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Evaluation of Constructed Wetland Performance in New Mexico, 2007

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by

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Committee Approval

The Master of Water Resources Professional Project Report of Jennie Skancke is approved by the committee:

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Abstract

Wastewater treatment wetlands, also referred to as constructed wetland systems (CWS), were installed in New Mexico and other states during the 1990's to provide low cost and low maintenance wastewater treatment options to small communities served by on-site treatment systems. An analysis completed in 1995 examined the design and performance of 18 subsurface flow constructed wetlands. At that time, most of the systems were relatively new and little information was obtained about their long term performance. This project examined the performance of 11 constructed wetlands built between 1990 and 1996, five of which were included in the 1995 study. The systems were analyzed to assess their overall performance. The analysis consisted of site visits, sampling of some systems, and evaluation of monitoring data submitted as required by ground water discharge permits where available. Four systems do not meet NMED permit requirements for total nitrogen, three systems consistently meet these requirements and four systems exhibit variable compliance. It was found that systems with some level of pretreatment beyond that provided by a septic tank were able to obtain sufficient nitrogen removal, whereas a wetland cell alone achieved poor nitrogen removal. The principal limiting factor appears to be the lack of aerobic zones which prevents the systems from achieving adequate levels of nitrification. Performance may be improved by incorporating components such as aeration within the cells, a trickling filter within the system, or nitrification tanks. Maintenance of all electrical, mechanical and plumbing equipment in a wetland system is critical as treatment rates were seen to drop drastically with the failure of electrical components such as pumps or aerators.

1.0 Introduction

Constructed treatment wetland systems (CWS) are engineered systems which utilize natural wetland processes to treat anthropogenic discharge such as storm water run-off from communities; mine tailings; wastewater from individual residences, schools, campgrounds, small communities, or other facilities in areas not served by community sewers; or as tertiary treatment from large municipal wastewater facilities as well as other emerging uses. This study examined only constructed wetlands which treat domestic wastewater.

The treatment wetland concept began in Europe in the 1960s with about 500 of the systems in operation by 1990 (Siedel 1966, US EPA 1993). Constructed wetlands are beneficial in their reduction of contaminants such as organic constituents (commonly measured as biochemical oxygen demand or BOD), suspended solids, nitrogen, phosphorus, and fecal coliform bacteria from municipal wastewater through biological, physical, and chemical processes.

During the 1990s, constructed wetland technology began to be more widely applied throughout the US. During this time, research was conducted to examine the performance of the systems and develop design criteria. Of special relevance to the project described here was a study of 18 subsurface-flow systems in New Mexico (Boivin 1995). However, the systems considered in this study were new and relatively little information has been published about the long-term performance of these and similar systems. The primary objective of the project described here was to obtain information about the long-term performance of treatment wetlands, compliance with state wastewater discharge regulations, and wetland design and operational parameters important to their success or failure in the arid, high altitude environment found in New Mexico.

1.1 New Mexico's constructed wetlands

Wastewater treatment wetlands began to be introduced in New Mexico in the early 1990s with around 40 operating by 2000. It should be noted that because NM does not have a state wide permitting process for systems serving individual residences, the exact number of such systems that have been installed is not known. Several engineering firms advocated the systems to small communities or facilities that were not served by municipal wastewater collection and treatment systems. The constructed wetland systems appealed to the property owners due to their low cost and maintenance requirements relative to other treatment options such as variations of the activated sludge process which are expensive and can be difficult for small communities to operate (EPA 2000). Household liquid waste systems with design flows of less than or equal to 2,000 gallons per day are controlled by NMED with N.M. Environmental Improvement Board (EIB) Liquid Waste Regulations and permitted through the county in which they are located (McQuillan and Parker 2000). Systems which discharge more than 2000 gallons per day (gpd) must apply for a discharge permit issued by the New Mexico Environment Department (NMED) under ground water protection regulations promulgated by the New Mexico Water Quality Control Commission (WQCC) (NMAC 20.6.2

1.2 Constructed wetland design

Constructed wetlands are engineered systems made up of a liner, wetland plants, and a water source and are of two basic designs types, surface-flow (SF) or subsurface-flow (SSF) (Figure 1 and Figure 2). In both types, wastewater travels through one or more wetland cells lined with an impermeable membrane and vegetated. Occasionally, the soil at a site is sufficiently impermeable that a liner is not required. Surface-flow systems have open water exposed to the atmosphere, whereas water flow in subsurface-flow systems occurs below the surface of a porous substrate such as gravel. Each design type has positive and negative aspects. While surface-flow systems may be more ascetically pleasing and provide better wildlife habitat, subsurface-flow systems require less space, reduce the potential for human contact with wastewater and are less likely to be breeding grounds for mosquitoes (US EPA 2000). In both types, flow is commonly gravity fed, eliminating the need for pumps and the associated costs.

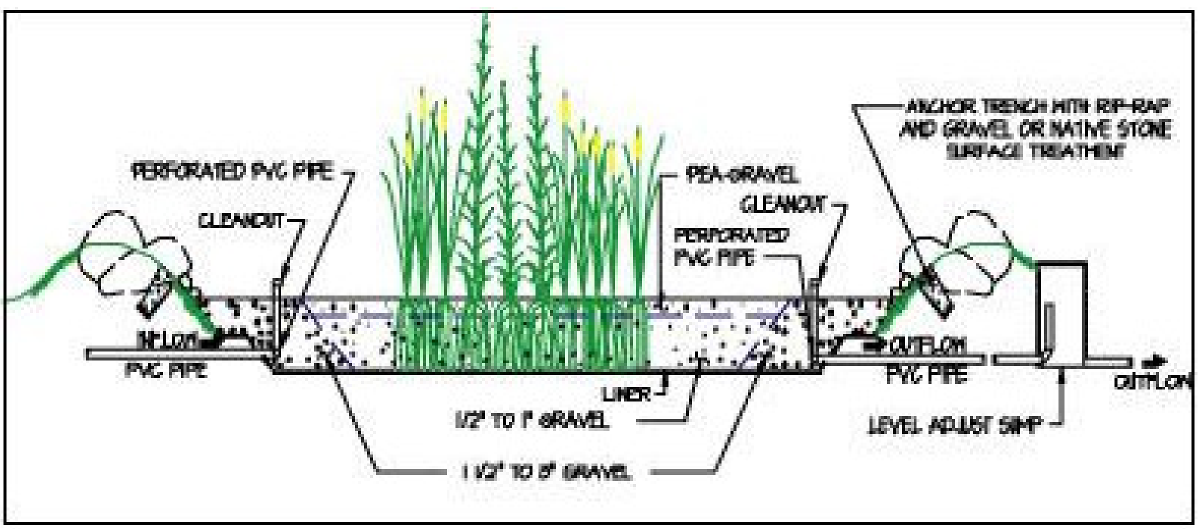

Figure 1. Sub-surface flow wetland. Physical, chemical and biological processes (Natural Systems International 2007)

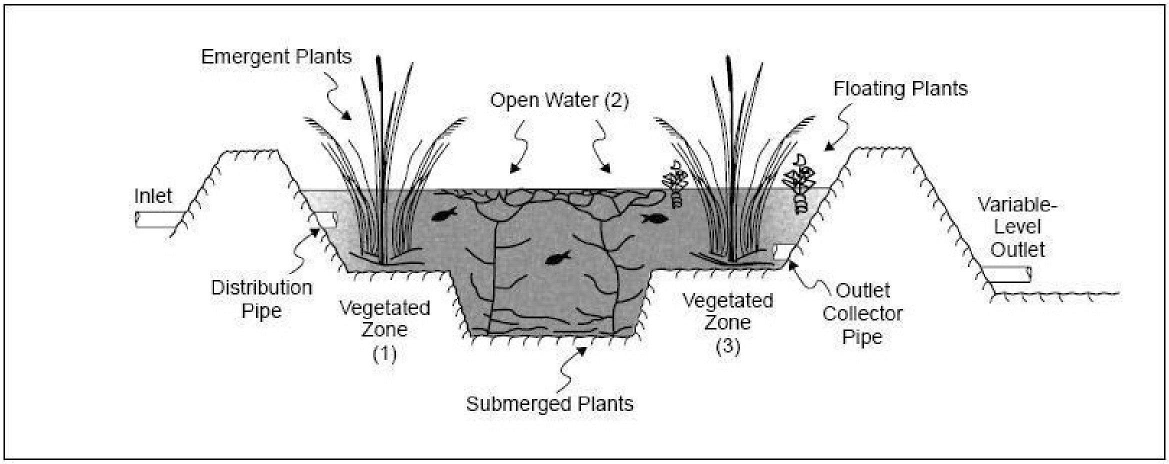

Figure 2. Free-water surface flow constructed wetland (US EPA 2000)

In a surface-flow system, a soil or sand layer on top of the liner is provided so that wetland plants can attach to the bottom of the cell. Water flows horizontally through the vegetation, as in most natural wetlands. Often, water depth will vary across the cell(s). Subsurface-flow systems do not contain open water. Instead, a medium, commonly gravel or sand, is placed throughout the cells, plants are rooted near the surface of the cell, and water flows through the cell(s) as well as the roots and rhizomes of the plants (EPA 2000). Water depth remains constant across the cell and should be determined by the depth to which the roots and rhizomes of macrophytes will grow, usually around 0.6 meters (Cooper et al. 1996). In both types, vegetation usually consists of one to three species including bulrushes and reeds although research has taken place to determine the variation seen between wetlands with multiple species or a single species as well as native species versus non-native species (Boudraa et al. 1999, Kadlec and Knight 1996).

Initially, most SSF systems were designed for horizontal flow. However, it is now also common to see vertical subsurface-flow systems (VF), with the influent applied across the surface of the wetland cells and withdrawn through perforated collection pipes along the bottom of the cell. Vertical-flow systems typically involve frequent draining and filling of the wetland cells (US EPA 2000). All systems achieve treatment of contaminants through a combination of biological, chemical, and physical processes (Figure 3). Physical processes include sedimentation, settling, adsorption, and flocculation which aid in BOD and TSS removal as well as small levels of nitrogen reduction. Organic nitrogen and phosphorus removal occurs through plant uptake and nitrification-denitrification (Kadlec and Knight 1996, Moshiri 1993).

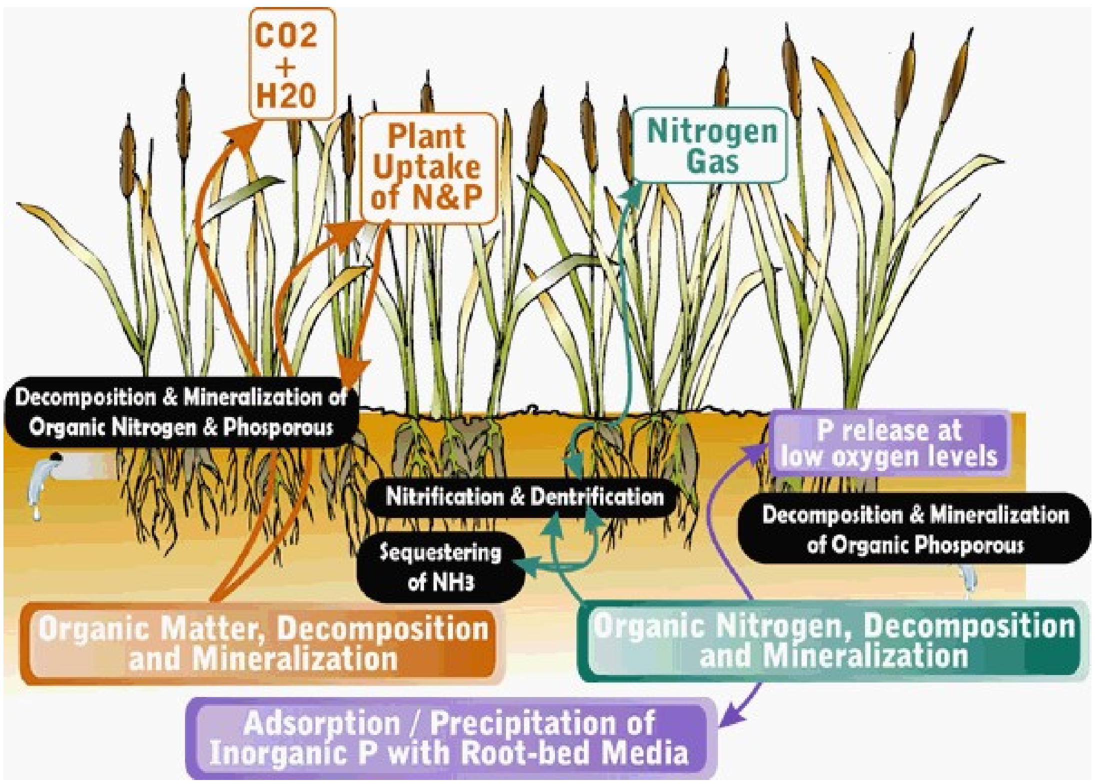

Figure 3. Constructed wetland processes (Rozema, L 2007)

The US EPA (2000) suggests that "design should be based on parameters (e.g., hydraulic loading, nitrogen loading, detention time, etc.) and operating criteria that are required to meet a specific effluent limitation." The most important factor in determining the size of a constructed wetland is the rate of removal for the contaminant of concern (ITRC 2003).

Several manuals and books have been published which provide guidance for the design of constructed wetlands (ITRC 2003, Kadlec and Knight 1996, US EPA 2000). However, much remains to be learned about the processes that occur within treatment wetlands and how to best design systems in order to take advantage of the processes. Therefore, engineers have relied heavily on the North American Database on wetlands (NADB) as well as other reported successes and failures to guide their designs. Still, an organized approach to the study of the processes is badly needed to advance the overall understanding of the systems and their design (US EPA 2000).

The New Mexico ground water standard for total nitrogen is 10 mg/l. NMAC 20.7.8 defines total nitrogen as the sum of nitrate nitrogen, nitrite nitrogen, organic nitrogen, and total ammonia nitrogen (NMCPR 2007). Total nitrogen levels in ground water and effluent are monitored because nitrates may have toxic effects in infants if ingested. Constructed wetlands often discharge to an infiltration basin or the effluent may be used for irrigation. Although nitrate levels are often low in effluent, all of the nitrogen in effluent could potentially be converted to nitrate in groundwater through the nitrification process. Thus, nitrate levels in ground water may be greater than those in effluent. Therefore, the NMED requires monitoring of nitrate and nitrite nitrogen as well as TKN (ammonia nitrogen and organic nitrogen). Most ground water discharge permits contain an effluent limit of 20 mg/L total nitrogen in recognition that natural attenuation and transformation processes occur that will limit the nitrate concentration in underlying ground waters (McQuillan and Parker 2000). Constructed wetlands have the potential to remove nitrogen through several processes, including denitrification, sedimentation, and plant uptake, as well as others (Davies & Hart, 1990). Nitrogen compounds may be transported throughout wetlands through the processes of settling and resuspension, diffusion, plant uptake, and sorption, without being molecularly transformed (Kadlec and Knight 1996). Chemical and biological transformations of nitrogen in wetlands may occur through: 1) ammonification (hydrolysis of organic nitrogen to ammonia), 2) nitrification, 3) denitrification, 4) nitrogen fixation, and 5) nitrogen assimilation. Less than 20 percent of total nitrogen is removed through plant uptake and harvest of vegetation, leaving denitrification as the primary removal process (EPA 2000). Nitrogen removal is primarily accomplished through the nitrification-denitrification process. This two-step process begins with the oxidation of ammonia to nitrate (Figure 4). Nitrification is performed by bacteria which are ammonia oxidizing autotrophs. In anaerobic zones, denitrification of nitrate to nitrogen gas, mediated by heterotrophs, occurs. The processes of ammonification, nitrification, and denitrification in constructed wetlands are all temperature dependent and show a greater response at temperatures below 15^{o} C (Kadlec and Reddy 2001).

(1) Organic N + H_2O = $NH_4^+ + OH^-$ (ammonification)

(2) $2\ NH_4^+ + 3\ O_2 = 4\ H^+ + 2\ H_2O + 2\ NO_2^-$ (nitrification)

$2\ NO_2^- + O_2 = 2\ NO_3^-$

(3) Organic Carbon + NO_3^- N_2 (denitrification)

Figure 4. The denitrification cycle (Mitsch & Gosseling 1986, Davies & Hart 1990)

In theory, leakage of oxygen from rootlets, rhizomes and roots allows for the formation of an aerobic film around the root hairs of vegetation. However, commonly roots do not penetrate throughout the media and aerobic zones become limited which limits nitrification and in turn, denitrification (US EPA 1993). Increasingly, subsurface-flow constructed wetland designs include some type of aeration within the cells or a nitrification process is used prior to the wetland cells.

1.3 Government regulation and monitoring

Constructed wetlands may be regulated by federal, state, or city agencies. Federal regulation may exist under the Clean Water Act (CWA) Sections 402 and 404, the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), or the Migratory Bird Treaty Act (ITRC 2003). Regulation through the US EPA is through the National Pollutant Discharge System (NPDES) which requires a permit for discharge into regulated waters. Federal NPDES applies to surface waters of the US and most often, constructed wetlands utilized for wastewater treatment do not discharge effluent to waterways of the US and are not currently considered waters of the US. Therefore, they are usually not subject to federal regulation under the Clean Water Act, but are permitted through state agencies which may have regulations governing discharge to groundwater (ITRC 2003).

Constructed wetlands are capable of removing many contaminants. Most often, state permitting agencies require systems to achieve a designated level of nitrogen, fecal coliform, suspended solids, dissolved oxygen, or biochemical oxygen demand in treated effluent and groundwater. The specific contaminants to be monitored as well as the maximum levels allowed vary widely between states. For example, many states set effluent CBOD and suspended solid limits, but do not require monitoring of nitrogen.

In New Mexico, regulation of constructed wetlands is under the jurisdiction of the New Mexico Environment Department Ground Water Quality Bureau. The NMED enforces New Mexico Water Quality Control Commission (WQCC) regulations 20.6.2. The regulations state that total nitrogen measured in groundwater must not exceed 10 mg/l. The NMED often sets total nitrogen effluent limits of 20 mg/l for constructed wetland systems. Additionally, requirements frequently include the removal of solids from the wastewater treatment system and the quantity of effluent discharge must be recorded and submitted to the NMED. Most permits require that Chloride and Total Dissolved Solids also be monitored, but effluent limits are not usually set. The discharge permits do not commonly require monitoring of other contaminants which do not pose a health threat in ground water, such as BOD, TSS, Phosphorus, and Fecal Coliform Bacteria. The monitoring frequency of contaminants in effluent and groundwater is determined on a case by case basis and may occur monthly, quarterly or bi-annually. Many of the constructed wetlands in New Mexico have a similar design with the system made up of a septic tank(s), wetland cell(s), and an infiltration basin. In response to the inability of many of the systems to comply with the discharge limitations, the NMED commonly requires modifications to be made before permit renewals are granted. Similarly, before any new constructed wetland discharge permit request would be approved, appropriate modifications would need to be in place which would ensure adequate contaminant removal (George 2007).

1.4 Advantages, limitations and challenges

Constructed wetlands have a number of advantages over alternative treatment options. First, the systems are less expensive than mechanical systems based on activated sludge processes, especially the operations and management costs (O&M costs). For example, a subdivision with a flow of 60,000 gpd might pay approximately the same amount for a sequencing batch reactor (SBR) or for a subsurface-flow constructed wetland. However, the operating costs for the SBR average $2.50/1000 gallons whereas the constructed wetland operating costs are 10 cents/1000 gallons (ITRC 2003). Additional advantages of constructed wetlands include low maintenance, carbon dioxide sequestration, and wildlife habitat creation.

However, there are several limitations associated with constructed wetlands. These include the initial time required for installation and establishment of vegetation, possible odors, the amount of land required, and performance limitations that may occur due to climate extremes. The most commonly encountered limitation is the failure of the systems to consistently meet the NMED wastewater discharge permit requirements. The inability of systems to meet groundwater discharge requirements does not necessarily reflect the inability to remove contaminants from wastewater. As shown in table 1, the US EPA advises that constructed wetlands alone cannot be expected to remove nitrogen at the efficiency necessary to meet state permit requirements. Thus, constructed wetlands in states without nitrogen limits often appear to be more successful than those with them. However, in conjunction with another process the systems are often able to treat wastewater to meet all permit requirements.

Table 1. Constructed wetland design parameters (EPA 2000)

Summary of SSF Wetland Design Criteria

Parameter	Criteria
Pretreatment	Recommended primary treatment—sedimentation (e.g., septic tank, imhoff tank, primary clarifier); SSF not recommended for use after ponds because of problems with algae (clogging).
Surface area	Based on desired effluent quality and areal loading rates as follows:
BOD	6 g/m^2-d (53.5 lb/ac-d) for 30 mg/L effluent
BOD	1.6 g/m2-d (14.3 lb/ac-d) for 20 mg/L effluent
TSS	20 g/m2-d (178 lb/ac-d) for 30 mg/L effluent
TKN	Use another process in conjunction with SSF.
TP	Not recommended for phosphorus removal.
Depth Media Water	 0.5–0.6 m (20–24 inches) 0.4–0.5 m (16–20 inches)
Length	As calculated; minimum of 15 m (49 feet)
Width	As calculated; minimum of 61 m (200 feet)
Bottom slope	0.5%–1 %
Top slope	Level or nearly level
Hydraulic conductivity, K_h First 30% of length Last 70% of length	 Use 1% of clean K_h for design calculations. Use 10 % of clean K_h for design calculations.
Media Inlet—1st 2 meters (6.5 feet) Treatment Outlet—last 1 m (3.2 ft) Planting media—top 10 cm (4 inches)	 40–80 mm (1.5–3 inches) 20–30 mm (0.75–1 inch) 40–80 mm (1.5–3.0) 5–20 mm (0.25–0.75 inches)
Miscellaneous	Use at least 2 SSF wetlands in parallel. Use adjustable inlet device to balance flow. Use adjustable outlet device to balance flow.

Other problems that may be encountered in constructed wetland systems include: 1) clogging due to accumulation of wastewater solids, microbial growth or overgrowth of roots in the media 2) inadequate removal of BOD, nitrogen or other parameters, 3) surfacing wastewater, 4) accumulation of mercury or other metals, and 5) mosquito breeding. Often, solids accumulate within the wetland cells which may lead to elevated

TDS levels in the effluent and/or clogging within the cells. This issue may be minimized by occasionally flushing cells, pumping septic tanks more frequently, and providing a higher degree of pre-treatment, such as a trickling filter prior to the wetland cells.

A common problem encountered where flow varies seasonally, as seen at the elementary schools in this study, is the lack of an adequate wastewater source to keep vegetation alive for several months at a time. Additional concerns continue to emerge, such as the potential for bioaccumulation of contaminants in wildlife. (Barber et al. 2006).

Furthermore, as previously mentioned, systems may have difficulty achieving the required performance, especially for nitrogen removal. Meeting the NM state ground water standards of 10 mg/l in groundwater and 20 mg/l in effluent as contained in many ground water discharge permits has proven difficult for constructed wetlands in New Mexico unless additional treatment components such as nitrification tanks or trickling filters are present. Plant uptake and harvesting of vegetation removes less than 20 percent of nitrogen (Reed et al. 1995). Thus, nitrification and denitrification are relied upon for the remainder of nitrogen removal. An aerobic zone is necessary for nitrification of ammonia to nitrate. The nitrification reaction requires about 4.6 g of O_2 per gram of NH_3-N oxidized (Kadlec and Knight 1996). In subsurface-flow constructed wetlands, aerobic zones within the cells are found solely around the roots of the vegetation leaving most of the area to be anaerobic. Therefore, nitrification is limited unless a free water area is introduced or additional aeration for nitrification is provided (US EPA 2000). Finally, elevated TDS levels in effluent are commonly seen in the systems in New Mexico due to the high levels of evaporation that occur throughout the wetland cell (George 2007)

2.0 Background

Little information is available regarding the long term performance of constructed wetlands. Many systems are often small and are not required to collect or report performance data. Increased information sharing could help with the design of new systems and the avoidance of common problems. There is a database available for the collection of treatment wetland design and performance information, the Constructed Treatment Wetland System Description and Performance Database started by the US EPA and managed by students at Humboldt State University (Finney 2000). Submission of information is voluntary and not common. Only one of the 40 or more systems in New Mexico is in the database.

Frequently, research has focused on individual systems or a single aspect of treatment wetlands such as the effects of various vegetation or substrate types. Several studies have attempted to gain a broader perspective about the function and design of treatment wetlands. Furthermore, state discharge limits and monitoring requirements for contaminants vary widely between states, making it difficult to compare the removal performance for specific contaminants such as total nitrogen.

2.1 Previous Work in NM

This project was derived from a previous project completed by E. Daniel Boivin (Boivin, 1995) that described the design and performance of 18 sub-surface flow constructed wetlands throughout New Mexico. The systems included in the 1995 study as well as the additional five included in this study are listed in Table 2. Boivin (1995) found that designs for the 18 wetland systems were based on organic loading rates which were much lower than the actual rates. All systems provided wastewater pre-treatment by septic tanks but none had an effective primary treatment option, such as a lagoon or trickling filter. Boivin (1995) found that none of the systems were able to consistently remove nitrogen to the New Mexico state ground water standards.

Table 2. Constructed wetlands included in this study and 1995 study by Boivin

Wetland Name	1995 Study	2007 Study
El Dorado Elementary School-Santa Fe	X	X
Pueblo Encantado Resort- Santa Fe	X	X
Santa Fe Opera	X	X
Los Padillas Elementary School – Albuquerque	X	X
Riverside Mobile Home Park – Tesuque	X	X
Paa Ko Subdivision – East Mountains		X
Prairie Hills Subdivision – East Mountains		X
Tablazon Subdivision – East Mountains		X
Woodlands – East Mountains		X
Corrales Elementary School		X
Ghost Ranch Conference Center – Abiquiu		X
Logan’s Mobile Haven	X	
Port-Of-Entry, Gallup	X	
Manhattan Apartments	X	
Village of Los Ranchos	X	
Manulito Rest Area-Gallup	X	
Sevilleta National WR	X	
Mountain Shadows Health Care Center	X	
Stakvel Residence	X	
Watson Residence	X	
10,000 Waves-Santa Fe	X	
Wemple Residence	X	
Logan-Condon Residence	X	
Elephant Butte State Park	X	

2.2 Colorado Inventory of Constructed Wetlands

The Colorado Governor's Office of Energy Management and Conservation (OEMC), in 2000, recognized the lack of data available regarding the design, construction, operation, and energy efficiency of constructed wetland systems and undertook an inventory of the systems in Colorado. The inventory resulted in a report with data and contact information for 20 treatment wetlands in the state. Forty-one wetland systems were identified although those that lacked performance data or did not treat a point source were not included. Of the 20 systems studied, 13 were surface-flow, five were subsurface-flow and two were a combination of both. Furthermore, 17 of the systems included primary treatment in a lagoon with an aeration device. Three-quarters of the systems were consistently meeting permit requirements for BOD and TSS. However, nitrogen removal data was not included and permits did not require total nitrogen monitoring. The success of the 15 systems may be attributed to the higher quality of the influent provided by the lagoons as well as the greater oxygen transfer provided by surface-flow systems.

Table 3. Colorado Constructed Wetlands Inventory System Details (Colorado OEMC 2001)

Site	Type	Size (acres)	Design Flow (mgd)	Average Flow (mgd)	Population	Meeting permit limitations	Montana Method Score	Educational Uses	Year Online	Primary Treatment
Avondale	FWS	0.87	0.110	0.080	1000	No	2.4	No	1996	Lagoon
Bennett	FWS / SF	2	0.42	0.80	2200	Not online	2.6	Yes	Not online	Lagoon
Calhan	SF	0.31	0.80	0.065	850	Yes	2.6	Yes	1996	Lagoon
Crowley	FWS	3.04	0.170	0.126	1200	Yes	2.5	No	1996	Lagoon
Crowley Correctional Facility	FWS	3.3	0.150	0.110	600	Yes	2.0	Yes	1998	Lagoon
Delta	FWS	1.38	0.067	0.038	590	Yes	1.3	Yes	1997	Lagoon
Dove Creek	FWS	1.0	0.115	0.035	743	Yes	2.6	No	1999	Lagoon
Highland Presbyterian Camp	SF	0.014	0.0005	0.0005	240	No	0.98	Yes	1996	Septic Tanks
Hi-Land Acres	SF	0.21	0.055	0.022	300	Yes	0.90	Yes	1998	Lagoon
Horizon	FWS	1.0	0.015	0.010	220	Yes	2.2	Yes	1988	Lagoon
Island Acres	FWS	1.0	0.020	0.015	380	Yes	2.6	No	1995	Septic Tanks
La Veta	FWS	1.6	0.125	0.075	850	Yes	2.7	Yes	1993	Lagoon
Las Animas	SF	2.1	0.50	0.25	3500	Yes	2.1	No	1999	Lagoon
Manzanola	FWS	2.3	0.125	0.045	450	No	2.8	No	1998	Lagoon
Ouray	FWS	0.76	0.363	0.26	700 – 2000	Yes	2.6	No	1995	Lagoon
Platteville	FWS	3.0	0.348	0.130	2500	No	2.0	No	1992	Lagoon
Ridgway	FWS	1.5	0.015	0.015	290	Yes	2.8	Yes	1994	Septic Tanks
Rocky Mountain Shambhala Center	SF	0.23	0.05	0.05	200-500	Yes	1.5	Yes	1996	Septic Tanks
Silt	FWS	0.830	0.236	0.110	1700	No	2.3	No	1992	Lagoon
Valmont	SF	0.03	0.50	0.25	100	Yes	2.1	No	1993	Septic Tanks

3.0 Methodology

3.1 Selection of Wetlands

A total of 11 treatment wetlands were chosen for this project, five from Boivin's 1995 thesis and six others (Table 2). Due to time and budget constraints the project was limited to systems near Albuquerque. All systems included in this study have been in operation for more than 10 years which made it possible to examine their long-term performance.

3.2 Site details

Most constructed wetland systems in New Mexico are horizontal subsurface-flow. One of the systems in this study, Ghost Ranch, located near Abiquiu, is surface-flow and none are vertical subsurface-flow. Eight of the 11 systems included in this study were designed by the engineering firm Southwest Wetlands Group which has subsequently changed its name to Natural Systems International. Details about each site, including the average actual flow during 2006 is included in Table 4

Table 4. Constructed wetland design statistics

Wetland Name	Years in Operation	Wetland Cells	Total Cell Area (ft^2)	Average Actual Flow	Hydraulic Loading Rate (cm/day)
Corrales Elementary	11 Yrs	4	15,400	6086 gpd	0.4
El Dorado Elementary	17 Yrs	2	7,440	2017 gpd *	0.27
Pueblo Encantado	14 Yrs	3	6,525	2391 gpd	0.37
Ghost Ranch Conference Center	15 Yrs	3	39,999	8654 gpd winter 16,056 gpd summer	0.40
Santa Fe Opera	13 Yrs Switching to MBR 7/2007	2	5300	12,000 gpd summer	0.44
Paa Ko Subdivision	13 Yrs Switching to MBR 10/2007	3	41,580	37,552 gpd	0.9
Los Padillas Elementary	14 Yrs Switching to city vacuum system	2	5000	1359 gpd *	0.27
Prairie Hills Subdivision	11 Yrs	1	8229	5500 gpd	0.66
Riverside Mobile Home Park	14 Yrs	2	1800	1189 gpd	0.66
Tablazon Subdivision	13 Yrs	4	15632	6895 gpd	0.44
Woodlands Subdivision	11 Yrs	1	10,595	4,000 gpd	0.38

The smallest system is Riverside Mobile Home Park with two 900-sf cells and an average flow of 1189 gpd. Seven of the 11 systems lack pre-treatment beyond that provided by a septic tank. Woodlands, Prairie Hills, Tablazon, and Ghost Ranch have additional treatment components. The Woodlands system has an anoxic denitrification tank which recirculates with 2 trickling filter tanks. Ghost ranch has two ponds prior to the wetland cells. Tablazon has a FAST system prior to the wetland cells that provides aerobic treatment of influent wastewater and is intended to provide removal of soluble organics and achieve nitrification of the wastewater. During winter months two 15 KW electric heaters heat the water to improve nitrification. Additionally, the Prairie Hills system has a Biotower which is intended to provide removal of organics and nitrify the wastewater and operates on a recycle system with the wetland cell.

Initially, most of the constructed wetland systems in New Mexico were operated with very little maintenance or monitoring (Boivin 1995). This study found that most of the systems are visited quarterly or monthly while several systems have dedicated operators, such as Fred Black from Entranosa Water and Cynthia Arnold from N.M American Water, who visit the systems weekly.

3.2.1 Corrales Elementary School

Corrales Elementary School is located in Corrales, New Mexico. The constructed wetland system has been in operation since September 1996 and is owned and operated by Albuquerque Public Schools (APS). The discharge permit limits flow to a maximum of 13,300 gallons per day (gpd), while the average flow is around 7,000-gpd during the school year. Pretreatment is provided by two 8,000-gallon septic tanks. Effluent flows through a splitter into four parallel 3850-sf aerated subsurface flow wetland cell. (Figure 5). The effluent from the cells flows through a sump with a weir into a small aerated pond. The electricity for the aeration is provided through solar cells. Designated APS staffs are very familiar with the system and perform frequent maintenance such as minor electrical and blower repairs and annual removal of vegetation. Samples are collected quarterly from both the splitter and effluent sump, analyzed by an independent laboratory for TN, TDS, and Chloride, and reported to the NMED along with flow levels. The discharge permit is currently under evaluation for renewal and is expected to be renewed for five additional years. Unlike many of the other systems, the wetland is maintained to maximize its appeal to the public and is appreciated by the community. Several birds and a nest with eggs were observed within the cells during the site visit.

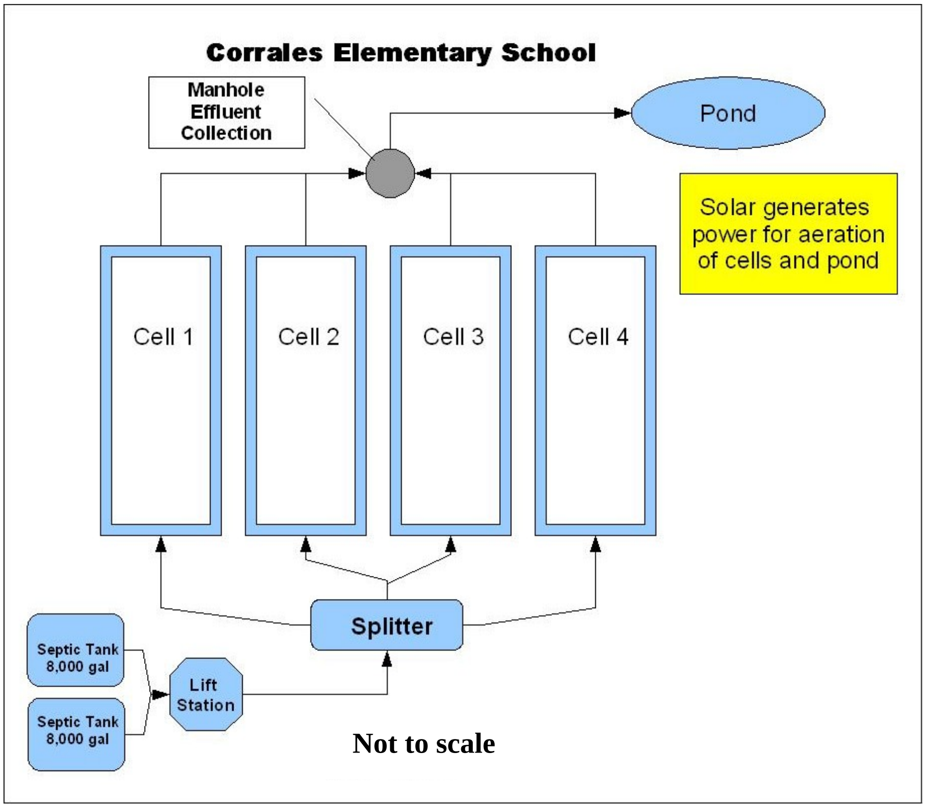

Figure 5. Corrales Elementary School Constructed Wetland

3.2.2 El Dorado Elementary School

El Dorado Elementary school is located in the community of El Dorado, approximately 10 miles north of Santa Fe. The system is operated by the Santa Fe Public School System (SFPS) and maintained by M & E Engineering, Santa Fe. The permitted flow is 5,000 gpd, while the average actual flow is approximately 2,000 gpd. The system, designed to treat up to 10,000 gpd, is the oldest in this study and began to be utilized in 1990. It consists of two 7,000-gallon septic tanks which flow into two parallel 3720-sf subsurface-flow wetland cells. Effluent from the cells flows to an infiltration basin. There was not any effluent during the site visit and the permit renewal application states that there was no effluent between May 2003 and November 2006. This may be due to a high level of evaporation from the cells or a leak in wastewater collection system before influent reaches the cells or in the liner of the cells.

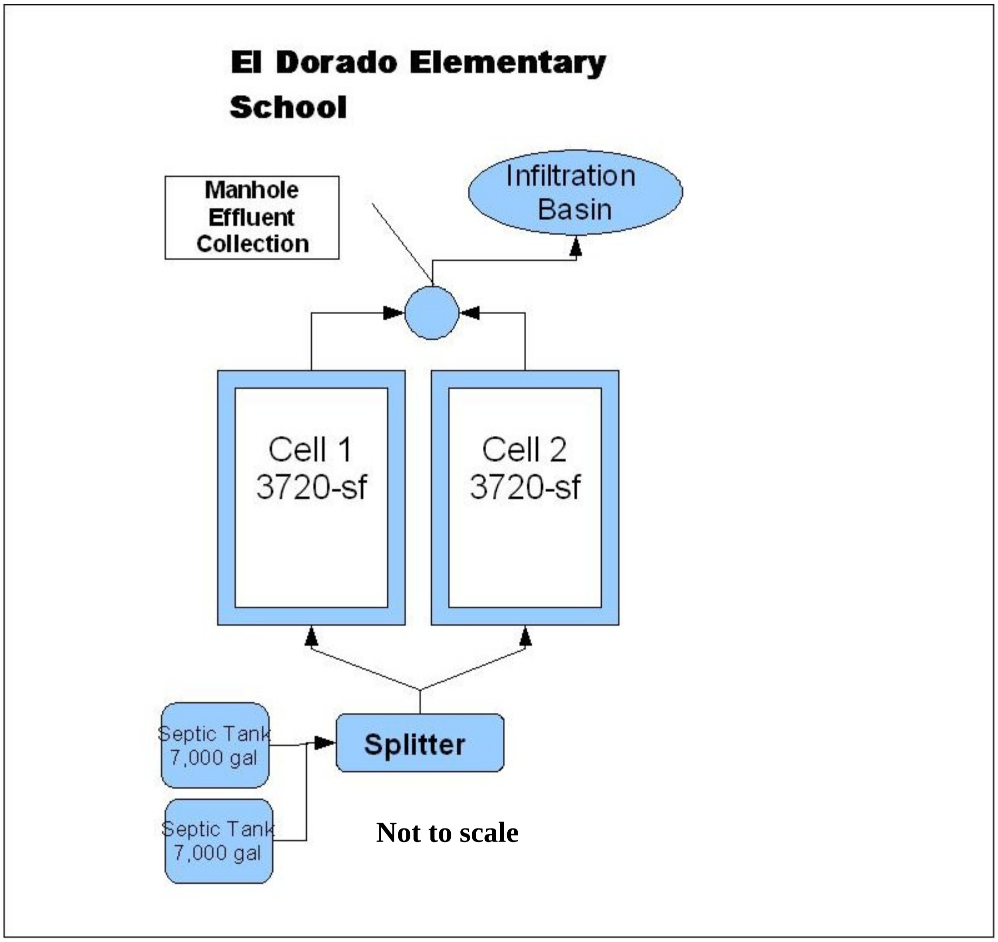

Figure 6. El Dorado Elementary School Constructed Wetland

3.2.3 Pueblo Encantado

Pueblo Encantado is a privately owned resort with 40 condominiums for rent located eight miles north of Santa Fe. Maintenance was performed by L.A Bustamante, a private contract operator. However, Bustamante recently ended her position and a new operator has not been assigned. The constructed wetland system began operation in 1993. Designed to treat up to 12,000 gpd, the treatment system receives an average of 2400 gpd. Flow is extremely variable due to the fluctuating number of residents at the resort. The system is made up of two septic tanks, 5500-gal and 3500-gal, followed by three subsurface wetland cells in series, one 2925-ft^2 cell and two 1800-ft^2 cells with aeration trenches (Figure 5).

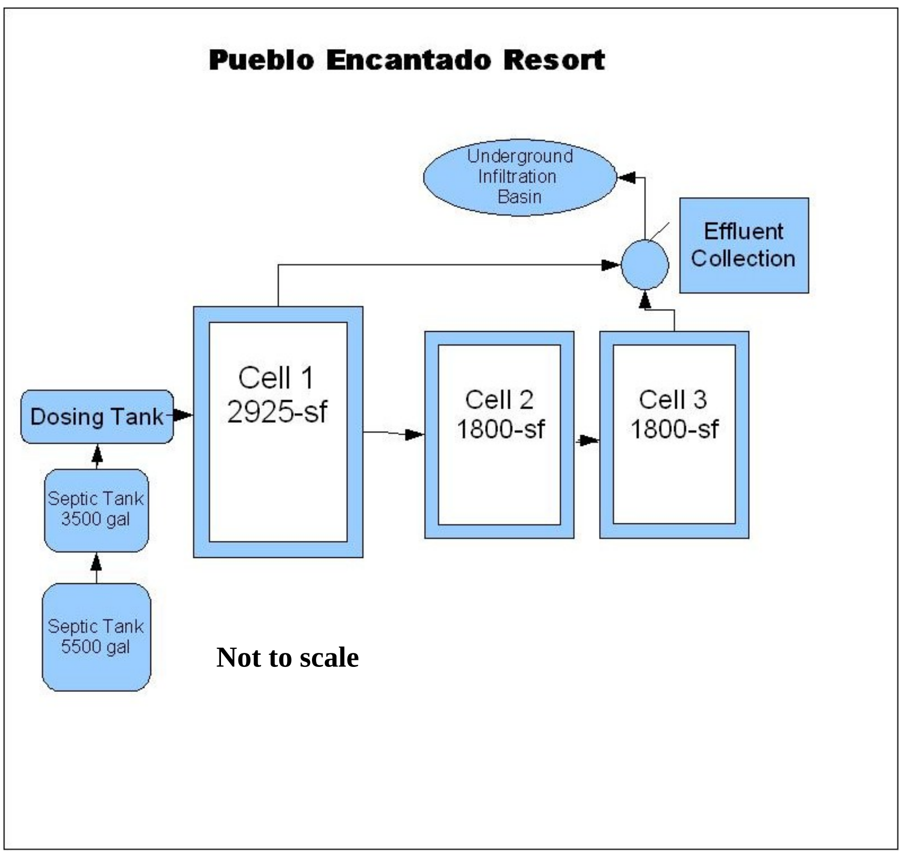

Figure 7. Pueblo Encantado Constructed Wetland

An additional feature is a carbon source distribution pipe intended to “trickle in wastewater to the deeper denitrification zones of cells two and three”, as stated in the original discharge permit application. The permit also states that the carbon distribution system should not be necessary after several years due to the accumulated plant detritus which will provide an adequate carbon source. In order to maintain the supply of carbon from decaying plant material, the permit application states that wetland plants will not be harvested. The effluent from wetland cell three flows over a weir to an underground infiltration basin.

Figure 8. Pueblo Encantado Constructed Wetland: Cell 3

There are currently no groundwater monitoring wells at the site and the discharge permit only requires bi-annual monitoring of TN from cell three. However, Bustamante was often unable to collect effluent monitoring samples due to lack of flow. During the site visit flow from cell one was very high, but there was no flow from cells two or three. Additionally, vegetation in cell three was very patchy and sparse. Communication with NMED staff confirms there is clogging in cell three preventing the effluent from reaching the manhole where samples are taken. A sample from cell one effluent was taken during the site visit for this study. However, as the effluent would still pass through two more cells, the results were not representative of final effluent which could not be collected due to lack of flow.

3.2.4 Ghost Ranch

Ghost Ranch Retreat and Conference Center, located near Abiquiu, New Mexico is the only surface flow wetland system in this study. The system has been in operation since 1992 and is operated by Willie Picaro, a maintenance person at Ghost Ranch. Designed by Roy Miller, the system consists of two 15000 gal septic tanks followed by two lagoons, 14,200 ft^2 and 17,600 ft^2, both of which are concrete lined (Figure 9). Originally, the lagoons were operated in series, but excessive sludge accumulated in the first lagoon. Now, the second lagoon receives effluent from the first lagoon as well as from the septic tanks. The second lagoon flows to five fully vegetated surface-flow wetland cells in series, then into a 19300 ft^2 pond which may recycle to the first pond or flow to an infiltration basin. However, due to evapotranspiration, effluent rarely reaches beyond the second or third wetland cell. Flow is extremely variable due to the nature of the facility, but averages 16,000 gpd during the summer months and 8600 gpd during the rest of the year. The discharge permit requires quarterly monitoring for NO3-N, TKN, TDS and Cl from the final wetland cell and two groundwater monitoring wells with results reported to the NMED.

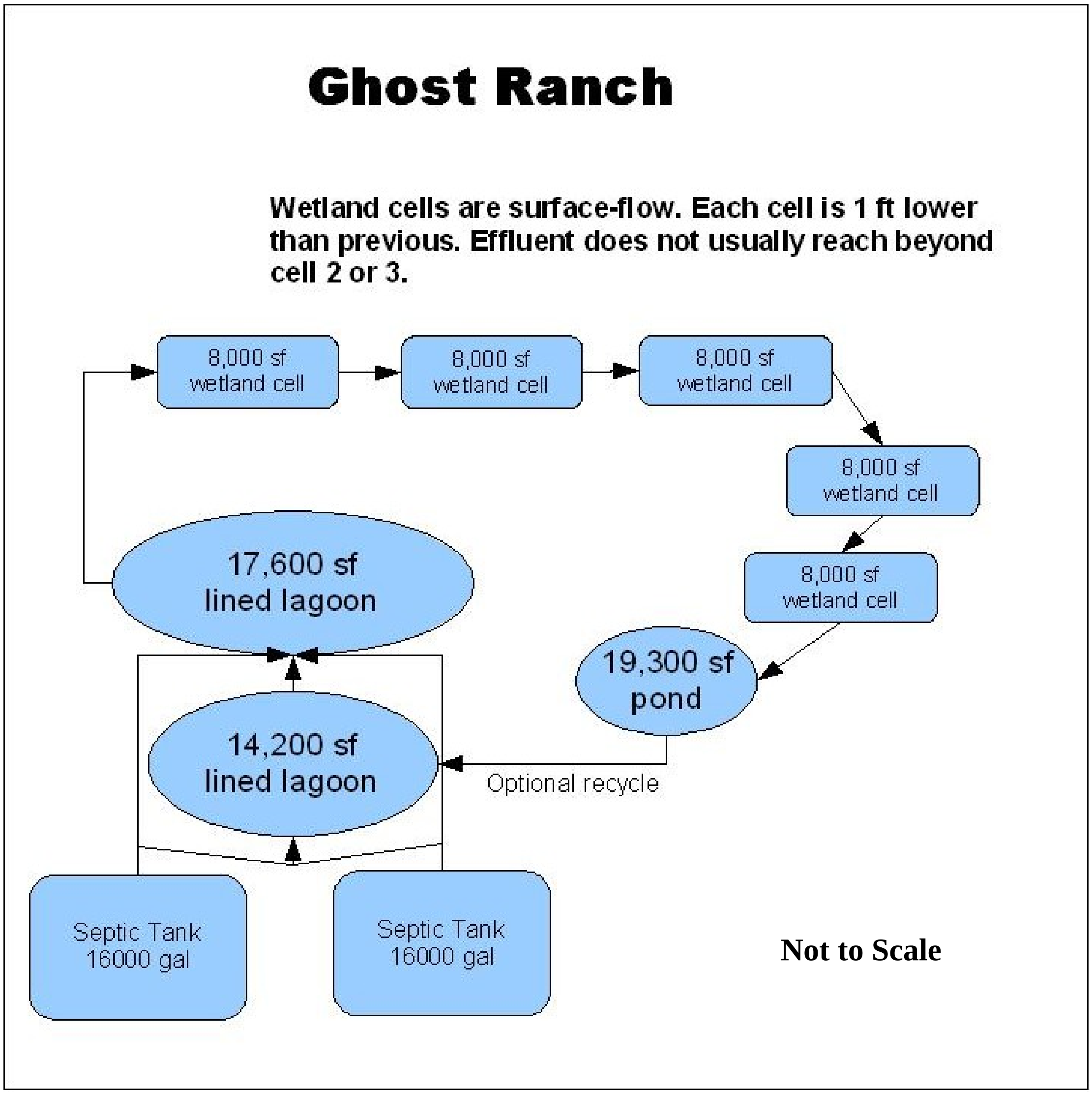

Figure 9. Ghost Ranch Constructed Wetland

3.2.5 Santa Fe Opera

The Santa Fe Opera constructed wetland was designed by Southwest Wetlands Group and has been in operation since 1994. The system is made up of two 16,000 gal septic tanks which have had aeration added to improve system performance. Wastewater flows from the septic tanks to two parallel subsurface 2650-sf wetland cells followed by a small trickling filter and an UV disinfection system. Effluent is used for irrigation on the property. Flow is greatly reduced in the fall, winter and spring months when summer employees are not living on the property, which reduces the productivity of the wetland plants and overall performance of the system. After many years of poor results, the Santa Fe Opera switched over to a membrane bioreactor system in May 2007.

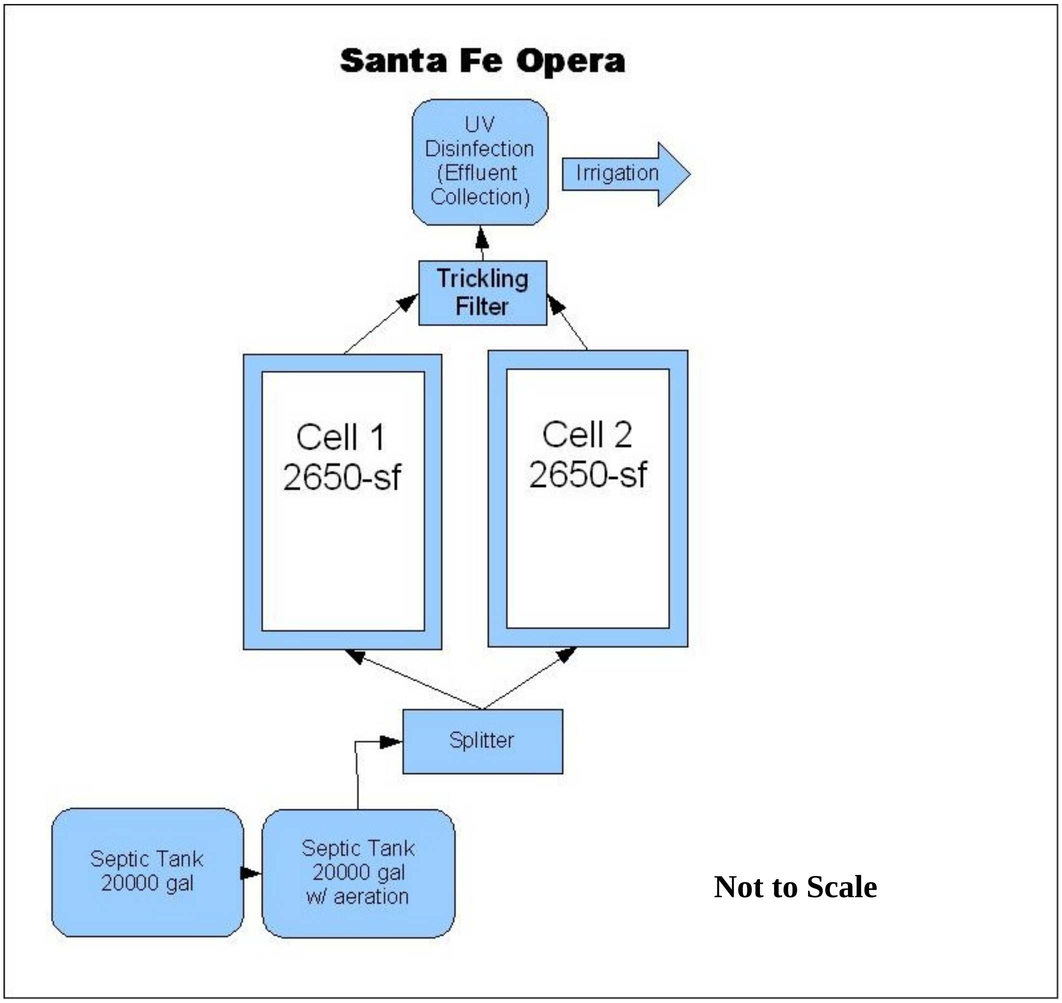

Figure 10. Santa Fe Opera Constructed Wetland

3.2.6 Paa Ko Subdivision and Golf Course

The Paa Ko community, a golf course and more than 50 private homes, is located in the East Mountains of Bernalillo County. The community has utilized a constructed wetland system since 1994, but is switching over to a membrane bioreactor at present due to consistently poor treatment performance. The system is made up of septic tanks at all residences which flow to a main 20,000 gal tank. Wastewater from the main septic tank flows through four 13,860 ft^2 parallel subsurface-flow wetland cells (Figure 11). Occasionally, one or more cells may not be utilized if maintenance is required. Effluent from the cells flows to a trickling filter followed by a chlorination system and is then utilized for irrigation of the golf course. When irrigation is not necessary, one or more infiltration basin is utilized.

The system was built with a single wetland cell. Two more cells were added in 1997, three years after the system went online. At that time the trickling filter and chlorination system were also added but the system was not able to meet the permit regulations for total nitrogen below 20 mg/l in effluent and 10 mg/l in the monitoring well. In 2007, a groundwater monitoring well, from which TN results were commonly above 10 mg/l, was abandoned. A new well has been installed and utilized for monitoring, from which TN results have been well below 10 mg/l even as effluent results remain above 20mg/l.

Due to the shallow depth to groundwater in the area and the consistent inability to meet the NMED permit requirements the community is required to perform monitoring monthly. New Mexico Water performs all required maintenance on the system. Maintenance does not include harvesting of vegetation in the cells as they have found that the cells are too large to perform the work by hand and large equipment may compact the media in cells. Vegetation removal did occur during the first three to five years of operation, but often resulted in higher TKN levels, likely due to the increased detritus within the cells (Arnold 2007).

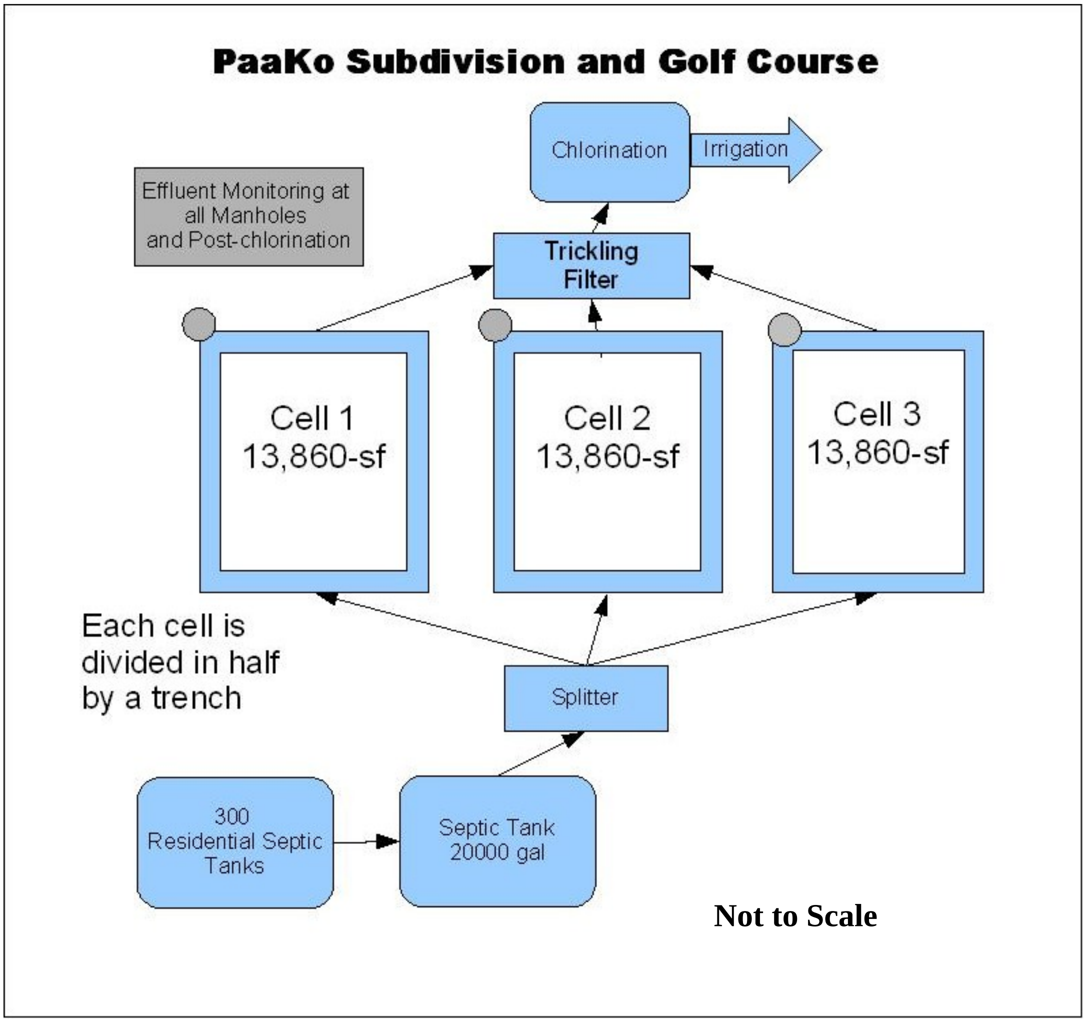

Figure 11. Paa Ko Constructed Wetlands

3.2.7 Los Padillas Elementary School

The Los Padillas Elementary School is located on the southern edge of Albuquerque and was beyond the boundaries of the city's wastewater system until recently. The school has been utilizing a constructed wetland system since 1993, but will be switching over to the city vacuum system in 2007. The system is made up of two 1000 gal septic tanks in series followed by two 2500-sf subsurface-flow wetland cells in parallel. The wetland cells are aerated with power provided from solar panels. Effluent from the wetland cells flows to a UV lamp then to a lined evaporation pond. To improve performance, one cell has a recycle line. Whereas the depth for most SSF wetland cells is 24-in, the depth of the Los Padillas cells was increased to 42-in during installation. Albuquerque Public Schools performs frequent maintenance on the system including harvesting of dead vegetation each spring. The discharge permit for the system requires quarterly monitoring of TN and fecal coliform with a limit of 100 CFU/100 ml. The system has consistently failed to meet the NMED permit limits. Out of 12 sampling events, 2002 to 2005, effluent TN exceeded permit levels eight times and the fecal coliform limit was exceeded six times. Furthermore, TN levels were exceeded during Boivin's fall and winter sampling in 1995 and the 2007 spring sample collected for this study.

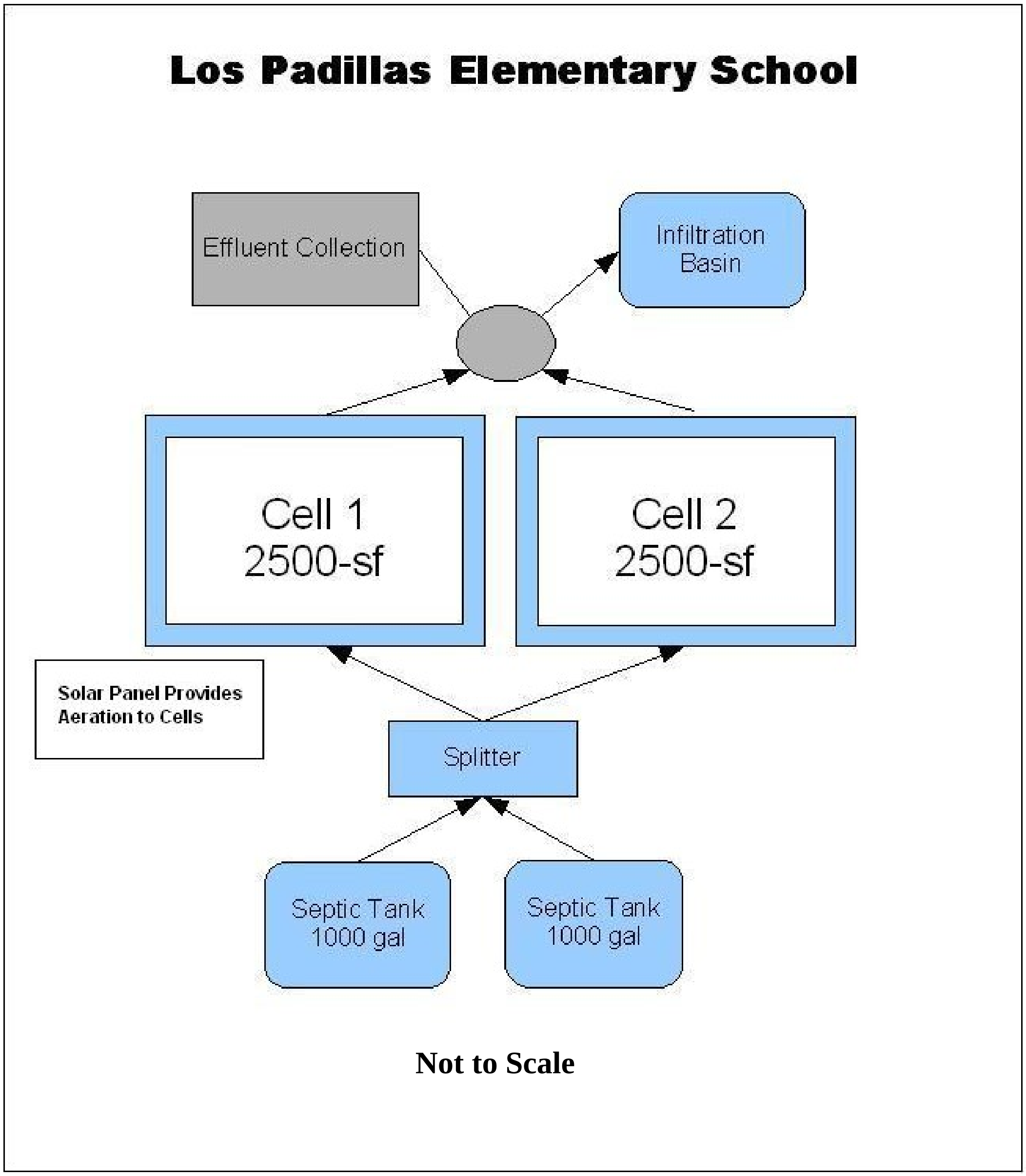

Figure 12. Los Padillas Elementary School Constructed Wetlands

Figure 13. Los Padillas Constructed Wetland - March 2007

3.2.8 Prairie Hills Subdivision

The Prairie Hills subdivision currently supports 25 homes and a maximum of five additional homes may be added within the next four years. Each home has a septic tank at the residence with influent collecting at a distribution box near the treatment wetland. Total flow through the wetland system has been less than 6000 gal/day. The system contains a nitrifying unit following a single subsurface wetland cell. Effluent from the cell flows to a tank with a splitter where it mixes with nitrified water from a “bio-tower” which contains a trickling filter. The water from the bio-tower may be recirculated to the wetland cell or sent to the dosing tank. When the dosing tank reaches a certain volume effluent is sent to a leachfield. Until that volume is reached, recirculation to the bio-tower continues (Figure 14). The bio-tower and recirculation work effectively to accomplish the nitrification necessary to achieve the required levels of denitrification within the cell. The system nearly always meets the NMED permit limits for total nitrogen.

The electrical box which controls the distribution system and trickling filter has been shot at several times. The box was shorting out often which created an extremely variable flow through the entire system and resulted in lower treatment results than normal. Entranosa Water performs regular maintenance on the system including weekly visits to the site to reset the electrical system and quarterly monitoring. The electrical issues resulted in a significant decline in performance of the system and total nitrogen results above the permitted level of 20 mg/l. The electrical system was being repaired in April and Entranosa Water reports that they were able to collect two consecutive samples in May with TN concentrations below 20 mg/l.

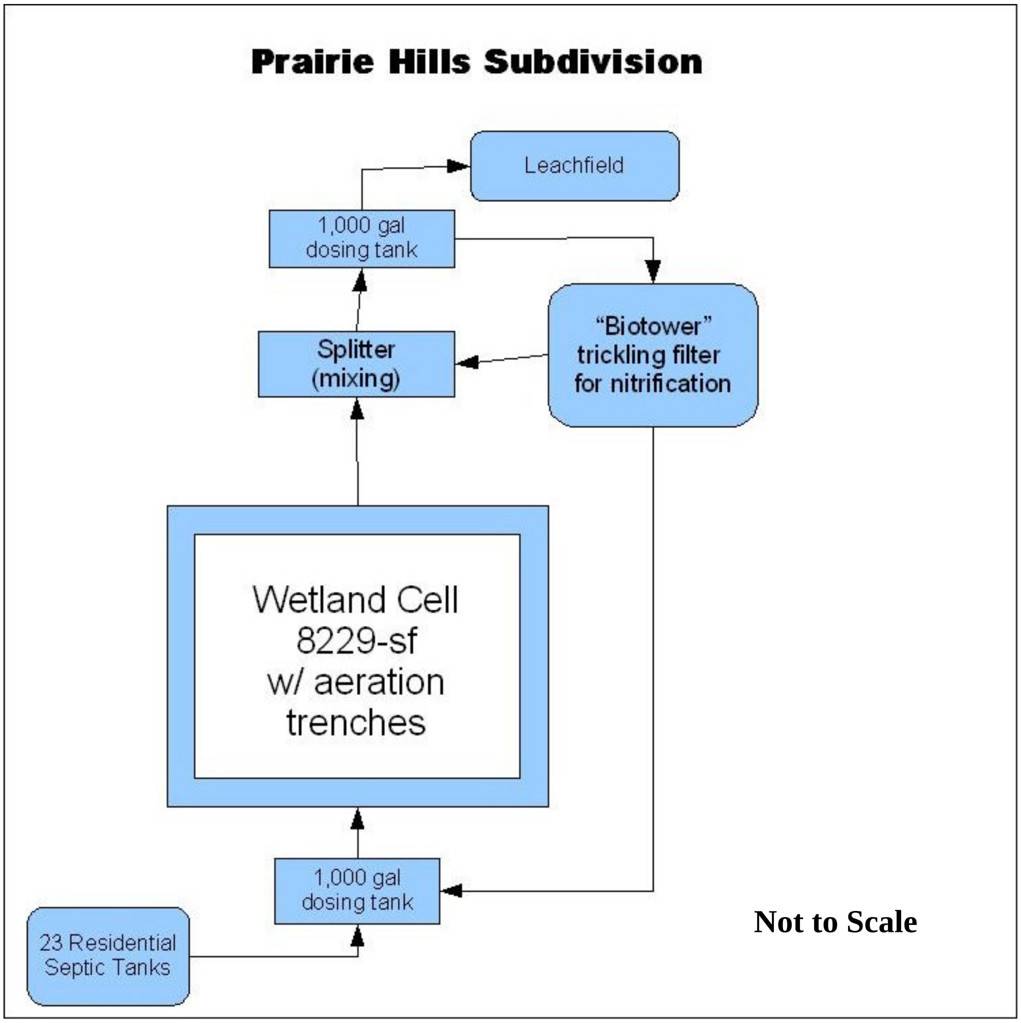

Figure 14. Prairie Hills Subdivision Constructed Wetland

Figure 15. Prairie Hills Constructed Wetland - August 2007

3.2.9 Riverside Mobile Home Park

The Riverside Mobile Home Park, which contains 12 residences, is located in the village of Tesuque. Total discharge is less than 2,000 gpd. The constructed wetland, in operation since 1993, was designed and is maintained by Natural Systems International. The system is made up of three septic tanks followed by two parallel subsurface wetland cells and an infiltration basin (Figure 16). The system typically meets its permit requirement of TN less than 20 mg/l as long as there is not significant build-up in the septic tanks. However, the effluent TN for the sample collected for this study was well above permit levels at 31.9 mg/l. At the time of the site visit there were signs of previous wastewater surfacing in one of the wetland cells (photo). Considerable controversy between the Tesuque Pueblo, NMED, and Environmental Protection Agency (EPA) has taken place in recent years with the Pueblo asserting that the mobile home park is located on Pueblo land which would negate the need for permitting through the NMED. NMED and the owner of the park believe otherwise. The discharge permit was renewed in 2005 although the debate about land ownership continues.

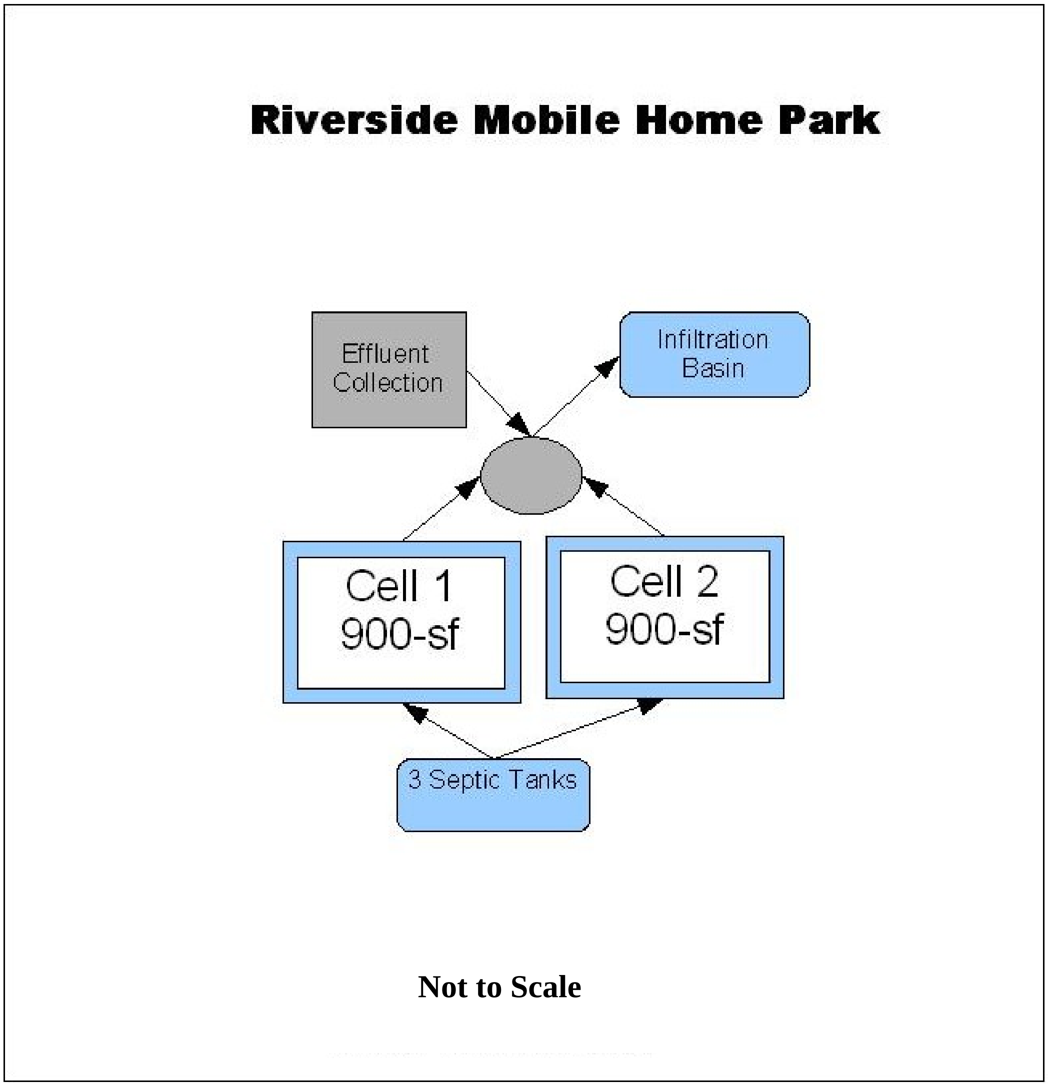

Figure 16. Riverside Mobile-home Park Constructed Wetland

Figure 17. Riverside Mobile Home Park Constructed Wetland - April 2007

3.2.10 Tablazon Subdivision

The Tablazon Subdivision is located approximately 15 miles east of Albuquerque. The subdivision contains 28 private homes with an average total discharge of 6900 gpd. The system is made up of septic tanks at each residence which flow into a 10,000 gal septic tank near the wetland. Effluent from the septic tank flows to a Bio-microbics FAST 9.0 tank then to a splitter which distributes flow equally to four subsurface-flow wetland cells.

The discharge permit for the subdivision requires quarterly monitoring of the wetland effluent as well as a groundwater from a monitoring well near the wetland. When the effluent exceeds the permit requirements a follow-up sample must be collected within one month and two samples within compliance must be acquired before the quarterly sampling can be removed. Therefore, due to frequent permit exceedances the subdivision collects samples monthly rather than quarterly as required in the discharge permit. Additionally, in 2005, Tablazon subdivision requested a NMED evaluation of the system. The evaluation resulted in several recommendations including: removal of a bio-filter on the effluent side of the septic tank which had been causing clogging, removal of the plants within the cells, and flushing the chlorides and TDS from the cells. All of the recommendations were carried out and the cells are now being flushed quarterly. Furthermore, a heater has been added to the FAST system which had previously performed poorly in the winter months.

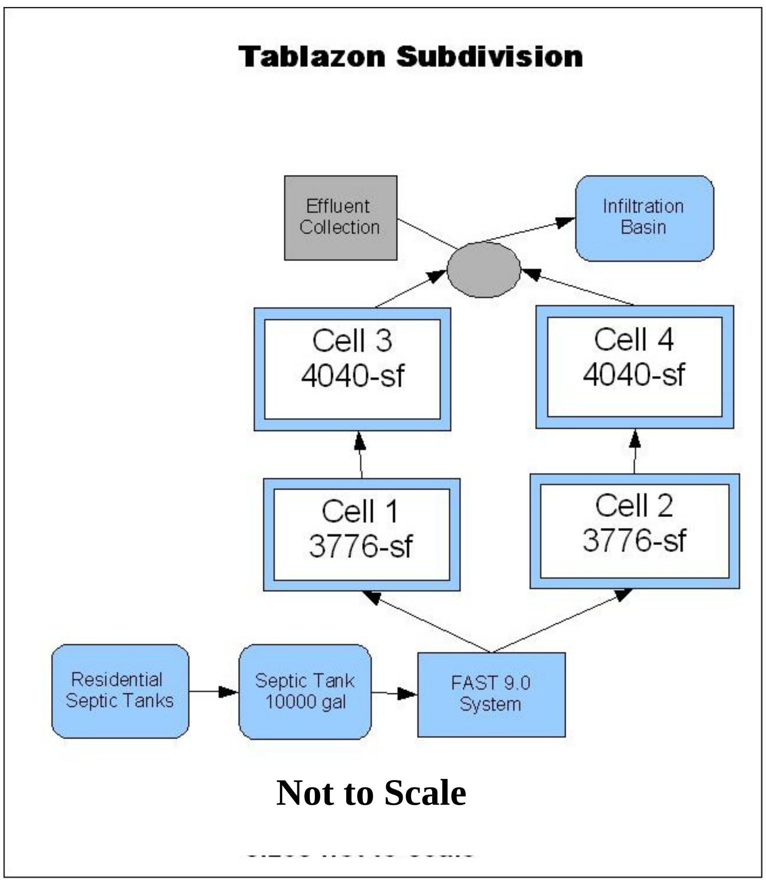

Figure 18. Tablazon Subdivision Constructed Wetland

3.2.11 Woodlands Subdivision

The Woodlands subdivision with 56 single-family lots is located approximately 15 miles east of Albuquerque, north of I-40. Not all lots have been developed. The treatment system, permitted to treat up to 31,800 gallons of wastewater per day, is made up of a 15,000 gallon septic tank, two trickling filters, two 10,000 gallon anoxic tanks and one subsurface wetland cell with another available for future use (Figure 19 and Figure 20). Recirculation occurs between the trickling filters and tanks. Effluent flows to the wetland cell when a specified level is reached in the trickling filters. The system was designed by Southwest Wetlands Group with monitoring and maintenance performed by staff from the Entranosa Water utility. The system has consistently functioned well with a good nitrogen reduction occurring within the trickling filters and denitrification tanks.

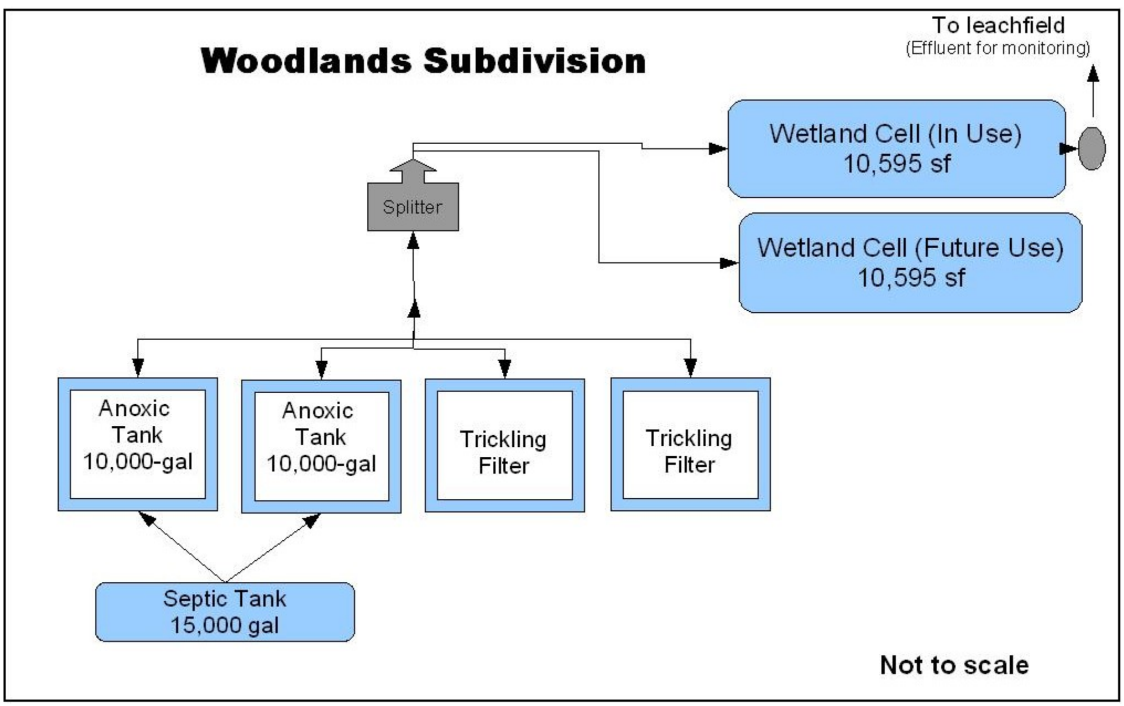

Figure 19. Woodlands Subdivision Constructed Wetland

Figure 20. Woodlands Constructed Wetland - August 2007

3.3 Evaluation Criteria

The evaluation of system performance was based upon the consistent ability to meet NMED permit requirements as well as the amount of maintenance and system modifications needed during the lifetime of the systems. Commonly systems are able to meet permit requirements for TDS and Cl, but are not able to meet the 20 mg/l TN effluent limit. Several attributes may indicate that a system is not operating properly. These include surfacing wastewater in subsurface-flow systems, spotty or absent vegetation, and lack of effluent.

3.4 Permitting and Monitoring

All systems in this study are permitted through by NMED Groundwater Quality Bureau. Frequently, initial requirements were semi-annual monitoring and reporting of Total Nitrogen (TKN + NO3-N) and total monthly discharge to and from the treatment system. Most of the systems have been through several permit renewals and changes. Current requirements for each system are listed in Table 5.

Table 5. NMED permit monitoring requirements

Site	Frequency	Contaminants	Monitoring Wells	Additional Requirements
Corrales Elementary	Quarterly	TN, TDS, Cl	7	
El Dorado Elementary	Semi-annual	TN, TDS, Cl	0	
Pueblo Encantado	Semi-annual	TN	0	
Ghost Ranch Conference Center	Quarterly	TN, TDS, Cl	2	
Santa Fe Opera	5x per year	TN, TDS, Cl	0	Amount used for irrigation
Paa Ko Subdivision	Monthly	TN, TDS, Cl	4	Amount used for irrigation
Los Padillas Elementary	Quarterly	TN, TDS, Cl	4	
Prairie Hills Subdivision	Quarterly	TN, TDS, Cl	2	
Riverside Mobile Home Park	Quarterly	TN, TDS, Cl	1	
Tablazon Subdivision	Monthly	TN, TDS, Cl	1	
Woodlands Subdivision	Semi-annual	TN, TDS, Cl	0	

The NMED discharge and groundwater contaminant limits are identical for all systems in this study. Total nitrogen must be below 20 mg/l in effluent and 10 mg/l in ground water. Total dissolved solids and chloride are also monitored but effluent limits are not usually set. If TDS and Cl levels are above 1000 mg/l and 250 mg/l, respectively, corrective action may be required. Robert George (2007) at the NMED states that "enforcement of TDS and Cl levels is often less aggressive as treatment processes that can remove them are generally expensive and impractical".

Four of the 10 systems currently do not perform or report ground water monitoring as they do not have a monitoring well. An additional requirement for all systems is semi-annual inspection of septic tanks for scum and solids build-up. Monitoring requirements vary from state to state as does the agency charged with permitting constructed wetland systems and not all states require monitoring of nitrogen levels. As nitrogen removal requirements are the most difficult to achieve, constructed wetland systems in other states may appear to have greater success than those in New Mexico. For example, the Colorado OEMC inventory reported 75 percent of the 20 systems in the study met permit requirements. However, the requirements did not include monitoring nitrogen concentrations.

Discharge permits must be renewed through the NMED every five years at which time the frequency of monitoring as well as the contaminants monitored may be changed, particularly if the system has frequently been out of compliance. As previously mentioned, when the permit levels are exceeded the site must collect a follow-up sample with-in 15 days. Thereafter, monthly samples must be collected until three consecutive samples are within the permit limitations, at which time the regular sampling schedule may be resumed.

3.5 Site Visits

Each constructed wetland system identified in

Table 4 was visited during the course of this study. Influent and effluent samples were collected from five of the sites to assess their performance. Note that several of the systems are required to submit quarterly or monthly water quality testing results. The monitoring data provides sufficient information to evaluate the systems' performance, hence the NMED was not interested in receiving extra sampling data so a site visit was made but samples were not collected. Twice, at Pueblo Encantado and El Dorado elementary school, a sample was needed but could not be collected due to lack of flow. Site visits were made during the months of March and April at which time all systems were operating.

The samples collected for this study were analyzed by the Scientific Laboratory Division of the New Mexico State Health Department. Influent and effluent samples were collected. The influent sample was collected downstream from the septic tank and any other pretreatment such as a trickling filter, but prior to the wetland cells. The effluent sample was collected from the location utilized by the site manager for all previous monitoring. Samples from this study were analyzed for TSS, TKN, NO3-N, BOD, and Chloride. In addition to sample collection, observations were made during each site visit, including vegetation presence and any surfacing wastewater within the wetland cells.

4.0 Results and Discussion

4.1 Operation dates

The average time in operation for the 11 sites was 13.3 years (

Table 4). The longest running system, at 17 years in operation, is located at El Dorado Elementary School. The discharge permit, currently under review, is expected to be renewed with several additional requirements. The newest of the systems are Corrales Elementary, Prairie Hills Subdivision and Woodlands Subdivision, built in 1996. Shortly after, the NMED stopped granting discharge permits for constructed wetlands based on the poor results received from such systems. Three of the systems, Paa Ko, Los Padillas and Santa Fe Opera will shut down their wetlands by the end of 2007 and utilize alternative treatment options.

Table 6. Site operation dates, permit compliance, and average flow

Site	Permit Compliance	Years in Operation	Average Flow	Comments
Corrales Elementary	Always	11 Yrs	6086 gpd	Previously reported results are in compliance. Results for this study were not.
El Dorado Elementary	Usually	17 Yrs	2017 gpd *	Commonly no effluent- no monitoring sample collected
Pueblo Encantado	Never	14 Yrs	2391 gpd	Commonly no effluent- no monitoring sample collected
Ghost Ranch Conference Center	Always	15 Yrs	8654 gpd winter 16,056 gpd summer	
Santa Fe Opera	Never	13 Yrs Switching to MBR 7/2007	12,000 gpd summer	No flow in winter
Paa Ko Subdivision	Never	13 Yrs Switching to MBR 10/2007	37,552 gpd	Out of compliance since 1997
Los Padillas Elementary	Never	14 Yrs Switching to city vacuum system	1359 gpd *	
Prairie Hills Subdivision	Usually	11 Yrs	5500 gpd	Commonly in compliance-varies with electrical problems
Riverside Mobile Home Park	Usually	14 Yrs	1189 gpd	Previously reported results are in compliance. Results for this study were not.
Tablazon Subdivision	Usually	13 Yrs	6895 gpd	Poorer results in winter when FAST performance slows
Woodlands Subdivision	Always	11 Yrs	4,000 gpd	

4.2 Site performance

Three of the 11 sites, Woodlands Subdivision, Ghost Ranch, and Corrales Elementary consistently meet the NMED discharge permit requirements. Four of the systems, Prairie Hills, Riverside, El Dorado, and Tablazon are occasionally out of compliance, and four others, Paa Ko, Los Padillas, Santa Fe Opera, and Pueblo Encantado, consistently do not meet the permit requirements (Table 4). Results of sampling conducted during this project are presented in table 7. Most sites are not required by their permits to monitor influent. Therefore, while it is possible to obtain the fractional reduction in TN and BOD for the samples collected for this study, it is not possible for those sites where only results from previously collected samples were utilized.

The Prairie Hills system showed the greatest TN reduction and lowest TN effluent for those systems sampled during this study. The effluent sample at Prairie Hills was collected from the splitter which operates on a recycle system, receiving effluent from the wetland cell and nitrified effluent from the biotower and sending effluent to the biotower or the leachfield.

Boivin (1995) found that BOD, TDS and TN removal efficiencies at the 18 subsurface-flow wetlands decreased as the hydraulic loading rates (HLR) increased. Furthermore, under the assumption that depth and void space in the media did not vary between systems, it could be assumed that hydraulic residence time (HRT) would directly correspond to HLR. Thus, removal efficiencies would decrease with lower residence times (Boivin 1995). Huang et al. (2000) also found that constructed wetlands treating residential wastewater were able to achieve increased removal levels of TKN and NH4 if residence times were increased. This study did not support the findings of Boivin (1995) and Huang et al. (2000). As seen in Table 7, lower hydraulic loading rates do not always correlate with increased contaminant removal. For example, the El Dorado and Los Padillas systems have the lowest HLRs at 1.10 cm/day, but Los Padillas demonstrated a TN removal of 9.6 percent and both systems frequently produce effluent greater than 20 mg/l. Additionally, Prairie Hills with the highest TN removal rate also has one of the highest hydraulic loading rates at 2.69 cm/day. Furthermore, Riverside Mobile Home Park operates with a hydraulic loading rate identical to the Prairie Hills system, but the TN removal rate was only 21.8 percent. These results confirm that other factors, such as additional treatment components, are more important to total nitrogen removal than HLR.

Site	Date	Effluent TN (TKN + NO3-N)	Percent TN Reduction	Percent BOD reduction	HLR (cm/day)
Corrales	4/10/07*	7.7	89.3	Not Known[1]	1.63
Corrales	4/10/07**	35.2	67.7	93.9	1.63
El Dorado	11/21/06	42	Not Known[1]	Not Known[1]	1.10
Pueblo Encantado	Avg (11/06, 12/06, 1/07)	23.1	Not Known[1]	Not Known[1]	1.51
Ghost Ranch	1/10/07	15.7	Not Known[1]	Not Known[1]	1.63
Santa Fe Opera	9/1/06	41.6	Not Known[1]	Not Known[1]	1.80
Paa Ko	Avg (2/06-1/07)	34.3	Not Known[1]	Not Known[1]	3.67
Los Padillas	3/1/07	56.5	9.6	72.6	1.10
Prairie Hills	4/9/07	3.9	90.2	29.6	2.69
Riverside	4/9/07	31.9	21.8	85.3	2.69
Tablazon	Avg (10/06, 11/06, 12/06)	13.8	Not Known[1]	Unknown	1.79
Woodlands	4/9/07	7.8	40.8	95.8	1.55

[1]Nitrogen reduction cannot be calculated from these sites because influent N data is not available

Table 7. Effluent monitoring results. * Sample collected by APS and analyzed by a private lab. ** Sample collected alongside APS employee and analyzed by NM state lab.

4.2.1 Systems performing well

The most successful system in this study is Woodlands Subdivision. The system provides nitrification and denitrification prior to discharge to the wetlands through use of trickling filters and anoxic basins. Furthermore, harvesting of vegetation, has been performed routinely since the system went online. Consequently, the system has consistently produced treated effluent with TN concentrations less than 20 mg/l and there has not been a need to utilize the additional wetland cell. The influent sample collected for this study was taken prior to the wetland cell, but following the nitrification and denitrification tanks. The influent sample had a TN of 13.2 mg/l while the wetland effluent sample had a TN of 7.82. TKN decreased following the cell whereas Nitrate increased resulting in a TN removal of 41 percent. The results demonstrate the importance of the primary treatment components and indicate that the wetland cell is not necessary to meet state discharge standards.

The Corrales Elementary School commonly meets the discharge permit requirements and is appreciated by the community. During this study, influent and effluent samples were taken at Corrales Elementary alongside an Albuquerque Public Schools employee. The results were inconsistent with the results obtained from the samples collected for this study which were analyzed at the NM State Scientific Laboratory. The results for this study showed an effluent TN of 35.1 mg/l and a removal of 68 percent. The samples taken by the APS employee were analyzed at a private laboratory and the effluent TN was 6.5 with a removal of 91 percent. The system does not have any pretreatment, thus the high removal and low TN levels obtained by APS are unexpected.

The Ghost Ranch system is the only surface-flow constructed wetland in this study and has never failed to meet the permit requirements. Willie Picaro (2007), head of maintenance at the resort, reports that the benches, located adjacent to the marsh type wetland cells, are frequently utilized by guests who enjoy the birds attracted to the system.

One system, Prairie Hills, reported variable compliance throughout 2006 and 2007 while experiencing problems with its electrical system which powers the pumps which provide recycle of wastewater between the wetland cell effluent and the biotower. When the electrical system is operating properly, permit requirements are consistently met. The system is unique as it contains a nitrifying component that receives effluent from and recycles to the wetland cells. During this study, the sample results obtained at Prairie Hills indicated a mislabeling of the samples as influent TN results were much lower than those for the effluent. Assuming a mislabel of the samples, results for that time period show a 91 percent removal of TN, a level much higher than those normally seen in these systems.

4.2.2 Systems performing poorly

One of the most significant failures is the Paa Ko Community system, which has consistently exceeded the permitted levels for effluent with an average TN of 34.3 mg/L during 2006. The Paa Ko community has been forced to spend a great deal of money making additions and changes to the system over the years, bringing the total amount spent on construction, additions and repairs to around $800,000, often with no significant improvement in performance. For example, the PaaKo system added two additional

13,860-sf wetland cells in 1997, just 2 years after it went online, at which time the effluent levels began to be consistently out of NMED compliance. The early failure of the system indicates a design failure rather than a problem resulting from improper operation, such as clogging. The hydraulic loading rate of the system is significantly higher than other systems in the study. Furthermore, a trickling filter was installed in 2000, but was placed after the wetland cells. The trickling filter may have increased the system performance, had it been placed prior to the cells, by providing nitrification and removal of organics (Arnold 2007).

Los Padillas Elementary School reported eight TN exceedances over a three year period. Results from this study showed an effluent TN of 56.5 mg/l and a nine percent removal rate. During installation, the depth of the cells was increased from 24 inches to 42 inches. The US EPA (1993) found that nitrogen removal increased significantly in subsurface-flow cells where the roots extended throughout the entire media. Furthermore, the roots frequently did not penetrate to the bottom of the bed in 24-inch deep subsurface-flow cells. Accordingly, it is likely that the roots are unlikely to penetrate to the bottom of the 42-inch deep bed at Los Padillas. Therefore, nitrogen removal is limited by predominantly anaerobic environment in the cells.

Several other systems in the study, Santa Fe Opera, Tablazon, Pueblo Encantado, and El Dorado have also experienced extended periods of time during which they were unable to meet their permit requirements.

4.3. Concerns

Several concerns came about during the collection of the monitoring data for this study. First, the laboratory results obtained for the samples collected at Corrales

Elementary School by APS staff were not consistent with those obtained for this study. The samples were collected from the same location, at the same time and using identical collection techniques, but were analyzed at different labs. The total nitrogen levels reported for the samples collected for this study were approximately double those reported by APS staff.

Next, inconsistent results were obtained for samples collected at Prairie Hills during the month of April. Entranosa Water Utility staff collected samples twice during the month of April, shortly after the sample collection for this study. The first sample results showed a TKN of 34.4 mg/l. The second sample, taken a week later, was sent to three separate private labs. One lab reported a TKN of 24.4 while another reported 42.3 mg/l. The discrepancies among these results bring in to question the reliability of the results obtained from the multiple laboratories in the Albuquerque area.

5.0 Conclusions and Recommendations

Constructed wetlands are engineered systems which utilize natural wetland processes to remove contaminants such as BOD and nitrogen from wastewater. This study examined 11 constructed wetlands in New Mexico which have been in operation for 11 to 17 years. One of the systems was a surface-flow constructed wetland while the others were subsurface-flow. Surface-flow constructed wetlands, such as the Ghost Ranch system, are often able to effectively remove nitrogen as they incorporate both aerobic and anaerobic zones. However, eight of the 10 subsurface-flow systems in this study occasionally or always failed to meet NMED permit requirements due to their inability to remove nitrogen to state groundwater standards. Increasing cell depth in order to increase retention time was not effective. In fact, aerobic zones may become more limited and performance may decrease as the roots of vegetation are unable to reach beyond 18 to 24 inches (US EPA 1993). Nitrogen removal is likely limited by the lack of sufficient aerobic zones necessary for the oxidation of ammonia to nitrate which is necessary to achieve denitrification. In response to the poor performance of many of the constructed wetlands in New Mexico the NMED would require significant modifications to any new system before a discharge permit would be issued. Performance may be improved by incorporating aerobic zones through a nitrification tank within the system or aeration within the cells.

5.1 Recommendations

The systems in this study were designed and built between 1990 and 1996. At that time, designers and the US EPA asserted that constructed wetlands were effectively treating contaminants such as BOD and TDS and could be expected to remove nitrogen to desired levels as well (US EPA 1993). Documents utilized in the design of constructed wetlands assert that the size should be based on the removal rates for the contaminant of concern. Accordingly, retention times and size will be based on the treatability of that contaminant (ITRC 2003). In many states, the contaminant of concern is BOD and system design has been based on established BOD removal rates. The designs for the systems in New Mexico were also based on BOD removal rates. However, in New Mexico, nitrogen is a contaminant of concern as well and designs did not take into account the factors required to remove nitrogen at acceptable levels. It is now widely acknowledged that additional treatment components or techniques which contribute to the nitrification-denitrification cycle are needed for subsurface-flow constructed wetlands to remove nitrogen to the levels required (US EPA 2000).

Multiple options exist which may incorporate additional oxygen into systems. The options for existing systems are more limited than for new systems. The most effective option for existing systems is the addition of an aerobic tank that will contribute nitrified wastewater to the wetland cells. The possibilities for new systems are more extensive. Recently, engineers have been experimenting with different design strategies which seem to be significantly more effective than those laid out by the US EPA during the 1990s (TVA 2007, Zaytsev et al. 2007). For example, the Tennessee Valley Authority (2007) advocates the draining and filling of two or more subsurface-flow wetland cells and determines surface area of the cells based on hydraulic loading. The technique may be able to achieve higher rates of nitrification and denitrification as a biofilm is formed on the media which is exposed to aerobic and anaerobic conditions during the drain and fill cycles.

This study has shown that constructed wetland cells alone are often not able to adequately treat wastewater to New Mexico state groundwater standards. The systems with some level of additional treatment, such as Woodlands, Prairie Hills, and Ghost Ranch, produce significantly better treatment rates than those without. Thus, systems should have some level of additional wastewater treatment prior to entering the cells, such as a lagoon, as in the majority of the systems in the Colorado OEMC study, or a nitrification tank and/or trickling filter as in the Woodlands and Prairie Hills systems.

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