# Demonstration/Evaluation of Constructed Wetlands as an Alternative On-Site Waste Water Treatment System

**RICHARD E TILLMAN**
County Extension Agent-Marine
Brazoria County, Texas
1800 CR 171
Angleton TX 77515

**EDUCATION**

**M.S.** Food Technology, Texas A&M University, 1980
**B.S.** Food Technology, Texas A&M University, 1972

**EXPERIENCE:**

**Brazoria County, Texas Agricultural Extension Service. (May, 1996-Present).** County Extension Agent-Marine--Marine and Natural Resource education programs for county residents. Developed and implemented a grant for an ongoing Aquatic Science In-school Enrichment program, "Something's Fishy". Work with coastal communities to reestablish sand dunes and control erosion.

**Aransas/San Patricio Counties, Texas Agricultural Extension Service (February, 1983-May, 1996).** County Extension Agent-Marine--Marine and Natural Resource education programs for county residents. Worked extensively with the commercial shrimp, oyster, and red snapper industries; assisting with economic analysis and seafood technology issues. Conducted shoreline erosion

**U. S. Army (May, 1972-February, 1979).** Infantry Officer.

**U. S. Army Reserves (February, 1979- Present).** Medical Service Corps Officer, Untied State Military Academy Liaison Officer.

**BRUCE J. LESIKAR**
Assistant Professor, Associate Department Head and
Extension Program Leader for Agricultural Engineering
Texas Agricultural Extension Service
Department of Agricultural Engineering
Texas A&M University System
College Station, TX 77843

**EDUCATION:**

**Ph.D.** Agricultural Engineering, University of Illinois (U of I), May, 1992.
**M.S.** Agricultural Engineering, Texas A&M University (TAMU), May, 1989.
**B.S.** Agricultural Engineering, Texas A&M University, August, 1987. (Honors Program)

**EXPERIENCE:**

**Texas Agricultural Extension Service, Texas A&M University System -- College Station, Texas. (January, 1996 - Present).** Assistant Professor, Associate Department Head and Extension Program Leader for Agricultural Engineering -- Research, Extension and Administrative responsibilities. Research into effectiveness of on-site wastewater treatment systems under various climatological, soil, and water table conditions; constructed wetlands for wastewater treatment; wetland enhancement; innovative/alternative wastewater treatment systems for confined animal feeding and aquaculture facilities; non-point source pollution; and air quality. Technology transfer in the areas of domestic water and wastewater systems, municipal/community solid waste management, hazardous waste management, underground storage tanks, groundwater quality, wellhead protection, pesticide container disposal/recycling, waste pesticide disposal/treatment/reuse, nonpoint source BMP implementation, and air quality protection, including grain dust emissions. Administration of the Extension Agricultural Engineering program unit with responsibilities for long-range planning, staff development and financial management.

**Texas Agricultural Extension Service, Texas A&M University System -- College Station, Texas. (May, 1992 - December, 1995).** Assistant Professor and Extension Specialist in Agricultural Engineering/Water Quality and Environmental Systems -- Research and Extension responsibilities. Research into effectiveness of on-site wastewater treatment systems under various climatological, soil, and water table conditions; constructed wetlands for wastewater treatment; wetland enhancement; innovative/alternative wastewater treatment systems for confined animal feeding and aquaculture facilities; non-point source pollution; and air quality. Technology transfer in the areas of domestic water and wastewater systems, municipal/community solid waste management, hazardous waste management, underground storage tanks, groundwater quality, wellhead protection, pesticide container disposal/recycling, waste pesticide disposal/treatment/reuse, nonpoint source BMP implementation, and air quality protection, including grain dust emissions.

**PROFESSIONAL SOCIETY ACTIVITIES:**

American Society of Agricultural Engineers (ASAE)
- Hydraulics and Transport Processes Committee, SW-217
- Pollution by Sediment Committee, SW-224
- Student Branch Treasurer 1986-87

National Society of Professional Engineers
Water Environment Federation
American Water Works Association

**HONORS & AWARDS:**

ASAE Paper Award - 1990, 1992
1997 Texas Section of ASAE, Young Engineer of the Year
1998 Young Engineer of the Year, Brazos Chapter of TSPE

# Demonstration/Evaluation of Constructed Wetlands as an Alternative On-Site Wastewater System

Richard E Tillman, Brazoria County Extension Agent-Marine, Angleton, Texas

Dr. Bruce Lesikar, Texas Agricultural Extension Service, College Station, Texas

Claude Maynard, U. S. Fish & Wildlife, Brazoria National Wildlife Refuge

Russell Persyn, Texas Agricultural Extension Service, College Station, Texas

## INTRODUCTION

Texas has nearly 1.3 million households in rural areas. Because these homes are not served by central wastewater collection systems, they must rely on septic systems for disposal of domestic wastewater. Failing septic systems allow pathogens and nutrients to enter the waters of Texas and have been identified as a potential cause of nonpoint source pollution in many waters of the state (TNRCC, 1996). These contaminants threaten the health and well being of rural residents and limit use of these waters for drinking water, recreation, and agriculture.

Typically, on-site systems in Texas include a septic tank and soil absorption field. However, in many parts of the state, soil and/or ground water conditions are not conducive to conventional wastewater treatment using an absorption field. Therefore, the need for advanced treatment came to the forefront of the state's wastewater treatment research agenda. Consequently, considerable effort has been expended on implementation and evaluation of alternative on-site wastewater treatment methodologies, including constructed wetlands.

Constructed wetlands offer practical wastewater treatment in areas where poor soil conditions or high ground water do not allow installation or satisfactory performance of conventional on-site systems. Because they are natural systems, constructed wetlands are effective, reliable, simple, and relatively inexpensive to install and maintain. In addition, constructed wetlands, especially when planted with ornamental vegetation, provide a more aesthetically pleasing alternative than many other on-site wastewater treatment systems.

The Texas Sea Grant College Program, Texas Agricultural Extension Service , and Brazoria National Wildlife Refuge designed and built a constructed wetland system, in February - June 1997, to provide secondary treatment of septic effluent from an eight pad volunteer camp site at the refuge. The system consists of two 1000 gallon septic tanks, two constructed wetland cells, with water control structures, and a 1200 foot traditional drain field. The wetland cells are 14 x 28 feet and filled with 18 inches of pea-gravel. Decorative flowering plants (canna lilies, irises, green tarrow, Thalia, umbrella palms, and rushes) are planted in the gravel. The effluent flowing through the wetlands is maintained at a level at least 3 inches below the surface of the gravel, eliminating objectionable odors.

## BACKGROUND

Two-thirds of the US's land area is unsuitable for traditional septic systems (Perkins, 1989). On-site wastewater treatment and disposal in difficult areas has come under close scrutiny by federal and state agencies. This scrutiny resulted in increasingly stringent regulatory controls on design, testing, manufacture, installation, and maintenance of on-site treatment systems. One solution for wastewater handling problems on difficult sites is additional treatment of septic tank effluent prior to land application. Advanced treatment systems include, but are not limited to: sand filters, aerobic treatment units, trickling filters, and constructed wetlands.

Constructed wetlands have been evaluated for on-site wastewater treatment in a few earlier studies. Steiner and Combs (1993) used constructed wetlands to treat single-site wastewaters. They reported concentration reductions for three sites in Kentucky and Tennessee. Each system featured two wetland cells in series. The two Kentucky sites received wastewater from private residences and the site in Tennessee received wastewater from a nature center. Five-day biochemical oxygen demand ($BOD_5$) reduction at these three sites ranged from 73 to 89 %. Fecal coliform reductions were also high, varying from 78 to 99 %. Averaging 78 and 95 % at two of the sites, removal of total suspended solids (TSS) typically was good. Effluent concentrations of TSS at the third site, however, were quite variable, ranging from 0 to 73 %. Byers and Young (1995) also evaluated constructed wetlands for on-site wastewater treatment at four sites in rural Kentucky. Each site featured a long, narrow wetland that was lined and filled with gravel. Reduction of fecal coliforms was very good, averaging 93.8 % over the four sites. However, reduction of $BOD_5$ and TSS were less than anticipated. The researchers attributed poor performance for $BOD_5$ and TSS to decaying mulch and vegetative litter on the surface of the gravel media. Concentrations of ammonia and ortho-phosphate dropped 37 % and less than 30 %, respectively.

Constructed wetlands have also been applied to municipal wastewater treatment operations. Green and Upton (1993) reported the results of one such study conducted in the U.K. They used a lined, subsurface flow wetland to treat wastewater generated by 15 homes and two farms. Initially, runoff from animal feeding areas at the farms entered the wetland, reducing treatment effectiveness. After feed yard runoff was diverted from the wetlands, the researchers found $BOD_5$ reductions averaging 97 %. Corresponding reductions of TSS, ammonia, and ortho-phosphate were 80, 33, and 87 %, respectively. Constructed wetlands were also used to treat wastewater at three municipal sites in Kentucky (Choate et al., 1993). Wetland type varied within and between the sites and included free-surface wetlands, subsurface flow wetlands, and open-water ponds. The wetlands yielded effluent with $BOD_5$ and TSS concentrations less than 15 and 20 mg/L, respectively. Fecal coliform reductions averaged 88 to 99 %. Ammonia concentrations in wetland effluent were similar to those in the influent. The researchers attributed these steady ammonia concentrations to breakdown of organic nitrogen.

Data from the BNWR are currently being collected; preliminary results indicate similar BOD, TSS, fecal coliform, ammonium, and available phosphate reductions. All effluent analysis from the BNWR would have met TNRCC effluent standards (Table 5). We will rreport data from similar constructed wetlands built at four separate locations in Texas.

## SYSTEM DESIGN AND LOCATIONS

Construction of the wetland treatment systems described in this paper began in 1993. Data collection and field performance evaluation subsequently began in late 1993 and 1994. Specific sampling start times for each of the four treatment systems are provided in table 1. The sites are located in Weslaco, in the lower Rio Grande valley, D'Hanis, a community 64.4 km (40 mi.) west of San Antonio, and Stephenville and Dublin, located 112.6 (70 mi.) southwest of Fort Worth (figure 1). Table 2 provides annual average climatic conditions at each of these four sites (NOAA, 1982; NOAA, 1998).

Chapter 285 of Title 30 of the Texas Administrative Code (TAC) governs on-site wastewater treatment. Constructed wetlands are considered a non-standard treatment process according to 30 TAC 285.32. As such, constructed wetlands are authorized for one-of-a-kind, site-specific installation that *must be submitted to the permitting authority by a professional engineer or registered sanitarian.* Thorough evaluation of constructed wetland technology is needed to tighten design criteria and potentially ease state restrictions on installation.

In response to this need, the Texas Natural Resource Conservation Commission (TNRCC) established a general procedure for installation and monitoring of experimental constructed wetland systems. All installations were to consist of:

- a septic tank(s) in accordance with TNRCC standards,
- a subsurface flow constructed wetland based on outlined criteria,
- an on-site subsurface land application system, reduced in size from existing TNRCC standards, and
- setback allowances meeting existing TNRCC standards.

Normal residential on-site treatment is designed based on daily flow. Furthermore, an assumed $BOD_5$ of 140 mg/L is used in all sizing formulas.

The approach used for designing these four constructed wetlands followed TNRCC's procedure with some additional engineering judgments. Per TNRCC requirements, septic tanks were designed according to flow calculations based on the number of bedrooms in and square footage of the homes. Table 3 provides two flow estimates for each site. The first is the design flow based on the number of bedrooms in the home and an assumption of 1.5 persons per bedroom (30 TAC 285). For the homes included in this study, the design flow estimate is high. Accordingly, a second flow estimate based on home occupancy and an assumption of 284 L/person/day (75 gal/person/day) was determined.

The subsurface flow constructed wetlands were designed based on the Environmental Protection Agency's (EPA, 1993) document entitled *Guidance for Design and Construction of a Subsurface Flow Constructed Wetland*. Household wastewater typically has an influent $BOD_5$ concentration of 200 mg/L (Metcalf and Eddy, 1991) which is reduced approximately 30 to 40 % in a septic tank (TEEX, 1998). The wetlands in this study, however, were designed for a 200 mg/L concentration. This higher design concentration provided a more conservative design and allowed for possible improper septic tank maintenance. Wetland dimensions were calculated to give a target 25 mg/L $BOD_5$ effluent concentration in the coldest month of operation (typically January). Resulting wetland dimensions are summarized in table 1. Finally, all systems provided final effluent land application using subsurface drip irrigation.

## MONITORING

Influent and effluent samples were collected from each wetland once per month. Samples were immediately placed on ice and shipped from their collection location to College Station by overnight delivery. Constituents analyzed included $BOD_5$, TSS, fecal coliforms, ammonium nitrogen, and available phosphorus. Before April 1997, samples were analyzed for $BOD_5$, TSS, fecal coliform, and ammonium at the Agricultural Engineering Department's water quality laboratory. Analyses for $BOD_5$, fecal coliform, and ammonium followed procedures outlined in standard methods (APHA, 1989). TSS analysis followed standard methods from an earlier publication (APHA, 1981).

After April 1997, samples were analyzed by the Soil Microbiology laboratory within the Soil and Crop Sciences Department at Texas A&M University. At this time, available phosphorus was added as an analyzed constituent. As before, analyses were conducted following USEPA approved standard methods (APHA, 1995).

For comparison of influent and effluent means, Student's t-tests were performed. Single-factored ANOVA was used to assess similarity of means between wetland locations. When the ANOVA indicated significant differences, Fisher's Least Significant Difference was used to separate the means. For all statistical tests the Type I error, $\alpha$, was set to 0.05. Concentration reduction was calculated as:

$$PR = \frac{I - E}{I} \times 100 \qquad (1)$$

where: PR = percent reduction (%),
I = influent concentration (mg/L or cfu/100mL), and
E = effluent concentration (mg/L or cfu/100mL).

## RESULTS AND DISCUSSION

In almost all cases, constructed wetlands provided statistically significant reductions in concentrations of $BOD_5$, TSS, fecal coliforms, ammonium, and available phosphorus (table 4). Except for ammonium, average effluent concentrations were similar across the sites despite distinct variability noted among some of the average influent concentrations. This similarity indicates the wetlands have a buffering capacity and are able to effectively treat wastewaters with a wide range of chemical characteristics. Average wetland effluent concentrations were compared to Texas On-site Sewage Facility (OSSF) standards and effluents from other alternative wastewater treatment systems in table 5. A discussion of wetland performance for each of the analyzed constituents follows.

### $BOD_5$

$BOD_5$ influent concentrations for all sites averaged 99.87 mg/L with an corresponding average effluent concentration of 19.75 mg/L. Averaged over all sites, $BOD_5$ concentrations were reduced

80.3 %. $BOD_5$ reductions are similar to those reported by Steiner and Combs (1993) and are greater than those indicated by Byers and Young (1995).

Both influent and effluent concentrations were similar across the wetland sites. Influent $BOD_5$ concentrations, however, were somewhat lower than those previously reported. Perkins (1989) found average septic tank effluent contained 140 to 200 mg/L $BOD_5$ while Tchobanoglous and Burton (1991) indicated average septic concentrations of 123 mg/L. Lower $BOD_5$ concentrations in this study could be related to occupancy of the homes. The septic tanks were sized using a design flow rate based on the number of bedrooms in the home (table 3). However, the homes had comparatively low occupancy and much lower anticipated flow rates. For example, the system in Stephenville had a design flow rate of 1278 L/day whereas the anticipated flow was only 568 L/day. This difference in flow rate resulted in oversized septic tanks and, consequently, increased retention times. Greater treatment effectiveness in the septic tanks likely accompanied these higher retention times thereby reducing $BOD_5$ concentrations in septic tank effluent.

Average effluent $BOD_5$ concentrations were below the target design value of 25 mg/L at all sites. Two sites (D'Hanis and Stephenville) had average effluent concentrations meeting Texas OSSF 30-day average standards (table 5). The other two sites met OFFS standards for 7-day averages. Average $BOD_5$ effluent concentrations from the wetlands compared favorably to similar concentrations reported for intermittent sand filters and aerobic units. However, aerobic unit effluent concentrations reported by Perkins (1989) may be somewhat higher than those commonly generated by current systems. Wetland effluent had slightly higher $BOD_5$ concentrations than subsurface sand filters, but overall wetland performance was determined to be satisfactory.

## TSS

TSS concentrations dropped an average of 68.1 % across all sites with average effluent concentrations ranging from 16.15 to 45.18 mg/L (table 4). Overall, removal efficiencies for TSS were similar to those cited by Green and Upton (1993) and Steiner and Combs (1993). Comparatively, TSS removal within these wetland cells was greater than that observed by Byers and Young (1995), who indicated surface mulch added to the wetland surface had greatly impacted wetland performance in their study.

Average effluent TSS concentrations were consistent across sites. However, the influent concentration at the Stephenville wetland was statistically different from those at the other sites. Higher concentrations were due to recirculation of water from the land application system back into the septic tank. This operational problem passed excess water through the septic tank, decreasing the detention time and increasing TSS levels in the influent. The data suggest the Stephenville wetland continued to provide excellent treatment despite water recirculation. The TSS removal efficiency at D'Hanis was somewhat lower than the others, perhaps due to retention time within the wetland. Whereas the other homes have only two residents, the home at D'Hanis has three. The wetland, however, is not substantially larger (table 1). Higher influent flow rates with a similar wetland volume would reduce retention time within the wetland and probably lower treatment effectiveness.

Only the Dublin wetland met Texas OFFS standards for 30-day average effluent TSS concentrations. The wetlands at Stephenville, D'Hanis, and Weslaco, respectively, met standards for 7-day average, daily maximum, and single grab sample. Average TSS effluent concentrations from the wetlands were higher than those for subsurface or intermittent sand filters (table 5). Greater solids treatment in the sand filters compared to the wetlands was attributed to a substantially smaller media size in the sand filters and the associated increased solids trapping capability.

## Fecal Coliform

Fecal coliforms experienced a reduction of 83 to 99 % across the wetland locations. Averaged over all sites, fecal coliform reductions were 94.4 %. Although the Stephenville wetland exhibited no statistical difference between influent and effluent means, the wetland reduced fecal coliforms by approximately 96 %. Data from Stephenville exhibited great variability which likely inhibited detection of significant difference at the $\alpha = 0.05$ level. Choate et al. (1993) reported fecal coliform reductions of 88 to 99 % and Byers and Young (1995) indicated average reductions of 93.8%.

Influent and effluent fecal coliform means were statistically similar across sites even though average counts ranged from 337 000 to 2 444 000 cfu/100mL. Again, large variability in the data could have constrained detection of mean differences. As noted with $BOD_5$, effluent fecal coliform counts were similar for a wide variety of influent counts. This further supports the notion that the wetlands have a buffering capacity allowing them to assimilate periodically high influent concentrations.

### Ammonium Nitrogen

Ammonium concentrations were significantly reduced at all wetland sites. Reductions ranged from 23.7 to 67.7% across all locations (table 4). Greatest reductions accompanied the highest influent concentrations. To illustrate, D'Hanis had an average influent concentration of 92.91 mg/L with an overall reduction of 67.7 %. Dublin, by comparison, had the lowest average influent concentration, 17.46 mg/L, and an accompanying reduction of only 27.9 %. The buffering capacity of the wetland cells likely facilitated greater treatment effectiveness with higher influent concentrations.

Ammonium concentrations varied greatly by location. Stephenville and Weslaco had similar influent concentrations, 44.67 and 53.94 mg/L, respectively, yet were statistically different when compared to D'Hanis and Dublin with concentrations of 92.91 and 17.46 mg/L, respectively. On the other hand, effluent concentrations were similar for all sites except Dublin. Low effluent concentrations at Dublin probably resulted from significantly lower influent concentrations at the site.

### Available Phosphorus

Reductions of phosphorus ranged from 10.8 to 56.7 % and averaged 35.0 % across all sites. While all wetland sites provided average reduction of phosphorus, reductions were only statistically significant at D'Hanis and Weslaco. Because phosphorus analysis was initiated in May 1997, sample numbers for this constituent were much lower than for the others. The smaller population and relatively high sample variability may have limited detection of differences. Some of the reductions were quite small however, particularly at Dublin. As indicated with ammonium, treatment effectiveness varied directly with influent concentration. Greatest influent concentrations and percent reductions were observed at D'Hanis followed in descending order by Weslaco, Stephenville, and Dublin.

Influent phosphorus concentrations were similar for Stephenville and Weslaco, but were low at Dublin and high at D'Hanis, as seen with ammonium. However, effluent concentrations proved to be statistically similar across all four sites. Once again, reduction in concentration variability between influent and effluent means was attributed to wetland buffering capacity.

## Summary

Performance of these subsurface flow constructed wetlands was very favorable for many constituents. $BOD_5$, TSS, and fecal coliform reduction proved to be excellent and was consistent across all locations without regard to operational variability. Overall reductions of $BOD_5$, TSS, and fecal coliforms, averaged across all sites, were 80.3, 68.1, and 94.4 %, respectively. Effluent concentrations from the wetlands typically met Texas standards and were similar in magnitude to those from other alternative on-site treatment technologies. Nutrients such as ammonium and phosphorus had lower reductions and demonstrated more variability across the four locations. Reductions of ammonium ranged from 23.7 to 67.7 % while those of phosphorus ranged from 10.8 to 56.7 %. Reduction of nutrients appeared to be strongly related to influent concentration. Major findings of this study include:

- Constructed wetlands are a viable alternative for on-site wastewater treatment on sites not suitable for traditional septic tank and soil absorption field installation.
- Constructed wetlands typically meet Texas standards for on-site wastewater treatment effluent and provide treatment capacity similar in effectiveness to other alternative treatment systems, and
- Constructed wetlands, as designed for this study, possess a buffering capacity allowing them to assimilate a wide variety of influent constituent concentrations.
- Constructed wetlands, which an alternative, are not the answer for all homeowners. These systems require maintenance, it should only be considered by those desiring to solve a problem and capable of performing the limited maintenance.

## ACKNOWLEDGMENTS

Dow Chemical Company, Texas Environmental Analytical Laboratory
Brazoria County Health Department, Water Lab

## REFERENCES

American Public Health Association (APHA), American Water Works Association, and Water Environment Federation. 1981. Standard methods for examination of water and wastewater, 15th edition. Washington, D. C.: APHA.

American Public Health Association (APHA), American Water Works Association, and Water Environment Federation. 1989. Standard methods for examination of water and wastewater, 17th edition. Washington, D. C.: APHA.

American Public Health Association (APHA), American Water Works Association, and Water Environment Federation. 1995. Standard methods for examination of water and wastewater, 18th edition. Washington, D. C.: APHA.

Byers, M. E., and F. S. Young, III. 1995. Constructed wetlands for rural on-site wastewater treatment in Kentucky: current effectiveness and recommendations. In proc.: *Versatility of Wetlands in the Agricultural Landscape*, ed. K. L. Campbell, 647-656. St. Joseph, MI: ASAE.

Choate, K. D., J. T. Watson, and G. R. Steiner. 1993. TVA's constructed wetlands demonstration. In: *Constructed Wetlands for Water Quality Improvement*, ed. G. A. Moshiri, 509-516. Boca Raton, FL: Lewis Publishers.

EPA, 1993. *Guidance for Design and Construction of Subsurface Flow Constructed Wetland.* U.S. EPA - Region 6: Water Management Division, Municipal Facilities Branch, Technical Section. Dallas, Texas: U.S. EPA

Green, M. B., and J. Upton. 1993. Reed bed treatment for small communities: U.K. experience. In: *Constructed Wetlands for Water Quality Improvement*, ed. G. A. Moshiri, 517-524. Boca Raton, FL: Lewis Publishers.

Metcalf and Eddy, Inc. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse*. 3rd ed. New York: McGraw-Hill, Inc.

National Oceanic and Atmospheric Administration (NOAA). 1982. *Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States*. NOAA Technical Report NWS 34. Washington, D.C.

National Oceanic and Atmospheric Administration (NOAA). 1998. http://www.ncdc.noaa.gov/

Perkins, J. P. 1989. *On-site Wastewater Disposal*. National Environmental Health Association, Lewis Publishers, Inc.

Salvato, J. A. 1992. *Environmental Engineering and Sanitation, 4th ed.* New York: John Wiley & Sons, Inc.

Steiner, G. R., and D. W. Combs. 1993. Small constructed wetlands systems for domestic wastewater treatment and their performance. In: *Constructed Wetlands for Water Quality Improvement*, ed. G. A. Moshiri, 491-498. Boca Raton, FL: Lewis Publishers.

Tchobanoglous, G. and F. Burton. 1991. Wastewater Engineering: Treatment, Disposal, and Reuse. In: Metcalf and Eddy, Inc., 3rd ed. (1991).

Texas Engineering Extension Service (TEEX). 1998. *On-Site Sewage Facilities, Installer II Training Course*. College Station, TX: TEEX, Public Sector Training Division.

Texas Natural Resource Conservation Commission (TNRCC). 1996. The State of Texas Water Quality Inventory, 13th ed. TNRCC, SFR-50. Austin, TX: TNRCC.

Table 1. Dimensions, bottom slope, sampling start date, and gravel size and type for the four on-site wastewater treatment wetlands.

| Location | Length m | Width m | Water Depth cm | Slope % | Sampling Start Date | Gravel Size/Material |
|---|---|---|---|---|---|---|
| D'Hanis | 9.14 | 3.66 | 20.32 | 1 | Dec. 1994 | 1.9 cm; Quartz River Rock |
| Dublin | 9.14 | 3.66 | 20.32 | 1 | July 1995 | 1.9 cm; Quartz River Rock |
| Stephenville | 9.14 | 3.66 | 30.48 | 1 | Feb. 1995 | 0.95 cm; Quartz Pea Gravel |
| Weslaco | 7.62 | 3.05 | 20.32 | 1 | Sept. 1993 | 0.95 cm; Quartz Pea Gravel |

Table 2. Average annual climatic conditions of the four constructed wetland locations (NOAA, 1982; NOAA, 1998).

| Location | Annual ET mm (inches) | Annual Rainfall mm (inches) | Average High Temp C (F) | Average Low Temp C (F) |
|---|---|---|---|---|
| D'Hanis | 2025 (79.72) | 787 (30.98) | 26.4 (79.5) | 14.3 (57.7) |
| Dublin | 2159 (85.00) | 812 (31.96) | 25.4 (77.7) | 13.1 (55.6) |
| Stephenville | 2159 (85.00) | 812 (31.96) | 25.4 (77.7) | 13.1 (55.6) |
| Weslaco | 2024 (79.68) | 676 (26.61) | 27.3 (82.9) | 18.2 (64.7) |

Table 3. Home characteristics, septic tank size, and flow rates for the four wetland locations.

| Location | Occupants | Bedrooms | Septic Tank Volume L | Design Flow L/day | Anticipated Flow L/day |
|---|---|---|---|---|---|
| D'Hanis | 3 | 3 | 3785 | 1278 | 852 |
| Dublin | 2 | 3 | 3785 | 1278 | 586 |
| Stephenville | 2 | 3 | 4732 | 1278 | 568 |
| Weslaco | 2 | 2 | 2839 | 852 | 568 |

Table 4. Average influent and effluent characteristics for four on-site wastewater treatment wetlands located throughout Texas.

| | D'Hanis | | Dublin | | Stephenville | | Weslaco | |
|---|---|---|---|---|---|---|---|---|
| | n | Concentration | n | Concentration | n | Concentration | n | Concentration |
| $BOD_5$*, mg/L | | | | | | | | |
| Influent | 38 | 89.83 a‡ | 29 | 107.64 a | 35 | 104.33 a | 37 | 97.66 a |
| Effluent | 33 | 15.14 a | 31 | 21.49 a | 35 | 19.55 a | 33 | 22.80 a |
| % Reduction | | 83.1 | | 80.0 | | 81.3 | | 76.7 |
| TSS, mg/L | | | | | | | | |
| Influent | 38 | 63.52 a | 30 | 50.09 a | 35 | 414.27 b | 44 | 145.63 a |
| Effluent | 38 | 36.49 a | 30 | 16.15 a | 35 | 29.89 a | 44 | 45.18 a |
| % Reduction | | 42.6 | | 67.8 | | 92.8 | | 69.0 |
| FC, cfu/100mL | | | | | | | | |
| Influent | 34 | 336 824 a | 31 | 1 034 009 a | 26 | 376 086† a | 37 | 2 444 092 a |
| Effluent | 34 | 55 894 a | 36 | 10 242 a | 27 | 15 321 a | 36 | 21 614 a |
| % Reduction | | 83.4 | | 99.0 | | 95.9 | | 99.1 |
| Ammonium, mg/L | | | | | | | | |
| Influent | 37 | 92.91 c | 28 | 17.46 a | 33 | 44.67 b | 47 | 53.94 b |
| Effluent | 37 | 29.93 b | 29 | 12.59 a | 33 | 34.09 b | 47 | 29.59 b |
| % Reduction | | 67.7 | | 27.9 | | 23.7 | | 45.1 |
| Phosphorus, mg/L | | | | | | | | |
| Influent | 14 | 2.15 c | 13 | 0.74† a | 12 | 1.16† b | 14 | 1.20 b |
| Effluent | 14 | 0.93 a | 13 | 0.66 a | 12 | 0.85 a | 14 | 0.65 a |
| % Reduction | | 56.7 | | 10.8 | | 26.7 | | 45.8 |

* Constituents are: 5-day biochemical oxygen demand ($BOD_5$), total suspended solids (TSS), fecal coliform (FC), ammonium as $NH_4$-N, and available phosphorus.
† Influent and effluent means are not statistically different at the $\alpha = 0.05$ level.
‡ Letter (a, b, etc.) indicates statistically similar means across wetland location.

Table 5. Comparison of Texas effluent standards and typical effluent concentrations for several on-site wastewater treatment technologies.

| System Type | $BOD_5$ (mg/L) | TSS (mg/L) | Fecal Coliform (cfu/100mL) |
|---|---|---|---|
| Texas OSSF Standards* | | | |
| 30-day average | 20 | 20 | |
| 7-day average | 30 | 30 | |
| daily maximum | 45 | 45 | |
| single grab | 65 | 65 | |
| Soil Absorption Field at 1m Depth† | 0 | | 0-100 |
| Soil Absorption Field at 3 m Depth† | 0 | | 0 |
| Subsurface Sand Filter‡ | 4 | 12 | |
| Intermittent Sand Filter§ | 2-23 | 3-13 | |
| Aerobic Unit" | 26 | 53 | 19 000 |
| Constructed Wetland# | 15-23 | 16-45 | 10 000-56 000 |

* Texas On-site Sewage Facilities Standards, 30 Texas Administrative Code §285.33 (c)(2)(A)
† Tchobanoglous and Burton, 1991
‡ Salvato, 1992
§ TEEX, 1998
" Perkins, 1989
# Results of this study