30a, 87, 92
		Soakage Trenches	30a, 92
	Ponds	Micropool Extended Detention Pond	30a, 92, 144, 182, 187
		Multiple Pond Systems	28, 30a, 92, 101, 182, 187
		Wet Extended Detention Pond	30a, 92, 117, 182, 187
		Wet Pond	30a, 92, 143, 182, 187
	Porous Surfaces	Green Roofs	30a, 92, 133, 135, 136
		Modular Porous Paver Systems	30a, 92
		Porous Concrete	30a, 92
	Reuse	Rain Harvesting/Collection Systems	85, 92, 173
	Bank/Slope Stabilization/Erosion Control	Bioengineering with vegetation - riparian corridor development	26, 29, 48, 49, 89, 92, 96, 97, 98, 103, 158, 159, 160, 161, 185, 191
		Revetments	92, 141, 174, 175

ATTACHMENT C
STRATEGIES AND REFERENCE MATRIX

Description				Applicable Reference Number
Point Source Treatment Systems	Constructed Wetlands for tertiary treatment following mechanical or lagoon treatment plants		At individual WWTP (municipal, industrial, agri./aquacul.)	17, 24, 30d, 52, 53, 57, 58, 59, 60, 61, 67,76, 77, 80, 93, 94, 95, 100, 101, 102, 103, 104, 105, 109, 110, 111, 113, 114, 115, 116, 118, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 163, 166, 169, 186, 188
			Regional Wetland systems polishing flows from multiple WWTP in close proximity	
	Polishing Ponds		At individual WWTP (municipal, industrial, agri./aquacul.)	28, 46, 47, 53, 93, 100, 101, 106
	Chemical Nutrient Removal		Alum Treatment	33, 100
			Lime Treatment	
	Reuse		Storage/Irrigation	14, 32, 99, 101, 116, 145, 172, 177
Collective (NPS & PS)	Large-scale constructed wetland system		On-Channel - Llano Grande	17, 30d, 53, 57, 58, 67, 76, 77, 79, 80, 93, 95, 102, 103, 104, 105, 108, 109, 110, 111, 113, 114, 115, 116, 118, 120, 121, 122, 123, 124, 125, 126, 127, 173, 184, 186, 190
			Off-Channel - Regional Wetland System	
Management Strategies	IBWC	Maintenance Activities in Floodway	Mowing (freq. & timing)	25, 27, 149, 150, 151, 152, 153, 154, 156, 176
			Analysis of hydraulic impact of dev. of woody riparian	
			Levee Repair/Reconstruction	
		Dredging Operations	Disposal of Dredge Spoils	
			Configuration of Channel	
	Port of Harlingen		Off-Loading Procedure & use of Best Available Control Technology	146, 147, 155
			Containment and remediation of spills	
			Ballast water	
			SWPPP	
			Aeration of turning basin	

ARROYO COLORADO FEASIBILITY STUDY
REFERENCE LIST AND SUMMARIES

1. Texas Water Commission, *Waste Load Evaluation for the Arroyo Colorado in the Nueces-Rio Grande Coastal Basin*, July 1990.

   Produced in 1990 by the Texas Water Commission, the purpose of this report was to recommend wastewater treatment procedure and criteria to ensure that the Arroyo Colorado's dissolved oxygen level complied until the year 2000.

   Relevant Information:

   - Region characterized by its unconsolidated soil substrate, absence of topographic relief, subtropical to semi-arid climatic setting, grass land savannah natural vegetation, and intense agricultural and residential development.
   - Arroyo Colorado best considered as system of both natural and artificial hydrologic components which form continuous waterway 89.2 miles in length; overall drainage area of 2,344 square miles.
   - Arroyo Colorado serves as conveyance for flood waters; conveyance for municipal, industrial, and agricultural wastewaters, inland waterway for commercial boat traffic; habitat for wildlife; recreational resource.
   - Tributary inflows to Arroyo occur through network of drainage ditches. Three of the major tributary ditches are the Arroyo Anacuitas, the Donna Wastewater Treatment Plant ditch, and the ditch at IBWC Gate No. 23-L.
   - Natural overland drainage restricted due to level topography and intense land development.
   - Subsurface drainage similarly limited because of generally saturated condition of area soils due to the extensive irrigation practices of local agricultural operations. Shallow water table tends to intersect even shallow channels, which when combined with the high permeability of host sediments, produces a high degree of communication between groundwater and surface water regimes.
   - Critical low-flow used in modeling projections based on 7Q2 of 74.9 ft^3/s for the El Fuste station and 167.1 ft^3/s for the US 83 station.
   - Hydraulic conditions under low-flow conditions considered to be favorable to rapid, unrestricted flow due to entrenched, steep walled configuration of pilot channel, lack of vegetation, extensive channelization, and absence of major impoundments. Hydraulically impeding factors include moderate slope of channel bottom (0.0002 m/m), restriction of flow through flood control levees and minor impoundments caused by the erosion control drop structures. Flow velocities range from 0.68 ft/s to 1.61 ft/s. Measured flow width and calculated flow depths range from 16.1 feet to 110.6 feet wide and from 0.3 feet to 6.1 feet deep.
   - Locations defining hydraulic character include the Llano Grande Lake, the erosion control drop structures, and the tidally influenced, dredged shipping canal.
   - Volume of wastewater discharged to Arroyo Colorado increased dramatically from 1970-1990.
   - Wide diurnal fluctuations and super-saturated DO concentrations observed in the tidal portion indicate substantial impact on the DO regime due to the primary production of aquatic algae.

- Both segments of Arroyo Colorado classified as "Water Quality Limited."
- QUAL-TX water quality model used for Arroyo Colorado.

2. Fipps, Guy, Texas Agricultural Extension Service, *Texas A&M University System, Analysis of the Arroyo Colorado Water Quality Database*, August 30, 1996.

   Over the course of 12 years, the Texas Agricultural Extension Service collected water quality data pertaining to the Arroyo Colorado. The study was conducted as part of the project <u>NPS Prevention in the Arroyo Colorado Watershed</u>.

   Relevant Information:

   - Several maps identifying segment boundaries, monitoring stations, and major roads and highways are included in Appendix A.
   - Potential water quality problems in the Arroyo Colorado by segment number for 7 parameters are listed in Table 2. Nutrients were identified for all three segments listed (2200, 2201, and 2202); DO was identified for segments 2201 and 2202.
   - Comparison of the 7 water quality indicators for establishment of screening criteria and standards for Arroyo Colorado is provided in Table 3. From the table, "DO values never fell below the SWQC of 4 mg/L at station 13036 (floodway) or station 13074 (non-tidal). However, at station 13071 (tidal), low DO levels occurred in 35 of the 132 samples taken over the 13 year period, and levels fluctuated from almost 0 to over 17 mg/L. A high frequency of low oxygen levels occurred most recently in 1992."
   - Total nitrogen and total phosphorus levels were highest at station 13074 (non-tidal) compared to floodway and tidal stations. Total nitrogen high throughout.

3. Gorham-Test, Cynthia, Environmental Protection Agency, *DRAFT: 1993 REGIONAL ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM: Arroyo Colorado Tidal, Rio Grande Tidal, and East Bay Bayou, Texas,* April 14, 1998.

   This study addresses the ecological health of three small estuarine systems by identifying benthic community structure, fish community structure, and fish pathologies, measuring toxicity of sediments, and measuring concentration of various pollutants in the sediments.

   Relevant Information:

   - Arroyo Colorado watershed is an area of intense agriculture, and hence, an area of intense application of fertilizers and pesticides. Other sources of pollutants to this system include point source municipal and industrial discharges, urban runoff, and discharges from large aquaculture operations.
   - Major physical disturbance has been dredging and maintenance of a channel from the mouth of the river in the Laguna Madre Estuary to the Port of Harlingen.
   - Comparisons of the benthic structure of the Arroyo Colorado, the Rio Grande, and the East Bay Bayou indicates that all three are in poorer condition than Galveston Bay and the Louisianan Province as a whole. Benthic community values were lower in the Arroyo Colorado compared to surrounding regions.
   - The Arroyo Colorado benthic community structure values indicate stressed communities and degraded environmental conditions.

- Fish and shrimp mean abundances and species richness were poorest in the Arroyo Colorado, where dissolved oxygen concentrations are very low.
- Arsenic, chromium, selenium, and zinc values exceeding established criteria and a combination of C2-, C3-, and C4-Naphthalene values exceeding guidelines in fish and shrimp muscle tissue occurred in each of the three estuarine systems. Fish with pathological abnormalities also were found and the number of occurrences was higher in these three systems than within the entire Louisianan Province.
- Sediment toxicity test results indicated that acute toxicity due to contaminated sediments occurred in 10-33% of sediments samples representing the three estuarine systems.
- Elevated levels of nickel, mercury, chromium, tributyltin were reported.
- Pesticide concentrations in sediments were a major contributor to the poor sediment quality found in the Arroyo Colorado and the Rio Grande tidal area.
- The sediment samples from the Arroyo Colorado were categorized as having high metals and pesticides that were assumed to reflect anthropogenic uses within the watershed.
- The results of the study indicated that the Arroyo Colorado, the Rio Grande tidal area, and East Bay Bayou were significantly degraded estuaries.

4. Texas Natural Resource Conservation Commission, *Preliminary Assessment/Screening Site Inspection Work Plan Donna Reservoir and Canal System, Donna, Hidalgo County, Texas*, April 2001.

   The goal of this investigation is to report potential and confirmed releases of PCB from the "soil, surface water, streambed sediments, and suspended sediments that may have migrated through the DRCS." Identified areas of previously reported elevated PCB levels were tested using suspended sediment sampling to document occurrence, location of sources, and determine extent of contaminant migration.

   Relevant information:
   - Water that enters the DRCS that is not diverted for irrigation and/or drinking water supply eventually flows into the Donna Drain and thence, to the North Floodway.
   - The only apparent hydrologic connections between the Donna system and the Arroyo Colorado are the shallow groundwaters and possible leakage into and out of the Siphon.

5. Texas Natural Resource Conservation Commission, *Screening Site Inspection Report Donna Reservoir and Canal System Donna, Hidalgo County, Texas, Volume I of II*, November 2001.

   The main source of PCB contamination in the Arroyo Colorado is anthropogenic. Contributing factors include: farm land irrigation, pasture land, two closed landfills, and various unauthorized solid waste disposal sites.

6. Texas Natural Resource Conservation Commission, *Screening Site Inspection Report Donna Reservoir and Canal System Donna, Hidalgo County, Texas, Volume II of II,* November 2001

   This reference serves as the record of all sample data collected from the aforementioned source.

7. United States Army Corps of Engineers, *Dredging of the Gulf Intracoastal Waterway (GIWW) – Tributary Channel to Harlingen, Texas.* April 16, 2003

This letter report documents that water and elutriate samples collected prior to maintenance dredging of the GIWW – Tributary Channel to Harlingen, Texas were below EPA Water Quality Criteria, where criteria exist. Sediment quality data was compared to sediment quality screening guidelines. Two samples slightly exceeded the NOAA ERL, but were well below the NOAA ERM of 70.0 mg/kg. No unacceptable adverse impacts were anticipated from the proposed dredging and discharge operations.

Relevant information:

- Data for several sampling locations along the GIWW – Tributary Channel are included as tables with the letter report.
- The majority of the DO data reported are 5.0 mg/L with a few between 4.0 and 5.0 mg. However, the DO data for the last seven sites show a sudden drop below 3.0 mg/L with four of the seven sites below 1.0 mg/L.
- A call has been made to the USACE requesting information regarding the sampling site locations.

8. Nueces River Authority, *Basin Highlights Report, Nueces River Basin, San Antonio-Nueces Coastal Basin, Nueces-Rio Grande Coastal Basin*, March 2005.

   This report identifies the TCEQ monitoring stations for both the tidal and above tidal segments of the Arroyo Colorado. Each segment is divided into sub-segments, five for the tidal and four for the above tidal.

   Relevant information:

   - Ambient toxicity in sediment is identified as an impairment of the tidal segment.
   - Depressed DO is listed as an impairment in the 1 mile upstream to 3 miles downstream of Camp Perry and in the upper 4 miles of the tidal segment. Source of impairment was identified as crop-related.
   - States that initial studies reported that a 90% load reduction would be needed for tidal segment to meet standards, a goal that is considered to be feasibly unrealistic. Therefore, the Arroyo Colorado Watershed Protection Plan (WPP) is being developed to improve the overall water quality for the entire Arroyo Colorado watershed.
   - Concerns listed for the tidal segment include nitrate+nitrite in the approximately 1 mile upstream to 3 miles downstream of Camp Perry, approximately 3 miles upstream to 2 miles downstream of Marker 27, and in the upper 4 miles of the tidal segment.

- Ammonia is listed as a concern in the upper 4 miles of the segment.
- Source of nitrogen and ammonia was identified as crop-related.
- Bacteria was identified as an impairment in the entire above tidal segment.
- Ammonia, orthophosphorus, total phosphorus, and excessive algal growth were listed as concerns in all but the 11 miles upstream to 4 miles downstream of US 77 sub-segment.
- Nitrate+nitrite nitrogen was listed as a concern for the entire above tidal segment.
- Source of all the concerns was suspected to be from stormwater runoff.

9. Black & Veatch, *Nonpoint Source Pollutant Sampling Program*, October 1980.

The purpose of this study was to study the non-point source pollutants discharged into the Lower Rio Grande, and more specifically to determine the degree that agricultural activities contributed to this number. The conclusion of this report is that significant non-point source pollutants did not currently exist in the Lower Rio Grande Valley.

Relevant information:

- Arroyo Colorado and the irrigation drainage ditches are relatively rich in nitrogen.
- Potentially toxic quantities of ammonia were identified in irrigation drainage canals.
- Total phosphorus concentrations observed during study were very low.
- Significant non-point water quality problems in the Lower Rio Grande Valley were not indicated by this 1980 study.

10. Texas Commission on Environmental Quality, *Pollutant Loading and Dissolved Oxygen Dynamics in the Tidal Segment of the Arroyo Colorado*, July 2003.

This report summarizes the results of a four-year study designed to establish a TMDL for constituents associated with low dissolved oxygen in the tidal segment of the Arroyo Colorado. The conclusions of this report do not support a quantitative, water quality target-based allocation of loadings of constituents associated with dissolved oxygen dynamics in the tidal segment of the Arroyo Colorado.

Relevant information:

- Physical, anthropogenic modifications are major factors in the DO dynamics of Segment 2201.
- Numerous documented manifestations of environmental stress have occurred since 1966 when ecological surveys were first initiated. Major fish kills occurred in 1971, 1981, and 1982 with smaller fish kills occurring in April and May of 1989, September 1990, June 1991, and June 1992. More recently, massive fish kills (>1 million fish) have occurred in 1997, 1998, and 1999.
- Surface geology of the area is dominated by Quaternary alluvial deposits.
- In addition to extensive agricultural cultivation, considerable oil and gas activity occurs in the area.
- Urbanization is extensive in areas directly adjacent to the main stem of the Arroyo.

- Perennial flow in the Arroyo is sustained mainly by municipal discharges, with irrigation return flows and urban runoff supplementing the flow on a seasonal basis.
- Llano Grande Lake is a long, shallow depression, southwest of the City of Mercedes, that acts as a large settling basin, collecting much of the upstream sediment load.
- More than 90 percent of Hidalgo County and more than 80 percent of Cameron County are farm and ranch land. The Arroyo Colorado watershed contains approximately 290,000 acres of irrigated cropland in these two counties. Primary agricultural crops include cotton, corn, grain, sorghum, sugar cane, citrus, and a variety of vegetables.
- Significant urbanization began in areas adjacent to the Arroyo Colorado in the late 1980s and continued through the 1990s with population in the area doubling between 1970 and 1990.
- Floodwater overflows from the Rio Grande into the Main Floodway are rare.
- Many communities within or adjacent to the Arroyo Colorado watershed lack basic water and wastewater infrastructure facilities.
- Report contains comprehensive summary of data and findings from intensive studies and water quality modeling on the Arroyo Colorado conducted since 1975 by numerous entities including the precursors to the TCEQ.
- Analysis of the Arroyo Colorado through the HSPF modeling indicated that the physical setting contributes significantly to the observed DO impairment in the tidal segment and that even extreme reductions in the loading of constituents of concern will not achieve the TMDL endpoint target without mitigating the effects of some of the physical modifications.

The "Discussion and Conclusions" portion of this report lists 6 recommendations for a future Watershed Action Plan including: reduction of nitrogen, phosphorus, BOD, and sediment levels, improvement of aquatic life environment, increased monitoring, and more detailed hydrodynamic modeling.

11. Bryan, C.E., Texas Parks and Wildlife Department, *An Ecological Survey of the Arroyo Colorado, Texas 1966- 1969,* 1971.

    Large fish kills as well as a general decline in some species were reported. Additionally, the report found that the water quality of the Arroyo Colorado was "obviously very poor" due to a low D.O. caused by pollutants.

12. MISSING REPORT

13. MISSING REPORT

14. Fipps, Guy, Texas Cooperative Extension, The Texas A&M University System, Irrigation Water Quality Standards and Salinity Management Strategies, accessed online at http://lubbock.tamu.edu/irrigate/documents/2074410-B1667.pdf, August 2005.

This study examines the correlation between irrigation and salinity and best management practices to reduce the level of salinity pollution.

Relevant information:

- If treated wastewater is to be reused for irrigation purposes, the salinity levels must be considered.
- Outlines ways to prevent salinity pollution to crops during irrigation.

15. Matlock, Marty and Demich, Larry, Department of Agricultural Engineering Texas A&M University, *A Preliminary Assessment of the Nutrient Status of the Upper Arroyo Colorado River*, May 26, 1999.

    The objective of this study was to "measure changes in the chemical constituents in the water column of the Arroyo system, with special attention to macro-nutrients: nitrogen, phosphorus and carbon." The section of the Arroyo Colorado selected for the study included Llano Grande Lake downstream of the 1015 S bridge, the bypass channel, and the Arroyo downstream of Llano Grande Lake. The study concluded that the net assimilation and reduction of nutrients from the water column of the Upper Arroyo Colorado River was very small relative to the quantity of constituents currently in the system, therefore, the ability of ecological processes to reduce the concentration of nutrients in the system by assimilation is not apparent. However, Llano Grande Lake did exhibit significant assimilation of organic constituents and nutrients.

16. Palmer, M.A.; E.S. Bernhardt; J.D. Allan; P.S. Lake; G. Alexander; S. Brooks; J. Carr; S. Clayton; C.N. Dahm; J. Follstad Shah; D.L. Galat; S.G. Loss; P. Goodwin; D.D. Hart; B. Hassett; R. Jenkinson; G.M. Kondolf; R. Lave; J.L. Meyer; T,K. O'Donnell; L. Pagano; and E. Sudduth, *Standards for Ecologically Successful River Restoration*, Journal of Applied Ecology. 2005. 42, 208-217.

    This article provides a list of five criteria necessary for measuring a successful river restoration: Guiding image of dynamic state; ecosystems are improved; resilience is increased; no lasting harm is done; and an ecological assessment is completed.

17. Fortner, Brian, *Desert Wetlands*, Civil Engineering: September 2000.

    Wetland technology was used to construct a number of wetlands to improve water quality in the New River which flows from Mexico into southern California and is dominated by untreated and partially treated wastewater as it reaches the border then agricultural drain water from flood irrigation is added through the Imperial Valley of California. This scenario is unique due to the high levels of pollutants and the salinity value of the New River, the Alamo River, and the Salton Sea. Based on the situation, various designs were used in the initial stage of the project to determine the best course of action for the remainder of the project.

    Relevant information:

    - Gravity-fed wetlands treat water at a rate of about 4 cfs.

- Parallel sediment basins with retention time of about 8 days followed by four wetland cells with varying planting and flow schemes, and different configurations.
- Smaller Brawley site contains three cells – one sediment basin and two wetland cells and receives about 1 cfs of diverted flow.
- Except for the inlet pump system at the smaller Brawley site, the wetlands projects are gravity fed and contain a minimum of mechanical devices.
- Ratio of vegetation to open water is about 1:1.

18. Judd, Frank and Lonard, Robert, Department of Biology University of Texas-Pan American, *Community Ecology of Freshwater, Brackish and Salt Marshes of the Rio Grande Delta,* May 2004.

    Species composition and importance, species diversity and evenness, species richness, and community similarity are compared among 6 freshwater, 9 brackish, and 11 salt marshes in the Rio Grande Delta.

    Relevant information:
    - 81 species associated with freshwater habitats in the Lower Rio Grande Valley were identified in this study compared to 44 species identified in a 1937 study.
    - Location of six freshwater marshes sampled is given.
    - The first six species in importance contributed from 72.6% to 96.4% of the relative cover in the freshwater marshes sampled.
    - 81 species were present in nine brackish marshes sampled.

19. Fipps, Guy and Pope, Craig, Implementation of a District Management System in the Lower Rio Grande Valley Texas, accessed online at http://idea.tamu.edu/phoenix4.html, August 2004.

    Based on the level of growth in industry and population, this reports explains a GIS-based District Management System for the 28 irrigation districts within the Lower Rio Grande Valley that was initiated in 1992. Upon completion, the DMS will become an important "support system for scheduling, water management, and conservation planning."

    Relevant information:
    - Lower Rio Grande River is over appropriated; municipal and industrial water rights have priority over agriculture.
    - TWDB projections are "by the year 2010, municipal water demand will increase by 66% and industrial water use by 19%. By 2050, municipal demand is expected to increase 171% and industrial 48% over current usage."

20. United States Army Corps of Engineers, *Condition Assessment of the U.S. International Boundary and Water Commission, Lower Rio Grande Levees, South Texas*, October 2003.

This research project calls for a study of the structural integrity of the levees on the Lower Rio Grande Flood Control Project by the U.S. Army Corps of Engineers in conjunction with the International Boundary and Water Commission. Due to erosion of foundation soil from prolonged seepage and piping, it is a possibility that the flood control levees may be unstable. Studies were to be performed in 2002.

21. Arroyo Friends, *The Lower Rio Grande Flood Control Project*, accessed online at http://www.arroyofriends.com/ibwc.html, August 2005.

    This website article was published by Arroyo Friends, a community group that opposes the addition of bike trails with associated trail bridges inside the floodway. This article lists functions of the Lower Rio Grande Flood Control Project and its disappointment in the approval of the bike trails, which Arroyo Friends believes blocks water flow and raises flood levels.

22. Arroyo Friends, *Destruction of Wetlands and Natural Habitats*, accessed online at http://www.arroyofriends.com/ibwc.html, August 2005.

    Similar to the earlier article, this piece claims that the construction of the hike and bike trail will destroy natural habitat and the resulting human activities will drive away bird and mammal species from the area.

23. Arroyo Friends, *Homepage,* accessed online at http://www.arroyofriends.com/ibwc.html, August 2005.

    Homepage of Arroyo Friends, an activist group that opposes the construction of the City of Harlingen's Hike and Bike Trail.

    Relevant information:
    - Erosion problems on the Arroyo Colorado occur during periods of high rain.
    - Sink holes are a common problem in the area due to erosion.

24. Land Views, *Online Journal of Landscape, Art, and Design,* accessed online at http://www.landviews.org, August 2005.

    Article by Patricia Johanson presents concept of municipal water gardens where public landscape project creates wildlife habitat, processed sewage, and welcomed public visitors. Water garden park included ponds and wetlands to provide wastewater treatment. Multi-function landscapes provide beauty as well as being productive and life supporting.

25. Handbook of Texas Online, "Port Harlingen" accessed online at http://www.tsha.utexas.edu/handbook/online/articles/PP/rrp8.html, August 12, 2005.

Provides location, commerce information, and physical dimensions of the Harlingen channel connecting the Arroyo Colorado and the Gulf Intracoastal Waterway.

Relevant information:
- The channel connecting Arroyo Colorado with the Gulf Intracoastal Waterway is 12 feet deep and 125 feet wide.
- Turning basin measures 400 by 600 feet.

26. Mild, Christina, Rio Delta Wild. *Large Old Cedar Elms Lend Gandeur*, August 2005.

Describes the regional advantages of Cedar Elms which are native to South Texas, as well as proper time for planting in the region.

27. Port of Harlingen, Home Page, Location, and Facilities, accessed online at http://www.portofharlingen.com, August 2005.

Outlines the dimensions, provides a map, and other details of the Port of Harlingen, which is fed by the Arroyo Colorado.

28. Hibl, Harvey, *Blue-green Algae Bloom Control Through Circulation – Scientific Support,* August 9, 2005.

An Email from Harvey Hibl which describes the benefits in lake restoration of the SolarBee solar powered water circulator.

Relevant information:
- SolarBee circulators have been used to eliminate stagnant water in reservoirs
- In wastewater lagoons, SolarBee circulators improve treatment, reduce ammonia, enhance sludge digestion, and reduce aeration costs over conventional aerators.

29. United States International Boundary and Water Commission, *Rio Grande Wildlife Corridor on Agenda for September 22 Public Meeting,* September 9, 2004.

An announcement of a public meeting between the Lower Rio Grande Citizens Forum and the USIBWC. The meeting was to discuss the formation of a wildlife corridor in the area.

30. Schueler, Thomas and Hollard, Heather, Editors. *The Practice of Watershed Protection,* Center for Watershed Protection, Ellicott City, MD: 2000.
    a. Article 64. *Technical Notes #95 from Watershed Protection Techniques. 2(4): 515-520. Comparative Pollutant Removal Capability of Stormwater Treatment Practices.* National database developed containing more than 135 individual stormwater practice performance studies. Used to generate national statistics about the pollutant removal capability of various groups of stormwater practices and to highlight gaps in knowledge. Three criteria had to be met for study to be

included in database: at least five storm samples; automated equipment employed to take flow or time-based composite samples; and written documentation of the method used to compute removal efficiency.

b. Article 77. *Technical Note #62 from Watershed Protection Techniques. 2(1): 294-295. Performance of a Dry Extended Pond in North Carolina.* Reviews potential performance of well-designed dry ED ponds with study of demonstration dry ED pond in small coastal plain watershed in North Carolina.

c. Article 93. *Technical Note #53 from Watershed Protection Techniques. 1(4): 210-213. Pollution Dynamics Within Stormwater Wetlands: Organic Matter.* Critically examines the wetland purification process through the use of controlled experiments with mesocosms. Discusses the impact time of year, plant life, organic detritus, and residence time have on the ultimate successful removal of nutrients (nitrogen and phosphorus) in a wetland. Both nitrogen and phosphorus removal was demonstrated to continue through the fall and winter after plants die back through uptake of microbes on plant detritus (nitrogen) and vegetated sediments (phosphorus).

d. Article 99. *Technical Note #24 from Watershed Protection Techniques. 1(2): 83. Broad-Leaf Arrowhead: A Workhorse of the Wetland.* Lists 5 advantages of using the broad-leaf arrowhead in a wetland. (good adaptation to a wide range of conditions, nutrient uptake, heavy metal uptake, ease of plant propagation, resistance to disease and damage).

e. Article 110. *Technical Note #29 from Watershed Protection Techniques. 1(3): 114-116. Bitter, S.D. and J.K. Bowers. Bioretention as Water Quality Best Management Practice.* Gives an explanation of the processes involved in the bioretention concept as well as providing a schematic of a bioretention area.

31. Texas Natural Resource Conservation Commission, Strategic Plan, *State of the Rio Grande and the Environment of the Border Region Strategic Plan*, June 2002.

A summary/discussion of the TNRCC Strategic Plan for the Rio Grande. Discussion of water quality issues outlined in the Plan.

Relevant information:

- Arroyo Colorado above the Tidal Zone (Segment 2202) has elevated levels of bacteria so that the water does not meet standards for contact recreation.
- Presence of toxic organic chemicals in fish tissue caused the segment to be placed on the state's 303(d) cleanup list.
- TMDL developed to control several legacy pollutants in the Upper Arroyo Colorado.
- Texas Soil and Water Conservation Board has been helping individuals develop water quality management plans for properties as part of efforts to reduce the amount of nutrients in the water which contribute to low levels of dissolved oxygen. Focus is on changing irrigation practices and controlling nutrients in runoff.
- Tidal region of Arroyo Colorado (Segment 2201) currently meets standards designed to protect the health of aquatic life, but elevated nutrient levels result in periodic low dissolved oxygen levels that harm aquatic life.

- Laguna Madre on state's 303(d) list due to low levels of dissolved oxygen and high levels of bacteria. Both occur near the mouth of the Arroyo Colorado.

32. Phillips, Kathleen, *Reclaimed Wastewater: An Idea that Could Soak In.* AgNews News and Public Affairs. Texas A&M University System Agriculture Program. August 9, 2005.

    A study conducted by the Texas Agricultural Experiment Station in El Paso by Dr. George Di Giovanni, Texas Agricultural Experiment Station environmental microbiologist tested irrigation of crops with wastewater indicating that "managing reclaimed water by pretreating before using it to irrigate, monitoring for viruses, choosing correct crops and periodically leaching the soils should be successful and safe." The study used wastewater laced with bacteriophage, a type of virus that only infects bacteria, using reclaimed wastewater to irrigate plants. The study showed feasible use of wastewater if reclaimed water was effectively treated to remove or kill pathogens before use.

33. Texas Commission on Environmental Quality, *Wastewater Infrastructure Plan to Reduce Nutrients, Biochemical Oxygen Demand, Fecal Pathogens, and Suspended Solids Loading into the Arroyo Colorado*, draft copy, 2005.

    Relevant information:
    - Major area targeted for improvement is the reduction of pollutant loadings from wastewater facilities.
    - Between 1989 and 1999, municipal wastewater facilities accounted for 23% of the BOD, 22% of the ammonia nitrogen, 20% of the nitrate nitrogen, and 40% of the orthophosphate entering the Arroyo Colorado.
    - Information regarding municipal point source loadings and permitted flows.
    - Maps showing location of wastewater treatment facilities in Arroyo Colorado watershed and watershed sub-basins.
    - Specific outline of the current status of the Arroyo Colorado and the issues that need to be considered.

34. International Boundary and Water Commission, *Alternative for Improved Flood Control of the Hidalgo Protective Levee System,* July 2005.

    Provides a plant, wildlife, and wetland inventory of levee areas in the Lower Rio Grande Valley. Includes a list of threatened and endangered species potentially occurring within the levee corridor and borrow easements and required habitat for each.

35. Lower Rio Grande Valley Development Council, *Rio Grande Regional Water Planning Group,* August 2005.

    Includes information about water issues in the Lower Rio Grande: non-potable water reuse figures, water supply deficits, population growth, etc.

36. Texas Commission on Environmental Quality, *Get to Know the Arroyo Colorado,* August 2004.

This article has a section on: pollution states/fish kills, impact on the bay, contributors to pollution, suggestions for actions to take towards improvement.

Relevant information:

- From 1990-2004, 26 million fish died in 19 documented cases on the Arroyo Colorado.
- Of the 500,000 acres in the Arroyo Basin, 70% is cultivated.
- Contributions to pollution: population boom, wastewater discharges, agricultural issues, dredging of the Arroyo Colorado to the Port of Harlingen.

37. Arroyo Colorado Watershed Partnership, *Arroyo Colorado Watershed Partnership Newsletter,* June 2005.

This newsletter is a tool used to include the public in the Arroyo Colorado Watershed Partnership.

Relevant information:

- The physical setting of the Arroyo Colorado is a main contributor to the water quality issues.
- Even a 90% reduction of pollutant loading would not enable the Arroyo to meet water quality standards.

38. Texas Commission on Environmental Quality, *A Watershed Plan for Dissolved Oxygen,* May 2005.

This newsletter is a tool used to include the public in the Total Maximum Daily Load Program.

Relevant information:

- The Laguna Atascosa National Wildlife Refuge and several county and city parks are located in the Arroyo Colorado watershed.

39. International Boundary and Water Commission, *Environmental Policy,* May 2005.

The Environmental Policy states that the USIBWC will meet all regulatory compliance, work towards the prevention of pollution, and continually "seek out ways to improve USIBWC environmental performance."

40. Fipps, G. *Analysis of the Arroyo Colorado Water Quality Database.* Texas Agricultural Extension Service, Texas A&M University System, October 1997. accessed online at http://arroyo.tamu.edu/ July 2005.

As part of project: NPS Prevention in the Arroyo Colorado Watershed, database of available water quality data on the Arroyo Colorado was assembled. Report summarizes analysis of data and reports on the long-term trends of 7 water quality indicators: dissolved oxygen, sulfate, nitrate, fecal coliform, dissolved phosphorus, total phosphorus, and chloride as well as review of the toxic substance data. Includes maps of the Arroyo Colorado with monitoring stations shown.

41. Metropolitan Area Planning Council, *Bioretention Areas*, accessed online at http://www.mapc.org/regional_planning/LID/PDFs/Biortention.pdf, August 2005.

    Overview of Bioretention systems used as a low impact development strategy in Massachusetts Low Impact Development Toolkit. Provides applications and design principles. Discusses benefits and effectiveness, limitations, maintenance requirements, cost, and design details.

42. Toolbase Services, *Low Impact Development (LID) Practices for Storm Water Management*, accessed online at http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2007&CategoryID=1071, August 2005.

    Lists various low impact design strategies in two categories practices and site design: Practices include: bio-retention cells, grass swales, filter strips, disconnected impervious areas, and cistern collection systems. Additionally, prices are listed for low-impact developments. Site Designs include ways to decrease impervious surfaces: reducing roadway surfaces, permeable pavement surfaces, and vegetative roof systems; as well as planning site layout and grading to natural land contours to retain a greater percentage of the land's natural hydrology. Benefits and costs as well as limitations are presented.

43. Environmental Protection Agency, *Storm Water Technology Fact Sheet, Bioretention*, EPA 832-F-99-012. September 1999. accessed online at http://www.epa.gov/npdes/pubs/biortn.pdf, August 2005.

    This reference provides description of bioretention as a best management practice. Includes figure of treatment area and discusses treatment removal processes. Discussion on applicability, advantages and disadvantages, design criteria, sizing, performance, operation and maintenance, and costs.

44. United States Department of Transportation, Federal Highway Administration, *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*, accessed online at http://www.fhwa.dot.gov/environment/ultraurb/3fs3.htm, August 2005.

    The Bio-retention fact sheet for the USDOT is similar to the EPA fact sheet also presenting discussion on applicability, effectiveness, sizing and design considerations, maintenance considerations, and cost considerations. Includes detailed drawings.

45. Stormwater Center, *Stormwater Management Fact Sheets (Constructed Wetlands, Wet Ponds, Grassed Filter Strips, Grass Channel, and Bioretention)*, accessed online at http://www.stormwatercenter.net, August 2005

The Stormwater Fact sheets are generally applied to small sites, but can be applied to a wide range of development, in many climate and geologic situations, with minor design modifications. Fact sheets provide conceptual designs, operation and maintenance, and effectiveness data.

46. Cavalcanti, P.F.F.; A. Van Haandel; and G. Lettinga, *Polishing Ponds for Post-Treatment of digested sewage Part1: Flow-Through Ponds*, Water Science & Technology Vol. 44 No. 4 pp 237-245. IWA Publishing 2001. accessed online at http://www.iwaponline.com/wst/04404/wst044040237.htm, August 2005.

States that to lower the TSS and BOD concentrations very much, effluent must be retained for at least one week. Observed efficiency during study was well below the expected value for all retention times, attributed to imperfections of the flow regime. Required retention time for an effluent to be used in unrestricted irrigation was produced for a retention time of about 10 days.

47. Cavalcanti, P.F.F., A. Van Haandel, G. Lettinga, *Sludge Accumulation in Polishing Ponds Treating Anaerobically Digested Wastewater*, Water Science & Technology Vol. 45 No. 1 pp 75-81. IWA Publishing 2002. accessed online at http://www.iwaponline.com/wst/04501/wst045010075.htm, August 2005.

Study concluded that accumulation of solids in a polishing pond is so low that removal during the useful life span of the pond will most likely not be necessary. Bottom sludge had a high volatile solids concentration (58%) and macronutriet fractions were also high (3.9% N and 1.1% P of the TSS mass). The hygienic quality of the bottom sludge (solids) was very poor with about half the influent helminth eggs during one year of operation found in the bottom sludge and the faecal coliform concentration very high.

48. Kay and Associates, International Training Consultants, *Bio-Engineering Techniques for Slope Stabilization and Control of Sediment Generation*, accessed online at http://www.kayassociates.com/Articles/bioeng.html, August 2005.

List of bioengineering techniques that uses native plant species to: enhance slope stability, control sediment generation, maintain plant and wildlife biodiversity. Enhancement of native vegetation establishment includes stabilization of surface soils; increase in water infiltration; and formation of terraces with lower slope angles.

Relevant information:

- Detailing of hand and mechanical site preparation and planting methods.
- Incorporating of existing vegetation into remedial work plan
- Maintenance
- Worker safety

49. Franti, Thomas G., *Bioengineering for Hillslope, Streambank and Lakeshore Erosion Control*, Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. G96-1307-A. accessed online at

http://ianrpubs.unl.edu/Soil/g1307.htm, August 2005. Original document published February 1997.

This article provides information regarding various bioengineering solutions for erosion control. Advantages of bioengineering solutions include low cost and lower long-term maintenance cost than traditional methods; low maintenance of live plants after they are established; environmental benefits of wildlife habitat, water quality improvement and aesthetics; improved strength over time as root systems develop and increase structural stability; and compatibility with environmentally sensitive sites or sites with limited access. Limitations to use of bioengineering methods include installation season often limited to plant dormant seasons, when site access may be limited; availability of locally adapted plants may be limited; labor needs are intensive and skilled, experienced labor may not be available; installers may not be familiar with bioengineering principles and designs so upfront training may be required; and alternative practices are aggressively marketed and often more widely accepted by society and contractors. Tips for improving success of bioengineering efforts are listed and demonstration projects are recommended.

50. Low Impact Development Center, *Bioretention Specifications*, accessed online at http://www.lowimpactdevelopment.org/epa03/biospec_left.htm, August 2005.

    Provides detailed information for construction of bioretention facilities, including materials needed, soil mixture, plants, measurements, etc.

51. Texas Natural Resource Conservation Commission, *A Watershed Plan to Restore and Protect Aquatic Life and Recreational Uses in the Arroyo Colorado,* January 2002.

    Details the TCEQ's plan to facilitate and oversee the development of a watershed plan for the Arroyo Colorado including goals and objectives, organization of workgroups, schedule and TCEQ plan to improve wastewater infrastructure and Quality and Storm Water Management.

    Relevant information:
    - Goals and objectives of the watershed plan include:
        - Reduction in loadings of total nitrogen, total phosphorus, BOD, and sediment to levels that are realistically achievable with consideration given to economic viability issues.
        - Physical anthropogenic modifications that currently characterize the tidal and above-tidal segments of the Arroyo Colorado will be reviewed and, to the extent possible, will be redesigned or compensated for through additional ecologically engineered modifications in order to reduce loadings of nutrients, BOD, and suspended sediment, and also to improve aquatic habitat.
        - Biological, flow, and water quality monitoring in the Arroyo Colorado will be continued and enhanced.
        - Characterization of watershed loadings, in-stream rates and constants, and DO dynamics in the Arroyo Colorado will be improved to enhance understanding of the cause-and-effect relationships between flow, loadings, biochemical interactions, and physical setting.

- More detailed hydrodynamic modeling will be conducted on the tidal segment of the Arroyo Colorado.
- Fostering local stewardship through outreach and education.

➢ Six workgroups were formed to address and develop the Arroyo Colorado Watershed Action Plan
  - Wastewater Infrastructure
  - Agricultural Issues
  - Habitat Restoration
  - Further Study/Refinement of TMDL Analysis
  - Outreach and Education
  - Land Use

52. Environmental Protection Agency, *"Finding of No Significant Impact" City of Mercedes, Hidalgo County, Texas,* April 30, 2005 for *Environmental Assessment for the Wastewater Treatment and Collection System Improvement Project, City of Mercedes, Hidalgo County, Texas.* accessed online at http://www.epa.gov/earth1r6/6wq/usmexicoborder/mercedes.pdf

The U.S. EPA concluded that an expansion of the City of Mercedes' wastewater treatment facilities would have no significant impact on the human or natural environment.

Relevant information:

➢ Details of existing wastewater treatment plant design and capacity and proposed expansion of both the plant and collection system.

➢ Discharge will continue to an unnamed drainage ditch that discharges into Arroyo Anacuitas which discharges into the Arroyo Colorado above Tidal Segment No. 2202.

➢ Contains information regarding land resources, water resources, air quality, biotic resources, floodplain and wetlands, and cultural resources of the assessment area.

53. Kadlec, Robert H. and Knight, Robert L., *Treatment Wetlands*, CRC Press LLC, Boca Raton, Florida: 1996. 893 pgs.

Reference text for the design of constructed wetlands for water quality improvement.

54. Texas Natural Resource Conservation Commission, *Implementation Plan for the TMDL for Atrazine in Aquilla Reservoir*, January 2002. accessed online at http://www.tceq.state.tx.us/assets/public/implementation/water/tmdl/10-aquilla_imp.pdf

Aquilla Reservoir is a 3,280-acre reservoir located in Hill County. It was constructed in 1983 as a water supply and for flood control and recreation. Testing of treated drinking water found that excessive levels of the herbicide atrazine are affecting the lake's use as a source for public drinking water. Agricultural sources were the primary contributors to the reservoir. The goal of the project was to reduce atrazine concentrations to levels at or below the criteria in the surface water quality standards.

55. International Boundary and Water Commission, *Article 7880-147v(1) Grant of easement in lands to facilitate operation of Lower Rio Grande Flood Control Project by United States*, April 1998.

Rights to enter Rio Grande in order to construct, operate, and maintain the beds and banks of the Arroyo Colorado "for handling, flowing, carrying, diverting, confining, and controlling flood and drainage water or waters, together with the right to clear and grub said land, and maintain the same free of trees and brush…."

56. International Boundary and Water Commission, *Exhibit A: General Conditions of License.*

License rules to construct, operate, or maintain works within the IBWC jurisdiction.

57. Gillete, Becky, *Constructed Wetlands for Industrial Wastewater,* Biocycle, November 1994.

Relevant information:

- Large wetland – 40 acres, treats 600,000 gallons per day
- Safety factor must be reasonable; all operational conditions considered during design.
- Design engineers took advantage of the location's natural topography rather than building flat basins.

58. Staubitz, Ward W.; Surface, Jan M.; Steenhuis, Tammo S.; Peverly, John H.; Lavine, Mitchell J.; Weeks, Nathan C.; Sanford, William E.; Kopka, Robert J., *Potential Use of Constructed Wetlands to Treat Landfill Leachate*, 1989.

Describes use of rock-reed filter (subsurface flow wetland) for treatment of landfill leachate resulting in reduction in potential upsets at wastewater treatment plant and improved discharges of treated effluent. Wetland provided wide range of retention times according to upstream and downstream control points.

59. Surface, J.M.; Peverly, J.H.; Steenhuis, T.S.; Sanford, W.E., *Effect of Season, Substrate Composition, and Plant Growth on Landfill Leachate Treatment in a Constructed Wetland,* Constructed Wetlands for Water Quality Improvement, CRC Press, 1993.

Phragmites australis (common reed) used in constructed wetland for landfill leachate treatment effectively removed BOD, organic carbon, P, NH4, Fe, Mn, and K.

60. Steiner, G.R.; Watson, J.T.; K.D. Choate, *General Design, Construction, and Operation Guidelines for Small Constructed Wetlands Wastewater Treatment Systems,* Constructed Wetlands for Water Quality Improvement, CRC Press, 1993.

Design criteria as well as specific designs for small wetland water treatment systems (house, small resorts, etc.).

Septic tank sufficient for pretreatment, necessary to remove coarse and heavy solids.

61. Duckworth-Cole, Inc. *2002 DuPont Wetland Assessment Report*, 2002.

    Assessment report for year 3 operation of a 53-acre constructed wetland designed to polish up to 3 million gallons of treated industrial wastewater effluent prior to discharge to the Guadalupe River. Presents monitoring results regarding constituent reductions; sediment, vegetation, and fauna sampling; physical characteristics; nutria control; and conclusions. Includes information regarding educational program at site.

62. Tanner, Chris C.; Clayton, John S.; Upsdell, Martin P., *Effect of Loading Rate and Planting on Treatment of Dairy Farm Wastewaters in Constructed Wetlands- I. Removal of Oxygen Demand, Suspended Solids, and Faecal Coliform,* Elsevier Science Ltd., 1994.

    Constructed wetland show considerable potential for removal of BOD, SS, and FC from dairy farm wastewaters.

    Mass removal of FC and SS were similar in unplanted and planted wetlands, but removal of total BOD and CBOD5 was better in planted wetlands.

63. Hunt, P.G. and Poach, M.E., *State of the Art for Animal Wastewater Treatment in Constructed Wetlands*, 7th International Conference on Wetland Systems for Water Pollution Control, 2000.

    Study concluded that at high loading rates, constructed wetlands do not produce acceptable effluent for discharge, therefore, alternative disposal to cropland irrigation, vegetative strips, or woodlands was recommended.

64. Szogi, A.A. and Hunt, P.G., *Distribution of Ammonium*-N *in the Water-Soil Interface of a Surface-Flow Constructed Wetland for Swine Wastewater Treatment*, 7th International Conference on Wetland Systems for Water Pollution Control, 2000.

    Ammonium-N diffusion gradient and nitrogen losses were highest in wetland systems with the lowest water depth.

65. Liehr, S.K.; Anastasiou, C.; Classen, J.J.; Rice, J.M. *Comparison of Design Strategies for Nitrogen Removal from Animal Waste Using Constructed Wetlands,* 7th International Conference on Wetland Systems for Water Pollution Control, 2000.

    In areas of intensive animal feeding operations, lagoon and spray-field practices for animal waste management require upgrading in order to reduce nutrient release.

66. Kantawanichkul, S.; Neamkam, P.; Shutes, R.B.E., *Nitrogen Removal in a Combined System: Vertical Vegetated Bed Over Horizontal Flow SandBed,* 7th International Conference on Wetland Systems for Water Pollution Control, 2000.

This study determined that where farms had limited land available for waste treatment, vertical flow vegetated beds followed by a horizontal flow sandbed without plants was effective for removal of nitrogen.

67. Poach, Matthew; Hunt, Patrick; Sadler, John; Matheny, Terry; Johnson, Melvin; Stone, Kenneth; Huminek, Frank, *An Enclosure System to Measure Ammonia Volatized from Constructed Wetlands*, 7th International Conference on Wetland Systems for Water Pollution Control, 2000.

Study determined volatilization of ammonia into the atmosphere from constructed wetland for animal wastewater.

68. Bovendeur, J.; Zwaga, A.B.; Lobee, B.G.J.; Blom, J.H., *Fixed-Biofim Reactors in Aquacultural Water Recycle Systems: Effect of Organic Matter Elimination on Nitrification Kinetics*, Elsevier Science Ltd., 1990.

Accumulation of total ammonia can be the first capacity limiting factor of a water recycling program.

69. Hunt, P.G.; Szogi, A.A.; Humenik, F.J.; Rice, J.M.; Matheny, T.A.; Stone, K.C., *Constructed Wetland for Treatment of Swine Wastewater from an Anaerobic Lagoon*, American Society of Agricultural Engineers, 2002.

Study determined that nitrogen removal increased when ammonia is nitrified before wetland application.

Substantial removal of nitrogen was accomplished over a wide range of loading rates. Reduction in nitrogen resulted in much less cropland required to accept the N load.

When loading rates exceeded 4 kg P/ha/day, wetland cells were less than 50% effective in mass removal of phosphorus. Low P removals result of reduced Eh conditions of the wetland soil and high loadings.

Accumulation of plant litter layer functioned both as a source of carbon and an extensive reaction surface for microorganisms; provided the energy necessary to drive the denitrification process.

Soil in the wetland cells with bulrushes had higher Eh values (more oxidized) than the soil dominated by cattails; this was consistent with the relative oxygen transport capacities of the plants.

Nitrogen and phosphorus accumulations in both the litter layer and mineral soil were reported.

70. Rastorfer, D. David and Schnedier, John H., *Lincoln University Constructed Wetland for Swine Lagoon Effluent Treatment*, American Society of Agricultural Engineers, 1994.

Includes design plans for a constructed wetland for the secondary treatment of swine lagoon effluent.

71. Rogers, J.W.; Hill, D.T.; Payne, V.W.E.; Kown, S.R., *A Biological Treatment Study of Constructed Wetlands Treating Poultry Waste,* accessed online at http://www.agen.ufl.edu/~klc/wetlands/hill.htm, Alabama Agricultural Experiment Station, 2004.

BOD5 and TKN reduction were higher in vegetated systems rather than control cells with wooden dowels.

72. Arogo, J. and P.W. Westerman, and Z.S. Liang, Z.S., *Comparing Ammonium Ion Dissociation Constant in Swine Anaerobic Lagoon Liquid and Deionized Water,* American Society of Agricultural Engineers, 2003.

Concluded that high microbial activity, warm temperatures, large emission surface area, high pH, and high air velocity may increase ammonia volatilization in a wetland system.

73. Lin, Ying-Feng; Jing, Shuh-Ren; Lee, Der-Yuan; Wand, Tze-Wen, *Removal of Solids and Oxygen Demand from Aquaculture Wastewater with a Constructed Wetland System in the Start-Up Phase,* Water Environment Research, Volume 74, Number 2, 2002.

Treatment of aquaculture wastewater through constructed wetland resulted in good solids removal because of the low solids levels and high organic content of the solids present.

74. Wolfshohl, Karl, *A Wetland for Waste,* Progressive Farmer, 1996.

Livestock wastewater wetlands require a high level of monitoring. Lagoon effluent levels greater than 100 mg/L ammonia may be harmful to plants.

75. Baldwin, Ann Pohlen and T. Davenport, *Constructed Wetlands for Animal Waste Treatment: A Progress Report of Three Case Studies in Maryland*.

Seasonal water quality trends and treatment levels are important factors in the design of constructed wetlands for animal waste treatment.

76. Cooper, P.F. and B.C. Findlater, *Constructed Wetlands in Water Pollution Control,* International Conference on the Use of Constructed Wetlands in Water Pollution Control, Elsevier Science Ltd., 1990.

To obtain reliable nutrient removal, control of water depths and isolation of portions of the wetland system must be achievable.

77. Jackson, Jo Ann; T. Lothrop; and M. Sees, *Orlando Easterly Wetlands – Fourteen Years of Operational History*, PBS&J and City of Orlando, 2002.

Maintenance of open water areas important for wildlife utilization of constructed wetland system.

78. Environmental Protection Agency, *Wetland Treatment Systems: A Case History*, 1993.

Review of historical data is key in design of a constructed wetland.

79. Alan Plummer Associates, Inc., *Design Basis Memorandum for Tarrant Regional Water District Wetland Treatment System Expansion – Phase I: Project No. 307-3401*, July 11, 2005.

Describes background of project development, conceptual "ultimate" plan, description of project, and existing site conditions. Presents design criteria including projected quantity and quality of diverted flows, wetland areas and loading rates, and design criteria. Design basis includes operating philosophy, wetland system layout, process flow design, hydraulic design analysis, and details of wetland cell features.

80. Schneider, Charles, *Evaluation of Evapotranspiration Estimation Models As Design Tools for Constructed Wetlands,* Masters Thesis, Texas A&M, 2002.

Proper sizing of wetland is key in achieving effective water treatment. If wetland is sized too large, the effects of evapotranspiration may result in ineffective treatment.

81. Environmental Protection Agency, *Protecting and Restoring America's Watersheds*, June 2001.

Excessive nutrients have created a hypoxic zone in the Gulf of Mexico with an area averaging 5,000 square miles.

82. Cook, Michael and R. Evans, *The Use of a Constructed Wetland for the Amelioration of Elevated Nutrient Concentrations in Shallow Groundwater,* American Society of Agricultural Engineers, 2001.

Anaerobic lagoons may cause potential water quality problems due to seepage. Poor construction, coarse soil type, failure to utilize a liner, and animal burrowing may all contribute to seepage. Contaminated groundwater was pumped through a series of pumping wells installed in the seepage plume from an old, unlined lagoon located in the Middle Coastal Plain of North Carolina. Pumped flows were treated through a 0.35 ha constructed wetland for treatment. Overall, greater than 79% of the nitrogen and 26% of the phosphorus were assimilated on a mass basis while concentrations decreased by more than 87% across all nutrient species.

83. Miller, P.S.; Mitchell, J.K.; Cooke, R.A.; Engel, B.A., *A Wetland to Improve Agricultural Subsurface Drainage Water Quality,* American Society of Agricultural Engineers, 2002.

Study of the effectiveness of wetlands to cleanse event-driven agricultural drainage water in east-central Illinois. Nitrate-N mass load assimilation was approximately 174 kg (32.9%) over the course of the study, although assimilation rates were seasonally dependent. Phosphate-P and herbicide concentration and mass load assimilation were not significant. Groundwater flux into and out of the system was significant and resulted in periods of overloading of the wetland system.

84. Hammer, Donald, *Designing Constructed Wetland Systems to Treat Agricultural Nonpoint Source Pollutio*n, Tennessee Valley Authority.

To combat NPS agricultural pollution, landowners should use typical best management practices (dry-stacking, roof guttering, lagoons, land application, terraces, grassed waterways, nutrient management, conservation tillage, and crop rotation). In addition, the following order of controls should be employed: 1st order control is use of constructed wetlands for wastewater treatment; 2nd order control is placement of nutrient/sediment treatment systems downstream from constructed wetlands; 3rd order control is deployment of nutrient/sediment treatment systems constructed wetlands/pond complexes, and restored or created wetlands at specific sites within the watershed; 4th order control is larger wetlands in the lower reaches of an individual watershed that function primarily for hydrologic buffering.

85. Texas Water Development Board, *The Texas Manual on Rainwater Harvesting,* 2005.

Manual details rainwater harvesting system components, water quality and treatment, water balance and system sizing, best management practices, and costs for use of rainwater as potable water supply and/or irrigation.

86. Alameda Countywide Clean Water Program, *Schematic Design of an Enhanced Grass Swale,* access online at http://www.oaklandpw.com/creeks/pdf/Grassy_Swales.pdf, August 2005.

Shows schematic design, presents brief description, discusses effectiveness, opportunities for use, costs, design considerations, operation and maintenance requirements, and give case studies.

87. Cahill Associates, *Vegetative Stormwater Technologies, Constructed Wetlands and Infiltration/Water Quality Swales,* accessed online at http://www.thcahill.com/wetlands.html
August 2005
Gives examples of vegetative stormwater technologies used at various sites.

88. Metropolitan Council and Barr Engineering, *Wet Swales,* accessed online at http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STConstWLWetSwale.pdf, August 2005.

Provides description, advantages, limitations, plan, profile, and typical sections, design requirements, and sizing considerations for wet swales. Also includes construction and maintenance guidelines.

89. U.S. Army Corps of Engineers, *Final Environmental Impact Statement, Volume I of III Alternative Vegetation Management Practices for the Lower Rio Grande Flood Control*

Project, Cameron, Hidalgo, and Willacy Counties, Texas, Prepared for United States Section International Boundary and Water Commission. December 2003.

Presents and analyzes impacts of current and proposed IBWC vegetation maintenance activities within the US portion of the Lower Rio Grande Flood Control Project. Vegetation maintenance program established to fulfill obligations to protect life and properties from flooding events. No analysis of impacts in off-river floodways is included since no change in vegetation maintenance practices is proposed for these areas.

Continued maintenance Alternative (No-Action) is preferred alternative. Under this alternative, vegetation would be maintained within approximately 75 feet of the river, between RM 28.00 and RM 62.50, and maintenance activities would cover an estimated 291 acres. A 33-foot wide wildlife travel corridor would be established and maintained landward of the 75-foot maintenance strip.

90. Texas Natural Resource Conservation Commission, *Four Total Maximum Daily Loads for Legacy Pollutants in the Arroyo Colorado Above Tidal and the Donna Reservoir and Canal System,* 2001.

91. Texas Natural Resource Conservation Commission, *Twelve Total Maximum Daily Loads for Legacy Pollutants in the Arroyo Colorado Above Tidal and the Donna Reservoir and Canal System,* 2003.

These TMDLs address contamination of fish tissue by several legacy pollutants in water bodies including portions of the Arroyo Colorado above tidal. The use of pesticides on surrounding cropland is assumed to account for a substantial portion of the fish tissue residues in the Arroyo Colorado based on the compounds of concern.

92. North Central Texas Council of Governments, Freese and Nichols, AMEC Earth and Environmental, Alan Plummer Associates, and Caffey Engineering, *Integrated Storm Water Management Design Manual for Development/Redevelopment,* 2004.

Extensive information on structural storm water controls for urban areas.

93. Gearheart, R.A.; B.A. Finney; M. Lang; and J. Anderson. *Free-Surface Wetland Technology Assessment.* Presented at U.S. Environmental Protection Agency 6th National Wastewater Treatment Technology Transfer Workshop, Kansas City, Kansas, August 2-4, 1999.

Presentation regarding the advancement of design criteria for free water surface (FWS) treatment wetlands. Summary of performance data and loadings for wetland treatment systems analyzed in this assessment are given for biological oxygen demand, total suspended solids, ammonia-N, total kjeldahl nitrogen, nitrate-N, total nitrogen, organic nitrogen, total phosphorus, dissolved phosphorus, and fecal coliform.

Relevant information:

- "Net carbon production in emergent wetlands tends to be high compared to facultative ponds because of much greater primary production of plant carbon.

High production of plant carbon and the resistance of plant carbon to degradation combines with a low organic carbon decomposition rate in the oxygen deficient water column to create significant differences in biogeochemical cycling rates in wetlands compared to ponds and lagoons."

- FWS wetland systems are increasingly designed to provide multiple benefits including wetland habitat for waterfowl and other wildlife, public educational facilities, and outdoor recreation.
- FWS wetland treatment systems are designed to meet a wide range of discharge requirements.
- Plants (both emergent and submerged) play an important role in the treatment processes active within FWS constructed wetlands.
- Wetland vegetation also affects the hydraulic characteristics.
- General linear trend exists between increased BOD loading and increased effluent concentration over the loading range of 0.1 to 180 kg/ha-d. Considerable variation may occur and the effect of the background BOD due to plant decomposition is evident in systems with low loading rates.
- FWS treatment wetlands are very effective in the removal of TSS. Over a fairly wide range of solids loadings, relatively low effluent TSS concentrations can be attained.
- Wetland generally will not reduce TSS concentrations below 3 mg/L.
- Generally 50-60 percent of the TSS from oxidation pond systems are removed in the first 2-3 days of nominal hydraulic detention time.
- Total nitrogen effluent concentrations are generally correlated to loadings.
- A specific nitrogen balance for a specific system is necessary to analyze removal performance.
- Nitrogen dynamics are affected by the influent loading, the degree of plant coverage and maturity of emergent vegetation.
- Net production within FWS wetland systems results in an internal release of particulate and dissolved biomass to the water column, resulting in non-zero levels of BOD, TSS, TN, and TP.
- Combination of precipitation and evapotranspiration affect concentration reduction.
- Nitrogen removal has consistently been observed to decrease with temperature, indicating that it is controlled by biological mechanisms.
- When wildlife habitat is one of the goals, it is important to have 3 to 7 days detention time of emergent vegetation at the final wetland outlet to provide final clarification.

94. Alan Plummer Associates, Inc. *Conceptual Design for Natural Wastewater Treatment System, Western Flower Mound*. February 20, 2003

Report details natural treatment system conceptual design for portion of Flower Mound not cost effective to sewer. Recommended conceptual design included integrated facultative pond and a free-water surface constructed wetland. Proposed natural system would optimize treatment and operation flexibility, providing multiple levels of treatment processes for production of a high quality effluent with minimal odor production potential. An education facility was proposed to be constructed within the buffer zone as well as reuse of the treated effluent for irrigation of a tree nursery, as well as restoration and enhancement of native oak/savannah areas within the buffer area.

95. Alan Plummer Associates, Inc. *Pilot-Scale Constructed Wetlands Demonstration Project Summary Report 1993-2000*. Final Report. January 7, 2002.

Eight years of data from the operation of the Tarrant Regional Water District pilot-scale wetland demonstration project are analyzed and findings summarized. Performance summary based on mass balances indicated greater than 95 percent removal of total suspended solids, greater than 80 percent removal of total nitrogen, and greater than 65 percent removal of total phosphorus. The eight-year study provided initial data indicating that constructed wetland have the potential for providing long term reliable removals of nutrients and toxics.

96. Wenger, S. *A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation.* Office of Public Service & Outreach, Institute of Ecology, University of Georgia, Revised Version, March 5, 1999.

Literature review on the significance and effectiveness of riparian zones. Design criteria for establishment/protection of riparian buffer zones and the effective removal of sediment and nutrients in surface runoff are presented. Discussion of sediment loads from channel erosion and importance of riparian buffers to stabilize banks is presented. The effect of different types of vegetation on contaminant removal and other factors that influence the habitat of stream organisms are discussed. In general, riparian buffer zones of >50 feet were found to retain the major part of the nitrogen and phosphorus carried by surface runoff and provide similar habitat quality to old growth reaches. Maintenance and restoration of native vegetation was recommended.

97. Fischer, R.A.; C.O. Martin; D. Barry; K. Hoffman; K.L. Dickson; E.G. Zimmerman; and D.A. Elrod. *Corridors and Vegetated Buffer Zones: A Preliminary Assessment and Study Design.* Waterways Experiment Station. U.S. Army Corps of Engineers. July 1999.

Activities impacting upland portions of the watershed that are detrimental to riparian and aquatic habitats can also lead to long-term degradation of water quality, wildlife and fish habitat, and recreation resources, thus impacting economic benefits from these resources. Habitat fragmentation is a very serious threat to populations of birds and mammals because of their relatively low population densities. Riparian buffer zones can provide habitat, corridors for migration and dispersal of animals, and provide more ecological complexity and/or diversity to a region. Riparian width often is related positively to avian species richness, both within and adjacent to riparian zones.

A 3-year research project on corridors and vegetated buffer zones was initiated in FY97 at the U.S. Army Waterways Experiment Station as part of the Ecosystem Management Restoration and Research Program. The goals and objectives determined to enable reaching these goals are outlined in this report.

98. Fischenich, J.C. and H. Allen. *Stream Management – Concepts and Methods in Stream Protection and Restoration*. Prepared for U.S. Army Corps of Engineers, Fort Worth, District Under Water Operations and Technical Support Program. U.S. Army Waterways Experiment Station. June 1999.

Technical manual developed by the U.S. Army Waterways Experiment Station for the Fort Worth District of the U.S. Army Corps of Engineers to facilitate regulatory decisions and guidance for watershed planning. The manual discusses stream form and fluvial processes including stability and sediment transport and streambank failure mechanisms, ecological functions of streams, analysis of streambank erosion, soil bioengineering, planning and alternative selection, and bank stabilization design criteria.

99. Fedler, C.B. *Wastewater Renovation/Recycle From An Integrated Facultative Pond/Land Application System*, presentation paper, 1994.

Presentation regarding the advantages of an integrated facultative pond (IFP) over traditional facultative ponds and treatment efficiency of the IFP. Conclusions indicate that an IFP/Land Application System will provide a pond system that produces no significant sludge, provide trash and grit removal are used; requirement for less area and volume of storage than the conventional three-stage aerated lagoon; and prevention of periodic odors that occur from most conventional three-stage lagoon systems due to thermal inversion or wind induced mixing.

100. Daigger, G.T. *Nutrient Removal Technologies/Alternatives for Small Communities*. U.S. Environmental Protection Agency 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop, Kansas City, MO, August 2-4, 1999.

This paper reviews nutrient removal alternatives for small communities which include mechanical treatment alternatives similar to those used at large wastewater treatment plants with cost and performance characteristics of available systems presented; lagoon and wetland based systems; and alternative wastewater management options such as alternative discharge locations and/or reuse.

101. Fedler, C.B. and N.C. Parker. *Waste Treatment System Alternatives for the 21st Century*. 1995 International Summer Meeting of The American Society of Agricultural Engineers, Chicago, Illinois, June 18-23, 1995.

Integration of known technologies for wastewater treatment such as advanced facultative lagoons with aquatic plant production, new revenue sources can be produced to stimulate the economy and meet the food production needs of a growing world population.

102. U.S. Environmental Protection Agency. *Guiding Principles for Constructed Treatment Wetlands.* EPA 843-B-00-003. October 2000.

Guidelines developed to promote environmentally beneficial constructed wetlands for water treatment systems. Treatment wetlands offer opportunities to regain some of the natural functions of wetland. List of guiding principles include: provide guidance for environmental performance, especially for project which are intended to provide water reuse, wildlife habitat, and public use, in addition to other possible objectives; highlight opportunities to restore and create wetlands; and application in a watershed context.

103. Mitsch, W.J. and J.G. Gosselink. *Wetlands.* Van Nostrand Reinhold, New York. 1986.

Reference text regarding wetland and wetland science, types of wetlands, hydrology of wetlands, biogeochemistry of wetlands, biological adaptations of plants and animals to the wetland environment, wetland ecosystem development, coastal and inland wetland ecosystems, and management of wetlands.

104. Wetzel, R.G. *Fundamental Processes Within Natural and Constructed Wetland Ecosystems: Short-Term vs. Long-Term Objectives.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 3-11.

Keynote presentation at Conference. Several basic processes emphasized: (a) macrophyte productivity in relation to shoot-root ratios, and nutrient availability; (b) macrophyte life history strategies, succession, and biodiversity under constant pollutant stress; (c) importance of standing dead and particulate detritus; (d) functions and controlling mechanisms of heterotrophic and autotrophic periphyton in pollutant retention and recycling; (e) coupling of microbial metabolism to macrophyte retention of pollutants; (f) gaseous losses to the atmosphere; (g) losses of dissolved organic matter and its utilization; and (h) water losses by evapotranspiration and effect on wetland efficacy.

105. Knight, R.L.; R.A. Clarke, Jr.; and R.K. Bastian. *Treatment Wetlands as Habitat for Wildlife and Humans.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 37-52.

Although water quality is generally the primary objective of treatment wetland, creation of wildlife habitat is an inevitable outcome. However, purposely designing and operating treatment wetland projects to enhance wildlife habitat creation is increasing. This trend to multi-purpose treatment wetlands has broadened the basis for assessing the advantages of this natural treatment alternative. The North American Treatment Wetland Database (NADB) has been expanded to include critical wildlife habitat and human use data. This paper provides a preliminary inventory of the habitat and human use treatment wetlands in operation and summarizes lessons learned as well as identifying additional data needs.

106. DeBusk, T.A. and F.E. Dierberg. *The Use of Macrophyte-Base Systems for Phosphorus Removal: An Overview of 25 Years of Research and Operational Results in Florida.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 55-64.

For over 25 years, P removal by both treatment wetlands and floating aquatic macrophyte systems has been evaluated in Florida from both a research and operational standpoint. Factors contributing to the use of macrophyte-based systems (MBS) for P removal include: no conventional technologies exist that can cost-effectively achieve the low outflow P concentrations required to protect the integrity of Florida's relatively pristine surface waters (P removal targets al low as 10 ug/L; MBS typically provide some water storage so they can accommodate the wide ranges of flows typical for runoff sources such as agricultural drainage waters; sufficient area for deployment of the relatively land-intensive MBS technologies.

107. Comeau, Y., J. Brisson, J. Reville, C. Forget, and A. Drizo. *Phosphorus Removal from Trout Farm Effluents by Constructed Wetlands.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 87-94.

Three-stage system designed and operated to treat freshwater trout farm effluents. System included a 60-micron nylon rotating microscreen to retain solids and treating them with a phosphorus-retaining constructed wetland system. Washwater from the microscreen was pumped to a series of two horizontal flow beds filled with crushed limestone (two sizes) the first of which was planted with reeds (*Phragmites australis*). Preliminary results indicated that the microscreen captured about 60% of the suspended solids, but that more than 95% of the suspended solids and more than 80% of the total phosphorus mass loads were retained by the beds. Concluded that the potential of constructed wetlands as an ecologically attractive and economical method for treating fish farm effluents to reduce solids and phosphorus discharge appears promising.

108. Nungesser, M.K. and M.J. Chimney. *Evaluation of Phosphorus Retention in a South Florida Treatment Wetland*. 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 179-186.

Everglades Construction Project of the South Florida Water Management District will employ large constructed wetlands known as Stormwater Treatment Areas (STAs) to reduce phosphorus concentrations in runoff entering the Everglades. In five years of operation, the prototype STA has consistently exceeded its performance goals of TP outflow concentration of <50 ug P/L and a 75% TP load reduction.

109. Hammer, D.A. and D.L. Burckhard. *Designs for Nitrogen Removal – Minot's Constructed Wetland – 10 Years Later*. 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 247-252.

Minot, ND upgraded treatment system from a 5-cell facultative pond system with a 4-cell marsh-pond-marsh wetland system to meet low (1 mg/L) NH_3 discharge criteria. Wetland was built in late fall 1990 with initial operation in late summer 1991. Treatment system has achieved average discharge concentration of 0.8 mg/L NH_3 excluding November and December values when water temperatures were $<5^{o}C$ and coliforms 79.2 MPN without chlorination. The system has also accommodated additional wildlife inputs of fecal coliforms without chlorination.

110. Sartoris, J.J. J.S. Thullen, and L.B. Barber. *Effect of Hemi-Marsh Reconfiguration on Nitrogen Transformations in a Southern California Treatment Wetland.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 359-364.

Nitrogen transformations in the Hemet/San Jacinto demonstration wetland, which is used to polish ammonia-dominated, secondary-treated municipal effluent and provide migratory bird habitat, have been investigated since 1996. Originally constructed as a marsh-pond-marsh system in 1994, weekly inflow/outflow monitoring data indicated that nitrogen dynamics in the system were influenced not only by variations in treatment plant loading, but also by internal loading that increased as the emergent vegetation became more dense. Between April 1998 and January 1999, the wetland was reconfigured as a hemi-marsh system, having equal areas of interspersed emergent marsh and deep open water. Accumulated emergent biomass was burned off during the reconfiguration. Ammonia nitrogen removal efficiency improved to 72%. Habitat diversity and the diversity of wildlife utilizing the habitat also improved after reconfiguration of the wetland. Sustainability of the hemi-marsh configuration has yet to be determined.

111. Burgoon, P.S. *Enhanced Nitrogen Removal in Free Water Surface Wetlands.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pg 375.

Two free water surface wetlands were built in Quincy, Washington for polishing nitrogen from wastewater prior to discharge to a Class AA salmonid stream. Wastewater from a vegetable processing facility is treated in aerated lagoons prior to discharge to two pilot wetlands. The average influent NH4-N was 6.5 mg/L and effluent NH4-N targets were 1.45 mg/L (winter) and 1.19 mg/L (summer). Wastewater was applied at a rate of 2.1 m3/d (8000 gallons/day); the average hydraulic loading rate was 4.7 cm/d. The treatment system consists of a cascade trickle filter in the front end of each wetland, a novel design being test for enhancing nitrogen removal. Two types of trickle filters were examined, one of river rock and one of vertical flow plastic media; each being evaluated for construction costs and treatment effectiveness. The filters are low profile and may be built into the wetland dikes for structural support. The trickle filters were effective in nitrification and increasing dissolved oxygen.

112. Nguyen, L., D. Burns, and K. Rutherford. *Nitrate Movement and Removal in Two Riparian Wetlands with Contrasting Hydrological Settings.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pg 378.

Research conducted to quantify ammonia volatilized from wetlands constructed to treat swine wastewater. Preliminary field tests in November and December 1999 suggested that some ammonia was volatizing from wetlands.

113. Cin, L.D. and J. Persson. *The Influence of Vegetation on Hydraulic Performance in a Surface Flow Wetland.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 539-546.

Study conducted to examine hydraulic effects of vegetation in a constructed wetland with a deeper central channel. Study results verify that an increased density of vegetation reduces the effective volume. Also that a moderate increase of vegetation density doesn't hinder flow but increases dispersion. Concluded that for achieving better hydraulic performance, both vegetation zones and open water zones should be designed perpendicular to flow direction as is generally recommended.

114. Reitberger, J.H., L.E. Mokry, and R.L. Knight. *Achieving Multiple Benefits from a Constructed Wetland.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 749-758.

Presentation regarding incorporation of the DuPont Victoria, Texas plant's 53-acre constructed wetland as part of improvement program that eliminated discharge of aqueous waste to deep well injection. The wetland provides polishing of effluent beyond permit requirements and visually demonstrates water quality prior to return to the Guadalupe River. An outdoor education building provides a center for hands on education experiences for area school children. A full time educator provides program planning and coordination with teachers. The wetland and surrounding upland development provides 75 acres of wildlife habitat that has attracted over 180 bird species.

115. Gearheart, R. and B. Finney. *Fifteen Years of Performance and Utilization of a Free Surface Constructed Wetland, Arcata, California, USA.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 1085-1092.

Paper summarizes long-term performance data of constructed wetlands at Arcata, California which has been in operation since 1980. The Arcata system is comprised of three one ha treatment wetland operated in parallel and three four ha enhancement wetland operated in series. Performance analysis for the full-scale system is based upon sixteen sampling points monitored for flow, BOD, TSS, TIN, FC, temperature, and pH from the plant influent through to the WWTP effluent discharge. The enhancement wetland have consistently produced an effluent quality, which is less than 5 mg/L BOD, Suspended Solids, and Total Inorganic Nitrogen 90 percent of the time on a weekly basis. The high quality wetland and effluent supports a diverse community of epiphytes, invertebrates, mammals, aquatic macrophytes, and bird life.

116. Schwartz, L.N., P.M. Wallace, J.T. Wittig, G.K. Gruendling, P.M. Gale, G.R. Best, and T. Madhanagopal. *Long-Term Results from the Orange County Florida Eastern Service Area Reclaimed Water Wetlands Treatment System.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 1093-1100.

In the Eastern Service Area of Orange County, Florida, direct discharge of reclaimed water to surface waters has been eliminated through implementation of an integrated multiple reuse program. A portion of the high quality reclaimed water, produce through advance wastewater treatment at the Orange County Eastern Service Area Water Reclamation Facility, is distributed to a wetlands treatment system. A summary of the results from the eight-year research and monitoring program are presented and indicate that the system is functioning well with no adverse impacts on the wetlands or downstream receiving waters.

117. Rushton, B.T. and B.M. Bahk. *Treatment of Stormwater Runoff from Row Crop Farming in Ruskin, Florida.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 1425-1432.

A wet-detention pond, constructed to treat agricultural runoff from winter vegetables, was studied to document constituent concentrations, measure hydrology and analyze processes taking place over a two-year period. The first year of wetland operations experienced much higher than normal rainfall followed by much lower than normal rainfall the second year. Study documented effect on treatment efficiency under the two climatic extremes.

118. Crumpton, W.G. *Using Wetlands for Water Quality Improvement in Agricultural Watersheds; The Importance of a Watershed Scale Approach.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 1469-1476.

Emphasizes the need for watershed scale approaches to wetland siting and design to achieve water quality improvement in agricultural watersheds.

119. Bavor, H.J., C.M. Davies, and K. Sakadevan. *Stormwater Treatment: Do Constructed Wetlands Yield Improved Pollutant Management Performance over Detention Pond Systems.* 7th International Conference on Wetland Systems for Water Pollution Control. Lake Buena Vista, Florida, November 11-16, 2000. pgs 1489-1496.

Study provides comparison of treatment efficiency of constructed wetland systems and detention basins for stormwater bacterial and nutrient loads. Performance of a number of constructed wetland systems for stormwater treatment is evaluated considering the functional components of the systems.

120. Alan Plummer Associates, Inc., *Memorandum: Vegetation Survey at Field-Scale Wetland Conducted August 27, 2003,* September 29, 2003.

General observations resulting from the vegetative survey:

- Duckweed was very abundant throughout the wetland system and represented the dominant species for both transects in wetland cell 1, both transects in wetland cell 2, and the upper transect (A) of wetland cell 3. It was also present along the upper transect in wetland cell 4 although floating clumps of algae were dominant at that location. The appearance of duckweed in the system coincided with the decline of the water primrose in the upper cells. Deeper water areas within the cells were more apt to be dominated by floating species (e.g. water primrose, duckweed) or mats of algae floated off the cell bottom via oxygen bubble production during photosynthesis. Both duckweed and algae were noted flowing through the water column on currents through the cells.

- Curltop smartweed (*Polygonum lapathifolium*) was also very abundant in the upper transect of wetland cell 1 and was the second most dominant vegetation overall in this wetland cell. However, it's dominance declined through the length of cell 1 and it was not observed in the other three wetland cells.
- Open water or deeper water dominated by duckweed, algal mats and/or water primrose represents the majority of the marsh area of wetland cell 1, but some sedge, barnyard grass (*Echinochloa crus-galli*), burhead (*Echinochloa rostratus*), primrose willow (*Ludwigia decurrens*), fall Panic grass (*Panicum dichotomilflorum*), *Paspalum sp.(?)*, and the other unknown grass were also observed.
- Although duckweed was the dominant vegetation in wetland cell 2, sedge, spiderlily (*Hymenocallis liriosme*), burhead, lanceleaf frogfruit (*Phyla lanceolata*), flatsedge (*Cyperus spp.*), barnyard grass, and water primrose were also observed. Floating mats of algae and open water had substantial representation along with the duckweed for the lower transect within the cell.
- Floating algal mats and open water were again prevalent along with the duckweed in the upper transect of wetland cell 3, with some representation of sedge, flatsedge, burhead, sumpweed (*Iva annua*), water primrose, *Paspalum sp.* (?), and lanceleaf frogfruit. However, vegetative cover of burhead increased substantially in the lower transect with some representation of water primrose still present also. Over the whole cell, burhead represented the third most dominant coverage after algal mats and duckweed.
- Burhead was again prevalent in the upper transect of wetland cell 4, following in dominance behind algal mats and open water. A fairly diverse vegetative cover was observed along this transect with sedge, American water willow (*Justicia americana*), water primrose, grassy arrowhead (*Sagittaria graminea*), Baldwin's ironweed, lanceleaf frogfruit, swamp smartweed (*Polygonum hydropiperoides*), duckweed, and black willow (*Salix nigra*) recorded.
- The lower transect of wetland cell 4 was dominated by algal mats, water primrose, and open water. This transect went across one of the planted lines of softstem bulrush (*Schoenoplectus tabernaemontani*) which was also represented, but a deeper water channel (>2') was encountered through this area. Burhead was observed growing submerged in this deeper water as well as in the deeper water encountered along the upper transect in this cell. Some sedge, barnyard grass, swamp smartweed, and lanceleaf frogfruit were recorded along the shallow sections of the lower transect.
- A short transect was conducted across the shallow shelf at the downstream end of wetland cell 4 since the vegetative community of this portion of cell 4 represents a different habitat than the rest of the marsh area within the cell. Lanceleaf frogfruit was the dominant vegetation recorded for the shallow shelf area followed by water primrose. Squarestem spikerush, barnyard grass, burhead, Hierba Del Marrano, *Paspalum sp.*(?), and the other unknown grass were recorded as lesser dominants. Open water was recorded as dominant for the channel area, but burhead was growing submerged within the channel. Filamentous algae were growing attached to the burhead.
- Analysis of wetland data for cell 4 was conducted both without the shallow shelf data and with the shallow shelf data. The results indicate that the shallow shelf

has several of the same species as recorded for the remainder of wetland cell 4 with similar dominance patterns. Species recorded within the marsh areas of cell 4 but not on the shallow shelf include sedge, sumpweed, duckweed, softstem bulrush, Baldwin's ironweed, and grassy arrowhead. Several species photographed on the shallow shelf were not recorded in the transect. These included grassy arrowhead, Walter's millet (*Echinochloa Walterii*), American water willow, and sumpweed. Four additional species recorded in the transect on the shallow shelf but not in the marsh area were squarestem spikerush, *Paspalum sp.*(?), Hierba Del Marrano, and the other unknown grass.

121. Alan Plummer Associates, Inc., *Memorandum: Vegetation Survey at Field-Scale Wetland Conducted November 21, 2003,* December 4, 2003.

General observations resulting from the 11/21/03 vegetative survey:

- Seasonal diedown has occurred for many species including curltop smartweed, Levenworth's eryngo, barnyard grass, other grasses, water primrose, burhead, arrowhead, annual aster, lanceleaf frogfruit, and Baldwin ironweed.
- Squarestem spikerush was just starting to brown along the upper third of the culms.
- Softstem bulrush, crowfoot sedge, other sedges, flatsedges and other cool-season species continue to show active growth with green leaves and culms and the expansion of the softstem bulrush clumps is markedly observable.
- The emergent leaves of burhead and grassy arrowhead have died down, but these species continue to have active growth via underwater leaves. Burhead was growing submerged in many of the deeper water areas.
- Duckweed is still very prevalent but is exhibiting some seasonal die down due both to the cooler weather and the strong winds experienced with passing fronts that has swept the duckweed into windrows along berms and finger dikes.
- Several areas within the marsh zones of the wetland cells are up to 24 inches deep or greater. Namely, along WC1-B, WC3-B, and WC4-B. The only submerged vegetation observed in these areas to date is scattered burhead.
- Most of the water primrose observed consisted of dead stems from earlier growth. However, some new growth of water primrose was observed.
- Heavy feeding by ducks and other waterfowl has reduced the observable population of grassy arrowhead.
- New species observed was the cool-season growth of water clover (*Marsilea spp*) The species observed is either *macropoda* or *mucronata*; but sporocarps are need to determine and they were not observed yet. Another new species observed was American Germander (*Teucrium canadense var. canadense*), a member of the mint family.
- Although open water was clearly dominant due to both the season and the deeper water areas of the marsh zones, 18 species or categories of vegetation were observed during this survey. The floating plants duckweed and water primrose followed in dominance, but substantial populations of burhead, crowfoot sedge, softstem bulrush, squarestem spikerush, and spiderlily are present throughout the wetland cells.

122. Alan Plummer Associates, Inc., *Memorandum: Vegetation Survey at Field-Scale Wetland Conducted March 5, 2004,* March 15, 2004.

General observations resulting from the 3/05/04 vegetative survey:

- For most of the annuals observed from last year's growing season, very little dead plant material remains as a litter layer. Standing stalks of submerged burhead (*Echinodorus rostrata*) were observed along with some standing clumps of water grass or barnyard grass (*Echinocloa crus-galli*). However, the majority of the curltop smartweed (*Polygonum lapathifolium*) has decomposed; annual aster (*Aster subulatus*) has completely disappeared; and eryngo *(Eryngium leavenworthii*) was not observed. Some old stems of water primrose (*Ludwigia peploides*) were observed within the water column and new rosettes of water primrose leaves were observed on some stems.
- Stands of lanceleaf frogfruit (*Phyla lanceolata*), especially in shallower water in wetland cell 1, were observed putting on new leaves.
- Emergent leaves were appearing on several large colonies of grassy arrowhead (*Sagittaria graminea*) observed in wetland cell 4. Evidence of waterfowl foraging on arrowhead was observed, primarily rafts of clipped emergent leaves.
- Spiderlilies (*Hymenocallis liriosme*) were just beginning to bloom. Growth of submerged spiderlilies were observed in several areas of deeper water. Abundant numbers of spiderlily seeds were still observed in the cells, especially along berms, dikes, and stranded in shallow water areas.
- By far, the dominant condition during this survey was open water. New growth is just beginning to occur for many species. Colonies of softstem bulrush are still expanding, but substantial impacts to established areas of bulrush were observed as a result of nutria and beaver activities (foraging and resting platform construction). TPWD is reportedly doing some spotlight hunting of nutria.
- Dense algae (mats or phytoplankton) were not observed but Tim reported increases in pH through the system that may indicate some algal bloom activity. Wave action over the substantial areas of open water had significantly stirred bottom sediments and the water was observed as very turbid throughout the wetland system.
- Evidence of substantial hog activity was also observed including tracks, trails, and foraging areas, mostly in the shallow areas in the upper end of wetland cell 3. The observed impacts from hog activity was localized in nature rather than widespread.
- Some large fish were also observed jumping within the wetland cells. This may be contributing to the increased turbidity.

123. Alan Plummer Associates, Inc. *Memorandum: Vegetation Survey at Field-Scale Wetland Conducted May 18, 2004*, June 3, 2004.

General observations resulting from the 5/18/04 vegetative survey:

- Dead plant material from last year's growth still observable in March has disappeared.
- Several areas along both transects in WC2 were noted as having muck (loose organic material, very black). These were all noted in areas that had water depths of 3" or less.

- Spiderlilies were mostly bloomed out with seed heads developed and the expanded seeds from this year's crop observed floating in the water.
- The shallow plant shelf at the end of WC4 had dense growth of squarestem spikerush, crowfoot sedge, grassy arrowhead, and swamp smartweed. Substantial seedbank as well as rootstock of these materials should be present in the upper 4-6" of soil this area which can be used to revegetate the lower portion of WC4 after this summer's planned regrading.
- Much less damage to the softstem bulrush areas from nutria foraging was observed during this survey indicating positive results from the current nutria control program.
- Water clarity was substantially better throughout the wetland system during this survey with improved clarity from WC1 through WC4.
- Although vegetative cover had increased over the March 1004 survey, the dominant condition of open water still remains. Water depth measurements taken along the designated transects indicates an overall mean average depth of 8 inches despite all the weir gates being completely lowered. Water depths ranged from a minimum of 0 inches (saturated soil) to 22 inches observed along the lower transect in WC4 (WC4-B). A complete listing of the water depth measurements is included as Table 2.

124. Alan Plummer Associates, Inc., *Memorandum: Vegetation Survey at Field-Scale Wetland Conducted March 22, 2005*, April 6, 2005.

General observations resulting from the 3/22/05 vegetative survey:

- Dead plant material from last year's growth still observable.
- New growth apparent for grassy arrowhead (still growing submerged), softstem bulrush (established areas are expanding), crowfoot sedge and jungle rice (both with extensive blooming), water clover, spiderlilies (just starting to bloom), and water primrose. Pale dock (*Rumex altissiumus*), American germander, and largespike spikerush also growing. Duckweed still present throughout.
- Limited area of squarestem spikerush (*Eleocharis quadrangulata*) observed in upper end of WC4.
- Progressively improving water clarity was observed through the system.
- Numerous large carp observed just below WC4 outfall weir and some observed breeding in shallow marsh areas within upper end of WC4.

125. Alan Plummer Associates, Inc., *Memorandum: Vegetation Survey at Field-Scale Wetland Conducted June 20, 2005*, July 18, 2005.

General observations resulting from the June 20, 2005 vegetative survey:

- Growth of duckweed in wetland cell 4 much thicker due to bypass of flows around wetland cells 2 and 3 and resulting higher nutrients into cell 4.
- Curltop smartweed showing extensive growth across wetland cell 1 but other species including American germander and water clover also well represented.
- Even though wetland cell 2 and 3 were off line, water clarity observed at outfall of wetland cell 4 was excellent.

126. Alan Plummer Associates Inc., *Design Basis Memorandum for North Texas Municipal Water District, East Fork Reuse Project, Constructed Wetland*, Prepared for the North Texas Municipal Water District, Wylie, Texas; March 11, 2005.

This document details the criteria used for detailed design of a 1,840-acre constructed wetland for treatment of up to 165 million gallons per day of reclaimed water from the East Fork of the Trinity River in Kaufman County, Texas. Document includes discussion of design criteria, regulatory issues, design basis alternatives and recommended designs, construction schedule and opinion of probable construction cost. Appendices include water quality data, summary of water quality modeling, summary of one-dimensional hydraulic model, project schedule and preliminary opinion of construction cost.

127. Alan Plummer Associates Inc., *Wetland Nursery Planting Contract for the East Fork Reuse Project - Phase I Wetland Plant Nursery*, Prepared for the North Texas Municipal Water District, Wylie, Texas; October 2004.

Construction specifications for planting of a 20-acre wetland nursery used to propagate a larger nursery for the East Fork Reuse Project. This document provides wetland plant species and associated costs from constructing such a wetland.

128. Alan Plummer Associates Inc., *Wetland Plant Demonstration Project - Technical Memorandum*, Prepared for the City of Cactus, Texas; August 4, 2003.

This document summarizes emergent wetland plant specie selection and their response to high ammonia wastewater produced from a municipal wastewater treatment facility dominated by industrial wastewater throughout a three-year observation period. During this time, climatic extremes were experienced, including temperature variations ranging from 103 º F to 7º F. This project demonstrates that several plant species are viable for use in a proposed constructed wetland to treat high strength wastewater.

129. Alan Plummer Associates Inc., *Grayson County Airport Wastewater Treatment Plant, Master Plan Development for Collection and Treatment Facilities*, Prepared for the City of Denison, Texas; October 2000.

This master plan focused on improvements recommended for the Grayson County Airport Wastewater Treatment Plant (WWTP), Denison, Texas, which was constructed over 50 years ago. Recommendations included the construction of two treatment wetlands: an 8-acre wetland located near the existing WWTP, and a larger constructed wetland to serve developments located the far west CCN. The 8-acre wetland was built in 2002.

130. Alan Plummer Associates Inc., *Feasibility Study for a Western Flower Mound Wetland Treatment System*, Prepared for the Town of Flower Mound, Texas; July 1999.

Evaluation performed in a rural area of Flower Mound, Texas. Recommendations identified two areas where a natural treatment system, consisting of an integrated facultative lagoon and treatment wetland, would be feasible to serve existing developments.

131. O'Malley Engineers and Alan Plummer Associates, Inc., *Construction Documents for a Constructed Wetland Wastewater Treatment System*, Prepared for the Town of Bayside, Texas; March 2002.

Plans and specifications for construction of a wastewater treatment system consisting of a facultative lagoon followed by treatment wetlands, for the Town of Bayside, Texas. This project was prepared in conjunction with the design of a sanitary sewer collection system, whereby residents would discontinue use of septic systems. Project was funded by an EPA grant.

132. Washington State Department of Transportation, Bridge Pier Treatment Wetland, accessed online at http://www.wsdot.wa.gov/NR/rdonlyres/954A9B5E-FA5B-473B-B742-6B3235B4B1D5/0/Wetlands.pdf, September 2005.

Schematic diagram showing major design elements of a man-made micro-wetland treating runoff from a bridge over a lake. Includes a sedimentation vault, drain line and vegetation cell.

133. DeNardo, J.C.; Jarrett, A.R.; Manbeck, H.B.; Beattie, D.J.; Berghage, R.D.; *Stormwater Mitigation and Surface Temperature Reduction by Green Roofs*, 2005.

Green roofs are a valuable stormwater BMP based off their ability to: reduce the volume of runoff from roofs, delay any runoff that might occur, and reduce the peak rate of runoff. The study found that the green roofs retained an average of 45% of the rainfall value. Additionally, if used correctly, greenroofs can reduce or eliminate the need for detention basins.

134. Hathaway, Jon M.; Evans, Robert O.; Cook, Michael J.; Burchell, Michael R. II, *Constructed Wetlands as Remediation Tools for Shallow Groundwater Contaminated by Swine Lagoon Seepage*, 2005.

A wetland constructed to remediate groundwater contamination from swine lagoon seepage assimilated 76%(915 kg) of total influent nitrogen and 22%(150 kg) of total influent phosphorous.

135. Rowe, Bradley; Rugh, Clayton; Anderson, Jeffrey; Lloyd, John; Ebert-May, Diane; Turetsky, Merrit; Mrozowski, Tim; Gettler, Kristin; Xu, Kuiyan, *Green Roof Research Program*, accessed online at http://www.hrt.msu.edu/greenroof/#The%20future%20of%20green%20roofs%20in%20the%20United%20States, September 2005.

Greenroofs are highly versatile system. Not only are they an effective method of flood and erosion control, but they can also sustain drought conditions.

136. Moran, Amy; B. Hunt; and G. Jennings, *A North Carolina Field Study to Evaluate Greenroof Runoff Quantity, Runoff Quality, and Plant Growth*, accessed online at http://www.bae.ncsu.edu/greenroofs/ASAE2003paper.pdf, September 2005.

Greenroofs are a good system to use in areas where low surface area is available Although this report is initial, it is believed that the water leaving the greenroof will initially have high concentrations of nitrogen and phosphorous. However, the levels of nitrogen and phosphorus are expected to lower over time.

137. Rabalais, N.N.; M.J. Dagg; and D.F. Boesch. *Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters: Gulf of Mexico (Alabama, Mississippi, Louisiana and Texas).* Submitted by Louisiana Universities Marine Consortium to United States Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Office of Oceanography and Marine Assessment, Ocean Assessments Division, Rockville, Maryland 20852. Final Report. January 31, 1985.

138. San Diego-McGlone, M.L., S.V. Smith and V. Nicolas. *Stoichiometric interpretations of C:N:P ratios in organic waste materials*. Marine Pollution Bulletin. 40:325-330, 2000.

The relatively small differences among categories suggests that a single stoichiometric ratio for O2:C:N:P can be used for organic wastewater. Therefore, the BOD value alone can give a fairly accurate representation of the composition of mass.

139. Texas Commission on Environmental Quality, *Improving Water Quality in the Arroyo Colorado Twelve TMDLs for Legacy Pollutants*, March 2005.

TCEQ online information page that gives highlights of the TMDL project for the Arroyo Colorado and Implementation Plan timeline.

140. Texas Commission on Environmental Quality, *Improving Water Quality in the Arroyo Colorado One TMDL for Dissolved Oxygen*, accessed online at http://www.arroyocolorado.org/watersheds/pdf/arroyoDO.pdf , May 2005.

The TCEQ is partnering with the USGS to continue research into the causes of low dissolved oxygen in the Arroyo Colorado. Joint study began in July 2004 and is expected to be completed in Spring 2007. Study will include detailed characterizations of 1) tidal hydrodynamics; 2) short-term fate, transport, and cycling of nutrients and carbon; and 3) biochemical oxygen production rates, community respiration rates, and sediment oxygen demand in the tidal segment of the Arroyo Colorado.

141. Texas Natural Resource Conservation Commission, *1998 Annual Report TNRCC Urban Nonpoint Source Program*. Publication SFR-66, accessed online at http://www.tceq.state.tx.us/assets/public/comm_exec/pubs/sfr/066_98.pdf, January 1999.

Outlines the States Nonpoint Source Program goals and strategies and schedule for achieving these goals.

142. Werblow, Steve. *Constructed Wetland Awash in Creative Development Ideas*, Land and Water, Volume 45, Number 1; January/February 2001.

Developers of the Gateway Technology Centre (Newark, CA) converted a series of small jurisdictional wetlands, and unvegetated "waters of the United States" into a working tidal marsh, which created important habitat for birds, fish and local endangered species, as well as provided treatment of stormwater runoff. Challenges of the project included resolution of several regulatory hurdles and design issues concerning existing utilities and creating rights of way for indigenous mammals.

143. Baumert, Daniel J. *Stormwater Runoff Treatment systems Utilizing Wet Ponds and Created Wetlands*, Land and Water, Volume 46, Number 4; July/August 2002.

Article discussing the planning, design, construction and monitoring of two different stormwater treatment systems constructed in Rhode Island. Both systems included wet ponds and wetlands, providing removal of at least 75% of TSS, 45% of phosphorus and 25% of nitrogen. Each system included restoration of wildlife habitat, while providing treatment value.

144. Schueler, T., *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Region.* Metropolitan Washington Council of Government, Washington, D.C. October 1992.

This manual presents integrated and comprehensive design criteria for the construction of stormwater wetland systems in the mid-Atlantic region. The manual reviews four basic design variations for stormwater wetlands, and reviews factors that improve pollutant removal capability. Design criteria are presented to size stormwater wetlands, create deep-water cells, develop pondscaping plans, reduce future maintenance burdens, avoid secondary environmental impacts, enhance local wildlife habitat, and create community amenities. The manual also includes a review of wetland performance monitoring data, and a revised native plant guide for pondscaping.

145. Allred, B.; B. Clevenger; C. Thornton; B. Czartoski; N. Faunsey; F. Cooper; L. Brown; D. Riethman; P. Chester; and H. Belcher. *Novel Approach to Agricultural Water Management: Wetland Reservoir Subirrigation Systems*, Land and Water, May/June 2000.

A Wetland Reservoir Subirrigation System consists of a wetland and a water storage reservoir that is connected to a network of subsurface pipes that either drain or irrigate crops through the root zone. Benefits include: greater crop yield; additional wetland habitat; decreased flooding potential downstream; and reductions in the amount of nutrients, pesticides, and sediment discharged into local waterways.

146. Bailey, Diane; Plenys, T.; Solomon, G.; Campbell, T.; Feuer, G.; Masters, J.; Tonkonogy, B.; *Harboring Pollution – Strategies to Clean Up U.S. Ports,* Natural Resources Defense Council, August 2004.

Report identifies harbors as one of the most poorly regulated sources of pollution in the country. Issues identified in the report include: marine vessels, on-road and non-road vehicles, inland cargo transport, locomotives, land use, community relations, stormwater controls, oil spills, ballast water, and waste discharge.

147. American Association of Port Authorities, *Environmental Management Handbook*, accessed online at http://www.aapa-ports.org/govrelations/env_mgmt_hb.htm, September 1998.

Handbook provides description of development-related and operations-related Environmental Management Practices (EMPs) based on a detailed on-site survey at over 30 U.S. ports conducted by the American Association of Port Authorities. The EMPs presented include sour control EMPs and treatment control EMPs.

148. Wells, Frank C.; Jackson, Gerry A.; Rogers, William J., *Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Lower Rio Grande Valley and Laguna Atascosa National Wildlife Refuge, Texas, 1986-1987*, U.S. Geological Survey, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, 1988.

Investigation was conducted in response to increasing concerns that irrigation drainage in the Lower Rio Grande could potentially effect human, fish, and wildlife health. Although the study found that "none of the dissolved minor elements found exceed the USEPA's primary and secondary standards," the boron concentrations increased from 840 ug/L in the Main Floodway to 2,100 ug/L in the Arroyo Colorado near Rio Hondo. Additionally, the largest manganese concentrations in the study were detected in the same location near Rio Hondo.

149. Coastal Impact Monitoring Program, *Report of Literature Review on Discharges from the Rio Grande and Arroyo Colorado and Their Impacts*, Texas General Land Office, September 1995.

Report summarizes water quality and benthic impacts in the Arroyo Colorado:

- Significant inverse relationship between salinity and dissolved oxygen in Arroyo Colorado
- Arsenic, Cobalt, Lead, Manganese, and Zinc were detected heavy metals.
- Point and Non-Point sources of bacteriological indicator organisms were significantly greater downstream of Harlingen-San Benito area.
- Supersaturated dissolved oxygen levels were due to algal metabolism. The average inorganic nitrogen, phosphorus, and chlorophyll *a* levels are similarly elevated.
- The benthic community structure of the above tidal segment of the Arroyo Colorado is "generally poor" due to stress inducing factors such as salinity stratification and high primary productivity which occasionally result in depressed D.O. in bottom waters, as well as periodic maintenance dredging.

150. Valley Newsline with Ron Whitlock, *"Thousands Warned to Flee When Levee in Valley Breaks" "Beulah Toll Stands at 48,"* accessed online at http://www.valleynewsline.com/archives/2005/072405.html, September 2005.

News article regarding the The United States Army Corps of Engineers study that revealed major weaknesses and recommended a major overhaul of "The Floodway."

151. Taylor, Steve, *Duran Says IBWC needs $200 million to rebuild Valley's Levee System*, Rio Grande Guardian, July 27, 2005.

News brief indicating that the United States International Boundary and Water Commission (IBWC) needs $200-$250 million to raise the height of the 4.5 mile Hidalgo Protective Levee System by three to eight feet and clear away wild brush in the Valley's floodplains to increase storage capacity of the flood control system. However, the IBWC only has a budget of $2-3 million per year.

152. Del Valle, Fernando, *Officials Move Forward in Plan to Build Waterfalls Along Arroyo Colorado*, The Brownsville Herald, June 6, 2003.

A series of 1-foot high weirs ("small waterfalls") are proposed to be built along the Arroyo Colorado in Harlingen in order to increase dissolved oxygen levels.

153. McEver, Melissa, *Relief Coming to Area's Dilapidated Levees, Floodways*, The Monitor, July 5, 2005.

Because the IBWC's budget for flood control projects is significantly less than the amount needed to improve the system, the agency is relying on cost sharing with cities as well as federal grants to rehabilitate the levees and flood control systems in the Valley. All of the needed improvements will cost about $77 million reported IBWC officials.

154. Lee, G. Fred, *Suggested Approach for Defining Non-Aeration Alternatives for Managing the Low-DO Problem in the SJR DWSC,* December 8, 2003.

Alternative Approaches for solving low-D.O. problems include:

- Supplemental Aeration
- Recirculation of water
- Wastewater control
- Nutrient control
- Stop maintenance dredging

155. Port of Sacramento, *Stormwater Treatment for the Port of Sacramento*, July 19, 2002.

During loading, off-loading, and storage of bulk materials some materials are inevitably spilled. Although the Port of Sacramento implemented various Environmental BMPs to combat these problems, it became evident that some treatment would be needed to improve water quality. The Port constructed an interceptor system to collect and divert runoff from seven existing outfalls, a storage basin to reduce peak sotrmwater flows and store stormwater until it could be treated, and a treatment system consisting of a high-rate trickling filter followed by a 5-acre constructed wetland, The treated stormwater is then discharged to the Turning Basin.

156. International Boundary and Water Commission, *Hydraulic Model of the Rio Grande and Floodways Within the Lower Rio Grande Flood Control Project*, June 2003.

In general, the Lower Rio Grande Flood Control Project does not provide adequate protection along its full length for the 100-year flood at Rio Grande City. This reports contains the HEC-RAS hydraulic model run results for the Arroyo Colorado.

157. Texas State Soil and Water Conservation Board and the Texas Commission on Environmental Quality, *Managing Nonpoint Source Pollution in Texas: 2004 Annual Report.*

Between 1989 and 1999 agricultural NPS runoff was responsible for 87% of suspended sediments, 41% of BOD, 68% of nitrate, 64% of ammonia, and 49% of the phosphate load in the Arroyo (Segment 2201).

158. Alan Plummer Associates Inc., *Mechanically Stabilized Earth (MSE) Systems, Special Specification Item No. 695*, January 4, 2002.

APAI specifications for mechanically stabilized earth systems in Austin area. Although the composition of soils is different, this specification provides a listing of materials and products that could be potentially useful in the Arroyo Colorado region.

159. Brunet, Ghislain, *Ecological Solutions for Bank Stabilization,* Macaferri.

Mechanically stabilized wall systems do not interact well with the surrounding environment, this paper provides more "environment friendly" solutions for bank stabilization.

160. Di Pietro, Paulo, *Soil Bioengineering and Ecological Solutions*, Macaferri, 2000.

Historically, there are three causes of instability in banks:

- Progressive surface erosion (water run-off)
- Soil veneer sliding
- Deep sliding failure (global instability)

Bank protection systems using soil bioengineering techniques are presented.

161. Land and Water, Inc., *Vegetated Channel System Protects Eroded Stream Bank,* March 25, 2002.

A "geocell earth retention structure" is used to stabilize a stream bank composed of a near vertical wall constructed of erosion resistant materials interposed between erosive soils and water flows.

162. Leng, R. A. *Duckweed a tiny aquatic plant with enormous potential for agriculture and environment*, FAO, 1999.

Presents use of duckweed as element of natural water quality improvement system including ponds and wetlands due to its absorption of nitrogen, phosphorus, and heavy metals.

163. Knight, Robert; Adams, Robert; O'Brien, Colleen; Davis, Eduardo R., *Beltway 8 Wetland Water Quality Project- Constructed Wetlands for Stormwater Polishing and Wetland Impact Mitigation*, 1998.

The Harris County Flood Control Project implemented a wetland mitigation bank that uses highway stormwater runoff as a main source of water. The 220 acre project includes habitat wetlands and swales which include ponds, littoral marshes and transitional wetland forest areas.

164. Charoenchan, Sukasem, *Wastewater Becomes Crystal Clear with Water Plants and Water Air Pump*, August 2002.

Paper provides a brief analysis of the use of different types of aquatic plants in systems to provide water treatment.

165. Gelt, Joe, *Constructed Wetlands: Using Human Ingenuity, Natural Processes to Treat Water, Build Habitat*, Arroyo, March 1997.

Discusses the workings of constructed wetlands to harvest natural processes to provide water quality improvement. Presents several projects and ability of the projects to provide multiple benefits to the public.

166. East, Charles, *Innovative Wastewater Treatment, Crowley Facility Ranks Among Largest Systems of its Kind*, Louisiana Environmentalist, July-August 1993.

The Crowley Wastewater Treatment Facility is one of the largest combined "artificial marsh rock/reed filter" systems in the world and consists of: a facultative pond, open marsh area, torpedo grass buffer area, microbial rock filter, ultraviolet disinfection, and recirculation area. The Treatment Facility provides a significant cost savings for the city with more than a $2,000/month reduction in utility bills.

167. United States Environmental Protection Agency, *Bioretention Applications, Inglewood Demonstration Project, Largo, Maryland Florida Aquarium, Tampa, Florida*, October 2000.

- Bioretention offers significant benefits such as: retrofit opportunity, pollutant removal, volume reduction, and cost effectiveness. Pollutant removals provided by the Inglewood Demonstration Project in Largo, Maryland and Florida Aquarium in Tampa, Florida are presented.

168. Clar, Michael; Barfield, Billy; O'Connor, Thomas, *Stormwater Best Management Practice Design Guide, Volume 2, Vegetative Biofilters*, United States Environmental Protection Agency, September 2004.

Provides detailed design information and pollutant removal capabilities of various NPS treatment options described as vegetated biofilter types.

169. Oron, Gideon, *Effluent Reuse for Agricultural Production*, accessed online at http://www.idrc.ca/en/ev-42842-201-1-DO_TOPIC.html, October 2005.

This study provides different treatment efficiencies for secondary treatment of wastewater effluent using various types of irrigation (spray, on-surface drip, and subsurface drip)

170. Lower Columbia River Estuary Partnership, *Field Guide to Water Quality Friendly Development,* accessed online at http://lcrep.org/fieldguide/intro.htm, October 2005.

This guide provides a comprehensive list of various water quality improvement techniques as well as diagrams, pictures, and research information.

171. United States Navel Academy, *Revetments,* material originally from United States Army Corps of Engineers, accessed online at http://www.usna.edu/NAOE/courses/en420/bonnette/revetments.html, October 2005.

This website provides information regarding design consideration for revetments and presents Army Corps of Engineers schematics for different revetments for bank erosion control.

172. Gushiken, Elson, *Water Reuse Through Subsurface Drip Irrigation Systems,* accessed online at http://www.geoflow.com/wastewater/waterecg1.htm, October 2005.

Conservation of water in Hawaii is a major issue, and one avenue being used is reclaimed water. Irrigation is a good use for reclaimed water, and incorporating a subsurface drip system eliminates a few common problems:

- Health risks
- Overspray exposure liability
- Odor, ponding, and runoff

173. Environmental Protection Agency, *Water Recycling and Reuse: The Environmental Benefits.*

Discussion of beneficial reuse of a recycled water supply.

174. Ohio Department of Natural Resources, *Ohio Stream Management Guide, Gabion Revetments.*

Design guide from the State of Ohio regarding gabion revetments. Advantages of using gabion revetments for bank stabilization are cited as:

- Can be used for high velocity flows
- Can be installed in tight physical constraints

- Fits stream contours
- Minimal maintenance costs

175. City of Austin, Watershed Protection Department, *Streambank Restoration and Erosion Management*, accessed online at http://www.ci.austin.tx.us/watershed/erosionprojects.htm, October 2005.

Description and photographs of several stream bank and stream restoration projects conducted by the City of Austin.

176. Urban Harbors Institute, *America's Greenports: Environmental Management and Technology at U.S. Ports*, University of Massachusetts, Boston, March 2000.

Report identifies significant environmental issues related to ports. Relevant information to the Arroyo Colorado included in the report:

- Dredged material disposal and contaminated sediments
- Habitat restoration
- Land-based water pollution
- Brownfields

177. Wedel, Jami, *Photographs of Subsurface Drip Irrigation in Muleshoe, TX*, August 2003.

Photographs of subsurface drip irrigation used in Discussion Document.

178. Comis, Don, *Evaluating Riparian Buffers' Effectiveness*, United States Department of Agriculture, October 25, 2005.

The Agricultural Research Service designed a computer model to evaluate the performance of grass buffer zones in reducing levels of nitrogen and phosphorus in runoff. Removal data and information on effect on riparian habitat is provided.

179. Minnesota Pollution Control Agency, *Protecting Water Quality in Urban Areas Manual*, accessed online at *http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html, November 2005.*

Extensive information on structural storm water controls for urban areas.

180. Idaho Department of Environmental Quality, *Catalog of Stormwater BMPs for Cities and Counties*, access online at http://www.deq.state.id.us/water/permits_forms/permitting/catalog_bmps.cfm, January 2006.

Extensive information on structural storm water controls for urban areas.

181. Minton, Gary R., *A Survey of Installation and Maintenance Costs of Stormwater Treatment Facilities*, Bay Area Stormwater Management Agencies Association, August 2003.

Manual provides detailed information on design and cost of stormwater water treatment facilities.

182. Muthukrishnan, Swarna; Madge, Bethany, Selvakumar, Ari, Field, Richard, Sullivan, Daniel, *The Use of Best Management Practices in Urban Watersheds*, United States Environmental Protection Agency, September 2004.

This publication provides detailed information on design, effective use of BMPs, removal efficiencies, and cost data.

183. Stecher, Steve. "Re: Arroyo: City of Austin Bid Tabs." E-mail to Loretta Mokry, November 14, 2005.

Cost information for stormwater BMPs in the Austin area.

184. Robert, Knight L. "Re: Large Scale Wetland O&M Costs." E-mail to Timothy J. Noack, April 25, 2005.

Provides opinion of operation and maintenance costs for large scale wetland.

185. Allen, Hollis H. and Leach, James R. *Bioengineering for Streambank Erosion Control*, April 1997.

This study provides guidelines for proper use of bioengineering designs.

186. DeLaney, T.A., *Benefits to Downstream Flood Attenuation and Water Quality as a Result of Constructed Wetlands in Agricultural Landscapes*, Journal of Soil and Water Conservation, 1995.

Describes important benefits constructed wetlands can help reclaim in agricultural areas: the watersheds ability to absorb water, retention of sediments, and removal of nutrients.

187. Atlanta Regional Commission, *Georgia Stormwater Management Manual*, accessed online at http://www.georgiastormwater.com, August 2001.

Extensive information on structural storm water controls for urban areas.

188. United States Environmental Protection Agency, *Constructed Wetlands Treatment of Municipal Wastewaters*, National Risk Management Research Laboratory, September 1999.

Manual describes appropriate uses for constructed wetlands, detailed management requirements, and provides design information.

189. Landphair, Harlow C., McFalls, Jett A., and Thompson, David, *Design Methods, Selection, and Cost-Effectiveness of Stormwater Quality Structures*, Texas Transportation Institute and Texas Department of Transportation, November 2000.

Comprehensive design, cost, and effectiveness data for stormwater best management practices in the state of Texas.

190. South Florida Water Management District, *Everglades Construction Project: Design and Construction*, 2005.

Overview of project in West Palm Beach, Florida which utilizes six stormwater treatment areas (wetlands) to treat stormwater runoff.

191. Murphy, Michael and Dreher, Dennis, *Shoreline Stabilization: Bioengineering Alternatives*, Illinois Environmental Protection Agency and Northeastern Illinois Planning Commission, 1996.

Design information and cost data on four types of bioengineering: vegetative stabilization, live stakes, fiber rolls, and A-Jacks.

192. Southeastern Wisconsin Regional Planning Commission, *Costs of Urban Nonpoint Source Water Pollution Control Measures*, 1991.

Provides information on applicability; siting and design considerations; limitations; maintenance considerations; effectiveness; and cost for a variety of channel practices, including grassed channels, dry swales, and wet swales.