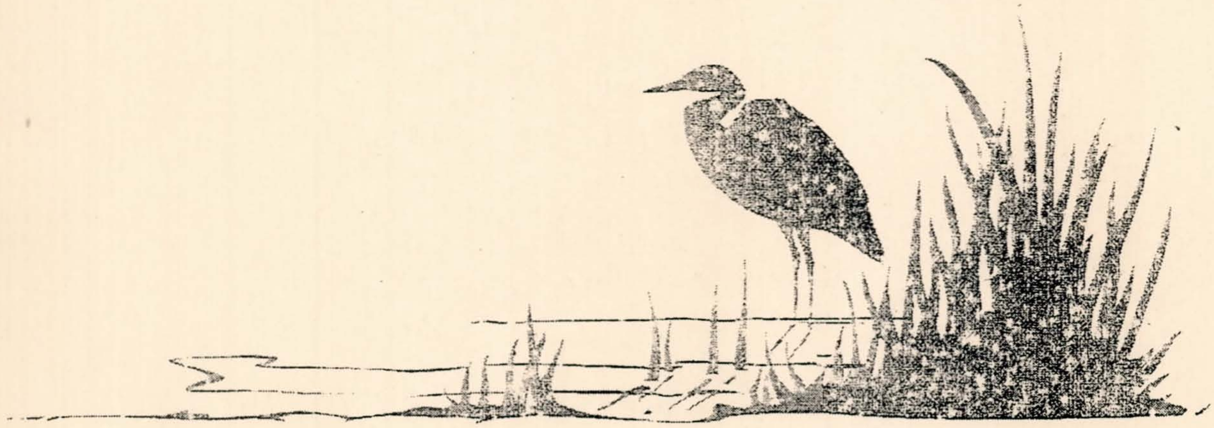
TRES RIOS DEMONSTRATION CONSTRUCTED WETLANDS

CONSTRUCTION REPORT



U.S. Department of the Interior
Bureau of Reclamation

in cooperation with

City of Phoenix
and the Subregional Operating Group

December 1998

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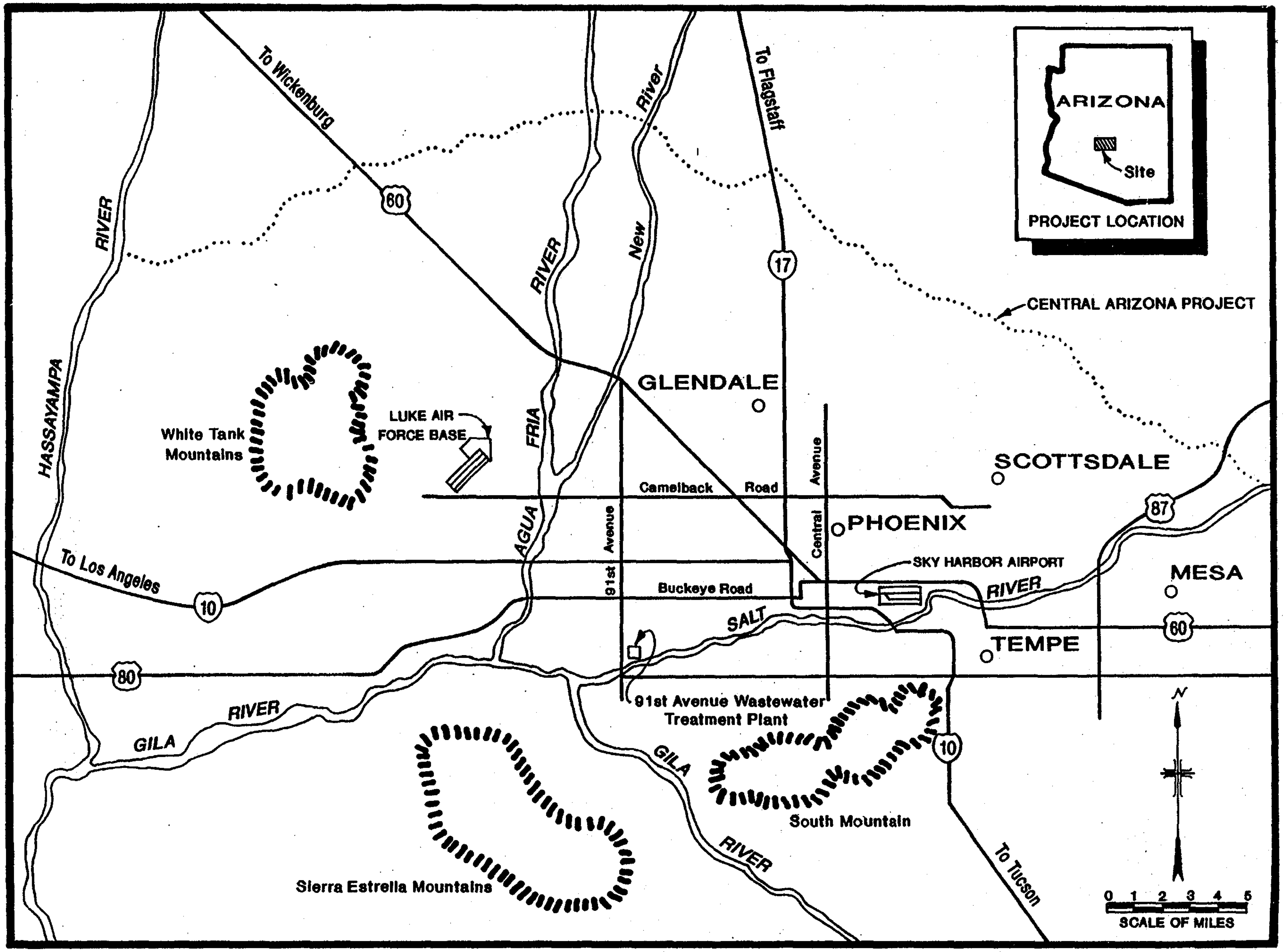

ARIZONA
Site
PROJECT LOCATION
To Wickenburg
To Flagstaff
River
New
RIVER
60
17
CENTRAL ARIZONA PROJECT
HASSAYAMPA
RIVER
AGUA
FRIA
RIVER
White Tank Mountains
LUKE AIR FORCE BASE
GLENDALE
SCOTTSDALE
Camelback Road
Central Avenue
91st Avenue
PHOENIX
SKY HARBOR AIRPORT
87
To Los Angeles
10
Buckeye Road
SALT
RIVER
MESA
TEMPE
60
80
91st Avenue Wastewater Treatment Plant
GILA
RIVER
GILA
RIVER
10
South Mountain
Sierra Estrella Mountains
To Tucson
N
0 1 2 3 4 5
SCALE OF MILES

Tres Rios Demonstration Constructed Wetlands
Construction Report

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PROJECT OVERVIEW

Sponsor: The City of Phoenix, Arizona, and the U.S. Bureau of Reclamation

Primary Objectives:

To test the capability of constructed wetlands to treat the present effluent of the treatment plant to levels that will satisfy proposed (not adopted to date) 1997 National Pollutant Discharge Elimination System (NPDES) permit requirements.

To develop appropriate design criteria for consideration in planning a full-scale constructed wetlands system in the Phoenix area.

Secondary Objectives:

To evaluate the wetland and aquatic habitat in an arid environment.
To serve as an education and passive recreation resource for the community.

Facility Construction Costs:

$1.5 million

Cost Sharing:

City of Phoenix (SROG) and the Bureau of Reclamation

Project Milestone Dates

Authorization of Phoenix Water Reclamation and Reuse Study	1992
Appropriation for Demonstration Wetland Project	1993
Phoenix Water Reclamation and Reuse Study, Tres Rios Demonstration Wetlands, Conceptual Design	December 1993
Decision to add research cells to Tres Rios Project	March 1994
Constructed Wetland Design Criteria finalized	September 1994
Tres Rios Wetlands Research Plan complete	February 1995
Construction Start	**March 8, 1995**
Construction Finish	**September 5, 1995**
Technical Advisory Review Panel meeting no. 1	November 28, 1995
Technical Advisory Review Panel meeting no. 2	February 5, 1996
Phoenix Wastewater Reclamation and Reuse Study published	March 1996
Technical Advisory Review Panel meeting no. 3	June 18, 1996
Technical Advisory Review Panel meeting no. 4	November 13, 1996
Technical Advisory Review Panel meeting no. 5	April 22, 1997
Technical Advisory Review Panel meeting no. 6	June 10, 1997
Tres Rios Demonstration Constructed Wetland Project, Research Plan-First Supplement (draft)	August 1997

Summary

The Tres Rios Demonstration Constructed Wetlands Project was funded jointly by the United States Bureau of Reclamation (Reclamation) and the City of Phoenix (Phoenix). The 1995 construction provides the foundation for evaluating the role of multipurpose wetland facilities in the comprehensive management of water and environmental resources in the arid Southwestern States. The demonstration wetlands were constructed near the confluence of the Salt, Gila, and Agua Fria Rivers downstream of the 91st Avenue Waste Water Treatment Plant (WWTP) in southwestern Phoenix.

Introduction

The demonstration wetland facilities are intended to provide a realistic basis to evaluate environmental, groundwater recharge, and water reuse attributes in addition to practical considerations associated with project planning, design, construction, and operations.

The primary objectives of the demonstration wetlands are to:

- Test the capability of constructed wetlands to treat the present effluent of the wastewater treatment plant to levels that would satisfy National Pollutant Discharge Elimination System (NPDES) permit requirements, originally proposed in 1997.

- Develop appropriate planning information and design criteria for incorporating constructed wetlands as part of comprehensive wastewater reclamation and reuse.

Secondary objectives are to evaluate habitat characteristics and evaluate the potential educational and passive recreational resources for the community.

Phoenix operates the 91st Avenue WWTP on behalf of the Subregional Operating Group (SROG), composed of the cities of Phoenix, Mesa, Glendale, Tempe, Scottsdale, and Youngstown. Phoenix, in partnership with Reclamation, initiated the Phoenix Waste Water Reclamation and Reuse Study to evaluate methods of reclaiming and beneficially using treated municipal wastewater. The U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers also participate in partnership meetings about river management.

Reclamation was authorized to conduct research and to construct, operate, and maintain cooperative demonstration projects under Title 16 of Public

Twelve cells constitute the Research Site on the grounds of the 91st Avenue WWTP. The cells are a converted sludge drying bed. Each cell is about 160 ft long (49 m) by 80 ft wide (24 m) and represents 0.30 acre (0.12 ha).

Pumping the effluent to Hayfield and Cobble Sites requires pumps near the outlet of the final chlorine contact chamber of plant 3A. Just before dechlorination, effluent is pumped out of the contact basin and sent to the three wetland sites. The volume of effluent flow to the sites is controlled with a manual gate valve for each pipeline. The gate valve control is only a few feet from the flowmeter. The infrastructure was designed to operate the cells in series, in parallel, or bypass.

The riparian channel between Hayfield Site and the river receives effluent after treatment by the two treatment cells created primarily to provide habitat for native fish and to provide postaeration of the wetland outflow. The area topography prevents exotic fish from entering the riparian channel from the Salt River.

Public access for environmental education and passive recreation is provided by hiking/jogging trails and observation points. The trail and observation points are atop the berms around the wetland cells. Visitor parking areas are available.

The initial operation and monitoring program was conducted from October 1996 to September 1998. A research and monitoring plan was prepared (CH_2M Hill, 1995) to guide the wetlands studies during this initial evaluation phase. Other research issues and collaborative studies were incorporated later. The results of these investigations are not discussed further in this report.

Discussion

Many agencies and organizations have used the wetland sites for research, news related topics, and youth leadership. However, no construction project is completed without at least a few problems, and the constructed wetlands are no exception. This section describes some of the problems discovered during project planning and construction.

Planting

Temporary pumps were used to augment the main pump station to wet the cells prior to planting. Planting took about twice as long as expected due to very dry soil conditions. Cobble Site required extended pumping at high rate to saturate the unlined cell due to a rapid infiltration rate that exceeded the normal pumping rate.

It appears that planting costs could have been reduced by either placing or randomly tossing the stalks on the cell bottom instead of manually planting each stalk at 3-foot centers. Bulrush plants will grow roots and attach themselves to the soil they contact in 48 hours. Alternatively plant stalks could have been placed in the invert of the cells, spaced at 3-ft (0.9-m) centers on a very moist soil surface.

The vegetation at Tres Rios has met or exceeded expectations of growth, survivability, and cover. No additional monies have been spent promoting growth or maintaining the vegetation. In fact, the growth has so flourished that no effect is evident within the wetland cells after a nursery cell was established nearby using bulrushes from the system.

During the first year of operations, a typical winter senescence (dormancy) occurred. By February, most plants had senesced. During March, regrowth occurred; by the beginning of May, more than 90 percent of the vegetation had returned to lush, green growth.

At the Research Site, none of the deep zones were deep enough or wide enough to prevent the aquatic vegetation from encroaching. In most cases, the entire cell was overrun with aquatic vegetation by the end of the first year (August/September 1996).

During the first year, cattails invaded the southernmost cell of the Cobble Site. Although cattails are aquatic vegetative plants known for improving water quality, they are invasive plants which will overrun the system.

Submergent vegetation was planted in all the deep zones at Tres Rios. Hornwort (*Ceratophylum*) was planted with little to no success. Within 6 months of being planted, the *Ceratophylum* had disappeared. It is thought that the plant disappeared due to overgrazing by waterfowl and predation by fish.

In summary, it appears that planting emergent vegetation as stalks, or in clumps, is beneficial to establish vegetation quicker and discourage undesirable species. The method of planting does not need to be intensive, however, since emergents such as bullrush are readily established. It appears that submergent vegetation should be planted after emergent plants and water supply conditions have stabilized.

Berm Construction

Cobble Site was designed with berms at a 3:1 to 6:1 slope. These slopes were much too mild to fit the wetlands basins within the designated site areas. To rectify the situation, the outer slope of the Cobble Site berm near the northeast corner was built more steeply, approximating a 2:1 slope. Although this approach required less material, the construction of steep slopes requires suitable soils and is often a greater challenge for equipment and laborers.

The center berm at the Cobble Site also could have been designed differently. Its composition appeared to contain parent material with gravel, which does not compact well. During a high flow condition, the center berm ruptured near the outlet end and left a 12-ft (3.7-m) void between the two cells. Future designs should consider suitable soils for berms, a concrete barrier, or other methods.

In summary, the ability to use parent materials for construction of some berms must be carefully considered. Imported soils or other types of impervious barriers may be required to subdivide wetland cells. It appears that open water zones at the cell's ends do not need to extend to the full cell width if cells are shaped to avoid stagnant zones.

Sampling Access

Tres Rios wetlands is a research site, yet sampling at the outlet structures is difficult. The walkway structures are between 2 and 3 ft (0.6 and 0.9 m) higher than the effluent surface. A guardrail along the sides of the walkway is for the operators' safety. A dipper can be used to draw samples; however, the mouth of the dipper is larger than the mouth of most sample bottles. Sampling at the outlet end requires lying on the grating of the structure and reaching into the wetland with a grab sample bottle.

Sampling from the inlet splitter box structures has been a much easier process and has lent itself to safe and efficient sampling. At Hayfield and Cobble Sites, a portion of the grating in a rectangular shape is removable so that grab samples can be taken within the flow structure.

The berms at the outlet end of Research Site are fairly steep at a 3:1 slope (or steeper) and are approximately 7 to 8 ft high (2.1 to 2.4 m). The steep slope proved dangerous and difficult to access for monitoring and sampling. By January 1996, stairs for each cell were constructed at the outlet end to allow easier access.

Walkways within Research Site cells were constructed at about midpoint between the inlet and outlet ends, and there is no handrail. Guardrails are not required because the wetland is very shallow. Aquatic vegetation that has grown around, over, and between the walkway shields the view. Future walkways would be designed wider, and vegetation would be lower.

The wetlands facilities were initially constructed to focus on demonstration, treatment, and research sites only. The secondary objectives of public use and habitat benefits might indicate more attention to public features. For example, the Americans With Disabilities Act (ADA) standards could be considered as part of future designs.

In summary, the design process should consider safe access to the wetlands for sampling, particularly if monitoring is a major part of the research project. Stairs and walkway guardrails, and wide walkways may be required and should be part of the design. Sampling from the inlet splitter box structures has been easy; a portion of the grating in a rectangular shape is removable so that grab samples can be taken within the flow structure. This design, perhaps, could be transferred to other areas or walkways.

Public Access

Security at the larger Hayfield and Cobble Sites was not considered in detail when the wetland demonstration program began. The close proximity of the wetland facilities to the open river corridor has raised some concerns. The river flood plain is used for a variety of potentially hazardous activities including hunting, fishing, and swimming. Unfortunately, the river has also been used as a convenient dumping ground for all varieties of materials.

The Cobble Site is particularly susceptible to these problems due to the location within the river corridor. During construction, some garbage dumping occurred as people evidently considered the new basin as a good dumping site.

Ultimately, concrete median dividers were installed at the entrance to Cobble Site, leaving room between two of the dividers for a vehicle to drive through. When no authorized personnel are at the site, a lockable chain is strung between the barriers.

Conditions are not quite as bad at the Hayfield Site since it is located within the treatment plant property. Access to the Hayfield Site is also more restricted.

In summary, planners should carefully consider public access and what the impacts of various public facilities might mean in a wetlands environment. Future wetlands need to incorporate low durable structures and discourage access into the wetlands through construction of barriers, gates, and/or fences. A public education program is an essential part of any full-scale wetlands in protecting public and environmental values in the river corridor.

Chapter 1

Introduction

The City of Phoenix (Phoenix) and the Bureau of Reclamation (Reclamation) jointly funded and constructed the Tres Rios Demonstration Constructed Wetlands Project facilities in 1995. This demonstration program provides the foundation for a state-of-the-art multipurpose approach to comprehensive water management in the arid Southwestern States. The multipurpose wetlands were constructed near the confluence of the Salt, Gila, and Agua Fria Rivers near the 91st Avenue Waste Water Treatment Plant (WWTP) in southwestern Phoenix.

Purpose and Objectives

The Tres Rios Demonstration Constructed Wetlands are to:

- Enhance water resource management through water supply augmentation and water reclamation and reuse
- Encourage and develop environmental purposes
- Maintain surface water quality standards
- Promote and protect public health, and
- Develop recreation opportunities.

Section 1608 of Public Law 102-575 specifically states that facilities should be constructed for environmental purposes, groundwater recharge, and direct potable reuse.

The primary objectives of the demonstration constructed wetlands are to:

- Test the capability of constructed wetlands to treat the present effluent of the treatment plant to levels that will satisfy National Pollutant Discharge Elimination System (NPDES) permit requirements, originally proposed in 1997.
- Develop appropriate design criteria for a full-scale wetlands development in the Phoenix area.

Secondary objectives are to:

- Evaluate aquatic habitat in an arid environment.
- Evaluate the potential educational and passive recreational resources for the community.

Participants

Phoenix, in partnership with Reclamation, initiated the Phoenix Waste Water Reclamation and Reuse Study to evaluate reclaiming and beneficially using treated municipal wastewater. Phoenix operates the 91st Avenue WWTP on behalf of the Subregional Operating Group (SROG) composed of the cities of Phoenix, Mesa, Glendale, Tempe, Scottsdale, and Youngstown.

Other agencies involved in planning and consultation include the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency (EPA). Each agency also participates in partnership meetings about river management. Others involved in conceptual planning include the U.S. Fish and Wildlife Service, Arizona Department of Water Resources (ADWR), Arizona Game and Fish Department (AGFD), Arizona Department of Environmental Quality (ADEQ), Maricopa County Department of Parks and Recreation, and Maricopa County Flood Control District.

Authority

Reclamation was authorized to conduct research and to construct, operate, and maintain cooperative demonstration projects to provide wastewater and treatment technologies to reclaim municipal wastewater under Title 16 of Public Law 102-575, Reclamation Wastewater and Groundwater Studies. Original studies, however, were conducted under Reclamation's General Investigation Program, with Phoenix sharing the costs. Construction funds were obtained under the Drainage and Miscellaneous Construction Act of 1956.

The cost to construct this facility is not detailed. Financial management of the construction and the research program was provided by Phoenix. The final contract amount was $1,100,000 to construct a total of approximately 16 acres (6.48 hectares [ha]) of demonstration wetlands facilities.

Scope of Report

This report includes the following:

- A history of the planning of the Phoenix Wastewater Reclamation program, which eventually led to the Tres Rios wetlands.
- Area description, including hydrology and biological resources, among other resources.
- Approach taken in designing the wetlands and fulfilling regulatory requirements.
- Wetlands construction activities and time table.
- Description of the facilities.
- Unanticipated events and lessons learned.

Future reports will provide operation, monitoring, and research program results for the first year of operation.

Chapter 2

Background

Alternatives to additional wastewater treatment processes for the 91st Avenue WWTP may have been sought as early as 1990. Early that year, the ADEQ released proposed Navigable Water Quality Standards that would significantly affect the water quality standards for discharges to the Salt River.

An NPDES permit was issued for the 91st Avenue WWTP in 1991 that contained an interim schedule to meet the new limits. The NPDES permit increased the number of metal and organic trace substances requiring regulation (from 4 to 25), established a higher limitation for viruses, and required biomonitoring and whole effluent toxicity testing.

ADEQ estimated the cost to upgrade the plant would be at least $635 million, without providing any additional capacity to the 153 million gallons per day (mgd) output of the plant.

Reclaimed Water Reuse

The effluent from the 91st Avenue WWTP is the primary water supply for much of the year for the downstream riparian habitat. A portion of the effluent is pumped to the Arizona Nuclear Power Plant directly from the 91st Avenue WWTP. Approximately 7 miles downstream, the Buckeye Irrigation District has a contract with Phoenix to divert water from the river for agriculture. These diversions, plus evapotranspiration and soil infiltration, reduce the water remaining in the river to between 45 and 55 mgd in the summer and 100 to 110 mgd in the winter. During 1995 and 1996, effluent releases from the plant to the river averaged between 110 mgd in the summer and about 125 mgd during the winter.

Previous Studies

Phoenix explored different alternatives to meet the water quality requirements at a reduced cost. In the early phase, constructed wetlands and groundwater recharge options were considered.

The most undesirable alternative from an environmental standpoint was to sell reclaimed water to water brokers. This alternative would have created zero discharge to the river, and discharge requirements would still be in effect. Selling the water would benefit SROG, since capital for improving the treatment plant and funds for monitoring discharge would no longer be needed. However, drying up the stream which meandered for many miles downstream from the WWTP would have some adverse environmental consequences.

In 1992, Reclamation began a reclaimed water reuse study for the Phoenix area. Phoenix and Reclamation then began what ultimately would be today's demonstration constructed wetland project called Tres Rios. This study defined alternatives in lieu of expensive wastewater treatment. The study considered constructed wetlands and groundwater recharge, among other alternatives, as a means to treat and recycle effluent. Wetlands and effluent recharge would provide a relatively inexpensive method to treat effluent with little operation and maintenance (O&M) needed. SROG had two components necessary to develop a pilot wetland project—available land and interest in the project.

The *Phoenix/Tucson Water Reclamation and Reuse Study* was published in **March 1993** and focused on four alternatives for the Phoenix area:

- Recharge along the banks of the Agua Fria River
- Recharge within the Agua Fria River flood plain
- Delivery of effluent water to the Gila River Indian Community
- Tres Rios constructed wetland

Phoenix recognized that a recycling project would be subject to regulatory compliance, environmental concerns, treatment requirements, and flood-control measures. Reclamation could participate in flood control if necessary and incidental to a Reclamation-sponsored project, and SROG was interested in providing flood control to neighboring communities downstream from the WWTP. The U.S. Army Corps of Engineers (COE) has primary responsibility for flood control and navigation on navigable waters of the United States. COE has been given a third primary responsibility—ecological restoration of United States waters.

Phoenix attempted to include the COE as a fourth party stakeholder because COE first proposed using constructed wetlands in an unpublished 1992 reconnaissance report examining water-resource related problems in central Maricopa County. The report compared several alternatives and recommended a wetland project at the confluence of the Gila, Salt, and Agua Fria Rivers (hence the name Tres Rios, Spanish for "three rivers"). The wetlands would provide water treatment for the 91st Avenue WWTP, wildlife habitat, and flood control. Although COE would provide some assistance, it could not provide funding for wetlands, wildlife habitat, or flood control due to a low benefit-to-cost ratio.

In **October 1993**, Reclamation and Phoenix published the *Phoenix Water Reclamation and Reuse Study, Tres Rios Demonstration Wetlands, Conceptual Design* report. The report was written in cooperation with AGFD, ADEQ, Maricopa County Department of Parks and Recreation, Maricopa County Flood Control District, and EPA. The report focused on planning, design, cost estimates, and environmental and regulatory processes needed for a pilot wetland project.

By **early 1994**, Phoenix wanted an alternative to improve effluent quality, but one that would continue discharging effluent to the Salt River. In addition, Phoenix was anticipating the need to meet new NPDES permitting guidelines within 3 years. SROG was particularly interested in a treatment system that could remove metals and organic contaminants. It appeared wetlands could at least partially do that. By about June 1994, Phoenix decided to participate in a demonstration constructed wetland project with Reclamation because:

- Phoenix had already constructed a demonstration recharge and recovery project in 1993. Water quality inputs and outputs were well documented. It was not likely Phoenix would construct a similar demonstration recharge project after collecting data from the 1993 project.

- Wetland projects are successful in improving water quality. SROG was particularly interested in how wetlands could improve water quality with respect to the new 1997 NPDES permit for the 91st Avenue WWTP.

- Reclamation had the authority and funding to participate as a cost-sharing partner on a demonstration wetlands project and could provide expertise in treatment wetland processes.

- Regulatory agencies had an interest in (1) maintaining flow in the Salt River and (2) increasing the number of tests on wastewater parameters at the WWTP to ensure good effluent quality in the river.

- Wetlands provide high quality habitat for wildlife.

- Wetlands can serve as an educational and recreational resource to the community.

A technical work group consisting of members from seven agencies, including Phoenix, EPA, and Reclamation, developed a conceptual plan for the general size and location of the wetlands and included planning for wetland diversity. Performance in parallel basins could be compared knowing that slight differences in the basins exist. This wetland diversity was reflected throughout and included plans for two basins each at the Hayfield Site and two other basins placed side by side at the Cobble Site.

A site proposed later was created for low volume flow in a dozen cells called the Research Site. In 1993, the Hayfield Site was designed to be placed on the banks of the Salt River, and the Cobble Site was within the river channel, near the bank. More diversity was added when planners decided that one of the Cobble Site cells would be lined with a clay layer, while the other Cobble Site cell would consist of the natural cobble material present within the Salt River.

Experience gained from the work accomplished in 1993 was subsequently used during design in 1994. See figure 1 for the site location.

In **September 1994**, a cooperative agreement between Phoenix and Reclamation was signed to construct a demonstration wetland project at the 91st Avenue WWTP. Phoenix hired the consulting and design engineering firm of CH_2M Hill to provide a research plan, design, and specifications for a wetlands project.

In **February 1995**, Phoenix published the *Tres Rios Wetlands Research Plan* prepared by CH_2M Hill. The plan documented how the wetlands research should be conducted over the next 2 years. The objectives of the research had not changed since the conceptual design report of 1993. At the time of its publication, CH_2M Hill had final design drawings to construct three demonstration wetland sites. Construction began in March and was completed in September 1995.

Wetland Technology

Free water surface (FWS) wetland technology has been under development for nearly 30 years in the United States. Early laboratory studies in Germany examined the effect of emergent plants on removing organic compounds in industrial wastewater (Seidel 1976). Constructed estuarine ponds with wetland vegetation were loaded with municipal wastewater during the 1960s and early 1970s in North Carolina to study their potential for reuse and aquaculture (Odum 1985). Large-scale engineered natural wetland systems receiving pretreated municipal wastewater were studied in Michigan (Kadlec et al. 1993) and Florida (Ewel and Odum 1984) beginning in the early to mid-1970s. Constructed marsh-pond-meadow systems were under study at the same time in New York (Small and Wurm 1977.) These detailed research programs led to an increasing number of research and full-scale treatment wetland projects treating wastewater from a variety of municipal, industrial, and agricultural sources.

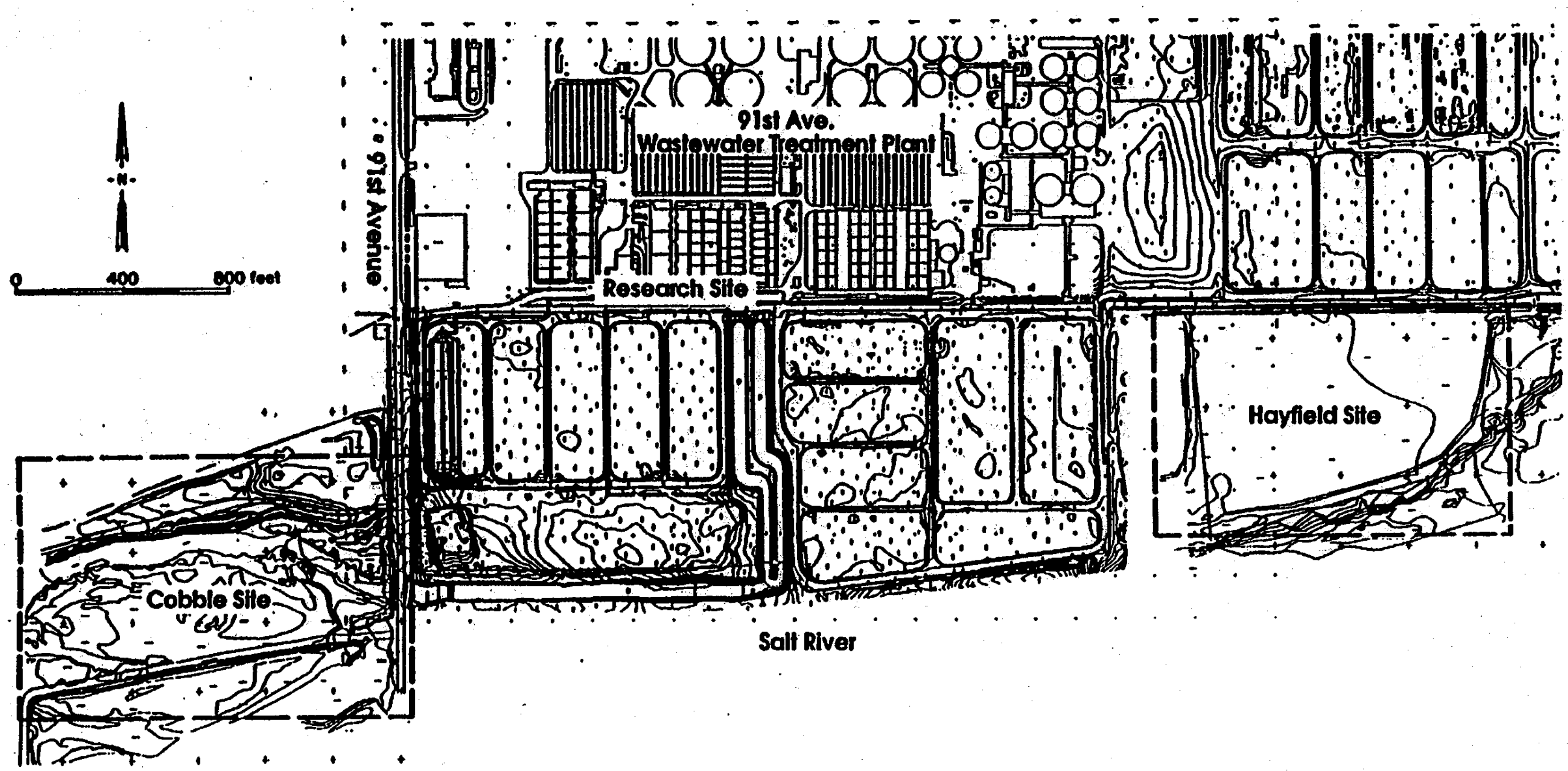

Figure 1.—Tres Rios wetland sites and the City of Phoenix 91st Avenue WWTP.

Subsurface flow wetlands using gravel substrates have been used extensively in the United States (Reed 1992). This technology is generally limited to systems with lower flow rates and less than secondary pretreatment.

Free water surface constructed and natural wetlands providing treatment beyond secondary were built throughout the United States and Canada during the 1980s and 1990s. In addition to providing advanced treatment, a growing number of these systems are being designed and operated to enhance wildlife habitat and to provide public recreation. These FWS treatment/habitat wetlands are typically much larger than the subsurface flow wetlands, including several systems greater than 1,000 acres (400 ha) in size.

Free water surface constructed wetlands are typically shallow vegetated basins. They are designed and constructed to exploit naturally occurring physical, chemical, and biological processes found in natural wetlands to provide solids, nutrient, and pathogen reduction. FWS constructed wetlands take advantage of these natural treatment processes by providing ample time for settling and for the wastewater to react with the many different reactive biological surfaces found in wetlands.

Wastewater normally has higher nutrient concentrations than natural wetland influents; thus, many of the wetland processes and constituent reductions happen at increased rates in FWS constructed wetlands. These increased reaction rates generally result in higher levels of biological production in FWS constructed wetlands receiving wastewater than in natural wetlands (Hammer 1992).

Area Description

The 91st Avenue WWTP and demonstration constructed wetlands are located on the north bank of the Salt River, approximately 2-1/2 miles (4 kilometers [km]) east of the confluence of the Salt and Gila Rivers. The confluence of the Gila and Agua Fria Rivers is 4 miles (6.4 km) downstream from the Salt and Gila River's confluence. The proximity of the demonstration wetland site to these three rivers has earned it the name Tres Rios, meaning "three rivers" in Spanish.

The immediate area surrounding the 91st Avenue WWTP is arid and generally flat. The local topography slopes gradually toward the Salt River, and the entire Phoenix metropolitan area slopes from east to west. The area is marked by agricultural land use (cattle, feed lots, dairy farms, and crops). The Salt River is approximately one-half mile wide in the vicinity of the treatment plant, and historical records show that flows within the Salt River have peaked at nearly 200,000 cubic feet per second. Between flood events, a near constant effluent volume is released from the plant and flows downstream toward the southwest. This plant has partially reestablished what was once a lush vegetative river promoting the growth of riparian trees (cottonwood and willow), small shrubs, and some aquatic vegetation.

Salt River Valley

The western part of the Salt River Valley in which the project is located covers approximately 1,500 square miles (3,885 square km) and is part of the Salt, Gila, Agua Fria, and Hassayampa River watersheds. These rivers provide the western valley with a limited surface water supply which is plentiful only after periods of moderate to heavy rainfall.

Hydrogeology

The lower layer of the basin either overlies or is in fault contact with the red unit and older crystalline rocks. The material consists of playa, alluvial fan, fluvial, and evaporite deposits. Generally, the soil is fine grained and consists of silt, clay, mudstone, siltstone, and finely grained sandstone. Some coarse-grained material exists, and poorly sorted sand, gravel, and conglomerates that are grayish brown or gray are present. Any reddish-brown sand or gravel found at the lower levels of this lower layer are associated with detritus material from the red unit. Calcium carbonate may form cement that reduces the porosity of some of the coarse-grained deposits.

This lower layer may be as thin as 1,500 ft (457 m) near the basin margins and may be more than 11,000 ft (3,353 m) thick near the middle of the basin. In the area where the Tres Rios demonstration project is located, this lower layer could be anywhere from 2,000 to 5,000 ft (610 to 1,524 m) thick.

The middle unit consists of playa, alluvial fan, and fluvial deposits of silt, clay, siltstone, silty sand, and gravel. Most of the unit is weakly consolidated, but moderately to well-cemented siltstone occurs locally, and calcium carbonate cement is common.

The thickness of this middle unit ranges from 0 ft near the mountains to 800 ft (244 m) west of Luke Air Force Base and south of Glendale.

The upper layer of the basin consists mostly of flood plain and alluvial fan deposits that are largely gravel, sand, and silt. Most of the layer is unconsolidated. However, alluvial fan deposits near the mountain fronts, the deposits underlying terraces near mountain fronts, and major streamcourses may be strongly cemented by caliche. Deposits near the Salt and Gila Rivers contain more than 80 percent sand and gravel, and the upper layer is approximately 400 ft (122 m) thick near the confluence of the Salt and Gila Rivers. Near the basin margins, this layer thins to approximately 200 ft (61 m) in thickness or less. Other smaller areas of greater than 80 percent sand and gravel occur in some of the local rivers and arroyos.

Climate

The southern Arizona desert is predominantly a dry climate with low humidity. However, periods of high humidity occur for 6 to 8 weeks during the latter part of the summer as tropical moisture pushes northward from Mexico. This weather pattern has been termed "monsoonal flow" and is sometimes associated with localized intense rainfall and high winds. The highest humidity occurs during the months of December, January, and February, although it is not as noticeable because of the cooler temperatures. Overall, a relatively dry climate persists year round. Total rainfall in the Phoenix area is between 6 and 8 inches in most years.

Wide temperature fluctuations can occur due to the low humidity. Winters are generally cool during the day and cold at night. Summers are hot during the day and warm at night.

Table 1 shows average temperatures and humidities taken by averaging the last 9 years of weather data for the Phoenix area. Weather data at the demonstration wetlands is not available, and the research program is using weather data from the local area HazMet weather service.

Table 1.—Average high and low temperatures in degrees Fahrenheit (°F) (°C as C), and average relative humidity for the Phoenix area, using successive weather data from 1988 to 1996

Weather item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High temperatures	66 19C	71 22C	75 24C	84 29C	91 33C	101 38C	103 39C	101 38C	97 36C	88 31C	74 23C	66 19C
Low temperatures	41 5C	46 8C	49 9C	56 13C	63 17C	71 22C	77 25C	77 25C	71 22C	60 16C	47 8C	40 4C
Avg humidity	55	50	45	30	24	19	33	40	39	38	45	53

The definition of macroclimate is that climate pertaining to the Phoenix area and surrounding communities. The microclimate is that weather immediately surrounding and affecting the wetlands, which may also be affected by the wetlands. The wetlands could significantly affect both temperature and relative humidity in the immediate vicinity.

Although easy to overlook, the elevation of the wetlands is lower than the elevation of the weather station that provided the data in the table above. The weather station is located at the intersection of 23rd Avenue and

Greenway in Phoenix at an elevation of 1315 ft (401 m). The elevation of the wetlands is approximately 1000 ft (305 m). The difference in elevation results in warmer daytime temperatures at the wetlands; but due to the location of the wetlands, nighttime temperatures are cooler.

Potentially hotter daytime temperatures will not adversely affect the wetlands. Aquatic vegetation prefers hotter temperatures, although it is unknown at what extreme temperature they will begin to wilt.

The nighttime temperatures at the Salt River will be cooler than the average nighttime temperatures provided. Since Phoenix nighttime temperatures are close to freezing a few nights of the year, a few degrees can make the difference between a frost kill along the Salt River and no frost several hundred feet away from the river.

Nighttime temperatures are expected to be cooler within the Salt River channel due to an elevation difference of some 15 to 25 ft (4.6 to 7.6 m) between the Salt River bottom and the terrain outside the river. Since the wetlands are located both within the channel (Cobble Site) and close to it (Hayfield Site), the cooler temperatures do affect them to some degree.

The cooling phenomenon being described takes place after dark, once solar radiation is no longer present to evenly distribute heat across the terrain. During the night, cold air drains into the lower portions of the region by gravity flow because cold air is denser than warm air.

Although it is difficult to draw parallels between the health of the plants and temperature variations, it is possible that the cool air along the river bottom is affecting one cell more than others. Infrared aerial photographs of the Hayfield Site, taken during the winter of 1996-97, show that plants in cell H1 are growing more vigorously than those in cell H2. Cell H1 lies about 4 to 5 ft higher than cell H2, and some 100 ft (30.5 m) farther from the river, which may mean H2 is more protected from the effects of the infringing cold air layer. This theory, however, does not hold true with the Cobble Site cells. It is possible that cell C2 is more affected than C1 because of its proximity to the river, yet the plants show more life in C2 than in C1. C1 should be warmer at night due to the warm effluent which runs beside it. The difference in plant life at the Cobble Site cells during winter may be related to other factors (i.e., other differences in the two wetlands versus the similarity of the cells at the Hayfield Site).

Variations in plant life at the Hayfield Site during the winter may not be related to, or may be only slightly related to, the microclimate. Other factors may be responsible for the health of plant life during the winter, although microclimate effects should not be overlooked.

Another microclimate variable is humidity. It is hypothesized that the humidity at the wetlands varies substantially more than the averages shown in the above table during the warmer months of the year. This is possibly due to the readily available moisture in the wetlands which easily volatilize with heat. During the summer, moisture from the wetlands is given off in the form of evaporation or transpiration, and the moist air tends to "hold in" the surrounding heat; thus, the wetlands are warmer than the surrounding air temperature.

Higher humidity also plays a role in the difference in temperatures at or near the freezing point; but in a dry climate, the effect is small. Humidity above background at the wetland site is related to the easy volatilization due to the effects of heat. Evaporation does not readily occur during the cooler winter months compared to the summer months. Therefore, it is expected that the humidity, although higher around the wetlands than in Phoenix proper, will not be substantially higher during the winter. This additional increment in humidity can, however, have the effect of producing excess frost if temperatures fall below freezing. In general, higher humidity at temperatures near freezing can have the effect of feeling colder than air with less humidity. This can have an adverse effect on aquatic vegetation which primarily prefers warmer air.

These effects are neither documented nor monitored, and no actual data is provided. Interestingly, the adverse effects of cold weather have had a significant effect on the wetlands in 1996-97. After the winter of 1996-97, the bulrush have had regrowth problems. Fewer bulrush shoots were observed during March and April 1997 compared to the same period a year earlier.

Dates on which frost could have settled onto the sites (times when nighttime temperatures dropped to 35 °F [1.7 degrees Celsius (°C) or less]) are listed in table 2. In one year's time, a comparison of the number of potential days of frost and how the bulrush responded to regrowth can be made.

Table 2.—Potential frost nights during the winter of 1995-96 at the Tres Rios Demonstration Constructed Wetlands

No.	Dates	Phoenix temperature Fahrenheit (°C)
1.	December 21, 1995	35 (1.7)
2.	December 22, 1995	35 (1.7)
3.	January 3, 1996	33 (0.5)
4.	January 21, 1996	33 (0.5)
5.	January 23, 1996	33 (0.5)
6.	January 24, 1996	33 (0.5)
7.	January 25, 1996	32 (0)
8.	February 27, 1996	34 (1.0)

Note: A potential frost night is defined by a nighttime temperature of 35 degrees Fahrenheit (1.7 °C) or less in Phoenix, which at the 91st Avenue WWTP and the Salt River may have accounted for frost.

Biological Resources

Historically, extensive marshes and woodlands dominated the flood plains of southwestern desert rivers. Accounts from early travelers such as Father Jacobo Sedelmayr (a Jesuit priest) described the Salt/Gila confluence as abundant with fields of reed grass and stands of cottonwoods and willows (Rea 1983). According to Amadeo Rea (1983), the confluence of the Santa Cruz, Salt, Agua Fria, and Hassayampa Rivers created a vast marshland the likes of which we can scarcely imagine today. By 1950, all the habitat was gone as a result of upstream dam construction, water diversion, and groundwater pumping.

All the major river systems in Arizona have been dammed since 1904 (CH_2M Hill 1997). No natural flow (other than flood releases) occurs in the Salt River downstream from Granite Reef Dam. Habitat along the lower Salt and Gila Rivers (project area) has been created and sustained, in part, by effluent discharge from local wastewater treatment plants.

Interruption of the natural streamflow through dam construction and diversion for irrigation and urban use has resulted in significant reductions in riparian habitat (Arizona Riparian Council [ARC], 1994). Without flood-induced scour zones, cottonwood seeds lack suitable substrate to germinate. Reduced surface flows and infrequent aquifer recharging floods have lowered the water table beyond the root zone for riparian trees.

The project area lies along the lower Salt River, approximately 2 miles upstream from the Gila River confluence. The majority of native habitat occurs along the Salt/Gila corridor. Much of the surrounding area has been converted for agriculture or residential development. The riverine corridor in the project area has been highly disturbed by altered streamflows, resulting in greater flood scouring, unauthorized dumping, and a flood-control project which removed vegetation along a 1,000-foot- (ft) wide corridor (Errol L. Montgomery & Associates, Inc., 1988).

Habitat Characteristics. Habitat within the project area is typical of the Sonoran Riparian Deciduous Forest (Brown 1982). The dominant vegetation is a mixed association of Fremont cottonwood (*Populus fremontii*), Gooding willow (*Salix goodingii*), and saltcedar (*Tamarix ramosissima*) located along the main channel of the river. Small patches of marsh habitat dominated by cattail (*Typha* sp.) occur in areas of perennial flow (CH_2M Hill 1997). Pockets of mesquite (*Prosopis velutina* and/or *P. glanulosa*), remnants of the once dominant bosques (dense growth of trees and underbrush) which covered the flood plain terraces of the southwestern river systems, are scattered along the riverbank.

The surrounding upland habitat is classified in the Saltbush Series of the Lower Colorado River Valley Subdivision of the Sonoran Desertscrub (Brown 1982). The dominant plants include saltbush (*Atriplex* sp.), wolfberry (*Lycium* sp.), and mesquite. Most of this habitat type has been altered by development.

The Tres Rios demonstration project has three separate constructed wetland features, all located near 91st Avenue and the Salt River. The Research Site cells, located in sludge basins within the 91st Avenue WWTP, had no natural habitat present and will not be discussed further.

The Hayfield Site was constructed in a 16-acre fallow agricultural field on a terrace adjacent to the river. The site was sparsely vegetated with annuals. Adjacent to the Hayfield Site, within the Salt River channel, is a small side channel bordered by riparian vegetation consisting primarily of cottonwood, willow, and saltcedar. Between the agricultural field and the riparian corridor is a small community of mainly mesquite, Mexican paloverde (*Parkinsonia aculeata*), saltbush, wolfberry, tree tobacco (*Nicotinia glauca*), and Russian thistle (*Salsola* sp.).

The Cobble Site is located in the Salt River channel along the north bank adjacent to the 91st Avenue WWTP effluent channel. The site is characterized as an alluvial deposit consisting of cobbles, gravel, and sand. Most of the vegetation was scoured during the January 1993 flood. The remaining vegetation consisted entirely of scattered, immature (< 5 ft high) saltcedar. A linear strip of riparian vegetation borders both sides of the effluent channel and the north side of the Cobble Site. South of the Cobble Site, the Salt River channel is approximately 0.5 mile wide.

Wildlife. Riparian areas are among the most productive ecosystems in the world (ARC 1994) and are a particularly efficient converter of solar energy. Through photosynthesis, plants convert sunlight into plant material or biomass and produce oxygen as a byproduct. This biomass serves as food for a multitude of animals, both aquatic and terrestrial (ARC 1994). Riparian habitat supports 60 to 75 percent of Arizona's resident wildlife (ARC 1994). Riparian areas have been recognized as critical habitat for neotropical migrants, such as southwestern willow flycatcher (flycatcher), summer tanager, Bell's vireo, yellow warbler, and yellow-billed cuckoo.

Riparian habitats provide travel corridors for deer, mountain lion, javelina, coyote, bobcat, and other animals as they move through desert areas (ARC 1994). Small mammals, such as mice, woodrats, cotton rats, skunks, and bats depend on riparian areas for protection and food. Riparian areas are also home to a diverse array of reptiles and amphibians.

Wildlife diversity in agricultural areas is generally lower than in riparian areas. However, in a study of agricultural areas and wildlife, Anderson and Ohmart (1982) found that field margins, canals, and human- inhabited areas supported high bird densities and species numbers. In some cases though, the high numbers were associated with non-native species such as house sparrows and starlings (Anderson and Ohmart 1982). Although agricultural areas are important to shorebirds, ducks, and geese during migration and winter, few riparian birds traveled more than 0.4 km (0.25 mile) into agricultural areas (Anderson and Ohmart 1982). No riparian bird breeds in agricultural crop land (Anderson and Ohmart 1982). Few species benefit when riparian habitat is cleared for agriculture, but bird populations may be enhanced when agricultural land lies immediately adjacent to riparian vegetation (Anderson and Ohmart 1982).

Wildlife found in agricultural areas may include small mammals, such as deer mice, pocket mice, and cotton rats. During the winter months, agricultural areas, especially edges, are used extensively by many species of sparrows as well as raptor species, such as the northern harrier.

The fallow agricultural site (Hayfield Site), because of its small size and lack of vegetation, supported a limited number of species. A preconstruction avian survey of the area recorded 10 species: killdeer, loggerhead shrike, redtail hawk, savannah sparrow, mourning dove, starling, Abert's towhee, great-tailed grackle, dark-eyed junco, and water pipet. At least four species (red tail hawk, great-tailed grackle, starling, and Abert's towhee) were present as a result of the adjacent habitat. While taking a census on the fallow field, 21 avian species were noted in the adjacent riparian habitat (Reclamation files).

The cobble area provides minimal habitat value, predominantly for species that prefer open, sparsely vegetated habitats, such as the killdeer. A preconstruction avian survey found two species: mourning dove and water pipet.

Threatened and Endangered Species. In September 1993, the Fish and Wildlife Service (Service) identified 3 endangered species, 1 proposed, and 13 candidate species (see table 3) as possibly occurring in the project area. Reclamation submitted a biological assessment (BA) to the Service which concluded no federally listed, proposed, or candidate species will be affected by the project. The Service concurred with the BA in a memorandum dated May 26, 1994.

The BA concluded that no foraging or roosting habitat for the lesser long-nosed bat occurs in the project area. The foraging habitat present for the peregrine falcon is minimal, compared with the total range available for this species. No clapper rails occur within the project area (Ron McKinstry, Service, personal communication, September 28, 1993).

Table 3.—Listed and candidate species within the project area in September 1993[1]

ENDANGERED	
Peregrine falcon	*Falco peregrinus*
Yuma clapper rail	*Rallus longirostris*
Lesser long-nosed bat	*Leptonycterus curasoae yerbabuenae*
CANDIDATE CATEGORY 1	
Cactus ferruginous pygmy-owl	*Glaucidium brasiliarum cactorum*
CANDIDATE CATEGORY 2	
Ferruginous hawk	*Buteo regalis*
Loggerhead shrike	*Lanius ludovicianus*
California leaf-nosed bat	*Macrotus californicus*
Spotted bat	*Euderma maculatum*
Yavapai Arizona pocket mouse	*Perognathus amplus amplus*
Northern Mexican garter snake	*Thamnophis eques megalops*
Chuckwalla	*Sauromalus obesus*
Sonoran desert tortoise	*Gopherus agassizi*
Lowland leopard frog	*Rana yavapaiensis*
Gila chub	*Gila intermedia*
Desert sucker	*Pantosteus clarkii*
Sonora sucker	*Catostomus insigus*
Roundtail chub	*Gila robusta*

[1] Since 1993, two additional species have been federally listed as endangered (southwestern willow flycatcher and the cactus ferruginous pygmy-owl). The Candidate 2 category was deleted from consideration under the Endangered Species Act.

Reclamation personnel participated in subsequent clapper rail surveys in 1996 and 1997; no clapper rails were identified in the project area. Although clapper rails have been occasionally reported above and below the 91st Avenue WWTP, the main concentration occurs approximately 20 miles downstream, in the Arlington Valley.

Two species of cactus ferruginous pygmy-owl (owl) and flycatcher were not listed at the time the project was initiated. The owls were federally listed on March 10, 1997. By this time, the project had been operating for 2.5 years. The owl was included in the 1994 BA as a Candidate Category 1 species. No owls have been identified in the general area, and implementation of the project would not affect the owl. The flycatcher was federally listed on February 27, 1995. However, this species was not included in the 1994 BA, and no additional Endangered Species Act (ESA) coordination was conducted. No riparian habitat was disturbed, and the flycatcher was not recorded in the area; consequently, this species would not be affected.

No flycatchers had been recorded nesting in the area since project operations began (AGFD 1997 and personal communication, Susan Sferra, AGFD, date unknown).

Currently, no proposed or Candidate Category 1 species exist in the project area. Candidate Category 2 was deleted from the ESA. Information on former Candidate Category 2 species is provided for reference purposes only. No habitat for candidate category species would be affected. The ferruginous hawk (winter visitor) and loggerhead shrike use the area outside the riparian corridor. No roosting habitat is available for either the spotted or California leaf-nosed bats. The Gila chub and roundtail chub do not occur in this reach of the Salt or Gila Rivers. Only two species (Mexican garter snake and lowland leopard frog) may actually occur in the project area. If present, these species would not be affected by the wetland development.

Several State listed species[1] occur in the project area on a seasonal basis. During the 1994 flycatcher surveys, the AGFD discovered both least bittern (candidate) and yellow-billed cuckoos (threatened) (Troy Corman, AGFD, personal communication, October 4, 1994). Habitat requirements for the southern yellow bat are not clearly understood, but they are believed to roost in fan palms or leafy vegetation in low to mid-elevation riparian areas (AGFD 1992). Habitat is available for this species in the project area, although no records have been recorded. The nearest record is in Tempe, Arizona, on the Arizona State University campus (Hoffmeister 1986). The following species also occur in the project area either as summer visitors or spring/fall migrants: great egret, snowy egret, cattle egret, and belted kingfisher. Habitat is also present for the American bittern, a rarer species. NOTE: In April 1996, an American bittern spent several weeks at the Hayfield Site. The red bat is normally found at slightly higher elevations and is absent from most deserts (Hoffmeister 1986). The nearest record of occurrence is in the Sierra Ancha Mountains, approximately 80 miles away (Hoffmeister 1986).

Cultural Resources

An archaeological Class I overview revealed that prehistoric archaeological site AZ T:12:2(ASU) was in the vicinity of the project area. The site was described as a "sherd area" by Arizona State University researchers during a 1963-64 survey of the Salt River from Granite Reef to the Salt/Gila confluence. The site did not contain any rooms, walls, mounds, bedrock mortars, or agricultural features. The site consisted primarily of ceramics (both plain and decorated ware) with limited chipped stone. No shell or bone

[1] Note: Since project initiation, the State list of threatened and endangered species has been undergoing a revision. The document is still in draft form.

was identified. Ceramics present at the site suggest an occupation from the Snaketown to Sacaton period of the Hohokam chronology.

Reclamation archaeologists completed a Class III cultural resource inventory on a 30-acre area encompassing the Hayfield Site (Reclamation 1994). Limited artifactual materials (50 plainware sherds and 20 lithics) were identified. The artifact density was not sufficient for this area to be defined a site as established by the Arizona State Museum. Reclamation concluded that no significant cultural resources would be affected by construction of the Tres Rios Demonstration Constructed Wetlands. This assessment received State Historic Preservation Officer concurrence on October 11, 1994.

Cultural resource monitoring was also conducted during the excavation of six geologic test pits. The pits were monitored for subsurface features or other evidence of prehistoric activities. No features or other evidence of human occupation were found.

On April 22, 1995, human remains were discovered during excavation of a water pipeline trench for the Hayfield Site. Identification, recovery, and analysis of the remains were completed by Archaeological Consulting Services, Ltd (ACS). The following description is taken from the report prepared by ACS (1995). Two individuals, an adult female aged 40 to 55 years and an adult male of undeterminable age, were recovered. Both individuals received damage as a result of the backhoe operations. The proximity of these individuals suggests they may have been related to one another or belonged to the same group.

A large number of artifacts (146) were recovered, but no items characteristic of Hohokam mortuary contexts were found. The nature of the assemblage suggests a trash deposit of chipped stone debris and discarded fragments of ground and worked stone tools within a late classic period Hohokam habitation site (ACS 1995). It was determined that the site was not eligible for the *National Register of Historic Places* due to the lack of integrity (ACS 1995).

Chapter 3

Design Development and Planning

Wetlands occur across many climatic zones from the arctic to the desert. In the arid Southwest, natural wetlands play important roles in providing wildlife habitat and improving water quality. Constructed wetlands are becoming increasingly popular for wastewater management (CH_2M Hill 1995). Currently, 26 wetlands exist in Arizona for wastewater treatment, and another 24 are awaiting permitting or are under construction.

This chapter explores some of the design considerations and regulatory requirements for permits before construction can begin.

Design Considerations

Tres Rios demonstration wetlands were designed primarily for treatment, water balance, nuisance potential, and to minimize construction, operation, and related costs. Wildlife habitat and education and recreation are secondary benefits of the program. Tres Rios demonstration wetlands facilities are intended to demonstrate the whole range of design and site development considerations. Planning and research results from the demonstration wetlands will later be used to plan and design a full-scale wetland development.

Treatment Performance

The wetland treatment process is one of the most fascinating aspects of a wetland system and is usually the greatest reason why a municipality constructs wetlands. Wetlands reduce the concentrations of many harmful constituents found in waters and wastewaters. The traditional constituents found in wastewaters are of interest from a research perspective. Important water quality parameters, such as biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), are a part of these traditional constituents. A wetland's efficiency and rate of removing total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP), trace metals, trace organics, and pathogens are of interest in traditional treatment wetland performance as well.

Unlike the performance of a mechanical system responsible for reducing a pollutant (which can be modeled as a volume-based reactor), the treatment performance of a wetland is generally described as an area-based function. If steady state conditions are assumed, the treatment performance of a wetland can be described as a first-order, area-based kinetic function. The general formulation of the first-order, area-based kinetic equation is:

$$J = kC$$

where: J = the reaction rate (grams per square meter per year)
k = the first-order, area-based rate constant (meters per year [m/yr])
C = the pollutant concentration (grams per cubic meter {g/m$^{3]}$)

For incoming and outgoing concentration levels from a wetland, the above expression can be integrated to provide the following equation which relates concentrations to a hydraulic (operating) loading rate:

$$\ln(C_2/C_1) = -k/HLR$$

where: C_1 = the inflow concentration (g/m^3)
C_2 = the outflow concentration (g/m^3)
HLR = hydraulic loading rate (m/yr)

The hydraulic loading rate, HLR, can be estimated as the following.

$$HLR = Q/A$$

where: Q = inflow (cubic meters per year)
A = wetland area (square meters)

Water Balance

One of the primary water balance functions for operating a wetland is the hydraulic loading rate (HLR) function. Maximizing the treatment at a specific HLR is desirable, but the specific HLR is unknown until a trial and error process of loading rates is attempted. HLRs between 1.0 and 5.0 centimeters per day (cm/d) are fairly typical in an operationally driven treatment wetland.

Another function related to HLR is the hydraulic retention time (HRT). Sometimes called detention time, the HRT is an estimate of the time a water molecule spends in the wetland, based on the loading rate and the volumetric size of the wetland. HRT is determined as the volume of the wetland divided by the inflow. The optimum detention time is typically between 7 and 14 days for domestic and industrial strength wastewaters. A shorter detention time (6 to 7 days) has been suggested that will provide optimal treatment of primary and secondary wastewater. Before a trial and error of HLRs, it was estimated that the HRT for Tres Rios would be in the range of 3 to 7 days.

The depth at which water is allowed to pond in a wetland is also related to the water balance. This depth can be altered at Tres Rios in two ways. Variations in inflow pumping can affect water depth, and altering the level of outflow weir gates can affect depth. The Tres Rios wetlands were designed for an average depth of 18 inches (45.7 centimeters [cm]). However, this depth has been reduced somewhat by the detritus material now present on the basin floor. In portions of cell C1, it is estimated that detritus material may be responsible for lowering the water depth to as little as 12 inches (30.5 cm). Without harvesting, it is anticipated that future changes in water depth are likely. Watson et al. (1989) recommends depths of 10 inches (25 cm) for marshes and about 2.0 ft (60 cm) for ponds as general guidelines for constructing wetland treatment systems.

Wetlands can be arranged into multiple cells that can be operated as a single cell, as parallel cells, or in series. The Tres Rios cells can be operated in any of these three ways. In addition, three loading alternatives exist, such that one or more of three types of loading alternatives can be implemented. The three types of systems are plug-flow (a once through, gravity fed wetland), step feed (typically a combination of recirculation with solids removal and a provision for carbon contact toward the end of system), and recirculation. The Tres Rios system is a plug-flow system.

Wildlife Habitat

Although the primary objective of the demonstration wetland revolved around water quality issues, the advisory group recognized that wetland habitat provided other benefits. Two secondary objectives were identified, one of which was to "enhance wildlife habitat." The research plan included a component related to determining the design/operation factors that are important for wildlife enhancement (CH_2M Hill 1995). The awarding of the Heritage Grant from the Arizona Game and Fish Department allowed for development of urban habitat, such as the ramada, viewing blinds, landscaping, and birdhouses.

The term "wetland" is used to describe ecosystems that are transitional between uplands and deeply flooded habitat (Service 1979, Hammer 1989, and Kadlec and Knight 1996). The productivity of wetlands far exceeds that of most fertile farm fields (Hammer 1989). In natural wetlands, nutrients are continually washed into the system from the surrounding upland habitat. This influx of nutrients supports an abundance of macro and microscopic vegetation which converts the matter to food for higher life forms. Wetland productivity is not limited to vegetation. Aquatic insects, amphibians, fish, birds, and mammals all feed on the existing vegetation or one another. This assemblage of wildlife, in turn, attracts other animals from nearby habitats, thereby extending the productive influence of the wetland far beyond its borders (Hammer 1989).

Although wildlife enhancement was not the major purpose for the demonstration wetland, proper planning can enhance the value of wastewater treatment wetlands for wildlife. Hammer (1989) offers the following suggestions to enhance wetlands for wildlife:

- Establish vegetation for wildlife food and cover.
- Construct wetlands that maximize edge.
- Provide transition zones into the upland habitat.
- Use existing wildlife corridors.

Education and Recreation

Constructed wetlands provide people not only the opportunity to visit the site and learn about treatment processes, project value, wildlife, and plants, but they also provide the wetland experts the opportunity to collect data on the numbers of people interested in these types of systems. By making these systems available to visitors, the visitors can share their ideas with those operating the system. Not all is known about wetlands, and it is important that new ideas be shared between visitors and managers of the wetlands.

Nuisance Potential

Nuisance potential in the research plan is associated with mosquito breeding. Much time has been and will continue to be devoted to this issue because of health concerns.

Because of the high quality of effluent and high dissolved oxygen content, the potential for mosquito development is high. The relationship between Gambusia fish and mosquito breeding is considered a wildlife research topic. Managers intend to observe the fish controlling mosquitoes and to determine whether the fish population is sufficient during the summer when mosquito breeding in Arizona is most prevalent.

Construction, Operation, and Related Costs

The research in this area is related to construction, operation, and miscellaneous costs related to wetlands in arid climates. More information is needed about developing and constructing this low cost treatment alternative to provide the maximum benefit to smaller and less affluent communities. The permitting process related to design and construction of wetlands for treatment systems needs to be more fully understood to minimize construction expenses. Phoenix recorded and tracked unit cost expenses of constructing the demonstration wetlands, which is described under chapter 4, "Construction Activities."

Wetlands provide wastewater treatment at a lower operating cost than traditional wastewater systems. As a natural system, it is difficult to know what size wetland is adequate for treatment and how incremental increases in size will improve water quality. Wetlands require substantially less funding for operation and maintenance than traditional treatment systems. One operator can manage dozens of acres of wetlands where no detrimental effects are present within the system, whereas the operator of a traditional system would have to devote his full effort to maintaining a healthy, stable system.

Miscellaneous costs are incurred and should be allocated for operation and maintenance of a treatment wetland. In general, wetlands are a study not only for treatment and habitat, but also for how much capital is needed for construction, operation, and maintenance.

Regulatory Compliance

Compliance with several regulations was required before construction of Tres Rios Demonstration Constructed Wetlands. They are briefly described in the following sections.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) of 1969, as amended, requires the responsible Federal agency to assess impacts to the human environment before federally funded or sponsored actions are implemented. In October 1993, a conceptual design report was prepared (Reclamation 1993). This document included preliminary environmental and regulatory analysis for the demonstration program. The preliminary analysis determined the level of compliance required under the various regulatory laws (NEPA, ESA, National Historic Preservation Act [NHPA], etc.) and indicated potential "showstoppers."

Categorical exclusion (PXAO-95-12) was prepared for the demonstration wetland project on January 27, 1995, to comply with NEPA.

Clean Water Act - Section 404

Two sections of the Clean Water Act (CWA), as amended, apply to the demonstration project. Section 402 of the CWA requires a permit to discharge pollutants into "waters of the United States" under the NPDES.

Water can be discharged to the treatment wetlands under the existing permit held by Phoenix.

Section 404 of the CWA requires a permit to discharge dredged or fill material into "waters of the United States." Reclamation received a delineation of wetlands located within the project area from the COE, and a section 404 Nationwide Permit 23 was issued for the demonstration constructed wetland facilities on February 21, 1995.

Endangered Species Act

All Federal agencies are required by Section 7 of the Endangered Species Act of 1973, as amended, to ensure their actions do not jeopardize the continued existence of any species federally listed as threatened or endangered.

Informal consultation (species list request) with the Fish and Wildlife Service was conducted on September 28, 1993. A BA of the proposed project impacts to the peregrine falcon, lesser long-nosed bat, and Yuma clapper rail was prepared and submitted to the Fish and Wildlife Service on March 23, 1994. The BA concluded that the project would not affect any listed, proposed, or candidate species. The Service concurred with Reclamation's BA in a memorandum dated May 26, 1994.

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act of 1934, as amended, requires Federal agencies proposing to construct or to issue permits for construction of projects affecting streams, lakes, or other watercourses to consult with the Service and State wildlife agencies before final approval of the project. Both the Service and AGFD have actively participated in developing the conceptual design of this project.

National Historic Preservation Act and Other Related Laws

Several Federal and State laws or regulations apply to developing projects that may potentially affect any historic or prehistoric properties. These laws include the NHPA and the Native American Graves Protection and Repatriation Act.

Both Class I (records search) and Class III (intensive) cultural resource surveys were conducted. The Class III survey report was submitted to the Arizona State Museum on September 12, 1994. The artifact density was not sufficient to define Tres Rios constructed wetland site as a cultural site as established by the Arizona State Museum.

Human remains were discovered during excavation of a water pipeline trench. Identification, recovery, and analysis of the remains were completed by ACS. It was determined that the site was not eligible for the *National Register of Historic* places because it did not meet the established criteria (ACS 1995).

Chapter 4

Construction Activities

Earthwork, piping, concrete inlet and outlet structures, weir installations within the concrete structures, and planting are the focus of the constructed wetlands demonstration program construction report. This report does not provide details of minor occurrences during construction. This section of the report, however, does provide an overview of how the wetlands were constructed, while providing starting and ending dates, when possible.

Wetland construction began with earthwork and was followed by the construction of concrete structures. Pipelines were constructed from the wetlands to the final contact mixing basin (Plant 3A) where the pump suctions were placed below the elevation of the effluent level in the chlorine contact chamber. Once the cells were fully operational, vegetation was harvested from a borrow site and planted.

Schedule

The larger wetland cells—the Cobble and Hayfield Sites—and research cells were constructed on Phoenix property using Phoenix administrative personnel to issue and administer the contracts. CH_2M Hill provided construction management services for Phoenix.

A construction contract was awarded to ARCHON, Inc., to construct the wetlands, and a notice to proceed was issued February 23, 1995.

Hayfield Site construction began on March 8, 1995. Research Site construction began on March 14, 1995, and Cobble Site construction began on March 23, 1995. The Hayfield Site was substantially completed on June 6, 1995, and the Cobble Site was substantially completed on July 14, 1995. By June 29 of the same year, effluent began to flow into the Research Site cells.

The time line, table 4, shows the start dates of the construction at the three wetland sites and the final completion date.

Earthwork

Earthwork involved excavating the basins, constructing berms, and grading the invert of cells. Final grading was not begun until after most of the earthwork was completed. Final grading was completed just before planting so that basin inverts would not be altered in grade either by natural occurrences or subsequent construction activities.

Table 4.—Tres Rios constructed wetlands demonstration project
Construction time schedule

Description	Early start date
Notice to Proceed	February 23, 1995
Mobilize	March 1, 1995
Survey	March 1, 1995
Submittals	March 1, 1995
Clear and grub Hayfield Site	March 1, 1995
Earthwork - Hayfield Site	March 8, 1995
Clear and grub Cobble Site	March 16, 1995
Earthwork - Cobble Site	March 23, 1995
Clear and grub Research Site	March 7, 1995
Earthwork - Research Site	March 14, 1995
Structures - Hayfield Site	March 24, 1995
Structures - Cobble Site	March 23, 1995
Structures - Research Site	March 29, 1995
Boardwalks	April 13, 1995
Piping	May 4, 1995
Place plant material - Hayfield Site	June 6, 1995
Place plant material - Cobble Site	July 14, 1995
Place plant material - Research Site	June 6, 1995
Construct pump station, electrical/mechanical	June 5, 1995
Access paths, hiking trails, visiting areas	June 1, 1995
Substantial completion not accepted	June 28, 1995
List prepared of items to complete before project complete	July 21, 1995
Original final completion date	July 24, 1995
Substantial completion certificate issued	September 5, 1995

Much of the earthwork requires excavating shallow zones for water approximately 18 inches deep and deep zones that are often 3 ft deeper to allow for areas of open water. The areas of open water prevent the emergent vegetation from covering the entire wetland area.

Each Hayfield cell was constructed with a continuous berm. Earthwork at the Cobble and Hayfield Sites included curved earthwork construction for deep zones. Excavation for the Hayfield Site began with the rough excavation of the basin floor of cell H2. At the Hayfield Site, cell H1, five deep zones, and deep zones at the inlet and outlet locations were constructed. Cell H2 required two deep zones and deep zones at the inlet and outlet locations.

The construction of deep zones at the Cobble Site were identical for both cells C1 and C2. Two medium-sized, curved zones and one large, curved deep zone were constructed for each cell. Two small inlet and outlet deep zones were constructed for each cell. In the direction of flow from inlet to outlet, deep zones were constructed in size from small, medium, large, medium to small zones. After the construction of the deep zones, but before construction of islands, approximately 6 inches (approximately 15 cm) of clay material was placed in the Cobble Site cell C2.

All materials used at the Hayfield Site were taken from the site. Soils were graded to specified slope and arranged such that soils were not compacted beyond what was done by the excavation equipment. Bird nesting islands were constructed in every large wetland cell except cell H1. Six islands were constructed in cell H2—three islands in each open water/deep zone location. Within each of the large deep zone of cells C1 and C2, two islands were constructed close enough together that they form one large island.

Final construction of the cells (except final cell invert grading) was completed on May 23, June 22, and July 6, 1995, for the Hayfield, Research, and Cobble Sites, respectively.

Once the cobble site basins were constructed, submersible pumps and a detachable pipeline were used to fill them with effluent from the discharge channel. Phoenix allowed the contractor to use temporary pumps to supplement the flow because the site was porous. Final grading of the basins was accomplished without much difficulty.

Final excavation and berm construction volumes are shown in table 5.

Table 5.—Earthwork - excavation and berm construction for the Hayfield, Cobble, and Research Site cells for Tres Rios Constructed Wetland Demonstration Program

Site	Excavation (cubic yard)	Berm construction (cubic yard)	Wasted material (cubic yard)
Hayfield, H1	2,800	7,100	2,000 (to Cobble)
Hayfield, H2	15,000	2,600	5,500
Research cells	6,050	4,725	1,325
Cobble cells	3,800	2,000	0

Conveyance and Hydraulic Controls

The demonstration constructed wetlands project systems include appurtenant structures that help to operate the system as projected and to promote plant growth. For Tres Rios, these are access roads, concrete structures, effluent conveyance facilities, pumps, and miscellaneous facilities.

Construction of the basins required developing access to and around the project sites. A grader was used to provide access to each of the three facilities, in and around the basins, and where needed.

Stainless steel pipe was ordered to meet the contractor's timetable. Pipeline construction for the Cobble Site began on May 4 and for the Hayfield Site on May 5, 1995. Both pipelines are 12 inches (30.5 cm) in diameter. The pipeline for the Research Site cells is 8 inches (20.3 cm) in diameter. Pipeline construction involved laying from one-fourth to one-half mile of pipeline to each of three sites. Construction of the pipelines ended for the Cobble and Research Site cells on May 10, 1995, and for the Hayfield Site on May 17, 1995.

On May 16, 1995, equipment for the pumping station began to arrive. On June 5, 1995, work on the pumping station in the chlorine contact chamber began after the chlorine contact chamber for plant 3A was emptied. Construction of the pumping plant station and associated electrical work continued through June and July and ended August 4, 1995. The volume of effluent flow to the sites is controlled with a manual gate valve for each pipeline. The gate valve control is only a few feet from the flowmeter in the direction of flow.

Construction of the inlet and outlet structures began with the inlet splitter box structure for the Hayfield Site on March 5, 1995.

Wetland Vegetation

A landscape plan was developed for emergent marsh and terrestrial vegetation. The actual species planted during construction were those species that occupy the water depth of the demonstration wetlands when planted. Emergent marsh plants were planted during construction to begin the wetland growth and treatment processes. Other terrestrial vegetation would be planted in the landscape later. Planting was the last major construction activity performed at Tres Rios.

The aquatic vegetation planted and the input of water from the treatment plant are common to all sites. Quality of water fed into each of the three sites is generally fairly consistent. Two species of aquatic plant types were planted throughout the sites. They are species of bulrush (*Scirpus* sp.)—the Scirpus validus (soft-stemmed) and S. olneyi (three square). Two other plants were used around the perimeter of the wetland sites in smaller quantities—S. *robustus* (alkali bulrush) and *Eleocharis* spp. (spike rush). The bulrush were transplanted into the Hayfield Site on June 6, 1995. Bulrush at the Cobble Site were planted in basin C2, beginning on July 14, 1995.

The larger of the plants, *Scirpus validus,* was harvested from the Kingman, Arizona, wetland project, which has been in operation since 1978. These plants were then taken to a nursery to develop further, and later transplanted to the Tres Rios site. *Scirpus validus* spreads into a thick, dense, green to dark green mass by spreading rhizomes efficiently. The plant can grow to 6-1/2 ft (2 m) in height. This species should not be confused with the hard stemmed bulrush which has a larger diameter and is a thicker stemmed plant.

The *Scirpus olneyi* was harvested from a nursery in Casa Grande, Arizona, and transported to Tres Rios. The *Scirpus olneyi* has a less dense stem and grows in a slightly less dense pattern overall compared to the soft-stemmed plant described above. It is characterized by having a three-sided stem; hence, it derives its name from the way it looks, "three square." The plant is characterized by a light green color, similar to the color of grass.

Alkali bulrush and spike rush were planted only along the inside perimeter of the cells and in fringe areas for enhancement. The alkali bulrush was purchased from a local Phoenix nursery. The alkali bulrush and spike rush are a small variation of the two plants above, with a soft green color. The plants grow to a maximum height between 1-1/2 and 2 ft (0.5 and 0.6 m).

The larger varieties were allowed to develop to about 1-1/2 to 2 ft (0.5 to 0.6 m) in height before being transplanted. Bulrush were planted by hand on approximately 3-ft centers in all basins. A small spade was used to unearth a small area of soil material. The root stalk was then placed entirely into the ground, with the stem protruding above the soil surface. In every basin, the bulrush were planted from the inlet to the outlet side. Planting in every cell took an average of 5 days. If moist soil conditions had existed throughout, planting should have taken 2 to 3 days.

The cells were planted with one type of bulrush, followed by another type, and the succession continued from one end of the cell to another, until each cell was planted with alternate strips of *validus* and *olneyi*. Both Cobble Site cells were planted with four successive strips of three square and soft-stemmed bulrush. The south cell of the Hayfield Site was planted with three successive strips of three square and soft-stemmed bulrush. The north Hayfield Site was planted with six successive groups of three square and soft-stemmed bulrush.

Submergent vegetation was planted in all the deep zones at Tres Rios. Hornwort (*Ceratophylum*) was planted with little to no success. Within 6 months of being planted, the *Ceratophylum* had disappeared. Although unsure why, it is thought that the plant disappeared due to overgrazing by waterfowl and predation by fish.

Costs

The City of Phoenix tracked the costs of constructing these facilities. Table 6 displays the costs of construction and planting for each of the three sites. Total costs were $1,138,900.

Table 6.—Construction and planting costs of Tres Rios Demonstration Constructed Wetlands

Item	Hayfield Site	Cobble Site	Research Site
Construction	339,400	265,800	354,600
Plants and labor	61,700	58,700	58,700
Total costs	401,100	324,500	413,300

Chapter 5

Facilities Description

Three wetland sites make up the Tres Rios facility located at the 91st Avenue Treatment Plant— the Hayfield Site, Cobble Site, and Research Site. The Hayfield and Cobble Sites are made up of two cells each, and the Research Site is made up of a dozen smaller cells.

Hayfield Site

Approximately one-fourth mile southeast from the treatment facility are two kidney shaped wetland cells called the Hayfield Site (figure 2). The site is about 10 acres (4.05 ha) and includes 3-1/2 acres (1.4 ha) of combined Salt River riparian area and desert. The configuration of open water areas for each cell is different, although the ratio of open water zones to overall surface area is the same—25 percent open water to 75 percent vegetation.

The inlet and outlet deep zones in each cell will have top widths of 28 ft (8.5 m). Each cell is approximately 748 ft (228 m) long by 200 ft (60 m) wide and has aspect ratios of 3.8:1. Exterior berms around both cells have a top width of 12 ft (3.7 m) and 3:1 side slopes. Berms are graded for light vehicle and foot traffic.

The northernmost cell, H1, covers 3.3 acres (1.3 ha). The deep water area is 0.84 acre (0.34 ha). The deep water areas are the inlet and outlet ends of the cell and five intermediate open water areas spaced at about 88-ft (27-m) intervals. Deep zones at cell H1 were 3 ft (0.9 m) below the invert of the cell, 12 ft wide (3.7 m) at the invert, and 30 ft wide (9.1 m) at the top of grade.

The southernmost cell, H2, covers 3.16 acres (1.28 ha). The deep water area is 0.8 acre (0.3 ha). The deep water areas are the inlet and outlet ends of the cell and two intermediate open water areas spaced at 180-ft (55-m) intervals. Cell H2 deep zones were 3 ft (0.9 m) below the invert of the cell, 61 ft (18.6 m) across in the deep zone invert, and 79 ft (24 m) across at the invert of the cell.

Actual percentages of open water areas are less than noted since nesting islands were considered part of the open water areas. Bird nesting islands were constructed in every large wetland cell except cell H1. Six islands were constructed in cell H2. Three islands were constructed in each open water/deep zone location. The islands in cell H2 are roughly 30 to 35 ft (9.1 to 10.7 m) in diameter and approximately 2-1/2 to 3 ft (0.8 to 0.9 m) higher than the water surface.

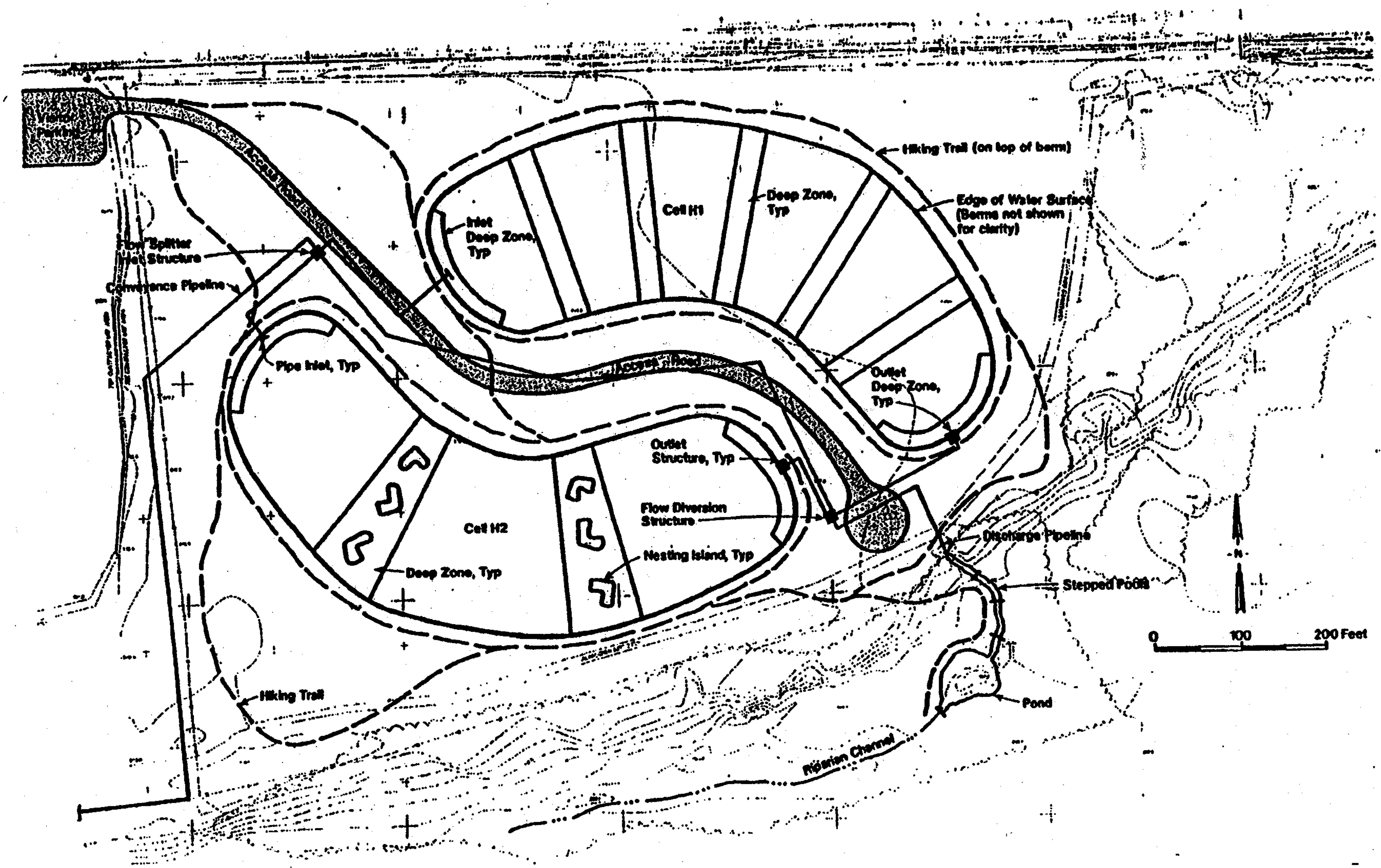

Figure 2.—Hayfield Site layout—Tres Rios Demonstration Constructed Wetlands.

Cobble Site

The Cobble Site is approximately one-half mile southwest of the treatment facility, west of 91st Avenue, and covers about 4.4 acres (1.8 ha). The name is derived from the parent soil material, consisting mostly of river cobblestones and sand. Unlike the Hayfield Site, the Cobble Site is constructed within the Salt River channel (see figure 3). One reason for choosing this location was to observe the effects a flood might have on a bermed wetland should a flood occur.

The two Cobble Site cells are actually one cell separated lengthwise with a berm. The two cells are also similar in configuration with respect to deep water zones and nesting islands. The difference between the two is that the invert of cell C1 is constructed with the parent cobble material. The southernmost cell, C2, is lined with 6 inches of a more impenetrable clay material. Cell C2 is referred to as "lined," and C1 is "unlined." A single exterior berm with a top width of 12 ft (3.7 m) surrounds the two cells and is 2 ft (0.6 m) above maximum water depth. This berm is used only for walking.

Cell C1 is 2.27 acres (0.92 ha) in size. Five open deep water zones account for 15 percent of the surface area, or 0.35 acre (0.142 ha). Cell C2 is 2.24 acres (0.91 ha) in size. Five open deep water zones account for 10 percent of the surface area, or 0.23 acre (0.09 ha).

Two islands were constructed within each of the large deep zones of cells C1 and C2. These islands are also approximately 30 to 35 ft (9.1 to 10.7 m) in diameter. The islands in cell C2 were constructed close enough together that they form one large island about 35 ft (10.7 m) wide and 155 ft (47.2 m) long. Actual percentages of open water areas are less than described because nesting islands have been considered part of the open water areas.

The deep zones at the Cobble Site are identical for cells C1 and C2. Two medium-sized, curved deep zones and one large, curved deep zone was constructed for each cell. Two small inlet and outlet deep zones were constructed for each cell. In the direction of flow from inlet to outlet, deep zones were constructed; the series progresses from small, medium, large, medium, to small deep zones. Small deep zones were constructed 3 ft (0.9 m) deep and 3 ft (0.9 m) across in the direction of flow from the invert of the deep zone. Medium deep zones were constructed 3 ft (0.9 m) deep, 12 ft (3.6 m) across in the direction of flow at the invert, and 30 ft (9.1 m) across at the cell invert. Large deep zones were constructed 3 ft (0.9 m) deep, 72 ft (22 m) across in the deep zone invert, and 90 ft (27.4 m) across at the invert of the cell.

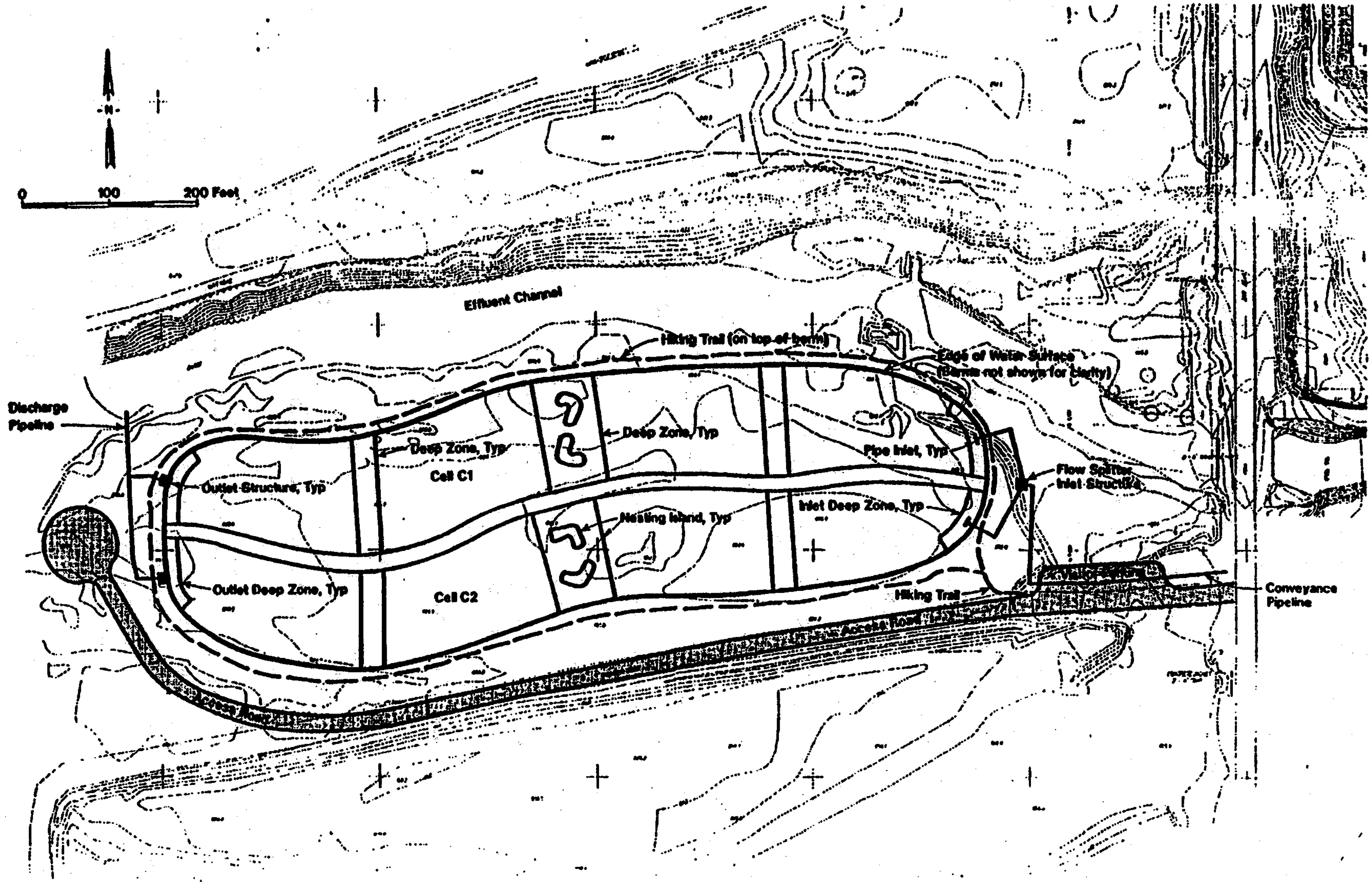

Figure 3.—Cobble Site layout—Tres Rios Demonstration Wetlands.

Research Site Cells

Twelve cells represent the Research Site on the grounds of the 91st Avenue WWTP. The cells, between existing sludge drying beds, are, in fact, a converted sludge drying bed (figure 4). Each cell is approximately 160 ft long (49 m) by 80 ft wide (24 m), each covering 0.30 acre (0.12 ha).

Common to all cells are inlet and outlet deep water zones. The number of intermediate deep zones varies from none to three. The original layout included three cells with no deep water zone, three cells with one intermediate deep zone, three cells with two intermediate deep zones, and three cells with three deep zones.

Effluent to the site is transported via an 8-inch (24.4-cm) pipeline from the chlorine contact chamber. The pipe is split and feeds two splitter boxes, each designed to deliver variable volumes to each of the six cells.

Operation

The research plan contained a section entitled "Wetlands Operation and Monitoring Plan" which outlined how the sites were to be operated and monitored after system startup. The operation and monitoring phase was scheduled to last 2 years.

The first 6 months of this period were expected to be used for startup, plant growth, and operational training; the next 18 months were to focus on wetlands research and data collection. Table 7 provides a recommended schedule of operations for the two constructed wetlands demonstration sites. The operating and monitoring results will be presented in another report.

Table 7.—Preliminary operations schedule for the Tres Rios Demonstration Constructed Wetlands

Operational period	Interval (months)	System/ cell	Average[1] inflow (m^3/d)	Water depth[2] (m)	Description
Startup	0-6	Hayfield	- 600	<0.1	Only enough water to keep soil saturated continuously.
		Cobble	-2,000	<0.1	
Phase 1	7-12	H1	700	0.3	Approximately 5 cm/d to both cells in parallel
		H2	700	0.3	
		C1	900	0.3	Approximately 10 cm/d to both cells.
		C2	900	0.3	
Phase 2	13-18	H1	350	0.45	Approximately 2.5 cm/d to both cells in parallel.
		H2	350	0.45	
		C1	1,800	0.45	Approximately 20 cm/d to both cells.
		C2	1,800	0.45	
Phase 3	19-24	H1	1,400	0.15	Approximately 5 cm/d over both cells operated in series (H1 to H2).
		C1	1,350	0.15	Approximately 15 cm/d to both cells.
		C2	1,350	0.15	

Note: m^3/d = cubic meters per day
[1] gpd = m^3/d X 264
[2] Average water depth in emergent areas: ft = m X 3.3

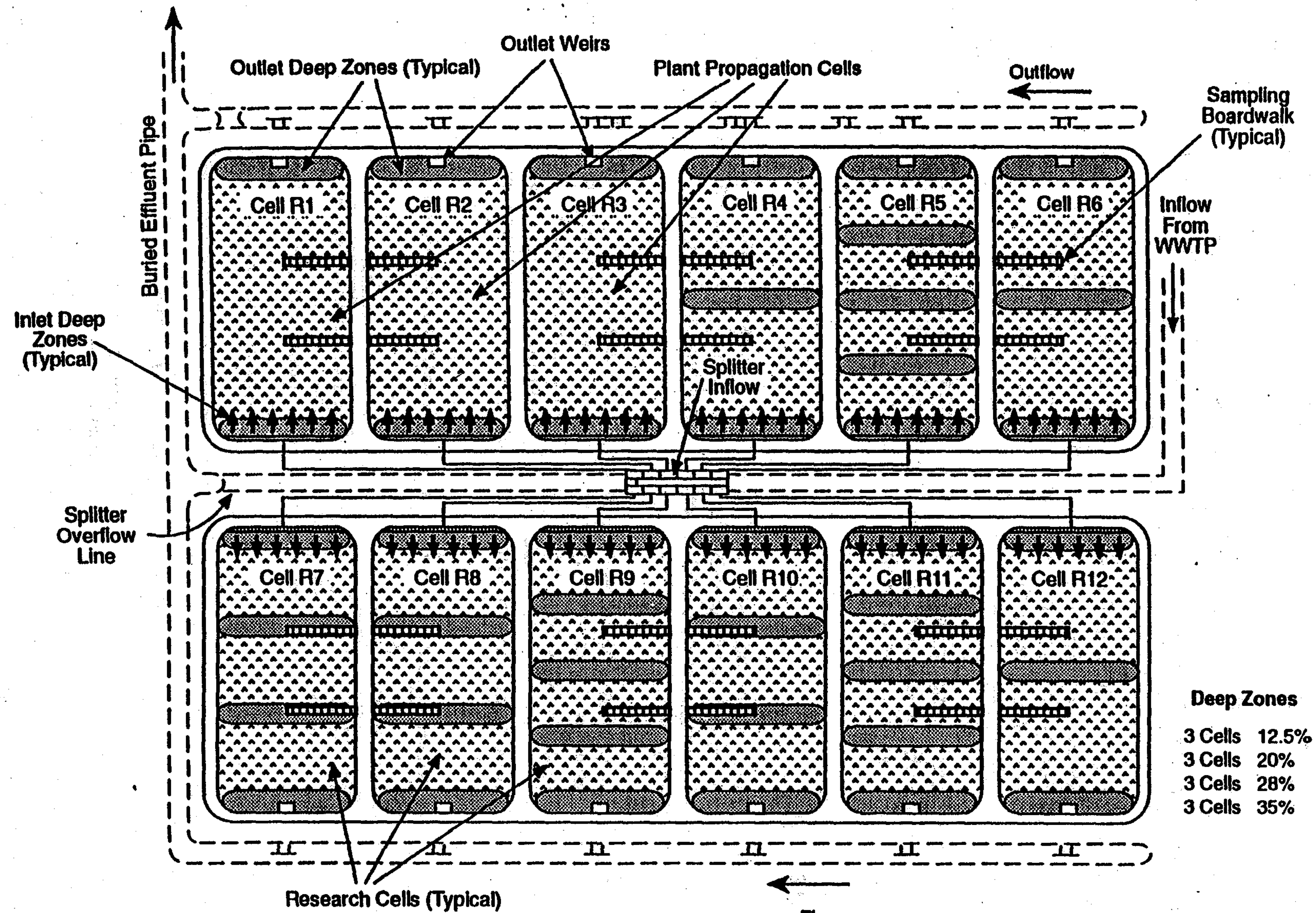

Figure 4.—Conceptual plan for Tres Rios research cells.

Hydraulic Control System

The hydraulic conveyance systems to the three Tres Rios wetlands demonstration facilities are similar in design and operations. Inflow is conveyed to each wetland site by pumped pressure supply pipelines that take water from one of the effluent chlorine contact chambers (plant 3A) at the 91 Avenue WWTP. The wetlands supply water is chlorinated effluent that is dechlorinated by an inline sodium bisulfite or other system for the Hayfield and Cobble Sites. This system is not available for the water supply at the Research sites. Valve systems and splitter control boxes reregulate the supply water at each wetland site.

The manual gate valve control is only a few feet from the flowmeter. At all three sites, inflow water enters the wetlands through a perforated PVC pipe manifold buried in a subsurface gravel bed that extends across the inlet end of the wetlands cell. Outflow from the wetlands is collected by a single concrete outlet weir-box located at the outlet end of each wetland cell. The Cobble Site is operated in parallel mode. The operation of the Hayfield Site will be described later.

Inlets in the Research Cells are T-pipes buried under a "river-rock" cover. Inlets in Hayfield and Cobble Sites are 12.0" diameter polyvinylchloride (PVC) T-pipes placed on the bottom without any cover.

Inflow is regulated at all three wetland sites by splitter boxes fitted with movable v-notch weirs that allow flow measurement. The range of inflows can be varied as shown in the tabulation below:

Pumping capacity:

Cobble Site	=	0 to 2,500 gpm (total pumping capacity to site)
Hayfield Site	=	0 to 1,700 gpm (total pumping capacity to site)
Research Site	=	0 to 1,200 gpm (total pumping capacity to site)

Maximum weir capacities:

Hayfield and Cobble Sites	60° V-Notch (inlets and outlets)	=	1,785 gpm
Research Cells	20° V-Notch (inlets and outlets)	=	223 gpm

When comparing pumping capacity and weir capacity, maximum water supply to the wetlands is controlled by the weirs at Cobble and Research Sites and by the pumps at the Hayfield Site; although the difference in the weir capacity and pumping capacity is only 85 gpm at the Hayfield Site. An example might clarify the maximum pumping capacity. Assuming all Research Site cells are operational, the maximum pumping capacity to each of the 12 research cells would be 100 gpm at any one time—1,200 gpm divided by 12.

Operational depth within the wetlands is controlled at the outlets of all three wetland facilities. At the Cobble and Hayfield Sites, depth is controlled by movable V-Notch weirs installed in the outlet boxes. The research cell depths are controlled by fixed stop-log weirs that are also installed in outlet boxes. The operational depth ranges from less than 0.1 m at startup to 0.45 m during phase 2. At all three facilities, the maximum operating depth is 0.6 m (2 feet), and all sites can be drained by lowering the outlet controls and pumping down water from sump areas within the wetlands. The deep zones are about 0.9 m or 3 feet deep.

The Hayfield Site infrastructure is designed so the cells may be operated in parallel—as the Cobble Site is operated—in series (from H1 to H2), or the effluent may bypass both cells and be wasted. The inlet and outlet structures and the inlet splitter box structure for the Hayfield Site allow the effluent to inflow to either both cells (for parallel operation), to either cell H1 or H2, or the effluent can be wasted via a bypass pipe to the outlet splitter box.

The inlet and outlet splitter boxes are also designed so that the Hayfield cells can be operated in series—all the effluent is distributed to cell H1, where upon entering the outlet splitter box, the effluent is forced into the pipe that is connected between the inlet and outlet splitter boxes. The effluent travels to the inlet splitter box because of the increased head at the outlet box end and the zero slope of the pipe connecting the two structures. The inlet box distributes the effluent discharged from the connecting pipe to cell H2. To better understand these options, see figure 5. The cell H2 weir gate and bypass weir gate at the inlet splitter box would be closed under this scenario. The cell H1 and series flow sluice gates at the inlet box would be open. At the outlet splitter box, the series flow sluice gate would be closed.

The riparian channel between the Hayfield Site and the Salt River receives effluent after treatment by the two treatment cells and was created primarily to provide habitat for native fish and to provide postaeration of the wetland outflow. The initial design called for a stepped-pool channel down the bluff from the hayfield to a collection pool constructed at the beginning of the riparian area. The stepped pools are intended to provide habitat for endangered desert pupfish. The area topography prevents exotic fish from entering the riparian channel from the Salt River. Mosquitofish and native fish have entered the Hayfield Site cells and are present in the open water areas.

Operation of the wetlands does not actually involve the islands; however, the islands in the open water areas were built to observe habitat and nesting patterns among aquatic (nonwaterfowl) type birds; this aids in research of habitat and wildlife activity.

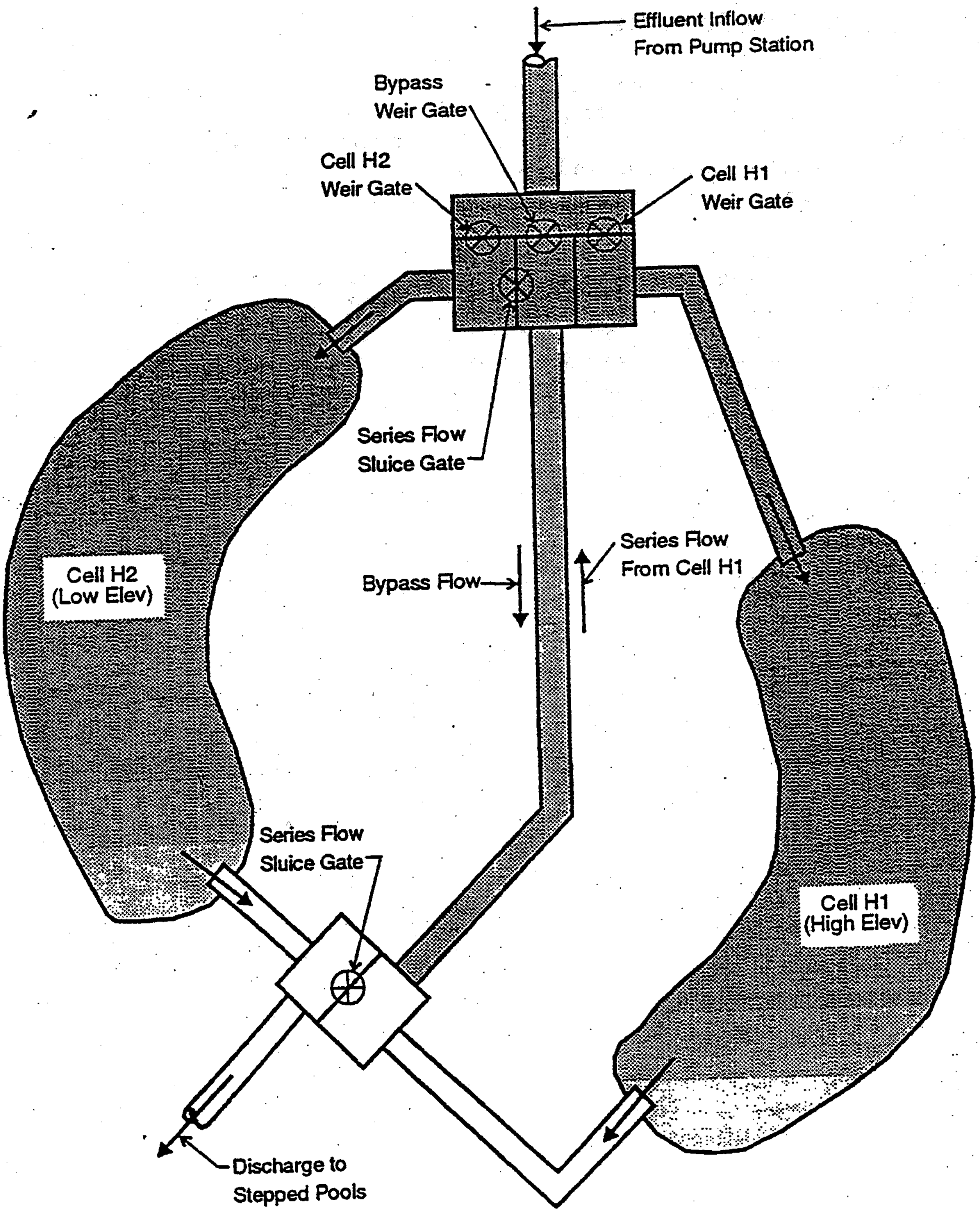

Figure 5.—Hayfield Site flow schematic.

Ancillary Site Features

Public access for environmental education and passive recreation is provided by a hiking/jogging trail and observation points. At the Hayfield Site, the trail and observation points are atop the berms around the wetland cells. A locked gate at the parking area allows controlled visitor access to this demonstration wetland site.

Public education and passive recreation is accommodated at the Cobble Site by a visitor parking area just west of 91st Avenue south of the treatment plant effluent channel. A trail around the wetland cells and an observation point atop the flood-control berm at the southern edge of the site permits visual access to the wetlands wildlife. Access to the west end of the site for operation and monitoring is provided by a locked gate on an access road along the south margin of the site.

Chapter 6

Discussion

Since the construction of the wetland sites, many agencies and organizations have used the sites for research, news related articles, and youth leadership activities. Recreation and research of this kind are expected to continue throughout the demonstration program.

No construction project, however, is completed without at least a few challenges, and the constructed wetlands are no exception. This section explores the challenges and the accompanying lessons learned, involving the schedule and planting process, berm construction, access to the sites for sampling, and public access. Each is discussed briefly in this section.

Planting

Challenges

Temporary pumps were used to augment the main pump station to wet the cells at the Cobble Site before planting. The planting in all cells took about twice as long as it should have because conditions were drier than normal for planting. In addition, cell C1 was difficult to wet because of the high infiltration rate, which made it nearly impossible to get water to the downstream portion of the cell. Once the bottom of the cell was clogged, the temporary pumping closed.

Although not considered a problem, planting costs could have been reduced by eliminating planting (including planting the stalks). Bulrush plants will grow roots and attach themselves to the soil they are in contact within 48 hours. To avoid time-consuming planting in future projects, plant stalks could be placed in the invert of the cells, spaced at 3-ft (0.9-m) centers. A very moist soil surface is necessary, and it must be kept wet for about 48 hours. If too much water is present in the cell, the plants will float away from the soil surface and never establish roots, eventually dying. If the water is a little too deep, the plants may float away from their intended spacing but will establish roots when evaporation or infiltration has reduced the water depth, thus altering the original spacing. The time and money saved by allowing the plants to establish their own root system can be considerable.

Lessons Learned

Timing of pumping plant construction can be critical if the pumping plants are required to provide moisture to the wetland area for planting.

The time and money saved by allowing the plants to establish their own root system can be considerable. Careful attention to soil moisture is required if this method is to be used to plant bulrush.

A hardy plant is important in the selection process. The aquatic vegetation at Tres Rios has shown tremendous growth and survivability. No additional monies have been spent promoting growth or maintaining the vegetation. In fact, the growth has flourished such that no effect is evident within the wetland cells after a nursery cell was established nearby using bulrush from the system. The vegetation has met or exceeded expectations in terms of growth, survivability, and cover.

Toward the end of the first year (August/September 1996), none of the deep zones in the Research Site were deep enough or wide enough to prevent the aquatic vegetation from encroaching, and, in most cases, the entire 160-ft by 80-ft (49-m by 24-m) cell was overrun with aquatic vegetation.

During the first year, a handful of cattails invaded the southernmost cell of the Cobble Site, apparently the seeds were carried in by wind or birds. Although cattails are an aquatic vegetative plant known for improving water quality, they are invasive plants which will overrun the system. Saltcedar was introduced to the wetlands and began to grow rapidly. Extensive maintenance is required to keep saltcedar under control. Plant diversity will occur whether by natural or manmade procedures.

Also during the first year of operation, a classic winter senescence (dormancy) occurred. By February, most plants had senesced. During March, regrowth occurred; and by the beginning of May, more than 90 percent of the growth had returned to lush, full vegetation.

Submergent vegetation was planted in all of the deep zones at Tres Rios. Hornwort (*Ceratophylum)* was planted with little to no success. Within 6 months of being planted, the *Ceratophylum* had disappeared. It is thought that the plant disappeared due to consumption by waterfowl and fish.

Berm Construction

Challenges

At the Cobble Site, the drawings for the berm showed the outer dimensions would be constructed at a 3:1 to 6:1 slope. They called for the berm to be constructed to the minimum slope at the northeast corner of the two cells, which would have posed a situation. The bottom of the slope would have been built within the confines of the treatment facility's effluent flow and, if completed, might have been in the streamflow. To rectify the situation, the outer slope of the Cobble Site berm near the northeast corner was built more steeply, approximating a 2:1 slope. Although this approach required less material, the construction of the slope posed a greater challenge for equipment and laborers.

The center berm at the Cobble Site could have been designed differently. It appears to contain some parent material with gravels. This material does not lend itself as well to compaction as a more uniformly graded material might. It also appears that the center berm should have been wider, except that land limitations prevented the extra width. During September 1995, the cells were being tested at widely fluctuating effluent levels. During a high effluent level loading, approximately 12 ft (3.7 m) of the center berm ruptured near the outlet end. The portion that broke was attached to the outer center berm and left a 12-ft (3.7-m) void between the two cells.

Small open water deep zones at the outlet end of each basin have advantages and disadvantages. Without the open water zone, emergent vegetation growth can overtake the outlet works and make access difficult. However, these zones have served to promote algae growth before discharging effluent.

Lessons Learned

The utility of parent materials for construction of some berms must be carefully considered. Too much gravel is not as effective in compacting the berms as a more uniformly graded material might be. Berm integrity requires future designs to either include a concrete barrier within the berm or concrete sidewalls. Another possibility would be to construct the cells by digging downward instead of building upward.

Small open water deep zones at the inlet and outlet ends of each basin have served to promote algae growth. Deep zones in this area should be avoided in future constructed wetlands.

Sampling Access

Challenges

The wetlands were initially constructed to be demonstration, treatment, and research sites only. With public use and habitat development taking a high priority, Americans With Disabilities Act (APA) standards would be part of future designs. The Research Site cells are constructed within a sludge drying bed. The berms at the outlet end of all the Research Site cells were constructed at a 3:1 slope or steeper and are approximately 7 to 8 ft high (2.1 to 2.4 m). The inlet of the cells faces the middle of the cell, while the outlet end faces the old sludge drying bed berm; thus, the reason for the high berm at the outlet end. By January 1996, stairs for each cell were constructed at the outlet end. This allowed for easier access and sampling for technicians.

Tres Rios wetlands is a research site, yet sampling at the outlet structures is difficult. The walkway structures are between 2 and 3 ft (0.6 and 0.9 m) higher than the effluent surface. A guardrail along the sides of the walkway was installed for the operator's safety, because of the Hayfield Site. A dipper can be used to draw samples; however, the mouth of the dipper is much larger than the mouth of most sample bottles. Sampling at the outlet end requires lying on the grating of the structure and reaching into the wetland with a grab sample bottle.

Sampling from the inlet splitter box structures has been a much easier process and has lent itself to safe and efficient sampling. At the Hayfield and Cobble Sites, a portion of the grating in a rectangular shape is removable so that grab samples can be taken within the flow structure.

Walkways within the Research Site cells were constructed at about midpoint between the inlet and outlet ends and are typical of walkways in wetlands. Aquatic vegetation has grown around, over, and between the walkway, and nothing indicates the walkway ends. No guardrails are required, though, because water depths are very shallow. Future walkways, however, should be wider to allow for wheelchairs turning around. Low growing vegetation should be planted around the walkway so a person can see the width and length of the walkway and still allow a person to feel part of the wetlands.

Lessons Learned

The design process should consider safe access to the wetlands for sampling, particularly if monitoring is a major part of a research project. Stairs, walkway guardrails, and wider walkways may be required and should be part of the design. Sampling from the inlet splitter box structures has been easy; a portion of the grating in a rectangular shape is removable so that grab samples can be taken within the flow structure. This design perhaps could be adapted to other areas or walkways.

Public Access

Challenges

Security at Hayfield and Cobble Sites was not an issue when the program began. Public access to any site can inherently bring some undesirable activities. The location of the treatment plant has constantly witnessed stray bullets from hunters, etc. The demonstration constructed wetlands has enlarged the area in which hunters and other visitors may visit. Typically, the river has been used as a dumping ground for everything from garbage, washing machines, stolen cars, and bodies. Some people, on seeing an open hole with the construction of the Cobble Site wetland cell, saw a new dump site.

Concrete median dividers were installed at the entrance to Cobble Site, leaving room between two of the dividers for a vehicle to drive through. When no authorized personnel are at the site, a lockable chain is strung between the barriers. Hayfield Site has the feeling of being more a part of the treatment facility property than a part of the river; the way to Hayfield Site from the Salt River is not obvious.

Lessons Learned

Planners should carefully consider public access and what the impacts of various public facilities might mean in a wetlands environment. Future wetlands need to incorporate low durable structures and discourage access into the wetlands through construction of barriers, gates, and/or fences. A public education program needs to address the "Salt River is our garbage dump" mentality.

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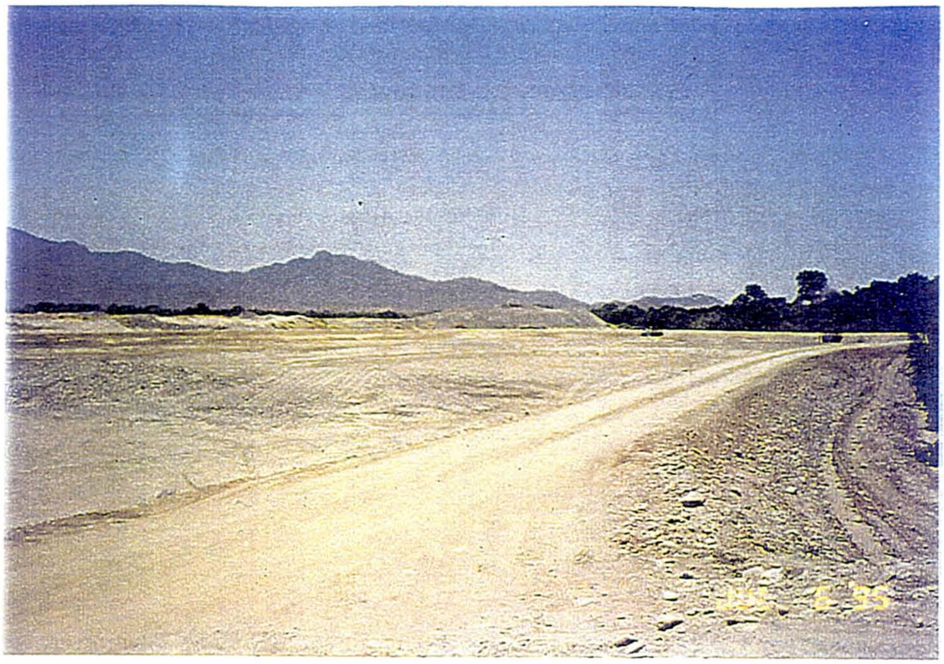
From
Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment, Environmental Resources Engineering Department, Humboldt State University, Arcata, California and CH2M-Hill Gainesville, Florida January 1998

Reed 1992

Small and Wurm 1977

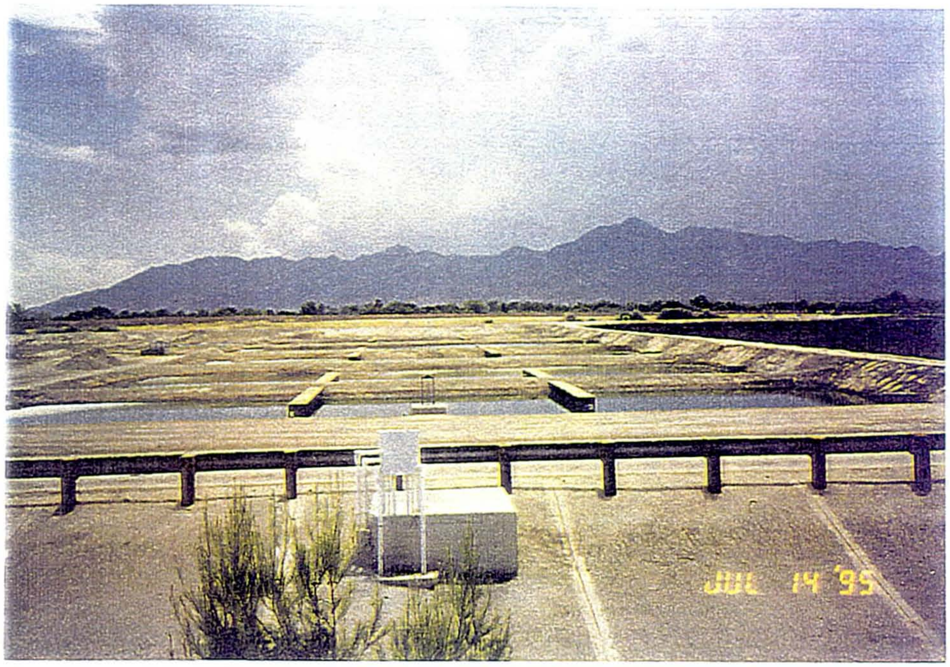
Attachment

Tres Rios Photographs



View looking southwest at the Cobble Site. Basins are nearly complete. Islands are still under construction. Note the outlet works in the background are complete, and the walkways to the outlet structures are complete. Planting has not yet occurred.
July 6, 1995

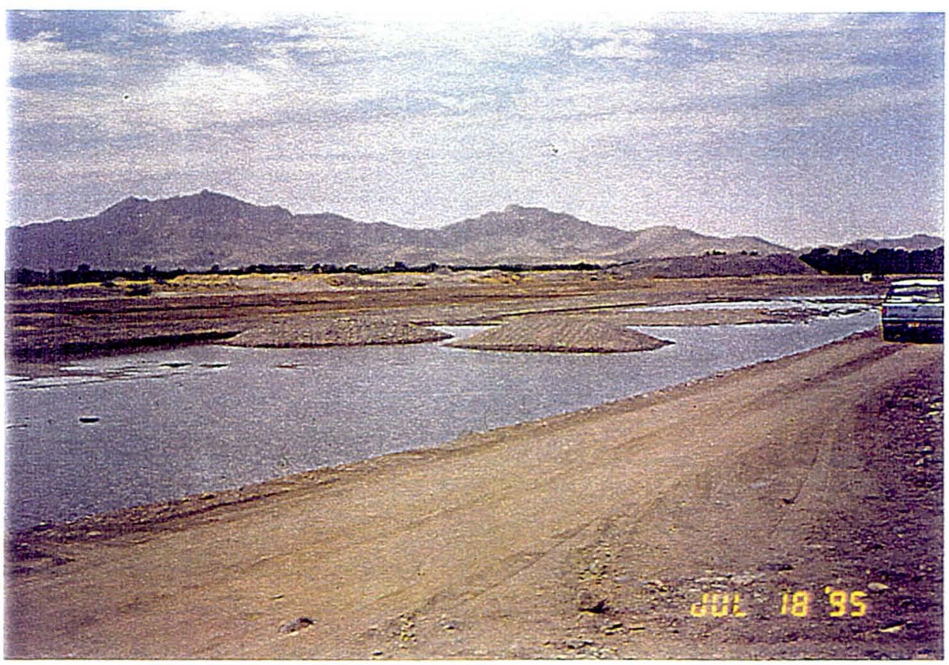
Almost the same view, looking more south. Note the evidence of tire tracks in the basin. Basin nearest photographer is Cell C1. Cell C2 is in the background.
July 6, 1995



View looking south at the Research Cells. Construction of the basins is complete, and the cells are planted. Note the walkways without guardrails. Also note the inlet splitter box structures located at the far left of the photo., Cell R7 through R12 are shown in the photo. Cell R7 is nearest the photographer. Note the outlet works at the far right side of the photo.
July 14, 1995

Hayfield Site, Cell H2 looking east. Note the small stalks of bulrush, and the riparian area (Salt River) on the right side of the photo. Cell H1, though not visible, would be to the viewer's left.
July 18, 1995

View of the Cobble Site looking south. The Estrella Mountains are in the background. Cell C1 is in the foreground and is flooded. Planting of bulrush appears to be taking place in Cell C2. Note the center berm is smaller in size and in height than the outer berm where the vehicles are parked.
July 18, 1995

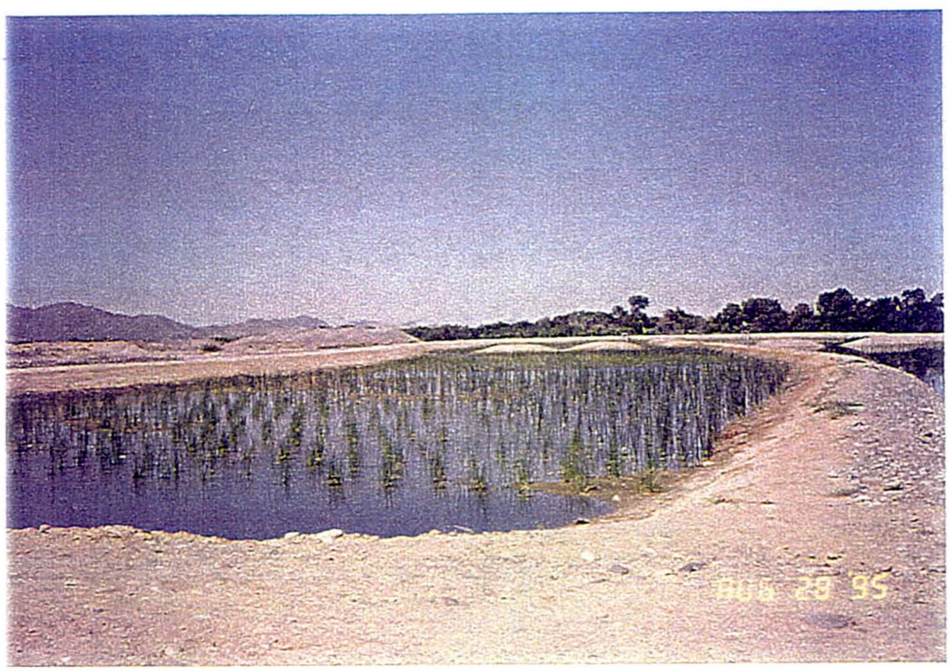


View looking southwest, with the Estrellas in the background. After wetting Cell C1, planting of bulrush will commence. Due to high infiltration, it was difficult to wet the far downstream end of this cell. The downstream end of the cell is in the direction the photo is taken.
July 18, 1995

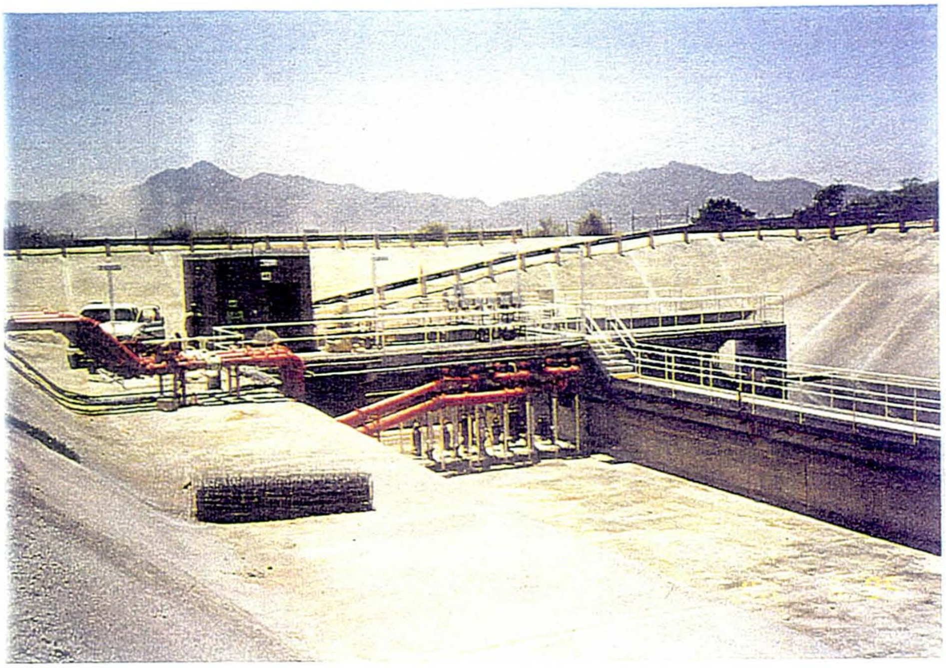
View of the Hayfield Site looking east. The cell photographed is Cell H2. The bulrush stalks show growth after only one and a half weeks from the time they were planted (planted on July 6, 1995). Note the riparian area of the Salt River in the background.
July 18, 1995

View of the Cobble Site looking west. The cell photographed is Cell C2, and is being planted from the upstream, to the downstream end. Cell C2 is "lined" with 6-inches of clay material. Note the riparian area in the background.
July 18, 1995

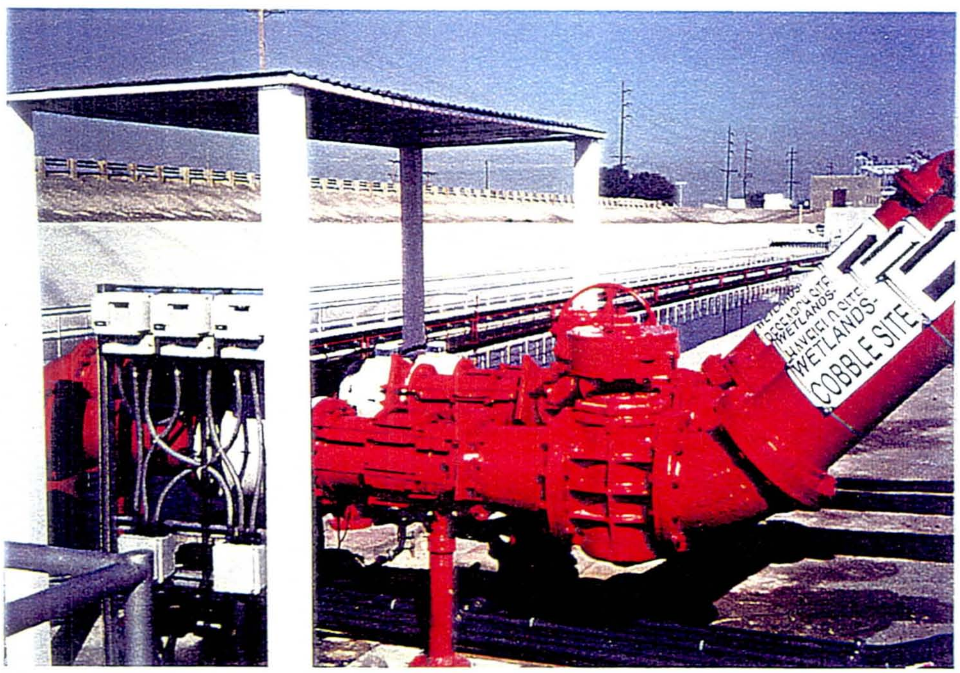
View of the Cobble Site looking west. The photo shows the difference in the material in the cell inverts. Parent material was used for Cell C1 (right side), while the C2 was lined with 6-inches of clay material (left side) over the parent material. Note the riparian area in the background.
Circa July 1995



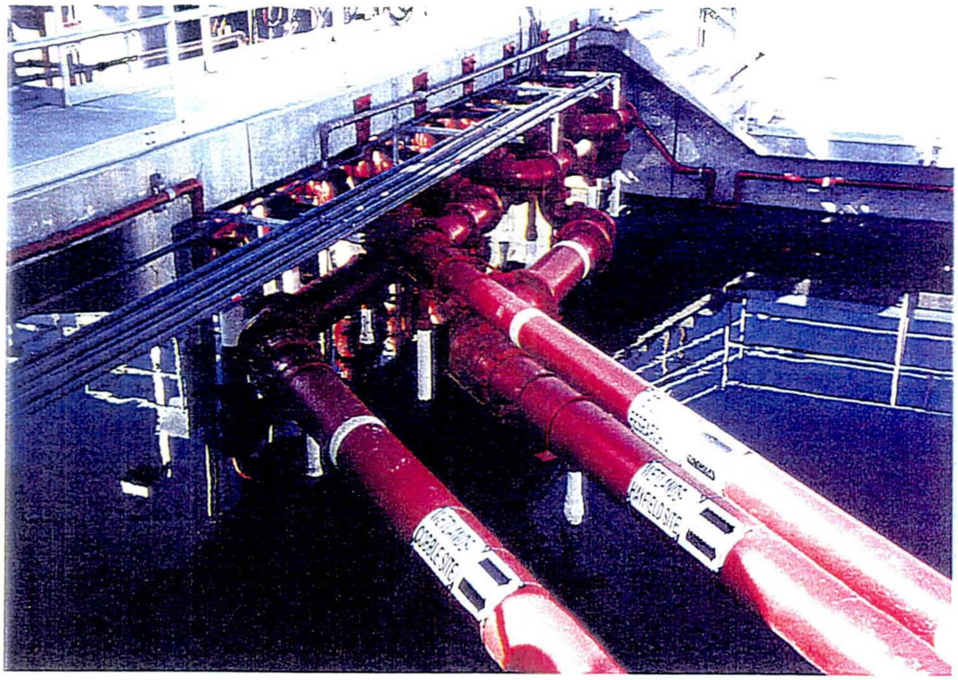
View of the Cobble Site looking west. The cell on the left is Cell C2, and barely visible is Cell C1 on the right with the center berm separating the two cells. Photo is approximately 6 weeks after the planting of bulrush stalks.
August 28, 1995



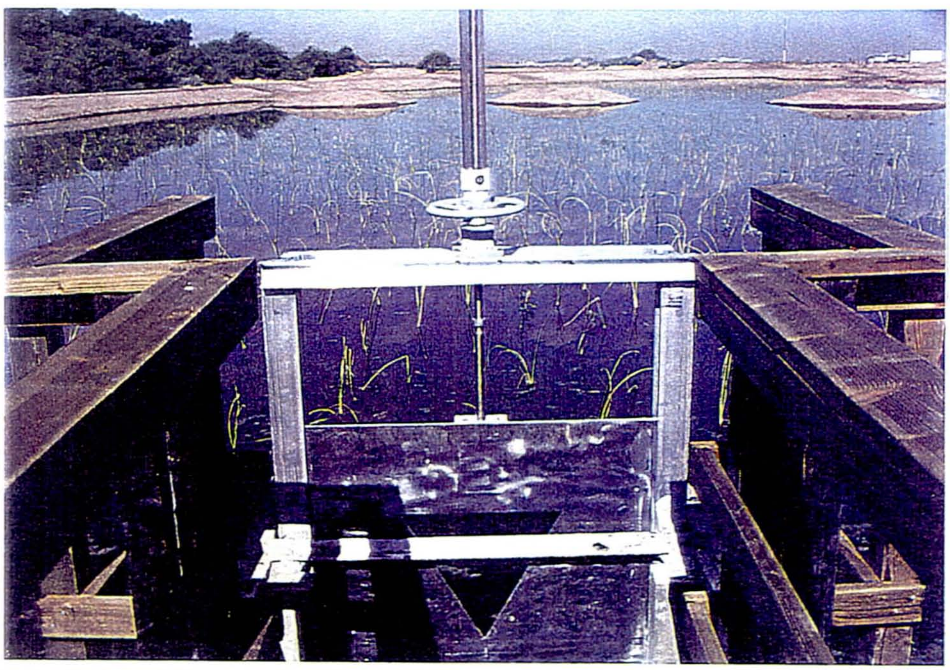
Pipe and pump infrastructure located in the 91st Avenue's plant 3A chlorine contact chamber. Not visible, but located about 20-feet downstream of the pipe is plant 3A's dechlorinating unit. Effluent is piped to the three wetland site prior to dechlorination. View is looking south.
July 6, 1995



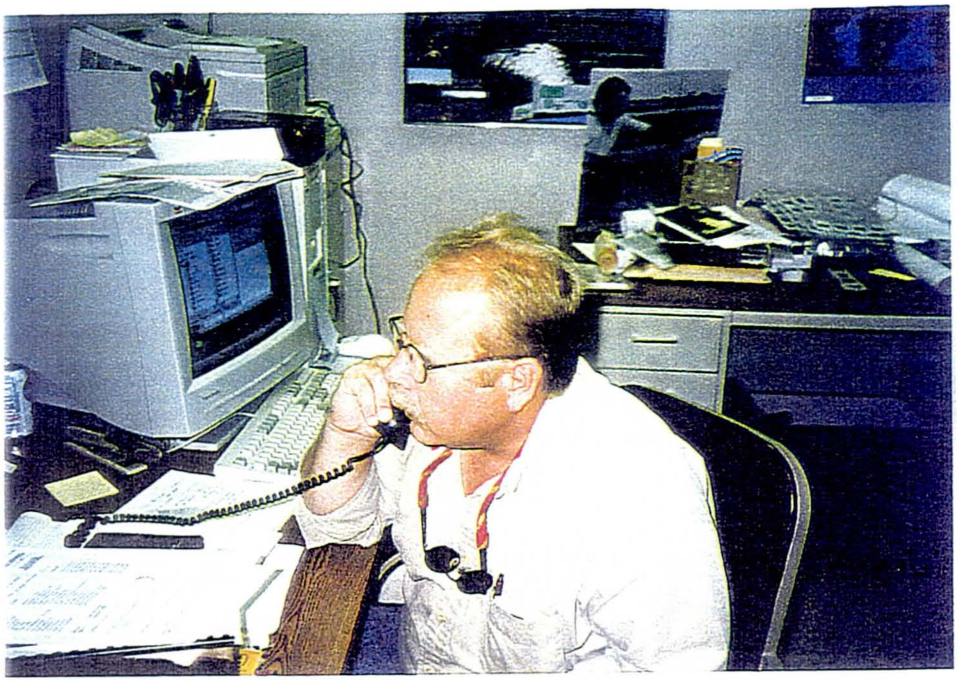
View of the piping infrastructure at the chlorine contact chamber. The three white boxes under the shade are the LCD volumetric flow readouts. Between these boxes and the signs are the valve adjusters for volume control. The first two pipes in the foreground are the 12-inch Cobble Site, and Hayfield Site pipes. The pipe in the background is the 8-inch Research Site pipeline. Note that in the top photo on this page that the LCD readouts, shade cover, and pipe markings are not present. They would be present in the top photo about where the man is standing.
November 7, 1995



Pipe and pump infrastructure located in the 91st Avenue's plant 3A chlorine contact chamber. Photo was taken after the units had been operating about four months.
November 7, 1995



View of the Hayfield Site, Cell H2, looking west. Photo is taken at the walkway/outlet end of the cell. Note the plastic stem guard, which were destroyed at the Cobble Site cells.
Circa August, 1995



Roland Wass, operations manager of the Tres Rios Demonstration Wetlands project.

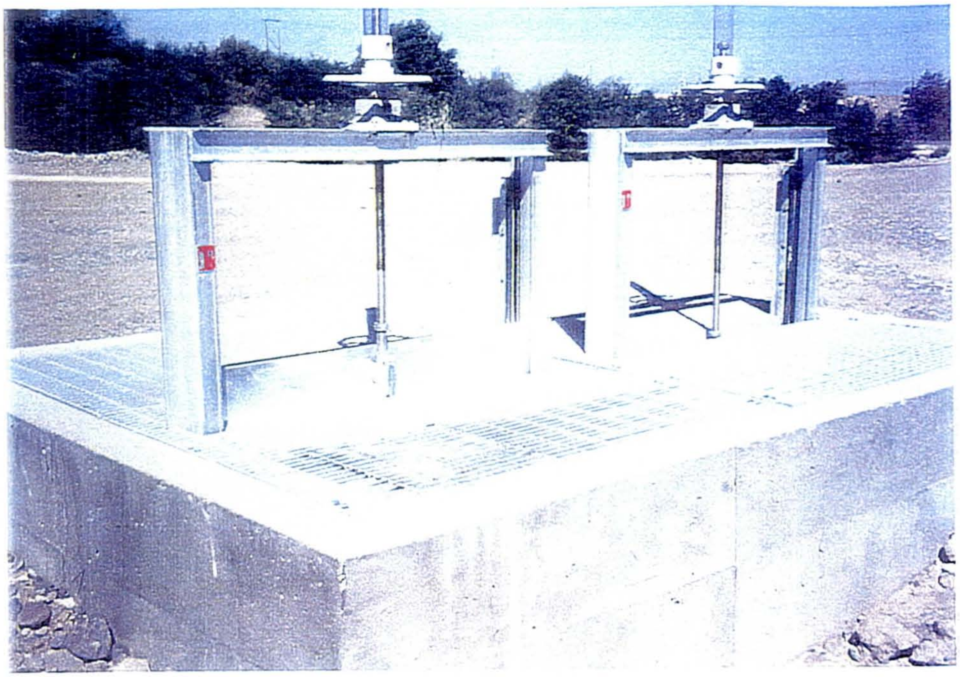
View looking north of the Hayfield Site's inlet splitter box.
September 28, 1995

Downstream end of Cobble Site Cell C1. Plant growth shown about two months after being transplanted. The downstream end of this cell exhibited the poorest growth. High infiltration rates at the upstream end may have prevented nutrients from reaching this section of the basin.
September 28, 1995

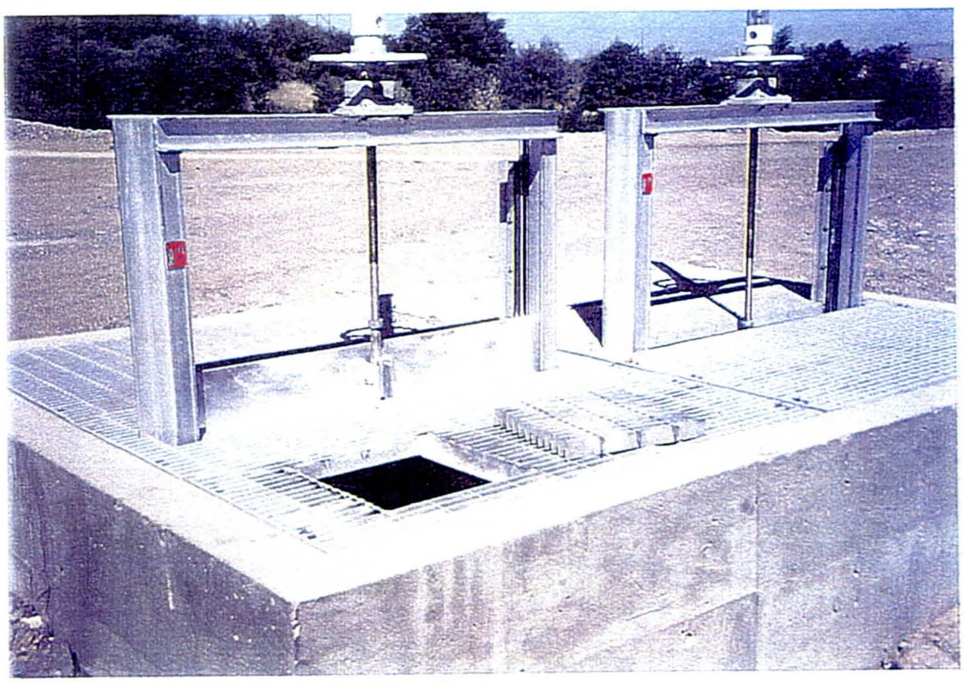
View of the downstream end of the the Cobble Site. The cell in the background is C1, and the cell in the foreground is C2. Note the poor growth in C1, and note the robust growth of the two stalks in C2 at the far right side of the photo. The portion of the berm shown in the photo had blown out about two weeks prior to this photo being taken. The photo shows the repaired berm, and the new material can almost be distinguished from original construction. About 3/4 of the way from the far left side of the photo is the point at which the new and original material for the berms meet.
September 28, 1995

View looking northwest at the Cobble Site. In the foreground is Cell C2, and in the background is C1. Note the riparian area in the background.
September 28, 1995

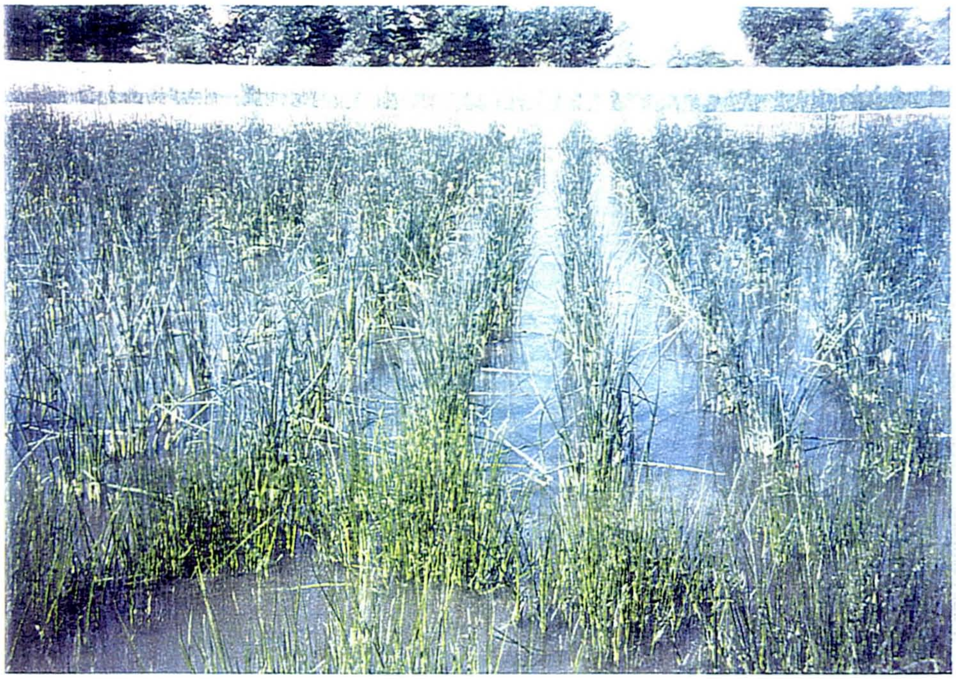
View of the the Hayfield's Cell H2 taken from the top of the H1 berm looking west. Note the robust growth of the plants after about three months of growth.
September 28, 1995



View of the inlet splitter box for the Cobble Site. View is taken looking toward the northeast. The right gate feeds Cell C1, the left gate feeds C2.
October 3, 1995



Same view as above, except that the grating has a trap door in order to pull grab samples. Note the plastic guard stems on the gate which were eventually destroyed by shotgun blasts.
October 3, 1995



View of the Cobble Site cell C2. Note the distinction of the *scirpus olneyi* in the foreground, and the *scirpus validus* in the background. Also note that the planting row pattern is still discernible about 2 ½ months after being transplanted
October 3, 1995

View of the Hayfield's H2 at the outlet side. Duckweed and algae, although more prevalent in the summer months, were noticeable in the outlet ends of the basins, and generally worsened water quality just prior to being released from the outlet works.
October 10, 1995

View of the downstream face of the Research Cells. Note the minimum 3:1 slope of the berm. Stairs would eventually be built in order to access all of the outlet structures shown (12 outlet structures in all).
October 10, 1995

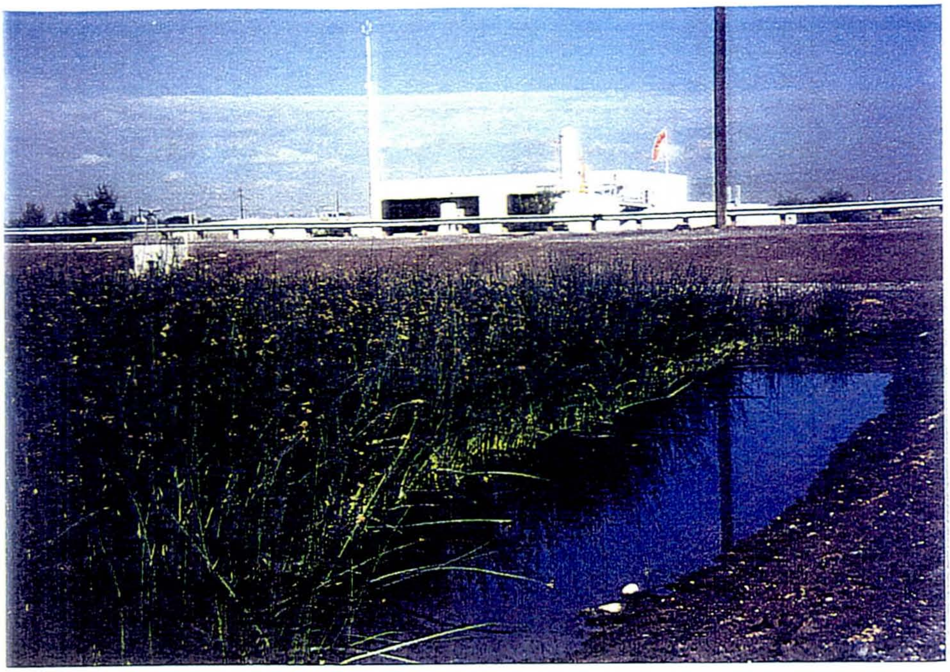
Workers shown preparing stairs for each of the Research cells.
October 10, 1995

View of the downstream face of the Research Cells with stair construction completed except for the handrailing.
November 2, 1995

Close up of the Hayfield's H2 cell taken at about the middle of the basin from inlet to outlet. Note the clarity of the water.
November 7, 1995

View of the outlet end of H2 at the beginning of the senescing period.
November 7, 1995

Clear distinction in the deep open water area of the Research Cell's R7 basin. Eventually the deep zone shown here, and all the deep zones in the Research Cells would be over-run with bulrush.
November 7, 1995



View of the inlet side of cell R7. Note the 91st Avenue Treatment Plant's Chlorine Building in the background.
November 2, 1995

View of the outlet end of cell C1. Plant growth has improved somewhat as compared with the growth shown on September 28.
November 7, 1995

View of cell C1, about midway between the inlet and outlet end. The plants are showing fairly robust growth considering the below average soil conditions for this cell. The senescing period is less than one month away from the time the photo was taken.
November 2, 1995

View of the downstream end of cell C1. The riparian area is in the background.
November 2, 1995

View looking west at the Cobble Site. On the right is cell C1, and on the left is C2. In the center of the photo is the center berm dividing the two cells.
November 2, 1995

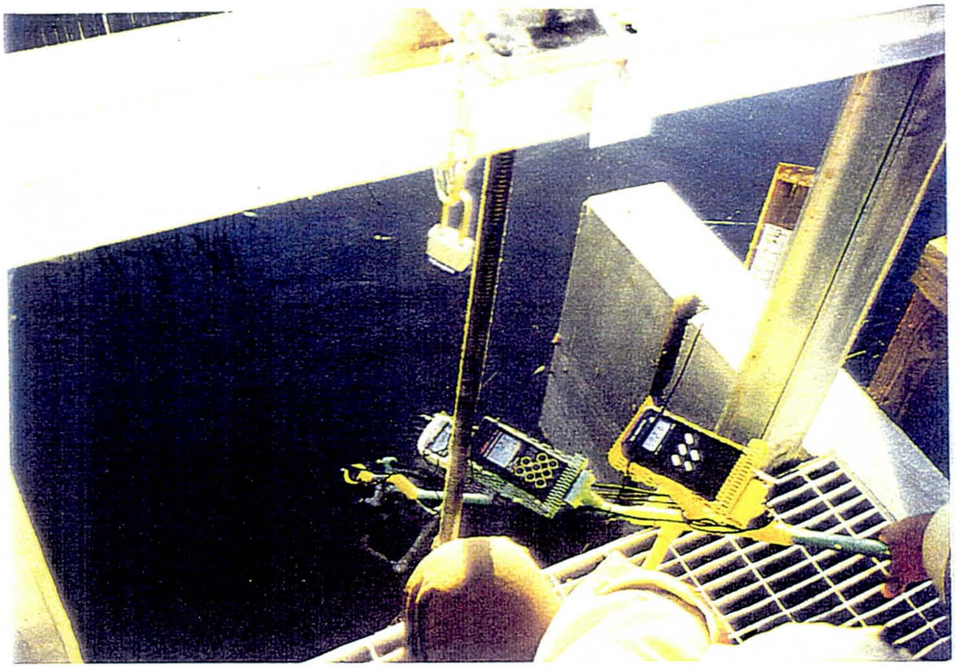
View of the downstream end of cell C2. The species shown is *scirpus validus*. Note the height of the plants which are as high as an average man after about 3 ½ months of growth.
November 2, 1995

View showing one of the downstream open water areas in H1. Note the senescence period is beginning, as some of the taller plants on the left side of the photo are lodging.
November 2, 1995

View of cell H1 showing a large area within the wetland which has senesced.
November 2, 1995

View showing the lodging associated with senescense taking place within the Research cells.
November 2, 1995

Another view of the lodging taking place within the Research cells.
November 2, 1995



View showing a custom made water quality tester. Note the rectangular plastic arrangement in the front of the tester which protects the probes. The probes are anchored above the plastic rectangular piece. The instrument is capable of holding three testers. The instruments placed on this custom tester can determine the water's pH, conductivity, temperature, and dissolved oxygen. Circa October 1995

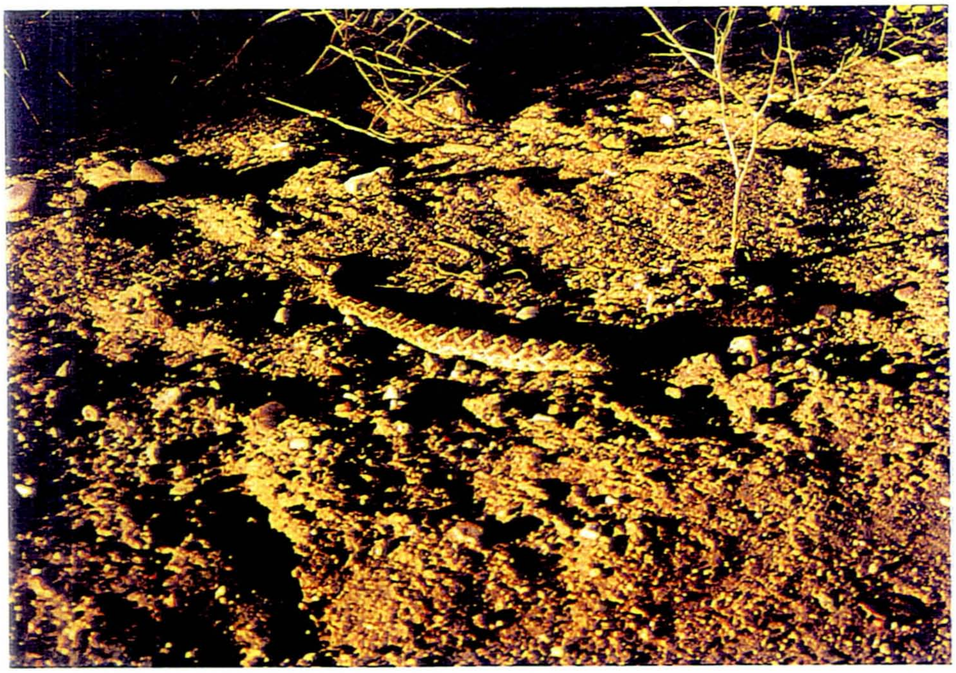
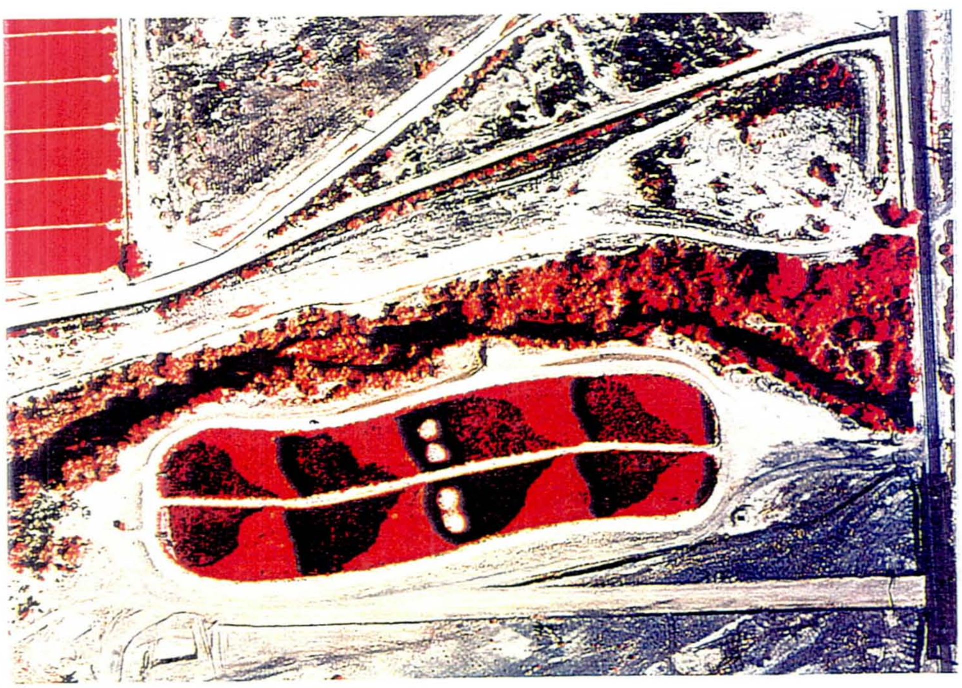


Photo showing one of the many wildlife creatures which inhabit the demonstration wetlands. This particular photo shows a rattlesnake. Circa 1996

Infrared photo of the Hayfield site. The top cell is H1, the bottom cell is H2. Note that no islands are present in the top cell.
Circa April 1996



Infrared photo showing the Cobble Site. The top cell is C1, the bottom cell is C2. Note in both photos how well the vegetation has regrown after the winter senescing period. The more red the color, the greener the plants.
Circa April 1996

Attachment

Alternate Maps for Report

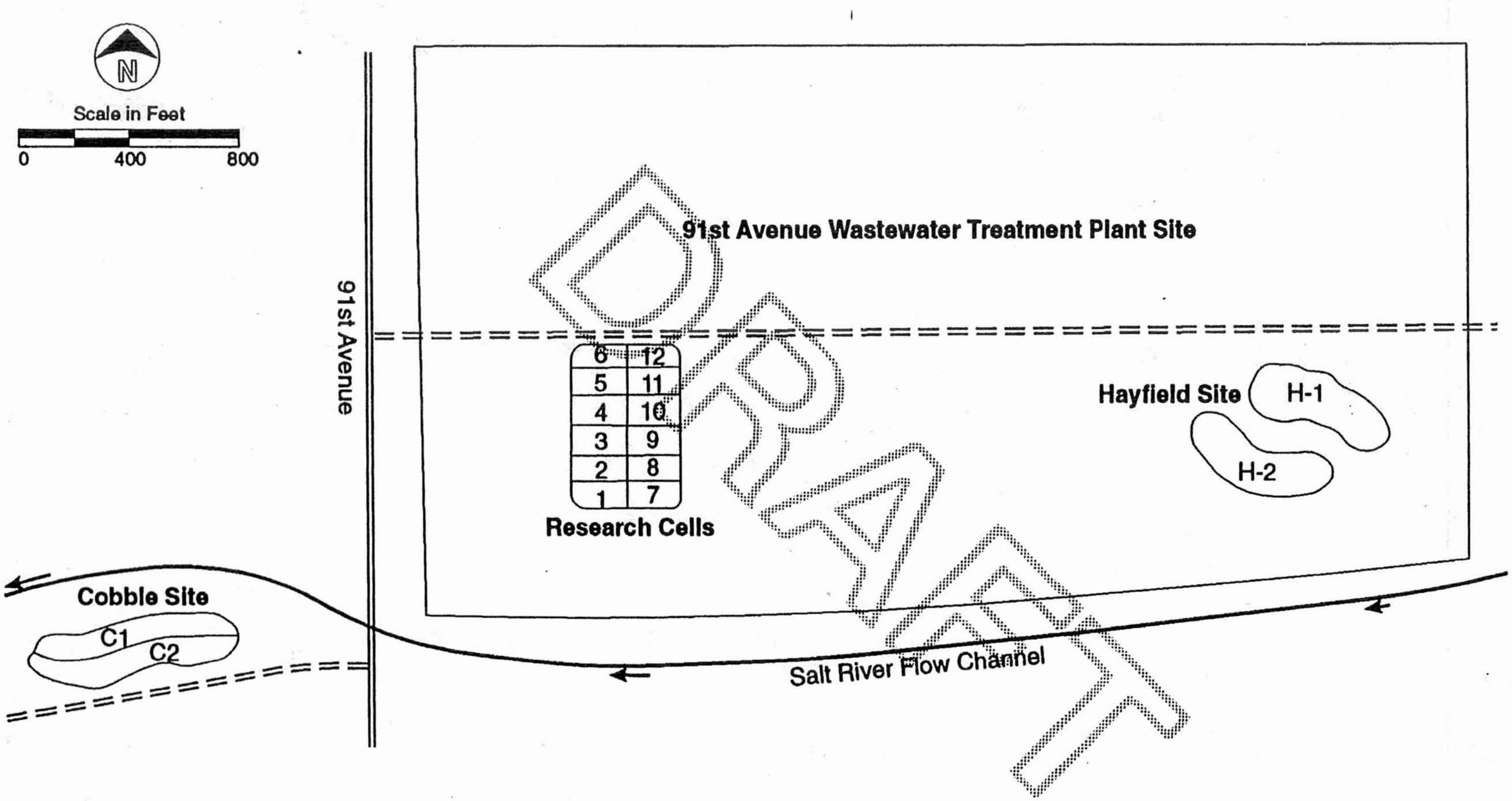


Figure 2-1. Tres Rios - Demonstration Wetlands and Research Cells

CH2MHILL

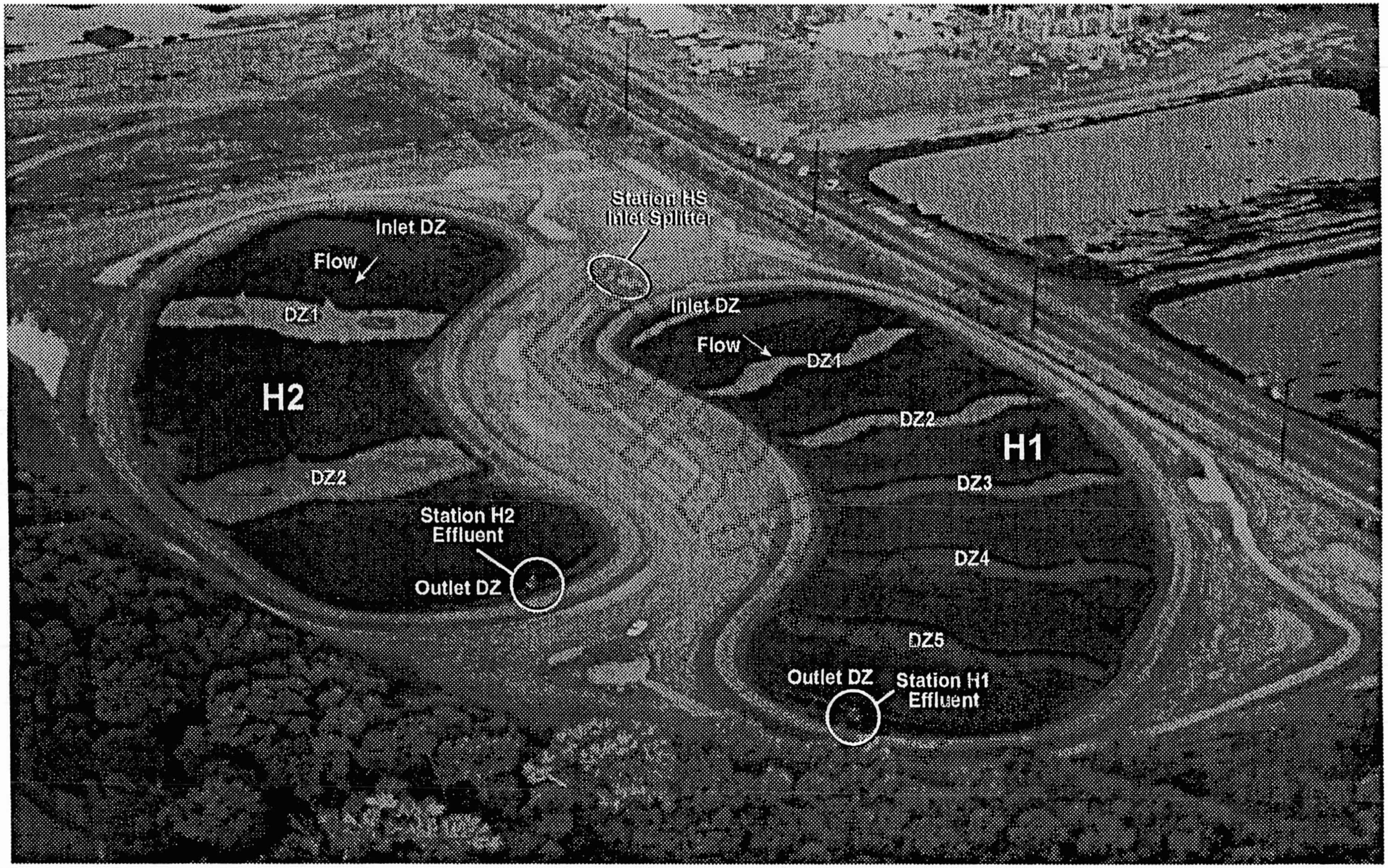


Figure 2-3. Tres Rios - Hayfield Site Sampling Stations

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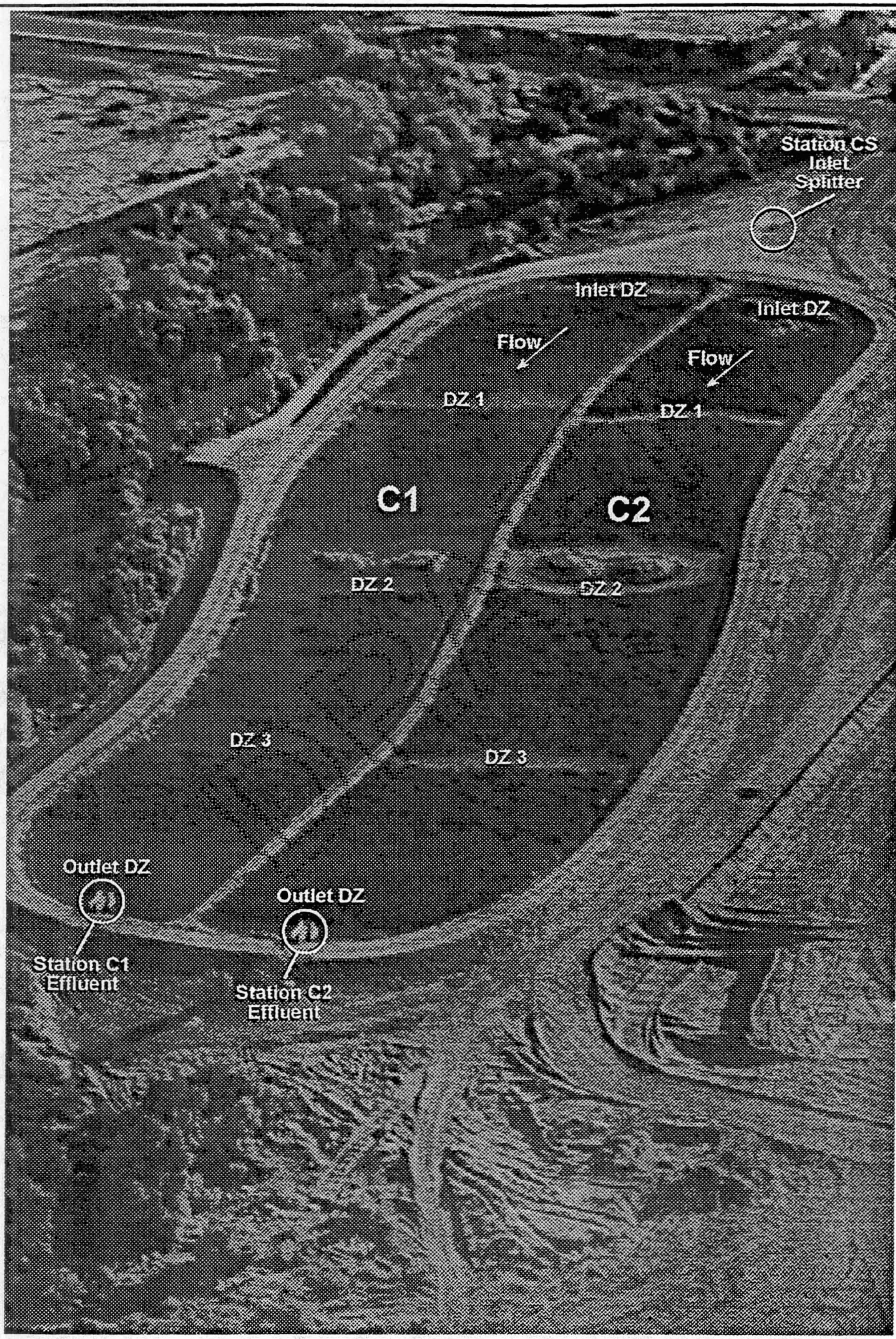

Figure 2-2. Tres Rios - Cobble Site Sampling Stations

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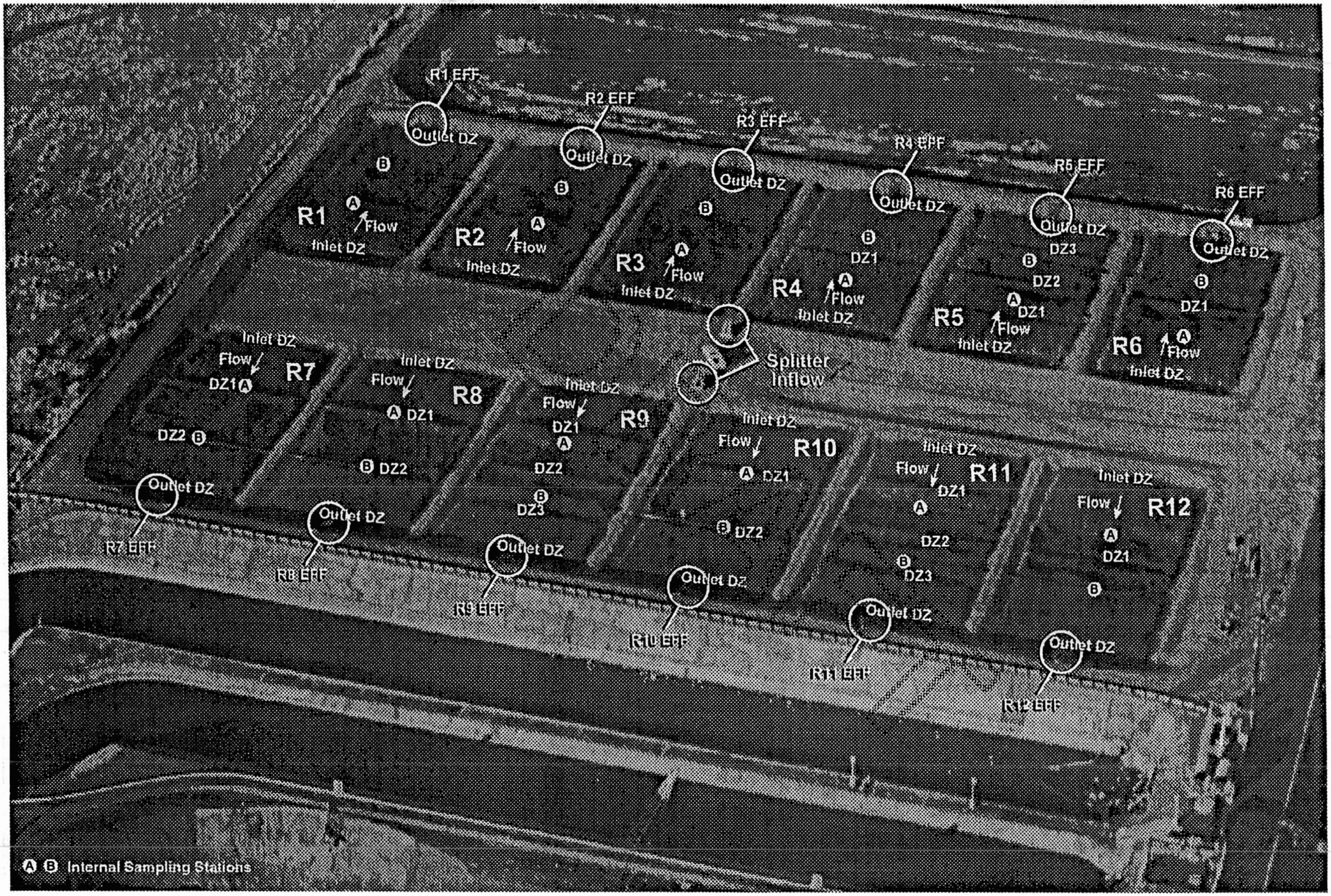

Figure 2-5. Tres Rios - Research Cells Site Sampling Stations

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