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Environmental assessment of Las Vegas Wash and Lake Mead artificial wetlands demonstration project

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ENVIRONMENTAL ASSESSMENT OF LAS VEGAS WASH AND LAKE MEAD ARTIFICIAL WETLANDS DEMONSTRATION PROJECT

Research Proposal

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PROPOSED RESEARCH

The effective use of artificial wetlands for treatment of municipal wastewater is well documented; however, design and economic data for artificial wetlands development are limited (Gersberg et al., 1984a). This is due partly to regional differences in climate, soils, and vegetation and partly to the desired waste treatment. As a result, specific treatment levels and cost benefits relative to the use of an artificial wetlands for a particular site cannot be evaluated adequately without a pilot demonstration project.

Las Vegas Wash (Figure 1) receives sewage effluent from the Las Vegas metropolitan area and has been designated as a wetlands community park. Las Vegas Wash is located in the Mojave Desert and a wetlands in this area is very unique. Unfortunately, the existing wetlands have been essentially lost due to erosion. Wetlands restoration is currently under consideration for both sewage treatment and erosion control. The effort proposed here is for a pilot wetlands demonstration for treatment of sewage effluent in Las Vegas Wash. Historically, substantial reductions in nutrient concentrations occurred in the Las Vegas Wash. These reductions were due to some combination of mechanisms associated with but not directly related to the historical wetlands as described in the "Historical Background" section

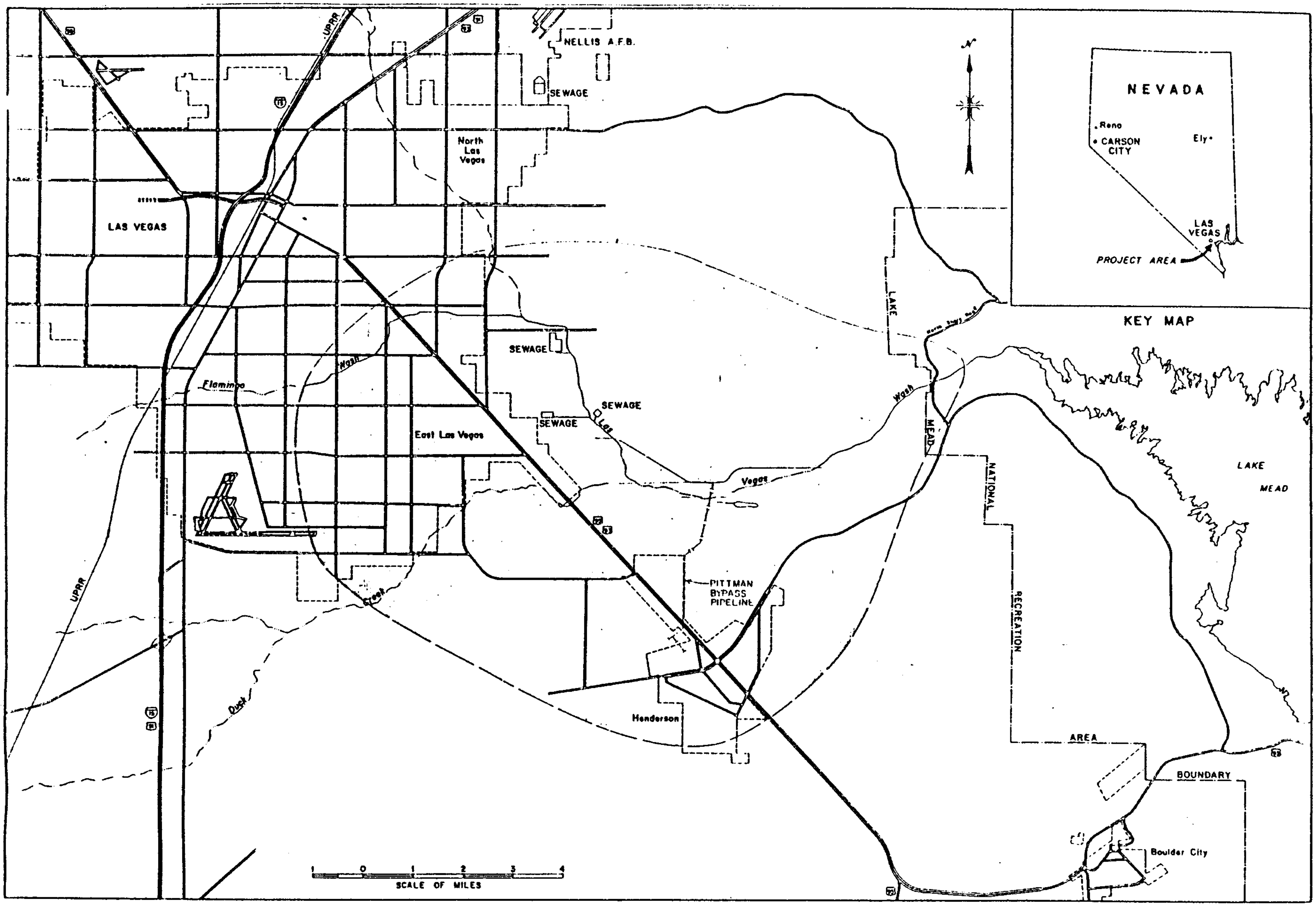

Figure 1. Las Vegas Wash and Surrounding Area (From USDI, 1982). The primary area discussed in this proposal is within the dashed line.

of this proposal. The proposed demonstration will be an artificial (managed) wetlands; and therefore, it will not functionally be representative of the historical wetlands in Las Vegas Wash.

Artificial wetlands have been shown to be very efficient in removing nutrients and other contaminants, but these systems have generally been small, treating less than 1 million gallons/day (MGD). Very limited data exist for artificial wetlands with large-scale effluent applications; however, a large artificial wetlands designed to treat up to 24.6 MGD (93,000 m^3/day) has resently been constructed in Florida as described in the "Wetlands Review" section of this proposal. This system and other systems that may be constructed should provide valuable information in designing and implementing future large-scale artificial wetlands for effluent treatment. The feasibility of developing a large-scale wetlands for effluent treatment in Las Vegas Wash will be partially based on results from the proposed demonstration and these newly developed large artificial wetland systems.

An artificial wetlands system to treat all of the Las Vegas effluent (80 MGD or 302,800 m^3/day) is probably not feasible. However, a 500 to 1000 acre (202 to 404 ha) wetlands treating 10 to 30 MGD (37,850 to 113,550 m^3/day) may be feasible if the proposed wetlands demonstration shows reasonable nutrient removal efficiency. The cost benefit in utilizing wetlands for treating partial flows (10 to 30 MGD) and for developing a wetlands park will have to be evaluated by the various controlling local agencies.

The wetlands demonstration project will address wetlands ammonia removal, consumptive water use, and salinity impacts. The proposed wetlands demonstration would have a total of 36 treatment plots (total area of ~ 12 acres or 4.9 ha) with a total effluent application of less than 1 MGD (3785 m^3/day). It is described in more detail in the "Research Design" section of this proposal.

HISTORICAL BACKGROUND

Las Vegas Wash is the terminus of the Las Vegas Valley drainage basin and empties into the Las Vegas Bay of Lake Mead. In the 1940s, a large area of wetlands developed in Las Vegas Wash as a result of the discharge of sewage effluent which established perennial flows. Currently, the City of Las Vegas and the Clark County sewage treatment plants contribute over 90 percent of the total surface flows into the Wash.

The first Lake Mead water quality study addressing effluent discharges from Las Vegas Wash was initiated in 1964 (Jones, 1975). Since that time, numerous studies and monitoring programs have been conducted. The following overview summarizes major reports and findings.

Ground-water contributions to the surface flows are very high in salinity. During a 30-year period, industrial wastewater effluent was discharged into unlined evaporation pools. Both inorganic and organic wastes were disposed. This practice, which contaminated the near-surface aquifer, was discontinued in 1978. In addition, accidental leakage from an underground storage tank in 1976 released approximately 30,000 gallons of benzene (Geraghty and Miller Inc., 1980).

Leaching of native salts by the perennial sewage effluent discharges also contributes highly to the salinity of the Wash water (French et al., 1982). The U.S. Bureau of Reclamation proposed the removal of ground water in the Las Vegas Wash as a means of reducing salinity in the Lower Colorado River (USDI, 1982). However, salinity concentrations have rapidly decreased in Las Vegas Wash since 1978 when saline industrial inputs were curtailed. Although salinity concentrations are still high (see Table 1, Conductivity), Las Vegas Wash is no longer considered a cost-effective salinity control site.

The Las Vegas Wash water entering the Las Vegas Bay of Lake Mead is typically high in both nutrients and salinity (Table 1). In the 1960s, concerns about the water quality in Las Vegas Bay and in other areas of Lake Mead (USDI, 1967; Hoffman et al., 1971) led to the construction of an advanced wastewater treatment plant to remove phosphorus. Despite major phosphorus reduction, summer algal concentrations (chlorophyll) have continued to increase in the inner portion of Las Vegas Bay over the past few years (Paulson and Baker, in press; NDEP, 1987). This increase has been associated with a number of confounding changes in Las Vegas Wash, including

TABLE 1. CHEMICAL CHARACTERISTICS AND DISCHARGE FOR LAS VEGAS WASH
Values Are Yearly Averages For U.S. Geological Survey Data
Calendar Year 1975 and 1985.

PARAMETER	1975	1985
Total-P (mg/l)	4.513	1.03
Total-N (mg/l)	10.357	N.R.[a]
Total Kjeldahl-N (mg/l)	1.53	13.22
Nitrate-N (mg/l)	8.757	1.844
Ammonia-N (mg/l)	0.458	11.6
Conductivity (µS/cm)	4158	2641
x Daily Discharge (cfs)	72	116

[a]Not reported

erosion and channelization, loss of the wetlands, increasing ammonia concentrations, decreasing salinity, and possible increases in summer water temperatures (NDEP, 1987; Roline and Sartoris, in press). Although Las Vegas Bay does experience highly eutrophic conditions due to nutrient inputs from Las Vegas Wash, the remaining areas of Lake Mead are now extremely nutrient poor, which has resulted in a very depressed sports fishery (Paulson and Baker, in press). Recently, the Nevada Division of Environmental Protection has established standards for algal growth (chlorophyll) and un-ionized ammonia throughout Lake Mead (Table 2).

TABLE 2. CHLOROPHYLL AND UN-IONIZED AMMONIA STANDARDS FOR LAS VEGAS BAY AND LAKE MEAD (NDEP, 1987).

PARAMETER/LOCATION	STANDARD
Chlorophyll a	
Inner Las Vegas Bay (Station 3)	
• Monthly $\bar{x}$	<45 µg/l
• Summer $\bar{x}$ July-September	<40 µg/l
• 4 Year Summer $\bar{x}$	<30 µg/l
Other Areas Lake Mead	
• Growing Season (April-September)	< 5 µg/l
• 10 percent of samples	<10 µg/l
Un-ionized Ammonia	
Lake Mead	
• Single value over 3-year period	< 0.45 mg/l
• 4 day $\bar{x}$ over 3-year period	< 0.04 mg/l

Historically, the Las Vegas Wash was very effective in polishing the sewage effluent. Ammonia concentrations were typically very low after passing through the wash, and earlier investigations reported large reductions in both total nitrogen and total phosphorus (Goldman, 1976; Brown and Caldwell Co., 1982; Morris and Paulson, 1983). These reductions in ammonia concentrations could never be related directly to the wetlands, but were due to some combination of mechanisms that were never precisely identified (Morris and Paulson, 1982). However, it is clear that ammonia concentrations have increased as erosion channelized flows within the Wash. Sustained wastewater flows and major floods in the 1970s and early 1980s caused substantial erosion and channelization of the flows which drained the wetlands. The remaining wetlands were essentially lost in a 1984 flood which channelized flows within the wetlands downstream of the sewage treatment plants.

The proposed pilot wetlands demonstration will not identify those mechanisms that were responsible for reducing ammonia in the past. It will, however, demonstrate the utility of using a wetlands for additional treatment of sewage effluent in the future.

A wetland has been defined as "land where the water table is at, or above, the land surface for long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes as long as other environmental conditions are favorable" (Cowardin et al., 1976). Kadlec (1976) considered wetlands to be "intermediate areas in the hydrological sense: there are too many plants and too little water to be called a lake, yet there is enough water to retard the growth of trees and wet the feet of the hiker."

Natural freshwater wetlands are classified as follows (Sloey et al., 1978): 1) riverine (adjacent to rivers, generally confined by channels and fed by ground water), 2) lacustrine (adjacent to lakes, exchange water freely with the lake) and 3) palustrine (nontidal, not confined by rivers nor marginal to lakes, hydraulically isolated from open surface water). Research has been conducted on the effects of wastewater applications to each of these broad types of wetlands.

Recently, considerable attention in North America and Europe has been directed toward the use of wetlands as water purification systems and nutrient traps which serve to reduce man's impact on ground and surface waters. The interest in utilizing natural wetlands for treatment of wastewater effluent has emerged as a result of several factors:

1) Public demands for more stringent wastewater standards.

2) Rising operational and maintenance costs associated with conventional treatment facilities.

3) Demonstration that wetland ecosystems may perform integrated wastewater treatment, such as: removing organic matter, solids, nutrients, and toxics in a single system.

4) Increases in the wildlife, aesthetic, and environmental benefits associated with wetlands enhancement.

Major studies in this field have been reported in papers from various symposia. These publications have been edited by Tourbier and Pierson (1976), Tilton et al. (1976), Good et al. (1978), and Reddy and Smith (1987). The general consensus from these articles is that applications to date have been generally successful, and wetlands do have cost benefits over conventional treatment. However, more quantitative assessment of the capabilities and limitations of wetlands treatment in long-term, large-scale applications are needed. As best summarized by Sloey et al. (1978), more widespread experimental application of wetland systems for wastewater treatment in this country "warrants greater State and Federal support and participation".

The incentives of the Clean Water Act of 1977 provide strong encouragement for the increased use of "innovative and alternative" technologies such as wetland treatment systems. A body of evidence now exists that wetlands treatment can be a practical approach for communities to meet treatment needs while being receptive to environmental, aesthetic, and financial benefits (Hammer and Kadlec, 1983).

The following section reviews what is known about wetlands treatment of wastewater. Special emphasis is placed on those aspects of wetlands treatment which would figure most prominently in the proposed Las Vegas Wash Wetlands Demonstration Study -- namely, controlled nitrification-denitrification systems for ammonia removal.

USE OF WETLANDS FOR WASTEWATER TREATMENT

In a study conducted near Houghton Lake in central Michigan (Richardson et al., 1976), nitrogen (N) and phosphorus (P) were added as "simulated sewage" to a 716 hectare peat wetlands. This study documented a slow rate of subsurface ground-water movement, high denitrification rates for waterlogged soils, high nutrient sorption capacity of organic litter and peat soils, and nutrient uptake by some plant species. The authors concluded that a peatland ecosystem has potential as a biological filter for plant nutrients. In a more recent update of the Houghton Lake Study in Michigan, Kadlec (1987) reported good overall water quality improvement by flow through this peatland site, with greater than 98 percent ammonia removal.

Sloey et al. (1978) studied Brillion Marsh in Wisconsin, a site which has been receiving domestic sewage since 1923. During the summer, phosphorus was reduced from about 2 mg/l to 1 mg/l. Ammonia concentrations in the influent to the marsh were approximately 8 mg/l. No ammonia was detected below the marsh. Nitrate declined from a range of 0.4 mg/l to 2.1 mg/l above the marsh to 0.1 mg/l to 0.2 mg/l below the marsh. On an annual basis, about 10 kg P/ha was removed by harvesting of the plants, while 38 kg P/ha was apparently entrained permanently in the organic sediments.

The feasibility of recycling treated sewage through cypress wetlands has been studied in Florida (Odum et al., 1975). Preliminary results indicate that most of the nutrients and 99 percent of the bacteria are removed from the wastewater input. In addition to wastewater treatment, this system also increases production of high quality cypress wood.

Similar removal efficiencies were observed in another wetland system near Wildwood, Florida. The system had been receiving about 570 m^3/d of advanced primary treatment wastewater. The wetland system (~ 200 ha) consisted of a small marsh and two connecting mixed hardwood forest wetlands. Even after 20 years of wastewater inflow, 96-98 percent of the ammonia was still being removed. Nitrogen removal ranged from 75 to 85 percent; phosphorus removal averaged 87 percent (Boyt et al., 1977).

Studies in other countries have produced similar results. Farnham and Boelter (1976) reported that in peat systems in Finland, which were being used for treatment of domestic sewage, phosphorus was reduced by an average of 39 percent and nitrogen by 62 percent. One project demonstrated 82 and 90 percent reductions of phosphorus and nitrogen, respectively. Toth (1972, cited by Sloey et al., 1978) studied the effects of reed (Phragmites) stands on the amount of sewage effluent entering Lake Balaton in Hungary. He reported a 98 percent reduction of total P (5.57 mg/l to 0.082 mg/l) and a 95 percent reduction of total N (21.6 mg/l to 1.024 mg/l).

Wetlands have also been successful in treatment of more diffuse sources of pollutants. A study of Lake Minnetonka in Minnesota showed that the major source of phosphorus was urban debris carried by storm runoff. A treatment plant was not practical because of the large volume of water and the periodic nature of the flow. Consequently, the storm water was routed through a marshy area (Wayzata Wetlands) before it entered the lake. Studies have since shown that the wetlands retain 78 percent of all phosphorus in the water and 94 percent of the total suspended solids. In addition, algal growth in Lake Minnetonka has been reduced substantially (Maugh, 1979).

Nichols (1983) has summarized published data on removal of nitrogen and phosphorus from wastewaters applied to natural wetlands for several types of systems in varying climates. His summary and other recent studies have provided convincing evidence that management of natural wetlands can be quite effective in stripping nutrients and other pollutants from wastewater effluents. However, in many cases, natural wetlands are unavailable at a treatment site or must be augmented in order to provide for the treatment of a design flow from a municipal sewage treatment plant. Studies of the wastewater treatment capability of artificial wetlands have suggested that it is possible to derive the benefits of wetlands treatment in constructed marsh systems. These artificial wetlands may range from the creation of a marsh in a natural setting, where one did not permanently exist before, to the creation of a totally new artificial system by bringing in soil and vegetation from some other site. The vegetation that is introduced is usually similar to that found in natural wetlands.

In a series of controlled experiments, Gersberg et al. (1984a) found artificial cattail and bulrush wetlands capable of removing a wide variety of wastewater contaminants, including: Biochemical Oxygen Demand (BOD) and suspended solids (SS) (Gersberg et al., 1984b); nitrate (Gersberg et al., 1984c, 1986); and bacteria and viruses (Gersberg et al., 1986, 1987). Artificial wetland ecosystems are very attractive for use by communities because they perform integrated wastewater treatment using natural processes with low energy input.

Dr. Seidel and her colleagues at the Max Planck Institute (MPI) in West Germany have studied the effectiveness of a wide variety of marsh plants in wastewater treatment (Seidel, 1976). In artificial MPI wetland systems, marsh plants have been shown to significantly reduce both inorganic and organic matter from sewage. Also, root excretions from certain species were effective in killing disease bacteria without affecting benign bacteria.

Kiefer (1968) reported that this MPI system was becoming acceptable for communities of population size between 20,000 and 40,000; overall space requirements are about 3 acres per 1 million gallons per day (mgd) of wastewater. Similar artificial wetlands are being used to treat municipal wastewater in Berlin and Krefeld, Germany (Seidel, 1976) and in the Netherlands (de Jong, 1976).

Spangler et al. (1976) reported on artificial marshes as wastewater treatment systems in Wisconsin. A number of basins (3 m X 3 m) and a larger trench (19 m X 6 m) were lined with 20 mil PVC plastic, and sand and gravel were added to various depths. These wetlands were planted with emergent vegetation, primarily species of bulrush (Scirpus). Both primary and secondary effluent from the adjacent municipal treatment plant were piped into the systems, and water quality parameters were monitored closely. Results confirmed the effectiveness of these systems. Phosphorus removal reached 64 percent, although values from 30 to 40 percent were more common. Most (75 percent) of the phosphorus removed by the system was retained in the sediments, and only 5 percent went into harvestable plant tissue. The highest BOD removal achieved was 91 percent. Overall, most of the purification appeared to be occurring in the substrate system rather than by vascular plant uptake.

At Brookhaven National Laboratory, an artificial cattail marsh-pond system handled 10,0000 gallons per day of raw sewage blended with septic effluent and sludge. The effluent from this marsh-pond system was potable water (Small, 1976a). Small (1976b) reported a reduction of total dissolved solids (TDS) from 203 mg/l to 164 mg/l (19.2 percent). This research group is also experimenting with a closed marsh-only system which is designed to process 1 mgd of blended sewage and septic effluent in under five acres of land.

Farnham and Boelter (1976) reported on the operation of artificial peat filter beds constructed in Minnesota for advanced treatment of secondary treated campground sewage effluent. The peat bed was built in a glacial till-like material, and vegetation became established at the surface. In one study, inflows to the system were 3.94 g P/m^2 and 16.02 g P/m^2, while outflows were 0.11 g P/m^2 and 1.82 g P/m^2. It was believed that the organic peat could retain almost all of the phosphorus, while nitrogen losses were due primarily to plant assimilation. In addition, coliform bacteria were reduced by 100 percent.

The U. S. Army Corps of Engineers has studied the feasibility of using aquatic vegetation to filter, dewater, and remove contaminants from dredged material (Lee et al., 1976). The study concluded that aquatic plants have the potential for removing turbidity, nutrients, organics, metals, and bacteria. The study also reported on a mixed-species vegetative system for wastewater purification; *Phragmites* (common reed) filtered out the solids, and *Scirpus* (bulrush) removed dissolved pollutants and bacteria.

Wolverton (1987) showed that the root complex and its well developed biofilm and associated microbial community can aid in degrading toxic organic chemicals. Benzene concentrations of 9.5 mg/l in inflowing waters were reduced nearly 99 percent after 24 hours of flow through artificial Phragmites (reed) beds.

Watson et al. (1987) demonstrated that the use of artificial wetlands for treating municipal wastewater can meet National Pollutant Discharge Elimination System (NPDES) requirements. They showed ammonia reduction averaging 77 percent (from 14 mg/l to 3.3 mg/l) and showed BOD and suspended solids reductions of 97 percent and 89 percent, respectively.

NITROGEN REMOVAL

The deleterious effects of nitrogen on the aquatic environment have led to a significant increase in basic and applied research aimed at the development of cost effective nitrogen removal processes. The undesirable features of nitrogen loading to natural waters include:

- increased euthrophication of receiving waters,
- consumption of oxygen at a rate of 4.5 g of O_2 per g of NH_4^+,
- toxicity to fish when in the un-ionized NH_3 form,
- reaction with chlorine to form potentially hazardous chloramines and increase the overall chlorine demand for disinfection, and

- increased risk of methemoglobinemia in animals and human infants due to elevated levels of nitrate or nitrite in drinking water.

The most successful procedure for the removal of nitrogen from municipal wastewater is sequential nitrification-denitrification. In this procedure, ammonium is first oxidized to nitrite and then to nitrate by the chemoautotrophic nitrifying bacteria (Nitrosomonas and Nitrobacter, respectively). It is then converted to gaseous end products (usually N_2O or N_2) by denitrifying bacteria which utilize nitrate or nitrite as the respiratory electron acceptors to carry out the oxidation of organic matter.

Gersberg et al. (1986) showed that sequential nitrification-denitrification was the primary mechanism of nitrogen removal in artificial wetlands. Ammonia removal (and total N removal) was greater than 90 percent in bulrush wetlands and 78 percent in reed beds, as compared to 11 percent in an unvegetated control bed. The high nitrogen removal efficiencies shown by the bulrush and reed beds can be explained by the ability of many aquatic macrophytes to transport oxygen down to the roots, thereby establishing an oxidized rhizosphere (Armstrong, 1964). Teal and Kanwisher (1966) and Howes et al. (1981) showed that Spartina (cord grass) was able to oxidize the sediment in the rhizosphere and that the redox potential was higher in the root zone of the grass than in unvegetated sediments. Sherr and Payne (1978) found that the presence of aquatic plants enhanced the formation of oxides of nitrogen in the rhizosphere. Iizumi et al. (1980) showed that oxygen released by the roots of the eelgrass (Zostera) sustained a sediment nitrification rate of the same order of magnitude as the denitrification rate. Similarly, Hansen and Anderson (1981) showed that the potential nitrification rate in sediments from a Phragmites swamp was three times higher than for sediments without plants from deeper waters. All this evidence supports the hypothesis that nitrifying bacteria can be directly stimulated by the oxidizing abilities of the rhizome.

All available evidence indicates that wetland ecosystems provide an ideal environment for the alternating aerobic-anaerobic conditions that are necessary for total nitrogen removal. Artificial wetlands have already been used in municipal wastewater treatment to meet the NPDES permit (with regard to ammonia levels) of a municipality (Iselin, Pennsyvlania, as described by Watson et al., 1987). Observations by Gersberg et al. (1986) indicate that if BOD levels can be managed to maximize denitrification, then ammonia (and total N) removal efficiencies can be very high in wetland systems.

REMOVAL OF HEAVY METALS

The concept of using wetlands for cost-effective and energy-efficient treatment of municipal and industrial wastewaters has been demonstrated both in Europe and in the United States with a high degree of success. Both salt water and fresh water wetlands have been shown to remove (and immobilize) trace metals through precipitation-adsorption reactions in the sediments as well as uptake by the marsh plant community (Banus, 1975; Lindan and Hossner, 1982).

In marsh study plots, Best (1987) showed that 100 percent of dissolved copper and 88 percent of dissolved zinc were removed from secondary-treated effluents. Although metals were spiked into the systems, there appeared to be little detrimental impact on the marsh vegetation.

Gersberg et al. (1984c) showed that removal efficiencies of Cu, Zn, and Cd were 99 percent, 97 percent, and 99 percent, respectively, for secondary-treated wastewaters applied at hydraulic application rates of 5 to 8 cm per day. The predominant immobilization mechanism was attributed to precipitation-adsorption phenomena. Precipitation was enhanced by wetland metabolism, which acted like a buffer and increased the pH of acidified inflowing waters from pH 5.5 to near neutrality.

REMOVAL OF PATHOGENS

Attention has recently been focused on the capability of wetland ecosystems to remove waterborne pollutants, including pathogens (Gersberg et al., 1987a). There is only a limited amount of information available on the survival of disease causing viruses in wetlands. Wellings et al. (1975) indicated that human viruses in ground waters of a cypress swamp receiving secondary effluent were typically reduced to nondetectable levels. However, on several occasions breakthrough occurred, and viruses were detected in water samples from monitoring wells within the experimental area of the swamp.

In a recent study of virus survival in experimental cypress wetland corridors, decay rates of 0.045/h to 0.075/h were measured for indigenous coliphages (Scheuerman et al., 1985). These decay rates were slightly higher than the value of 0.035/h that Gersberg et al. (1987b) measured for indigenous bacteriophages in artificial wetland ecosystems.

The specific effect of higher aquatic plants on virus survival in wetlands is difficult to assess quantitatively. Gersberg et al. (1987b) found that F-specific RNA bacteriophage removal by a vegetated (bulrush) bed was significantly higher than by an unvegetated bed. The mean effluent bacteriophage level in the outflow of an unvegetated bed was 500 percent of the mean level for the bulrush bed. The aquatic plants served to stimulate virus removal through adsorption by the root complex and due to rhizosphere interactions that were antagonistic to virus survival. At hydraulic application rates of 5 to 6 cm per day, both bacteriophages and seeded poliovirus (vaccine strain) were reduced by about 99 percent by wetlands treatment. Artificial wetlands offer an attractive alternative to conventional treatment systems for reducing the load of disease-causing viruses to the aquatic environment.

APPLICATION OF WETLANDS CONCEPT TO LAS VEGAS WASH

Increased costs of wastewater treatment, coupled with the decreasing share of capital costs borne by the Federal Construction Grants Program, place greater financial pressure on municipalities which are searching for practical and effective processes to meet their treatment needs. Innovative approaches such as wetlands treatment have fulfilled these needs with cost-effective solutions in various locations around the country. Wetlands treatment is beneficial to wildlife, and in some cases, can greatly increase productivity of an ecosystem by providing both nutrients and water in otherwise nutrient-poor or acidic ecosystems.

The use of artificial wetlands for wastewater treatment takes advantage of many of the same principles that apply in natural biological systems, but it does so in a more controlled and managed environment. Implementation of a wetlands enhancement scheme using treated wastewaters from the City of Las Vegas and Clark County, Nevada, can have multi-use objectives (i.e., using wastewater to restore marshes which have treatment, recreational, wildlife, and aesthetic value).

In desert ecosystems such as Las Vegas Wash, wastewater coming from municipal treatment facilities can be managed as a resource for use in restoring wetlands that have already been drained (or for increasing actual wetland resources), while at the same time enhancing water quality. In this way, it should be possible to restore the degraded wetland habitat in Las Vegas Wash, while at the same time help meet water quality standards for Lake Mead.

Perhaps one of the most appealing wastewater re-use alternatives is to create a multi-use park and wildlife preserve. The relatively arid environment of Santee, California provides an example of this approach. At

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this site, soil percolation of secondary-treated effluent treats water to a quality that allows the maintenance of seven recreational lakes with boating, and fishing. The shallow zones of the lakes all have well-developed stands of cattails and bulrush and attract a diverse bird community. The treated water is also used to irrigate a park.

Another such multi-use wetlands system is currently under construction at Orlando, Florida (Best, 1987). This wetlands system is approximately 500 ha in size and is designed to treat 62,000 - 93,000 m^3/d (16.4 MGD-24.6 MGD). The ultimate treatment capacity may be even higher.

Very limited data exist for wastewater renovation through wetlands in properly managed, long-term, larger-scale applications. The Las Vegas Wash System, with its large flows of treated wastewater, historic wetlands development, available land area, capacity for nutrient stripping, and arid nature, make it an ideal environment to evaluate the long-term functioning of wetlands for wastewater treatment and ecosystem restoration.

CONCLUSIONS

Constructed wetland ecosystems in Las Vegas Wash may offer many advantages over conventional treatment systems. Wetlands:

1) function as integrated wastewater treatment systems, removing ammonia, total N, BOD, suspended solids, pathogens, and toxics in a single system,

2) have low operation and maintenance costs due to low labor and energy requirements,

3) have a single process design with virtually no moving parts,

4) are adaptable for use with inexpensive pretreatment (primary treatment) or for advanced treatment of secondary wastewater,

5) are aesthetically pleasing habitats, and can be further developed into a regional park,

6) enhance wildlife productivity,

7) may restore barren desert lands or drained wetland habitats to productive ecosystems, and

8) can be incrementally developed to treat greater proportions of the total effluent discharges based on the desired treatment level and the availability of land.

RESEARCH DESIGN

A small area of wetlands with controlled sewage effluent flows will be developed in Las Vegas Wash to demonstrate the capabilities of utilizing a larger wetlands to reduce effluent ammonia loads discharged into Lake Mead.

Although ammonia removal will be the primary emphasis of this research, wetlands removal of other pollutants found in the effluent (e.g., heavy metals, toxic organic compounds, and possibly viruses) will be monitored also. Increased salinity and consumptive water use are viewed as negative impacts that may be associated with the restoration of a wetlands in Las Vegas Wash and will be evaluated also. Erosion control will not be addressed in the proposed wetlands demonstration because the wetlands will not be intentionally subjected to flood flows. The proposed wetlands demonstration will be indicative of the potential of a larger wetlands located off the main drainage of Las Vegas Wash for treating partial effluent flows from the sewage treatment plants. Specific objectives for the wetlands demonstration are to:

1) quantify long-term ammonia removal capabilities of a wetlands located in Las Vegas Wash relative to existing soil, vegetation, and climate conditions,

2) quantify consumptive water use associated with wetlands restoration, and

3) quantify salinity impacts associated with wetlands restoration,

4) provide City and County planners with water quality data to evaluate cost-benefits of wetlands treatment versus conventional treatment.

The wetlands demonstration project plan described in this section is tentative at this time. It will be finalized after negotiations with the City of Las Vegas, Clark County and other local agencies are completed. Proposals to these agencies will be for 1) access to approximately 12 acres or more of land in close proximity to the sewage treatment plants, 2) controlled releases of both secondary and tertiary sewage effluent, 3) assistance in construction of the wetland, and 4) analytical support. Land access and effluent releases are mandatory for the wetlands demonstration. Construction and analytical support will be a cost sharing requirement of all agencies participating in the demonstration. After these negotiations have been completed, individual wetlands plots will be developed and monitored.

Prior to construction of the wetland plots, physical soil characteristics (texture, permeability, etc.) will be examined to determine how representative the wetlands demonstration site is of the overall Las Vegas Wash area. Five to ten samples from the upper soil layer (~1m) should be collected and analyzed. Additional data will be obtained from the Soil Conservation Service and other sources.

The research design for this project will utilize a simple input-output budget approach where individual constituents are measured prior to entering and after leaving individual wetland plots. Because input-output models are dependent on flow-weighted concentrations, individual plots will be gauged for flow, and meteorological data will be collected. Changes in constituent input-output budgets will be considered as wetland effects. Quantitative analyses of chemical and biological processes related to these changes (wetland effects) are not proposed at this time. These processes are generally understood, as previously described. However, innovative process-oriented research programs could be integrated into the wetlands demonstration project in the future under separate research proposals.

Table 3 summarizes chemical parameters that will be measured on a routine basis. All analyses will follow EPA-approved methods (U.S. EPA, 1979). These parameters will be measured on samples collected from the input and output for individual wetland plots. Whenever possible, output sample collection will be time-weighted for retention time within the wetlands plots. Initially, samples will be collected twice a week, but the sampling interval may change relative to temporal variation and funding. Additional parameters (e.g. major cations and anions, heavy metals, and selected organic compounds) will be analyzed as needed. Inductively coupled plasma-mass spectrometry (ICP-MS) methodologies for trace element analyses are being developed at EMSL-LV and may have an application in this area. ICP-MS can readily provide information on the concentrations of 72 trace elements. A quality assurance plan will be developed for sample collection and analyses of those routine parameters given in Table 3 prior to implementing the field program.

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TABLE 3. CHEMICAL PARAMETERS TO BE MEASURED ON ROUTINE SAMPLES

Parameter	
Total-P	Total Organic Carbon (TOC)
Ortho-P	Dissolved Organic Carbon (DOC)
Total Kjeldahl-N	Total Dissolved Solids (TDS)
Nitrate-N	Biochemical Oxygen Demand (BOD)
Ammonia-N	Suspended Solids (SS)

The wetlands demonstration will consist of a series of adjacent-rectangular plots with a surface area of approximately 1/3 acre (15m x 90m). A total surface area of 4.9 ha (12 acres) will be required. The experimental design will be based on 1) effluent type (secondary or tertiary), 2) plot type (lined or unlined), and 3) plant type (three species). Each treatment will have three replicate plots for a total of 36 plots (Table 4). Replicate treatment plots will be used to determine variation within treatments and significant difference between treatments.

Applications of both secondary and tertiary-treated sewage effluents will be utilized. Secondary effluent from the sewage treatment plants is high in phosphorus, SS, and BOD. Wetlands denitrification processes are generally limited by carbon (Gersberg et al., 1984b). The secondary effluent should have higher available carbon relative to the higher levels of SS and BOD; therefore, wetlands application with secondary effluent may be more efficient in removing ammonia. Wetlands removal of phosphorus will also be quantified through secondary effluent applications. Initial application rates will be 5 cm/day (equivalent to ~0.05 MGD/acre).

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TABLE 4. EXPERIMENTAL TREATMENTS USED IN THE WETLANDS DEMONSTRATION.

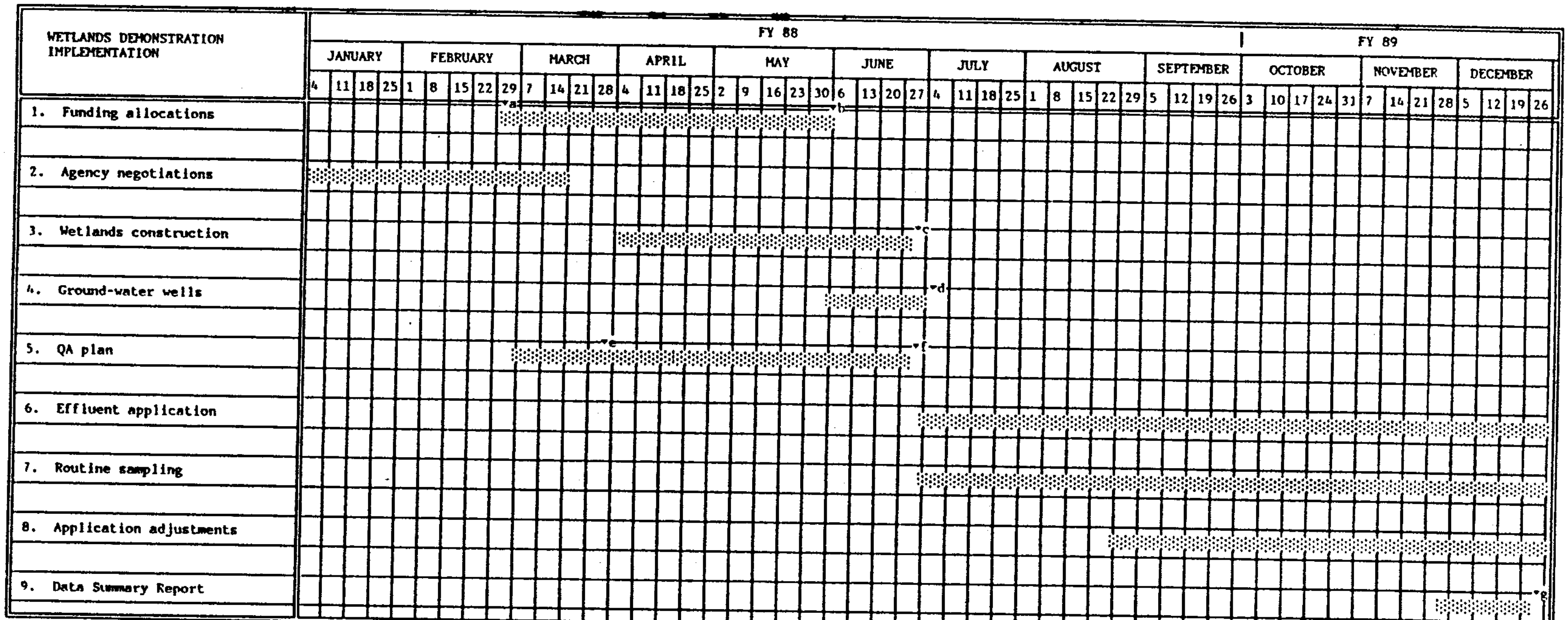
Treatments: Effluent Type	Plot Type	Plant Type	No. Replicate Plots
Secondary	Lined	Phragmites	3
		Typha	3
		Scirpus	3
	Unlined	Phragmites	3
		Typha	3
		Scirpus	3
Tertiary	Lined	Phragmites	3
		Typha	3
		Scirpus	3
	Unlined	Phragmites	3
		Typha	3
		Scirpus	3
		Total	36

Application rates will be altered after vegetation stands are established to determine optimal conditions for nitrification-denitrification.

Lined and unlined wetlands plots will be utilized to separate wetlands and ground-water effects. A polyethylene material (40-50 mil) buried at a depth of approximately 1m will be used to line the plots. Lined plots will eliminate or minimize ground-water effects and will provide direct measures of changes in water, nutrient (carbon, nitrogen, and phosphorus), and salinity budgets due to wetland effects. Differences between lined and unlined plots will be attributed to ground-water effects. In addition, four to six wells will be established within and downgradient from the wetlands demonstration plots to actually measure changes in the ground water. Data from the unlined plots will also be used to make predictions for larger-scaled wetlands development in Las Vegas Wash for proposed wastewater treatment.

The common reed (*Phragmites communis*), cattail (*Typha domingensis*), and bulrush (*Scirpus*) were well established in Las Vegas Wash in the past and will be used as wetlands vegetation. Each plot will be planted individually with one of the above species to develop single-species vegetation stands. Mixed-species plots may be considered after evaluating data from the single-species plots. *Phragmites* and *Typha* were the dominant wetlands vegetation in Las Vegas Wash and should be evaluated in the wetlands demonstration project. One option to scale down the wetlands demonstration is to exclude *Scirpus*, reducing the total number of plots to 24. If further reductions are required, *Typha*, which does not have as extensive a root system as *Phragmites* and will probably not provide the best overall treatment could be excluded also.

A timeline for the first year of implementing the wetlands demonstration project is presented in Figure 2. The timeline is based on having the demonstration in place for the summer 1988 growing season. The demonstration should be continued through two additional growing seasons.



LEGEND: ░ = scheduled; ▬ = % completed; ▓ = extended or rescheduled; ░ = added task; ||| = completion of ext./resched./addl.task; ▼ = milestone not completed; ▲ = milestone completed

Filename: Wetlands

DELIVERABLE	TYPE	TIP DATE	TWP DATE	TARGET DATE

MILESTONES

TASK	CODE	DESCRIPTION	DATE	STATUS
1	a	Initial funding EMSL-LV	03-01-88	
1	b	Total FY 88 funding EMSL-LV	06-01-88	
3	c	Wetlands completed	06-30-88	
4	d	Well installation completed	06-30-88	
5	e	Draft QA plan	03-31-88	
5	f	Final QA plan	06-30-88	
9	g	First year summary report completed.	12-31-88	

Figure 2. Wetlands demonstration project implementation timeline.

EMSL-LV ROLE

The U.S. EPA Environmental Monitoring Systems Laboratory-Las Vegas (EMSL-LV) has recently secured funding to establish a Monitoring Technology Support Center. The Center will provide state-of-the-art monitoring technology information, documentation, and hands-on experience in surface water quality, unsaturated and saturated zone hydrology, geophysics, meteorology, and geographic information systems for EPA regional personnel working on Superfund sites. Las Vegas Wash is located within 10 miles of EMSL-LV, and ground-water and surface water conditions in this area are ideal for demonstrating methods and providing hands-on experience for personnel participating in the Center. A lecture and research facility is planned in the City of Henderson near the Pittman Lateral which is located in the Las Vegas Wash drainage. As part of the overall activities of the Center, an extensive hydrologic assessment (e.g., ground water, surface water, meteorology, etc.) of Las Vegas Wash will be conducted. The Wetlands Demonstration Project will be an integral part of this assessment. The U.S. Geological Survey has had a long-term ground-water program in the Las Vegas Wash area, and this program should also be continued as part of the assessment.

In connection with the Monitoring Technology Support Center, EMSL-LV sponsored a workshop entitled "Environmental Assessment of Las Vegas Wash and Lake Mead," on 15 October 1987. The workshop was held with local scientists and government agencies to discuss environmental issues and concerns related to Las Vegas Wash and Lake Mead. There were 47 participants at the workshop, representing the following agencies and organizations:

The Cities of Henderson, Las Vegas, and North Las Vegas
Clark County
Las Vegas Wash Development Committee
Nevada Department of Wildlife
Nevada Division of Environmental Protection
Southern Nevada Water Systems
Las Vegas Valley Water District
Regional Flood Control District
University of Nevada, Environmental Research Center
University of Nevada, Desert Research Institute
Colorado River Commission
National Park Service
U.S. Bureau of Reclamation
U.S. Geological Survey
U.S. EPA Region 9
League of Women Voters
Shoreline Technology
J. M. Montgomery Engineers
Lockheed Engineering and Management Services Co., Inc.

At the workshop, wetlands restoration, excessive algal growth in the inner Las Vegas Bay of Lake Mead due to high ammonia loads from the Las Vegas Wash, and erosion were identified as major environmental issues needing immediate attention. This proposal on wetlands ammonia removal is in response to these workshop issues.

The EMSL-LV would administer the proposed wetlands demonstration in coordination with the Cities of Henderson, Las Vegas, and North Las Vegas; Clark County; Nevada Division of Environmental Protection; EPA Region 9; and the EPA Engineering Research Laboratory in Cincinnati, Ohio. Coordination activities are being conducted with the Clark County Department of Comprehensive Planning Task Force Committee on the Las Vegas Wash and with the Clark County Sewage Waste Advisory Committee. Both committees have expressed an interest in support of the proposed wetlands demonstration. EPA Region 9 has also expressed support, and this proposal will be sent to Region 9 for their review.

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RESOURCES

Costs for the Wetlands demonstration will be shared between those local agencies participating in the project and EPA. Local agencies will be asked to support heavy equipment (land moving) cost, partial cost for construction materials, and partial cost for sample analyses. EPA will provide additional funding for construction materials and sample analysis and will provide scientific expertise through the staff at EMSL-LV. EMSL-LV scientific support will also include scientists from the University of Nevada (Desert Research Institute and Environmental Research Center), Lockheed-EMSCO, and USGS. The Technology Support Center will coordinate the support of these groups through cooperative agreements, contracts, and interagency agreements. Table 5 summarizes the proposed EPA cost share for FY-88, 89, and 90. Support of the USGS ground-water monitoring program (water level measurements and possibly some water quality sample collection for a network of monitoring wells, but not including, well drilling and construction) would require roughly an additional $150K.

expressed an interest in support of the proposed wetlands demonstration. EPA Region 9 has also expressed support, and this proposal will be sent to Region 9 for their review.

RESOURCES

TABLE 5. PROPOSED EPA COST SHARE FOR THE WETLANDS DEMONSTRATION PROJECT

Budget Item	FY-88 $	FY-89 $	FY-90 $
Scientific Support	100K	50K	10K
Laboratory Support	50K	80K	80K
Materials	100K	10K	0
Reporting	0	10K	10K

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REFERENCES

Armstrong, W. 1964. Oxygen diffusion from the roots of some British bog plants. Nature 204, 801-802.

Banus, M.D. 1975. Lead, zinc, and cadmium budgets in experimentally enriched salt marsh ecosystems. Estuar. Coastal Mar. Sci. 3, 421.

Best, G.H. 1987. Natural wetlands - southern environment. Pages 99-120 in K.R. Reddy and W.H. Smith, eds. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Orlando, Florida.

Boyt, F.L., S.E. Bayley, and J. Zoltek Jr. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. J. Wat. Pollut. Control Fed. 49, 789-799.

Brown and Caldwell Co. 1982. Las Vegas Valley Water Quality Standards Study. Draft Final Report to City of Las Vegas, Clark County, State of Nevada, and U.S. Environmental Protection Agency. Brown and Caldwell Consulting Engineers, Sacramento, California.

Cowardin, L., V. Carter, F. Golet, and E. LaRoe. 1976. Interim classification of wetlands and aquatic habitats of the United States. U.S. Dept. Interior, Fish and Wildlife Service.

de Jong, J. 1976. The purification of wastewater with the aid of rush or reed ponds. Pages 133-139 in J. Tourbier and R.W. Pierson, Jr., eds. Biological control of water pollution. Univ. Pennsylvania Press, Philadephia.

Farnham, R.S. and D.H. Boelter. 1976. Minnesota's peat resources: their characteristics and use in sewage treatment, agriculture, and energy. Pages 241-255 in D.L. Tilton, R.L. Kadlec, and C.J. Richardson, eds. Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor.

French, R.H. and M.D. Mifflin. 1982. Salt storage in the lower Las Vegas Valley. Report submitted to U.S. Bureau of Reclamation, Contract No. 0-07-30-V0126. Desert Research Institute, University of Nevada System, Las Vegas, Nevada.

Geraghty and Miller Inc. 1980. Groundwater investigation: Stauffer Chemical Company, Henderson, Nevada. Syossef, New York.

Gersberg, R.M., R. Brenner, S.R. Lynn, and B.V. Elkins. 1987a. Survival of bacteria and viruses in municipal wastewaters applied to artificial wetlands. Pages 237-246 in K.R. Reddy and W.H. Smith, eds. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Orlando, Florida.

DRAFT

Gersberg, R.M., B.V. Elkins, and C.R. Goldman. 1984a. Wastewater treatment by artificial wetlands. Wat. Sci. Technol. 17, 443-450.

Gersberg, R.M., B.V. Elkins, and C.R. Goldman. 1984b. Use of artificial wetlands to remove nitrogen from wastewater. J. Wat. Pollut. Control Fed. 56, 152-156.

Gersberg, R.M., B.V. Elkins, S.R. Lynn, and C.R. Goldman. 1984c. The removal of heavy metals by artificial wetlands. Water Resource Symposium III, AWWA Research Foundation, 639-648.

Gersberg, R.M., B.V. Elkins, S.R. Lynn, and C.R. Goldman. 1986. Role of aquatic plants in wastewater treatment by artificial wetlands. Wat. Res. 20, 363-368.

Gersberg, R.M., S.R. Lynn, R. Brenner, and B.V. Elkins. 1987b. Fate of viruses in artificial wetlands. Appl. Environ. Microbiol. 53, 731-736.

Goldman, C.R. 1976. A review of the limnology and water quality standards for Lake Mead. Ecological Research Associates Report to Clark County Commission, Las Vegas, Nevada.

Good, R.E., D.R. Whigham, and R.L. Simpson, eds. 1978. Freshwater wetlands. Ecological processes and management potential. Academic Press, New York.

Hammer, D.E. and R.H. Kadlec. 1983. Design principles for wetland treatment systems. R.S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma. EPA-600/2-83-026.

Hansen J.I. and F.O. Anderson. 1981. Effects of Phragmites australis roots and rhizomes on redox potentials, nitrification, and bacterial numbers in the sediment. In A. Broberg and T. Tiren, eds. Proceedings of the 9th Nordic Symposium on Sediments. Scripta Limnologica, Norr Malmo, Sweden.

Hoffman, D.A., P.R. Tramutt, and F.C. Heller. 1971. The effect of Las Vegas Wash effluent upon the water quality in Lake Mead. U.S. Bureau of Reclamation, Engineering and Research Center, Report No. REC-ERC-71-11.

Howes, B.L., Howarth, R.W., Teal, J.M., and Valiela, I. 1981. Oxidation-reduction potentials in a salt marsh: spatial patterns and interactions with primary production. Limnol. Oceanogr. 26, 350-360.

DRAFT

Iizumi, H., A. Hattori, and C.P. McRoy. 1980. Nitrate and nitrite in interstitial waters of eelgrass beds in relation to the rhizosphere. J. Exp. Mar. Biol. Ecol. 47, 191-201.

Jones, F.L. 1975. Water, A History of Las Vegas. Vol. II. Las Vegas Valley Water District Publication.

Kadlec, R.H. 1976. Surface hydrology of peat lands. Pages 5-24 in D.L. Tilton, R.H. Kadlec, and C.J. Richardson, eds. Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor. 343 pp.

Kadlec, R.H. 1987. Northern natural wetlands. Pages 83-98 in K.R. Reddy and W.H. Smith, eds. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Orlando, Florida.

Kiefer, W. 1968. Biological wastewater treatment with plants. Umshau No. 7:210. Translated from the German for Great Lakes Basin Commission and Northeastern Wisconsin Regional Planning Commission.

Lee, C.R., R.E. Hoeppel, P.G. Hunt, and C.A. Carlson. 1976. Feasibility of the functional use of vegetation to filter, dewater, and remove contaminants from dredged material. Tech. Rep. D-76-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Lindan, C.W. and L.R. Hossner. 1982. Sediment fractionation of Cu, Ni, Zn, Cr, Mn, and Fe in one experimental and three natural marshes. J. Environ. Qual. 11, 540.

Maugh, T.H. II. 1979. Restoring damaged lakes. Science 203:425-427.

Morris, F.A. and L.J. Paulson. 1982. A desert wetlands created by wastewater flows: current trends and problems. Wetlands 2:191-206.

Morris, F.A. and L.J. Paulson. 1983. Water quality trends in Las Vegas Wash wetlands. Pages 125-136 in V.D. Adams and V.A. Lamarra, eds. Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Sci. Publ.

Nevada Division of Environmental Protection. 1987. Las Vegas Wash and Lake Mead proposed water quality standards, revisions, and rationale. Nevada Division of Environmental Protection, Carson City, Nevada.

Nichols, S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. J. Wat. Pollut. Control Fed. 55, 496-505.

Odum, H.T., K.C. Ewel, W.J. Mitsch, and J.W. Ordway. 1975. Recycling treated sewage through cypress wetlands in Florida. Occas. Paper No. 1, Center for Wetlands, Univ. Florida, Gainesville.

Paulson, L.J. and J.R. Baker. In Press. Management of fertility and productivity in Lake Mead. Proc. 7th International Symposium North American Lake Management Soc. Nov. 3-7, 1987, Orlando, Florida, N. American Management Society, Washington, D.C.

Reddy, K.R. and W.H. Smith. eds. 1987. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Orlando, Florida.

Richardson, C.J., W.A. Wentz, J.P.M. Chamie, J.A. Kadler; and D.L. Tilton. 1976. Plant growth, nutrient accumulation and decomposition in a central Michigan peatland used for effluent treatment. Pages 77-117 in Tilton, R.H. Kadlec, and C.J. Richardson, eds. Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor.

Roline, R.A. and J.J. Sartoris. In Press. Changes in the morphometry of Las Vegas Wash and impact on water quality. Proc. 7th International Symposium North American Lake Management Soc. Nov. 3-7, 1987, Orlando, Florida, N. American Management Society, Washington, D.C.

Scheuerman, R.R., Bitton, G., Farrah, S.R., Bassart, J.M., and R.J. Dutton. 1985. Abstracts of the 85th Annual Meeting of the Am. Soc. for Microbiology. Las Vegas, Nevada.

Seidel, K. 1976. Macrophytes and water purification. Pages 109-121 in J. Tourbier and R.W. Pierson, Jr., eds. Biological control of water pollution. Univ. Pennsylvania Press, Philadelphia. 340 pp.

Sherr, B.F. and Payne, W.J. 1978. Effect of Spartina alterniflora root-rhizome system on salt marsh soil denitrifying bacteria. Appl. Envir. Microbiol. 35, 724-729.

Sloey, W.E., F.L. Spangler, and C.W. Fetter, Jr. 1978. Management of freshwater wetlands for nutrient assimilation. Pages 321-340 in R.E. Good, D.F. Whigham and R.L. Simpson, eds. Freshwater wetlands. Ecological processes and management potential. Academic Press, New York.

Small, M.M. 1976a. Marsh/pond sewage treatment plants. Pages 197-213 in D.L. Tilton, R.H. Kadlec, and C.J. Richardson, eds. Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor.

Small, M.M. 1976b. Marsh/pond system. Data Rept., Brookhaven Natl. Lab., Upton, New York.

Spangler, F.L., W.E. Sloey, and C.W. Fetter, Jr. 1976. Artificial and natural marshes as wastewater treatment systems in Wisconsin. Pages 215-240 in D.L. Tilton, R.H. Kadlec and C.J. Richardson, eds. Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor.

Teal, J.M. and Kanwisher, J. 1966. Gas transport in the marsh grass Spartina alterniflora. J. Exp. Bot. 17, 355-361.

Tilton, D.L., R.H. Kadlec, and C.J. Richardson, eds. 1976. Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor.

Toth, L. 1972. Reeds control eutrophication of Balaton Lake. Journ. Internat. Assoc. Water Pollution Res. 6(12), 1533-1539.

Tourbier, J. and R.W. Pierson, Jr., eds. 1976. Biological control of water pollution. Univ. Pennsylvania Press, Inc. Philadephia.

U.S. Department of the Interior, Federal Water Pollution Control Administration. 1967. Report on pollution in Las Vegas Wash and Las Vegas Bay. Division of Technical Services, Cinn., Ohio and Colorado River Basin Water Quality Control Project, Denver, CO.

U.S. Department of the Interior, Bureau of Reclamation. 1982. Colorado River Basin Salinity Control Project Point Source Division, Las Vegas Wash Unit. Status Report Lower Colorado Region, Bureau of Reclamation.

U.S. Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-600/4-79-020.

Watson, J.T., F.D. Diodato, and M. Lauch. 1987. Design and performance of the artificial wetlands wastewater treatment plant at Iselin, Pennsylvania. Pages 263-270 in K.R. Reddy and W.H. Smith, eds. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Orlando, Florida.

Wellings, E.M., A. L. Lewis, C. W. Mountain and L.V. Pierce. 1975. Demonstration of virus in groundwater after effluent discharge into soil. Appl. Microbiol. 29, 751-757.

Wolverton, B.C. 1987. Artificial marshes for wastewater treatment. In K.R. Reddy and W.H. Smith, eds. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Orlando, Florida.