TREES ARE THE SOLUTION TO WASTEWATER TREATMENT FOR SMALL COMMUNITIES

JOHN G. MEXAL, WALTER H. ZACHRITZ, AND T.W. SAMMIS

John G. Mexal is Professor, Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, New Mexico 88003 USA; (505) 646-3335. Walter H. Zachritz is Executive Director of the Center for Arid Lands Environmental Management (CALEM), Desert Research Institute, Las Vegas, Nevada 89119 USA. T. W. Sammis is Professor, Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, New Mexico 88003 USA.

jmexal@nmsu.edu

Mexal, J. G., Zachritz, W.H., Sammis, T. W. 2002. Trees Are the Solution To Wastewater Treatment for Small Communities. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations-1999, 2000, and 2001. Proceedings RMRSP-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 327-335. Available at: http://www.fcnanet.org/proceedings/2001/mexal.pdf

Abstract

The application of municipal wastewater to land for treatment and disposal, or "land farms," was one of the earliest forms of wastewater treatment technology. There has been renewed interest in using these systems in arid regions worldwide to supplement and reuse dwindling water resources. However, arid regions present complex challenges to the use of land application systems. Many arid regions (for example, Egypt and US/Mexico border) are located in areas that lack infrastructure support and cannot afford expensive treatment technologies. A slow-rate, land application system offers a low-cost treatment for these regions that can be integrated with advanced, integrated ponds, facultative lagoons or other inexpensive primary and secondary treatment technologies. Properly designed land application units provide environmentally safe wastewater treatment by removing pathogens, nutrients, and suspended solids. Additionally, the wastewater can be reused to create value-added benefits such as wetlands; bosques; trees crops for fuelwood, pulpwood, or lumber; and restoration of desert ecosystems. Critical to the design is the selection of tree species adapted to an arid environment, balancing seasonal plant water requirements with plant uptake of nitrogen and the nitrogen and salt loading from the wastewater. These factors must be carefully considered to assure system sustainability and minimize impacts to groundwater. Cases in Ojinaga, Chihuahua, Mexico; Las Cruces, New Mexico USA; and Ismailia Egypt will be discussed.

Key Words

Short rotation woody crops, wastewater reuse, land application, agroforestry, restoration

Land application of wastewater is perhaps the oldest method for disposal and treatment of wastewaters. Early systems in England that received untreated wastewater were poorly understood and easily overloaded. Most of these systems were abandoned and replaced by other technologies such as trickling filters. In many areas of the world, wastewater reuse has been practiced using a combination of treatment technologies that achieve a high degree of treatment. Over the past twenty years, states in the western US have treated wastewater to tertiary treatment standards and then allowed the wastewater to be reused for irrigation or for recharge to groundwater aquifers. While this is an effective method of treatment and reuse, it is expensive and is rarely practiced in other regions of the world. Land application systems that utilize the land as a treatment unit and not just as a disposal area are gaining acceptance in many arid regions, because these systems are less expensive to construct and can be operated by personnel familiar with common irrigation systems.

With these systems, primary or secondary treated wastewater is applied to the land surface via furrow flood, micro-sprayer, or drip irrigation. Biological oxygen demand (BOD), total suspended solids (TSS), and fecal coliforms (FC) are partially removed in the primary or secondary treatment steps. The land application unit removes additional BOD, TSS, and FC as well as nitrogen and phosphorus. The soil and plants act as filters that trap and treat, through various mechanisms, contaminants in the wastewater and allow the remaining wastewater (effluent) to drain through the soil profile (Watanabe 1997). The wastewater provides an effective source of nutrients that the tree roots assimilate. The net effect is a beneficial system allowing for both the effective remediation of wastes and the recycling of water, nutrients, and carbon via biomass production (Kerr and Sopper 1982; Bastian 1986). Not only is the waste problem managed, but also there is a potential for creating value-added products for economic development within the community from the resultant biomass. Several options including fiber farm plantations, bosque restoration, parks, and Christmas tree plantations have been proposed.

The basic approach to the design of land application systems is based on balancing the input of water and nitrogen (Figure 1) as outlined by Metcalf and Eddy Inc (1990) and WCPF (1989). The yearly wastewater application rate is based on the amount of total nitrogen (TN) allowed to enter the groundwater. Typically this is given in terms of the concentration of NO3 -N in the wastewater reaching the ground water which can not exceed the drinking water standard of 10 mg NO3 -N /L. The nitrogen uptake by the crop is related to evapotranspiration and crop yield using the evapotranspiration production function. The water balance for this system with a selected tree species can be determined from locally derived data to determine the area required for the land application system. More importantly this information must incorporate plant nitrogen uptake rates and water use rates or crop coefficients to allow for proper balancing and ultimate system sizing. Finally, salt loading on the soil and its impact on tree survival and growth must also be considered. Many plants are less tolerant to salt during the establishment stage than in later stages, so alternative sources of water maybe required. Salt loading guidelines are provided in several resources such as WPCF (1990) and FAO (1992). Unfortunately, current design models do not take into account salt loading and interactions with soil EC. Systems we have dealt with have had salinities as high as 3,500 mg/L.

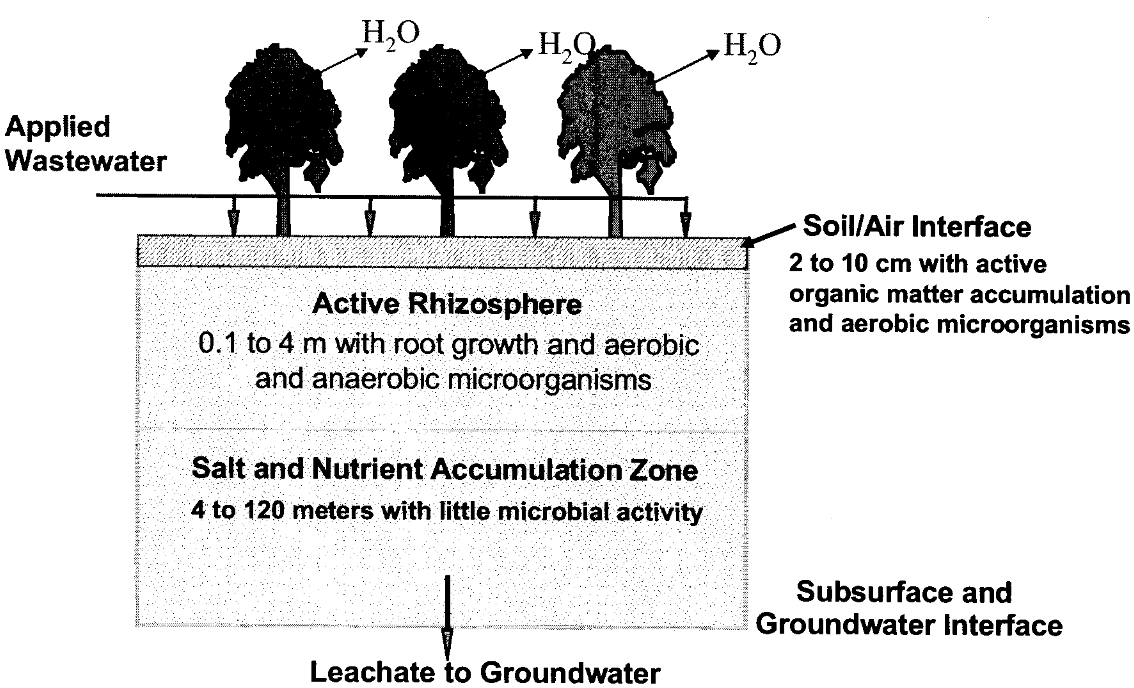

Figure 1. Mass flow schematic of the land application system for treating and reusing wastewater.

In the following sections, we provide summary information about three land application systems we have been involved with in arid regions.

OJINAGA, CHIHUAHUA, MEXICO

Ojinaga is located in the state of Chihuahua, Mexico, and situated at the confluence of the Rio Grande (Rio Bravo) and Rio Conchos on the U.S.-Mexico border. The climate is arid, with an annual rainfall of less than 250mm, and temperatures ranging from -10°C to 50°C. The combined population of Ojinaga with its sister city, Presidio, Texas, is approximately 27,000 inhabitants. Ojinaga is demographically typical of smaller and intermediate-sized border communities. However, the population of Ojinaga has dropped from about 26,000 in 1980 to 23,600 people in 1995 because of emigration (USEPA 1996). Ojinaga is an agricultural community with 12,000 ha of irrigable farmland, but less than one-half of this land is currently producing crops such as alfalfa, corn, wheat, cotton, melons, onions, and pecans. One of the primary reasons that the land remains unfarmed is the landholdings average only five hectares each, making them too small to provide a sole source of income (Nuiiez 1997). Consequently, many landowners have abandoned the land for employment in *maquiladoras* (twin plants) or in the US. Further, salty irrigation water has created unsuitable conditions for the production of many agronomic crops on some fields (Mexal 1997). Historically, the municipal sewage has been piped directly into an anaerobic lagoon, which acts as a settling pond for separating the solids from the waste stream and providing some reduction in waste strength. The 1.5 ha (45,000 m^3) unlined treatment lagoon, which had served the Ojinaga community for over 30 years, was taken off-line in 1994 because it had filled with settled solids. A new 2 ha (60,000 m^3) anaerobic lagoon was constructed and put online in 1995, but it is expected to fill with collected solids within a few years. The existing wastewater treatment system is a single cell anaerobic lagoon receiving primarily municipal wastewater. Industries in the area, including bicycle assembly, slaughterhouse, and several cottage industries, appear to contribute little in the way of metals or toxic organics, but do contribute to hydraulic and organic loading of the wastewater. The slaughterhouse wastewater is intermittent, but high strength. The single-stage anaerobic lagoon is designed to remove biological oxygen demand (BOD), total suspended solids (TSS), and fecal coliform (FC) to some degree (Table 1). Wastewater from this system currently flows to pasture land and directly into the Rio Grande, resulting in serious FC contamination of the river (Figure 2). The FC contamination presents a serious health hazard to down stream users on both sides of the border, including recreation users in the Big Bend National Park. In the future, the waste stream would flow to the land application unit for final treatment and disposal.

Table 1. System and wastewater characteristics of the three land application processes.

Parameter/Site	Ojinaga, Mexico	Las Cruces, USA	Ismailia, Egypt
Treatment Train	Screens/Primary-Anaerobic Lagoon	Screens/Primary-Aerated Lagoon	Screens/Grit/Primary-Aerated /Facultative Lagoon
Disinfection	No	No	No
Effluent BOD, mg/L	29-43	30	46
Effluent TSS, mg/L	15	30	23
Effluent TN, mg/L	14-37	45	45
Effluent TDS, mg/L	1,950-2,220	2,000-3,000	550
Flow, m^3/day	6,048	1,514	90,000
Land Application Area, ha	500	32	200-2000
Rainfall, mm/year	280	216	<2
PET, mm/year	2,450	2,220	2,341
Selected Crop(s)	Eucalyptus/ Hybrid Poplar	Creosote Bush, FourWing Saltbush, Mesquite	Italian Cypress, Stone Pine, African mahogany
Products	Wood Pulp	Habitat Creation	Wood Products and Fuel wood

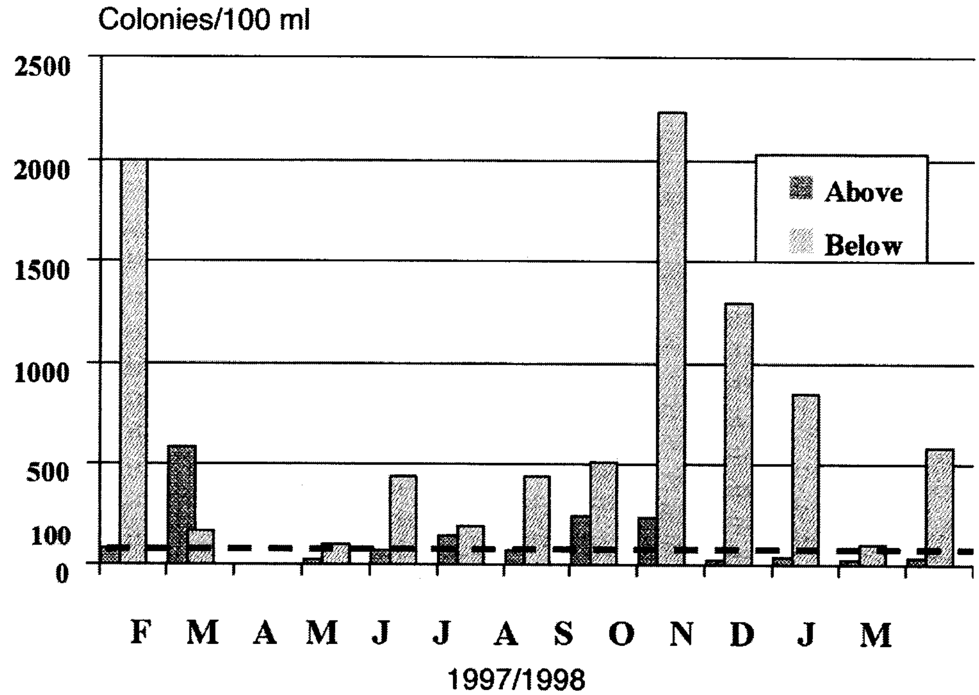

Figure 2. Fecal coliform contamination of the Rio Grande (# colonies/ 100 mL river water) above and below the discharge point of the primary treatment lagoon for the community of Ojinaga, Chihuahua, Mexico.

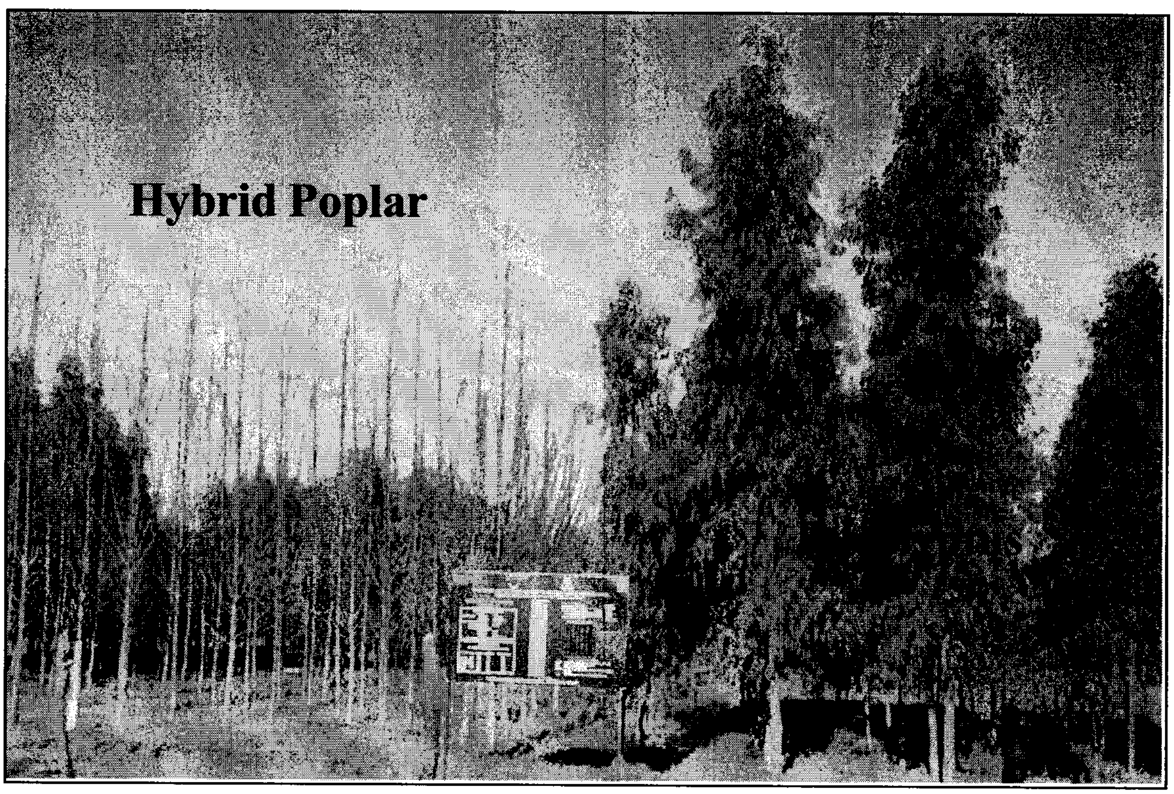

Figure 3. Three-year-old eucalyptus and hybrid poplar plantation under flood irrigation with treated wastewater in Ojinaga, Mexico.

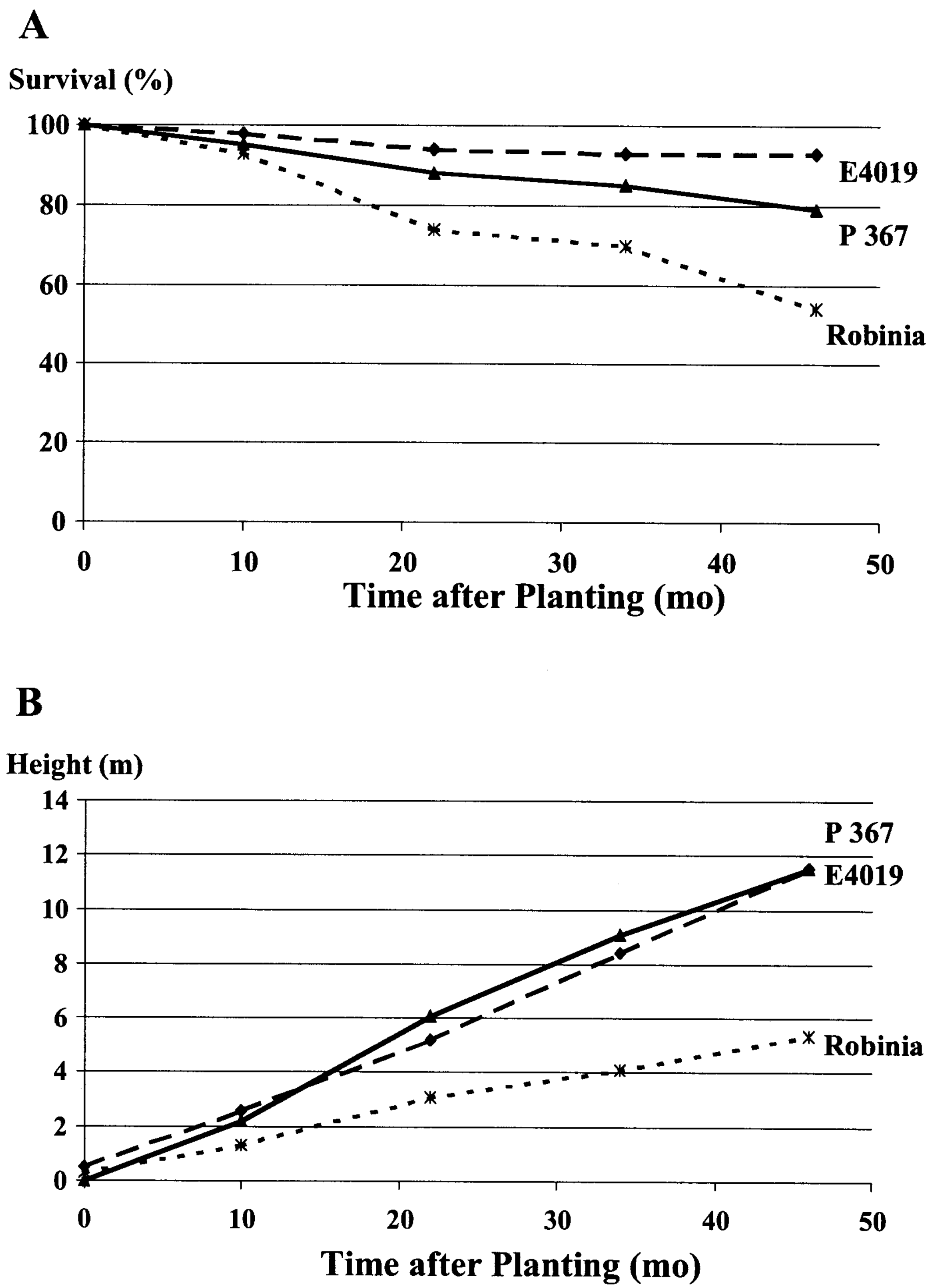

Figure 4. A) Survival (%) and B) height growth (m) of eucalyptus (clone E4019), hybrid poplar (clone P367), and Robinia pseudoacacia *after four growing seasons in Ojinaga, Mexico.*

A pilot land application site (- 1.1 ha total area) was established in April 1997. *Eucalyptus* and *Robinia* seedlings, and *Populus* cuttings were transplanted at a 2m x 2m spacing (Figure 3). All of the plots were manually flood irrigated with water from an oxbow lake during the first growing season. The plots were flood irrigated with wastewater effluent and monitored for three additional years. Monitoring included wastewater effluent and groundwater quality characteristics, soils, and plant growth. Local PET and rainfall data was used to schedule irrigation rates.

After four years, there was minimal impact to groundwater with no increases in fecal coliform or nitrate and about a 10 percent increase in groundwater salinity. Tree growth results indicated that the optimal tree species were *Eucalyptus* and the 367 hybrid popular clones (Figure 4). The best clones survived well (>75% survival) and were over 11 m tall after four growing seasons. The growth rates achieved for these clones exceed expectations and may allow harvesting on a five-year rotation. This is one to four-years faster than other studies of similar species and will improve the overall economic impact of the process.

A full-scale system for the community could support a land application system of about 100 ha, and the capital costs for this system could be 30% less than conventional treatment systems while producing a highly saleable byproduct of wood chips for pulp. This endeavor could produce community-based jobs and have a positive cash flow for the operation and maintenance. Ojinaga has been involved in a master plan development process for the past three years for the development of a new treatment plant.

LAS CRUCES, NEW MEXICO USA

The City of Las Cruces West Mesa Industrial Park has a stand-alone, centralized wastewater treatment plant. The industrial park was started in 1982, but the waste treatment facility was not completed until the summer of 2000. The goal of the system is to provide effective wastewater collection and treatment that will encourage the expansion of the Park, and also minimize the environmental impact of the Park on its surroundings by eliminating individual systems operated by Park tenants.

Aerated lagoons were selected as the best treatment technology because they are reliable with low capital and operations costs. The City of Las Cruces Pretreatment Ordinance requires industrial and commercial wastes be treated to reduce BOD to 250 mg/l and TSS to 200 mg/1. This pretreatment requirement also ensures that the facility will receive a fairly uniform influent quality. The proposed facility is expected to reduce these levels to produce an effluent quality of 30 mg/l BOD and 30 mg/1 TSS (Table 1). This lagoon system typically produces low volumes of sludge that could be applied to the land application site as a source of additional fertilizer and organic matter.

One lift station transports the pre-filtered, treated effluent to the land application site, which consists of 23 sprinkler zones, 1,600 sprinklers and 21,493 m of pipe covering 32 ha. Construction of the land application site used low impact methods to minimize disturbance to the native vegetation. The application of the effluent wastewater is operated on a rotational basis to allow infiltration of the wastewater and the nitrogen uptake by the native plants. The total capital costs for construction of the wastewater collection and treatment facilities was $2,700,000.

The goal of this system was to treat and dispose of wastewater in a cost-effective manner. A secondary benefit was the creation of improved desert habitat. Based on the water quality there was concern about accumulation of salts and the high concentration of nitrogen in the wastewater. Selecting native vegetation, primarily mesquite (*Prosopis* sp.) and creosote bush (*Larrea tridentata*) (Figure 5) allowed the system to accept high salt loadings while maintaining water application rates that would not have a negative impact on groundwater (75 m). Vegetation cover will be evaluated and soil will be monitored for the accumulation of salts beginning in 2002.

ISMAILIA, EGYPT

The Ismailia Serrabium Wastewater Treatment Plant was built by Egypt and US AID in 1995 and is operated by the Suez Canal Authority. Ismailia has a population of about 500,000 and is located 9.4 km from treatment plant. The treatment plant design capacity is 90,000 m^3/d and the current flow is 80-85,000 m3/d (Table 1). Wastewater flow is divided to two parallel treatment branches with three lagoons (aerated, facultative, and polishing lagoons) for each branch. The aerated lagoon has 20 aerators with 10 operating at any one time. The facultative lagoon also has 10 aerators that are used only as needed to increase dissolved oxygen. The polishing lagoon is 3.5 m deep to facilitate the removal of FC and *Ascaris* eggs. The total detention time of the system is 11 days, designed to reduce BOD, *TSS, Ascaris* eggs, and FC. *Ascaris* eggs and FC are considered the major health risk for using wastewater for reuse. The treatment plant does not have a disinfection unit nor does it provide tertiary treatment for nutrient removal. This treatment plant is a standard design for Egypt and several other similar systems are located in other areas of the country.

The land application facility is about 2 years old and uses a land area of about 200 ha with up to 2,000 ha available. The facility supports nursery and grow out operations. About 75 ha have been planted since July of 1998. Seedlings are planted on 3 m x 3 m spacing and drip irrigated with treated wastewater (Figure 6). The wastewater is filtered through an inline screen and then through several sand filters before it is delivered to the irrigation system. Ground water in the area is at about 8 m.

The nursery production capacity at Serrabium Forest is 100,000 trees per year. The trees are grown in polybags (12 x 15 cm), using a sand: clay: peat moss medium, and irrigated with wastewater. No additional fertilizer is applied during the nursery phase. Tree species produced are *P. pinea, P. halepensis, P. brutia* var. *eldarica, Khaya senegalensis, Cupressus sempervirens, Morus alba, Moms japonica,* and *Cassia* sp. The trees will be used for fuelwood, construction lumber, quality hardwood lumber, and silkworm production.

Figure 5. Landscape with mixed mesquite (Prosopis) *and creosote bush* (Larrea) *at the West Mesa Industrial Park land application site, Las Cruces, NM.*

Figure 6. Two-year-old Italian cypress plantation under drip irrigation with treated wastewater in Ismailia, Egypt

Initial observations illustrate the need to optimize this wastewater system. Individual trees are surrounded with 1 m wells for irrigation. Nevertheless, soil at the midpoint between trees ('-4.2 m from the trunk of each tree) was saturated just below the soil surface. There was no soil layering or caliche development but attenuation of root development occurred at a soil depth of about 40 cm, presumably from hypoxia. This indicates over application of wastewater to the tree plots with no consideration of actual PET requirements. There is a high risk of groundwater contamination with this rate of application and a concentration of 45 mg N/L in the wastewater and depth to groundwater of about 8 m. Egypt is planning to expand this model to at least a dozen other cities and without proper guidelines all these sites are at risk.

SUMMARY

These land application systems are in arid regions with low rainfall and high potential evapotranspiration. Thus, all water needs must be met by applied irrigation wastewater. This applied water must be balanced against the needs of the plant and salt and nitrogen loading to assure the development of a sustainable design. These conflicting interactions must be resolved through proper plant selection, site management, and irrigation scheduling. Proper safety precautions for personnel at these sites must be provided to minimize the risk of disease transmission. Finally the goals of the system in terms of the final product need to be incorporated into the process. Systems can be developed to produce revenue streams that can offset or some cases exceed operational costs. These systems can be publicly owned or private ventures, but infrastructure and community support must be developed well in advance and are essentially to the success of the project.

REFERENCES

Bastian, RK, and Ryan, JA. 1986. Design and management of successful land application systems, p.217-234. In Proceedings. Utilization, treatment, and disposal of waste on land. Soil Science Society of America, Madison, Wisconsin.

Flores, JC. 1994. Presidente, Junta Municipal de Agua y Saneamiento de Ojinaga. Personal Communication.

Foster, DH, and Engelbrecht, RS. 1973. Microbial hazards in disposing of wastewater on soil, p.247270. In WE Sopper and LT Kardos (Eds). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press: University Park, Pennsylvania.

Luecke, DF and De la Parra, C. 1994. From pollution to park. Experiment in Tijuana: a low-tech approach to wastewater management. California Coast & Ocean. 10 (1): 7-19.

Metcalf & Eddy, Inc. 1991. Wastewater engineering: Treatment, disposal, and reuse. McGraw Hill: New York, New York. 815 pp.

Mexal, JG. 1997. SCERP 1996 Quarterly progress report/Pilot study for an integrated waste treatment and disposal system along the US/Mexico border: Ojinaga community as a prototype. Unpublished.

Miller, RW, and Donahue, RL 1990. Soils: An introduction to soils and plant growth. 6th ed. Prentice-Hall, Inc.: Englewood Cliffs, New Jersey. 768 p.

Nunez, R. 1997. INIFAP agronomist. Personal communication, July, 1997.

Pescod, MB. 1992 Wastewater treatment and use in agriculture. Irrigation and Drainage Paper 47. The Food and Agriculture Organization of the United Nations.

Samani, ZA, and Pessarakli, M. 1986: Estimating potential crop evapotranspiration with minimum data in Arizona. Transactions ASAE 29(2):522524.

Stewart, HTL, Allender, E, Sandell, P and Kube, P. 1986. Irrigation of tree plantations with recycled water in Australia: Research developments and case studies, p. 431-441. In DW Cole, CL Henry, and WL Nutter (Eds). The forest alternative for treatment and utilization of municipal and industrial wastes. University of Washington Press: Seattle, Washington.

U.S. Environmental Protection Agency. 1996. US-Mexico Border XXI Program Framework Document. EPA 160-R-96003 and EPA 160-S-96-001. EPA: Washington, DC.

Watanabe, ME. 1997. Phytoremediation on the brink of commercialization. Environmental Science and Technology 31(4):182-186.

Water Pollution Control Federation (WPCF). 1990. Natural systems for wastewater treatment. Water Pollution Control Federation, Alexandria, Virginia. 270 p.