Wetlands for Water Quality Enhancement

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Wetlands for Water Quality Enhancement

Introduction:

As defined in the Clean Water Act (CWA) Amendments of 1977 [33 CFR.323.2(c)], the term *wetlands* means those areas that are inundated or saturated by surface or groundwater at a frequency or duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. The U.S. Fish and Wildlife Service developed a classification of wetlands characterized by water depth, water salinity and vegetation type. Arizona wetlands are known as *cienegas* and *tinajas*[1].

A. **Natural Wetlands & Function**

Natural wetlands were created by non-human geophysical factors such as erosion, subsidence, limestone solution, and earthquakes and are highly dependent upon localized annual or daily flooding or hydrologic disturbance. The different species of emergent vegetation undergo dynamic change each season. Flooding and drying events favor some plants and prohibits others. Natural wetlands depend mainly upon the quantity and flow rate of water through the system and the system's capability to retain water. Wetlands include swamps, marshes, bogs and similar areas[1].

Wetlands provide flood protection, ground water recharge and habitat for riparian wildlife, fish and other aquatic organisms. Wetlands also offer recreational opportunities and enhance aesthetics of a given area. In addition, several processes occurring in wetlands may reduce pollutant loads. These processes includes sedimentation, adsorption, filtration, chemical precipitation, microbial interactions and uptake by vegetation. Wetland plants diffuse oxygen through the rhizosphere (root zone) creating an aerobic micro-environment in an otherwise anaerobic zone[7].

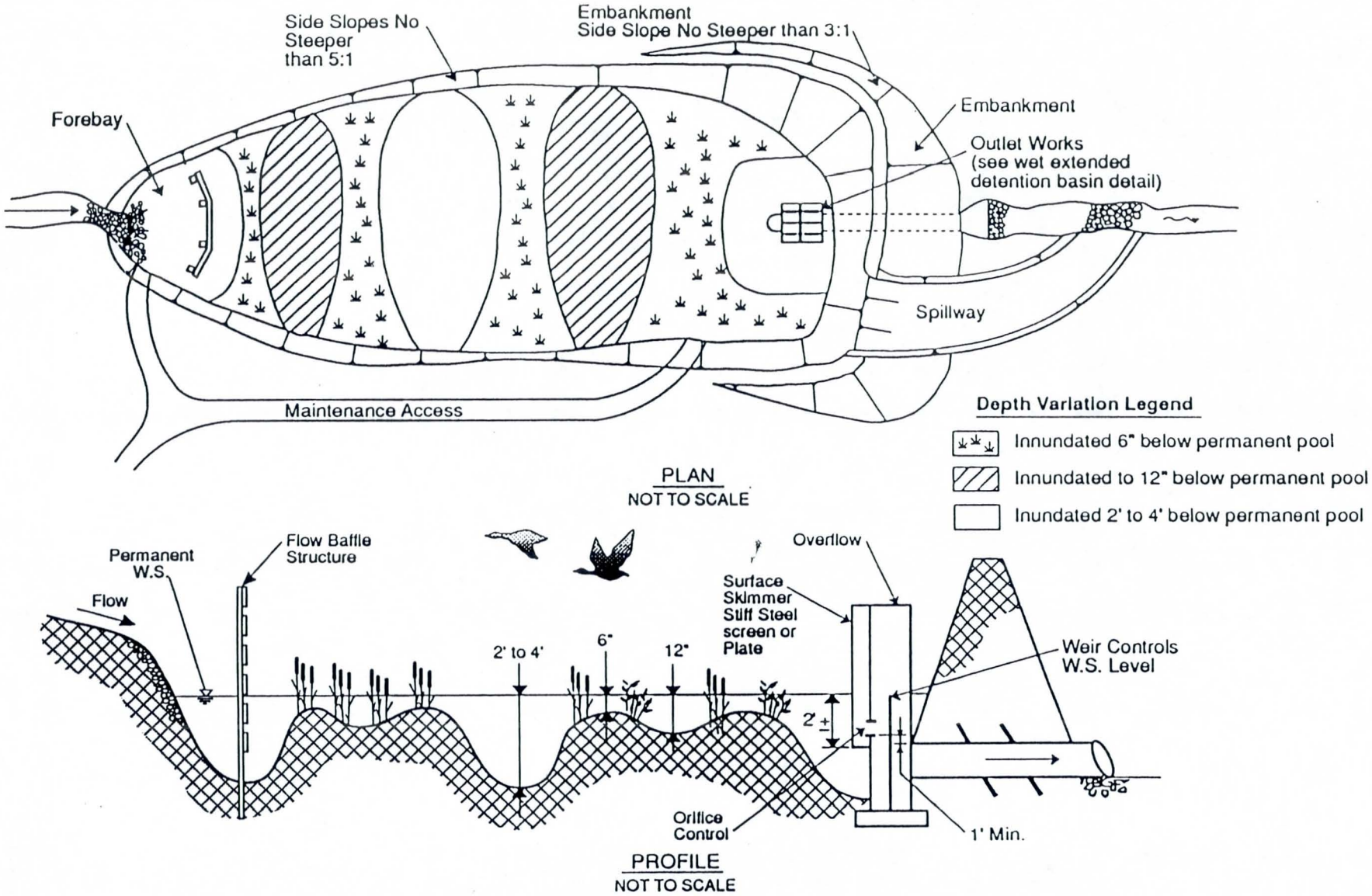
B. **Constructed Wetlands**

Constructed wetlands are man-made systems designed, built and operated to simulate the functions of natural wetlands for treating stormwater runoff and other types of wastewater. They provide a relatively simple and inexpensive solution for controlling water quality problems[6]. The simplest type of wetland consists of a forebay and wetland vegetation area as shown in Figure 1. The forebay traps floatables and allows larger particles to settle while providing a constant supply of water to the wetland vegetation. Figure 2 illustrates two basic types of constructed wetlands.

Types of Constructed Wetlands:

1. Surface Flow (SF): This type of constructed wetland is designed to simulate natural wetlands. It can be a lined or unlined basin containing soil to support emergent vegetation such as cattail, bulrushes, reed, sedge or other local species, as well as floating aquatic plants with water flowing at a shallow depth.

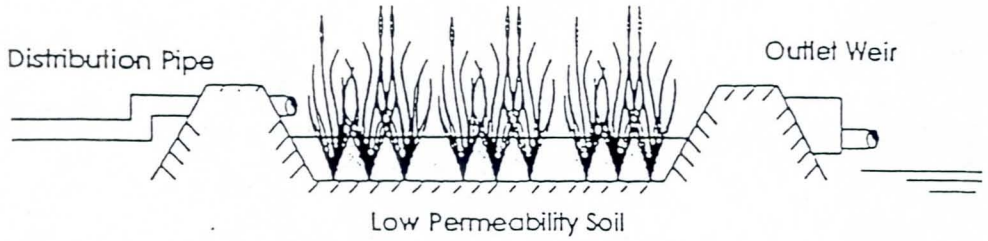
2. Subsurface flow (SSF): The basin is lined with a layer of clay or other impervious liner to prevent seepage and is filled with permeable substrate, usually gravel. Flow is maintained within the gravel matrix and no free water surface is present. This can help avoid the development of odors and other nuisance problems. The same emergent plants (macrophytes) used for SF can be found in SSF wetlands, with the exception of floating aquatic plants.



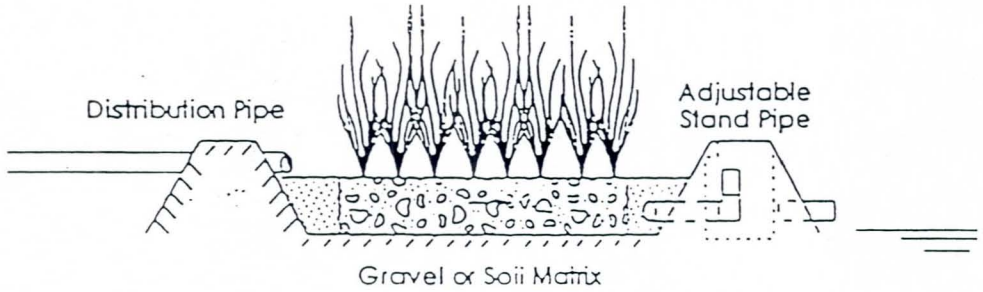
Plan and Profile of a Typical Wetland Pond

Figure 1

Source: Denver Urban Storm Drainage Criteria Manual



Surface Flow (SF) Constructed Wetland



Subsurface Flow (SSF) Constructed Wetland

Figure 2: Types of Constructed Wetlands. *The choice of the most appropriate technology depends on influent quality, effluent goals and land availability.*

Source: Arizona Guidance Manual for Constructed Wetlands by Arizona Department of Environmental Quality

C. Planning Considerations

The following factors are included in planning the design of a constructed wetland:

1. Site selection: Site evaluation is necessary due to design constraints such as topography, climatic factors, existence of floodplains, soil stability, existence of natural wetlands, land ownership, adjacent land uses, presence of protected species and cultural resources.

2. Treatment goals: Natural and constructed wetlands have been used successfully to treat municipal wastewaters to a level appropriate for discharge into "Waters of the U.S." Additional applications include treating agricultural and industrial wastewaters (pretreatment may be required) as well as stormwater runoff. Depending upon constituent loading and treatment goals, a wetland can be designed to reduce certain contaminants such as sediments, nutrients, bacteria, heavy metals, toxic materials, floatable materials, oxygen demanding substances, and oil and grease.

3. Land area required, depth of basin, hydraulic controls and side slope stability.

4. Availability of water.

5. Substrate and liner requirements.

6. Regulatory permits and Approvals such as: Aquifer Protection Permits, NPDES Permit, Environmental Assessment/Environmental Impact Statement, Section 404/Dredge Fill Wetland Permit, Local Permits, Water Reuse Permit (if effluent from Waste Water Treatment Plant is to be the source-water).

7. Type of vegetation: Two general categories of aquatic plants are typically used in constructed wetland systems. These include emergent and floating plant species. Emergent species are used in surface flow and subsurface flow wetland systems. The shallow water depths (less than 3 feet) associated with surface flow systems and the coarse saturated substrates of the subsurface flow systems provide ideal conditions for the survival and reproduction of emergent aquatic plants. Typical emergent plants include cattails, bulrush, and common reed. Treatment systems with water depths greater than 3 feet prevent the establishment and survival of emergent species due to the limited rate of oxygen diffusion at these depths. These systems do however provide the necessary conditions for floating aquatic species. Species typical of these deeper systems include water hyacinth and duckweed.

8. Capital costs.

D. Design Considerations

The type of wetland should be determined prior to start of design. Nuisance conditions such as odor, mosquitoes and poor plant growth have the potential of developing in Surface Flow (SF) wetlands. Stormwater management regulations for the State of Maryland included the following guidelines for the design of wetlands:

1. A permanent pool is essential to establish and maintain a shallow wetland. Water inflow from storms, base flow and groundwater must be greater than water outflow via infiltration, evaporation and discharge.

2. Wetland surface area should be maximized for pollution control and wildlife benefits. A detention time of 24 hours for a one-year storm enhances pollutant removal and provides storage volume recovery between

storms. Assign a freeboard of at least one foot (.3048 meter).

3. Sediment forebays, 1 m (3.28 feet) deep and 10% of pool volume, should be located at all inflow points along with energy dissipation devices to lessen scour and damage to plants.

4. A length to width ratio of 2:1 will reduce short circuiting and maximize the flow path, but if inlet and outlet structures are close, baffles, islands or peninsulas and vegetation planting arrangements will increase the flow path.

5. The soils must be suitable for wetland vegetation. If necessary, organic soils must be imported to the site.

6. Side slopes should be at least 4:1 to a water depth of .60 m (1.968 feet) except on very small facilities where retaining walls are used.

Concurrence in guidelines for sizing is not yet available. However, the Arizona Department of Environmental Quality (ADEQ) recommends the following design criteria.

Summary of Wetland Treatment System Design Criteria (WPCF, 1990) from Arizona Guidance Manual for Constructed Wetlands for Water Quality Improvement by ADEQ

Design Consideration	***Surface Flow (SF)***	***Subsurface Flow (SSF)***
Minimum size, ha/1000 m^3 • day	3-4	1.2-1.7
Maximum water depth, cm	50	Water level below ground
Bed depth, cm	Not applicable if unlined	30-90
Minimum aspect ratio	2 : 1	Not applicable
Maximum hydraulic loading rate, cm/d	2.5-5	6-8
Minimum hydraulic residence time, days	5-10	5-10
Configuration	Multiple cells in parallel and series	Multiple beds in parallel
Effluent Distribution	Swale; perforated pipe	Inlet zone (>0.5 m wide) of large gravel
Maximum loading, kg/ha.d		
BOD_5 (Biochemical Oxygen Demand)	100-110	80-120
TN (Total Nitrogen)	60	60
Additional considerations	Vector control with considerations	Allow flooding capability for weed control

E. **Implementation Requirements**[2]

1. Capital costs.
2. O. & M. costs.
3. Maintenance.
3. Training.

F. **Maintenance Requirements**[2]

In order to maintain the efficient function of wetlands, the following items need to be followed:

1. Check facility after every storm event. Remove debris and sediment buildup.
2. Schedule annual inspection for maintenance and repair.
3. Maintain water level.
4. Repair slope and bank erosion.
5. Remove nuisance species and vegetation (i.e., algae).
6. Control mosquitoes.

G. **Case Studies of Constructed Wetlands**

There has been growing interest among communities and agencies across the country in using constructed wetlands as part of water treatment to improve water quality. Aside from other benefits, such as creation and restoration of wildlife habitat, this system is less expensive and is a good alternative to conventional engineered water treatment systems. The following are existing wetlands:

1. **Show Low Constructed Wetlands, Show Low, Arizona**[3]

Type of wetland: Surface Flow (SF)

Purpose:
To provide additional treatment and reuse for municipal wastewater for the City of Show Low as an alternative to discharging directly into Show Low Creek. Flows from Show Low Creek reach Fool Hollow Lake causing eutrophication, algae blooms and fish fatalities. In cooperation with the U.S. Forest Service, effluent was pumped two miles north to a depression known as Telephone Lake. However in 1977, due to increased population, the treatment system was expanded to include additional depressions known as Pintail Lake and South Lake Marshes. In 1982, wastewater discharges exceeded the treatment plant's volume and disposal capacity causing direct flows to Show Low Creek and degraded quality of effluent in the marsh areas. The solution was to deepen and improve the treatment lagoons, and add aeration, increase pumping capacity, add stabilization ponds for secondary treatment, increase the capacity of Telephone Lake and increase the capacity of marshes for final treatment and reuse.

Design and Layout:
The present system is designed to handle 1.42 mgd to serve a population of 13,500. Several lakes and marshes are combined to function as an effective wetland system. It consists of two aerated lagoons which can operate in series or parallel, a lift station with two 1,150 gmp pumps, four biological stabilization ponds, chlorination contact chamber, effluent storage and clarification in Telephone Lake,

nutrient removal in constructed riparian areas, and finally reuse in constructed waterfowl marshlands.

Operation:
Flexibility is built into the system by varying the quantity, quality and delivery routes. Water control structures with adjustable water boards can hold water at desired levels. Some ponds are allowed to dry up for maintenance and vegetation management. Water quality improves as the effluent moves through the system. The effluent flows through polishing ponds into Telephone Lake, then through an open channel to a riparian area. From the riparian area, water goes through an open channel and eventually to Redhead Marsh.

Response:
Wildlife response to the constructed wetland is a good indicator of success. Bird surveys conducted during a 16 week period in 1991 show 125 species using the wetland. Other animals included rock mountain elk, mule deer, black beer, coyote, raccoon and various kinds of amphibians. The addition of water to the arid site enhanced establishment of vigorous emergent vegetation. Cattail, water grass, spike rush and various sedges developed naturally in the created wetland.

2. **Constructed Wetlands in Kingman, Arizona**[4]

Type of wetland: Surface Flow

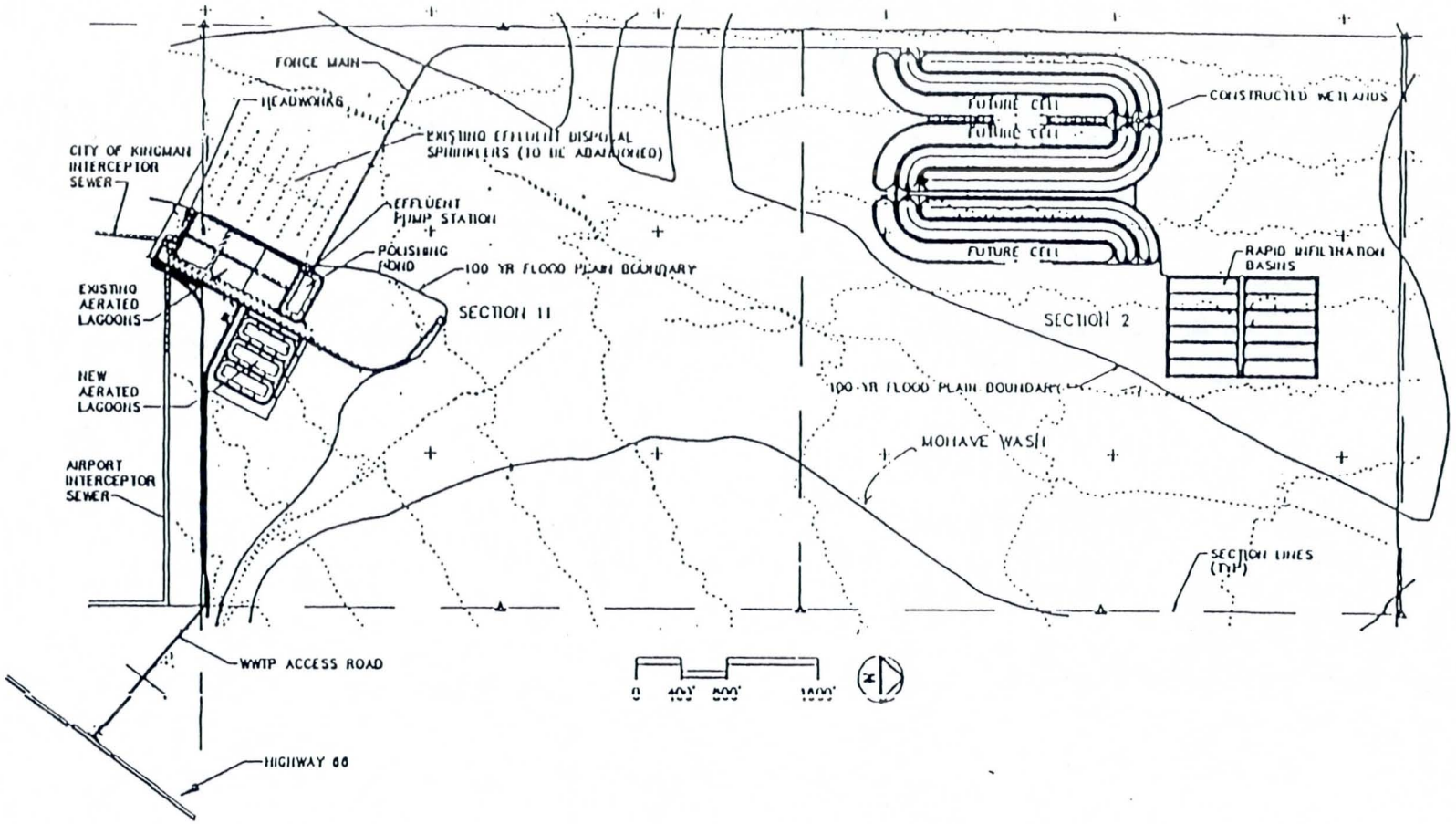
Purpose:
To provide a low tech and environmentally sensitive tertiary treatment (particularly removal of nitrogen), for effluent from the Hilltop Wastewater Treatment Plant. To meet requirements for water quality standards due to expansion, it was necessary for the City of Kingman to upgrade and expand the existing aerated lagoon for secondary treatment of effluent, and construct wetlands and rapid infiltration basins for tertiary treatment. The system is shown in Figure 3.

Design and Layout:
The wetlands system consists of two separate process trains. Each train is composed of three separate sequential cells with a capacity of 3,800 cu m/day (134,093 cu ft/day). Each cell is 46 m (150 ft) wide and 655 m (2,150 ft) long arranged to accommodate serpentine flow. Concrete structures exist between the cells to re-aerate the water and to isolate each individual cell for maintenance. The wetlands occupy an area of approximately 20 ha (50 ac). The cells are planted with bulrushes (*Scirpus* spp.) and cattails (*Typha* spp.). Two (2 ft) deep depressed areas which are trapezoidal in shape, shown in Figure 4, allow sediments to settle, catch suspended solids and prevent development of algae. The outlet areas are surrounded with deep water to discourage heavy plant growth and reduce the possibility of vegetation migrating from the wetlands.

Operation:
Secondary effluent from the polishing lagoons is pumped to the constructed wetland cells through a force main 2 km (1.5 mi) long, as shown in Figure 3. Normal operating depths within the cells varies from 0.15 to 0.91 m (0.5 to 3 ft). Shallow zones in the wetlands develop dense vegetation enhancing microbial nitrification. These alternate with deeper zones that promote anaerobic conditions leading to microbial de-nitrification.

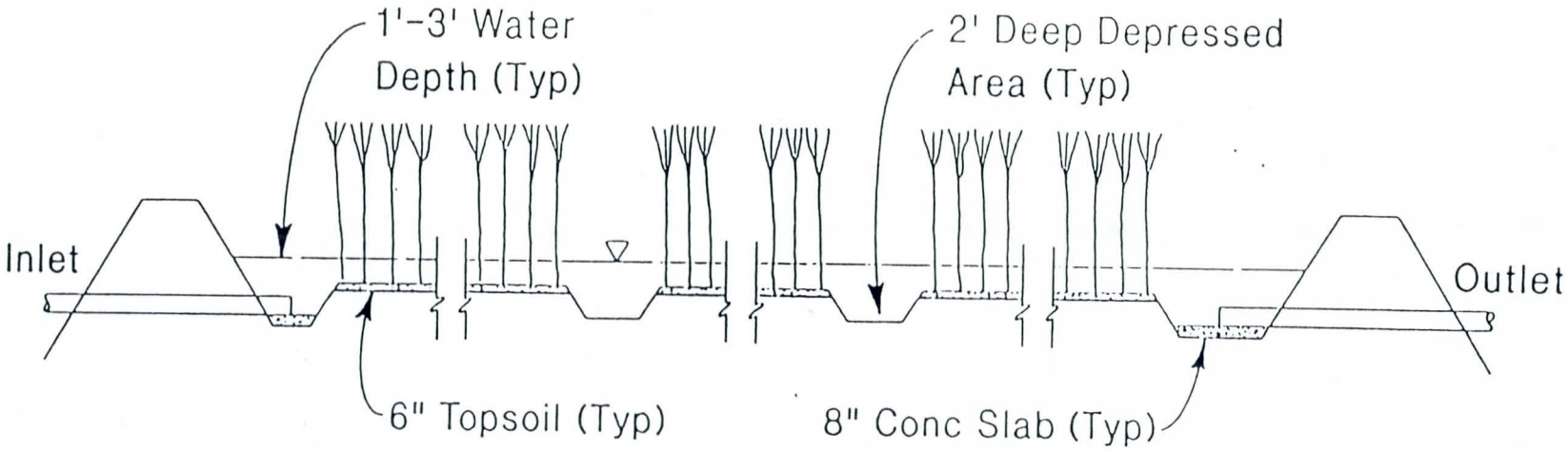
Effectiveness:
Test results to date indicate essentially complete BOD removal in the aerated lagoons. By the time effluent leaves the aerated lagoons the nitrogen is partially nitrified consisting of approximately 20%

Source: Nitrogen Removal by Constructed Wetlands for Tertiary Wastewater Treatment by D.P. Manthe and N.K. Ash of ENTRANCO Engineers for the City of Kingman



Hilltop Wastewater Treatment Plant
City of Kingman, Arizona
Figure 3

KINGMAN2



SECTION THRU TYPICAL WETLANDS CELL

Figure 4

nitrate, 20% nitrite and 60% TKN. At the outlet of the first wetland cell, the total nitrogen concentration has decreased by 50% to 85% of the influent concentration. As measured in the effluent, the overall treatment system nitrogen removal is 70% to 90%.

3. **Wetlands for Maricopa County North Valley Vehicle Maintenance Yard**

Type of wetland: Subsurface Flow or Submerged-Flow Vegetated Treatment System (SVTS)

Purpose:
To provide treatment for oil and grease contaminated runoff with oil and grease from the vehicle maintenance yard by promoting microbial degradation of petroleum hydrocarbons.

Maricopa County has obtained partial funding from an EPA 319(h) Source Demonstration Grant for this project. Matching funds were provided by the Flood Control District including construction and sampling assistance. ADEQ helped formulate sampling strategy and permitting requirements.

Design and Layout:
The Submerged-Flow Vegetated Treatment System (SVTS) is composed of four principal components: settling basin, flow separator, treatment zone and outlets. The structure is concrete. A 2.5 centimeter pipe allows flow from the settling chamber to the flow separator. The flow separator is a perforated PVC barrel to allow equal volumes of stormwater to enter the vegetated (SV) and non-vegetated (SC) sections of the treatment zone. The flow separator also acts as oil skimmer by trapping floating compounds on the surface. A ball-float valve controls the inflow of irrigation water (non-chlorinated ground water from the El Mirage, Arizona municipal system.). The water level can be adjusted to a minimum depth of 10 centimeters (4 inches) to 61 centimeters (24 inches). The treatment zone is 9.1 meters (30 ft.) long, 1.5 meters (5 ft.) wide and 0.9 meter (3 ft.) deep.

The soil-gravel matrix in the treatment zone, shown in Figure 5, contains two size classes of clean-fractured local aggregate. The coarse top layers strain large debris, prevent clogging of finer materials below, provide structural support for vegetation, and provide surface area for adsorption of pollutants and establishment of microorganisms. A 20 centimeter (8 inches) soil was placed below the gravel coarse layers to establish vegetation. The soil is alluvial and the vegetation used consists of cattails obtained from the East Maricopa Floodway.

Operation:
Valley gutter system splits runoff from the maintenance yard along a north-south line, directing flow from the east and west sides of the yard to separate dry wells within the detention basin. The SVTS, located on the east side of the basin, treats contaminated runoff from the fuel bays, service garages and portions of the parking lot area before it enters the dry well.

Effectiveness:
After eleven months of operation, sampling results indicate the system is efficient in removing oil and grease from the stormwater and maintenance yard runoff (87% of the effluent was removed). Monitoring of physical parameters suggest that high microbial activity occurs in the vegetated side of the treatment cell. Respiratory and plating experiments corroborate this finding. The vegetation appears to facilitate the removal of hydrocarbons by adsorption followed by subsequent biodegradation. Maintenance of the system appears to be minimal. This system has shown that the use of submerged flow vegetated treatment systems for dry-well head protection can be effective for petroleum type hydrocarbon removal. For comparison purposes a non-vegetated treatment system consisting of a series

Submerged-flow Vegetated Treatment System

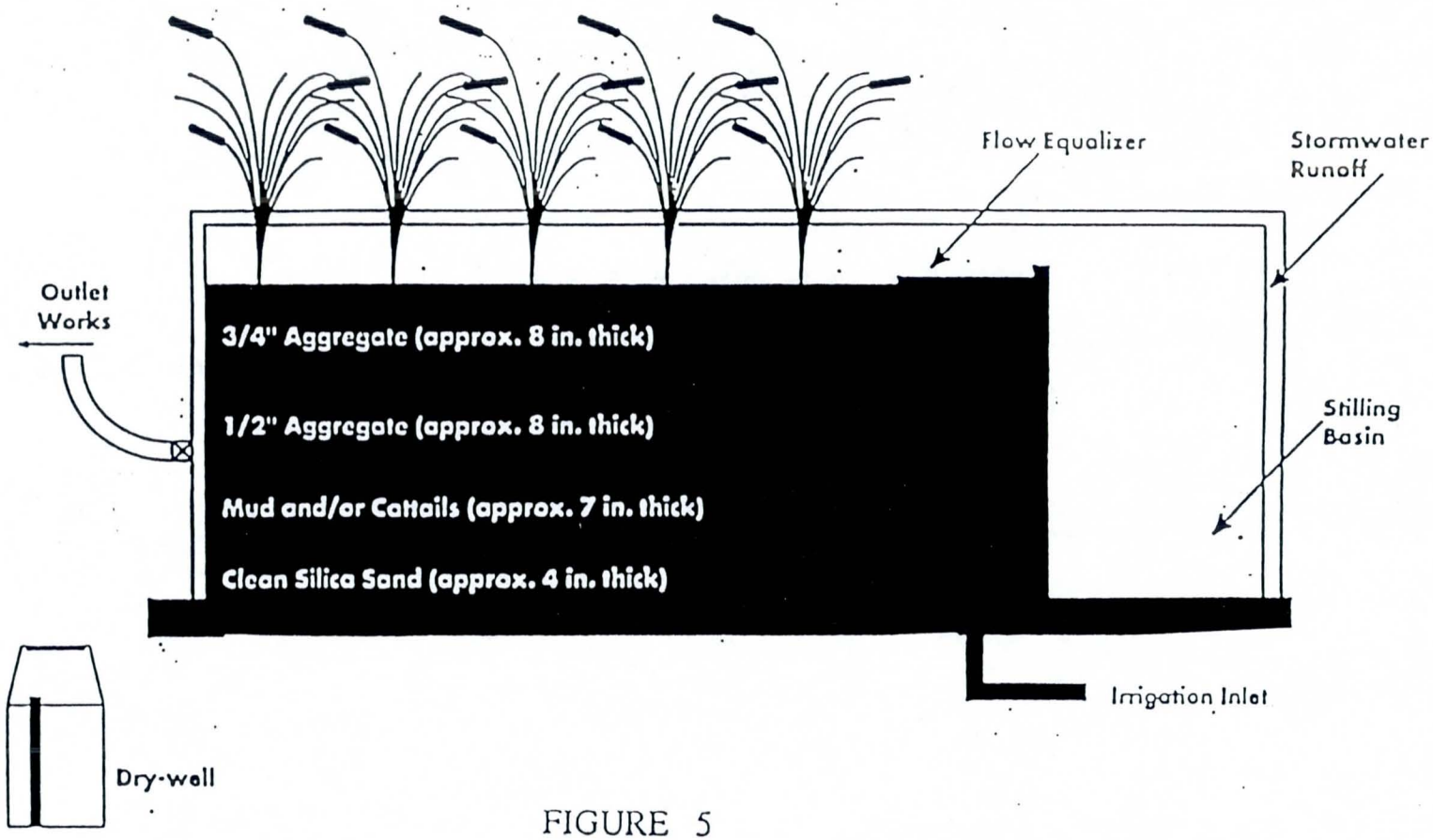


FIGURE 5

Source: Water Environment Federation, Industrial Wastewater
Title: Constructed Wetlands Enhances Stormwater Quality in Arizona
Authors: R. Wass and P. Fox

of graded biological fillters was also constructed. Monitoring results indicate that this system was not well suited for use as dry well head protection in arid environments. The system significantly was less effective at removing oil and grease, and was abandoned after three months of operation.

H. **Limitations and Drawbacks of Constructed Wetlands**[2,6]

Wetlands provide numerous benefits to the natural environment, water quality, people and wildlife. However, there are physical limitations when compared with conventional systems:

1. Large land area requirements.
2. Imprecise design and operating criteria.
3. Generally not feasible in densely developed or populated areas.
4. Require continuous base flow to maintain water level.
5. Cannot be placed on steep unstable slopes or in regions with shallow soils or high water tables.
6. Overgrowth of vegetation can lead to reduced hydraulic capacity. Require regular plant harvesting.
7. Concern for mosquitoes.
8. Wetlands may not provide adequate treatment in order to comply with water quality standards.
9. Nutrient release may occur during dormancy.

References:

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3. *Constructed Wetlands for Wastewater Treatment and Wildlife Habitat*, United States Environmental Protection Agency, 17 Case Studies, (Pintail Lake and Redhead Marsh), pages 124-130, September 1993.

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5. Roland D. Wass and Dr. Peter Fox, a Cooperative Effort by Flood Control District of Maricopa County and Arizona State University, *Nonpoint Source Water Quality Control: Biological Treatment of Stormwater Runoff from a Vehicle Maintenance Yard*, December 1993

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8. Sediment and Stormwater Division, State of Maryland, *Guidelines for Constructing Wetland Stormwater Basins*, Maryland Department of Natural Resources Administration, Annapolis, Maryland, May 1987.