

Jackson Bottom

Concept Master Plan



A Plan Which Integrates Wildlife,
Recreation, and Water Management

January 1989

JB

**Jackson Bottom
Concept Master Plan**

*A Plan Which Integrates Wildlife,
Recreation, and Water Management*

January 1989

Prepared by:
Walker & Macy
Landscape Architects and Planners
Portland, Oregon

Funded by:
City of Hillsboro
Unified Sewerage Agency
Greater Hillsboro Chamber of Commerce
Washington County Soil Conservation District



Acknowledgements

Jackson Bottom Wildlife Project Steering Committee

Tim Erwert, City of Hillsboro
Robert Evans, Hillsboro Chamber of Commerce
Lyell Gardner, Washington County Soil and Water Conservation District
Gene Herb, Oregon Department of Fish and Wildlife
Cal Krahmer, Washington County Soil and Water Conservation District
Gary Krahmer, Unified Sewerage Agency
Stan LeSieur, Unified Sewerage Agency
Claire Puchy, Portland Audubon Society
Ken Rutherford, Oregon Department of Fish and Wildlife
Ethan Seltzer, Tualatin Riverkeepers

City of Hillsboro Project Management

Winslow Brooks, Planning Director
Stan Dillon, Public Works Director
Russ Sterenberg, Parks Director
Mel Oberst, Urban Planner
Scott Talbot, Parks Planner

Consultant Team

Walker & Macy, Landscape Architects and Planners
J. Douglas Macy
Wayne P. Stewart
Bennett Burns
Mark Stewart
Loree Sheckels

Robert Gearheart, Professor of Environmental Engineering
Humboldt State University

Scientific Resources, Inc.
Stan Geiger

Lynn Sharp, Environmental Consultant

Kramer, Chin & Mayo, Inc.
Jerry Minor

Carol Ann Raphael, Editor

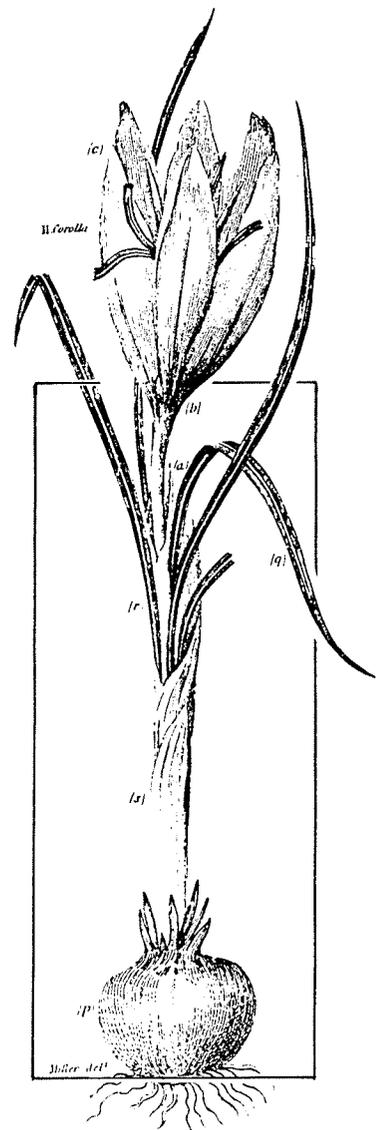
Table of Contents

I. Introduction	1
Combining Resources	2
II. Executive Summary	5
Benefits	5
The Master Plan	6
Phase One Project	7
Phase One Costs	8
III. Area History	9
The Land	9
Early Inhabitants	9
The Settlement Era	10
Recent Times	14
IV. Existing Conditions	15
Climate	15
Hydrology	15
Soils	17
Vegetation	18
Wildlife	23
Fish	25
Ownership and Current Uses	26
Urbanization	27
V. The Master Plan	29
Opportunities	29
Local and Regional Access	31
Components of the Master Plan	31
Plan Implementation	35
VI. Phase One Project	41
Objectives	41
Components	42
Design and Other Studies	42
Time Schedule For Improvements	45
Project Management	45
Research and Monitoring	46
Cost Estimates	46
Appendixes	
A. Wetland Wastewater Treatment Systems	
B. Wildlife Habitat	
C. Jackson Bottom Wildlife List	

List of Figures

1.	Canada Geese Swooping Over the Basin	1
2.	Vicinity Map	2
3.	Aerial View of Jackson Bottom	3
4.	Recreational and Educational Opportunities of Enhancing Wetlands	5
5.	Improving River Access	6
6.	Ownership	7
7.	1852 Surveys	11
8.	Log Drive on the Tualatin River	12
9.	Sawmill on Rock Creek and Baseline Road	13
10.	1905 Bridge Across Jackson Bottom South of Hillsboro	13
11.	Hydrology	16
12.	Stormwater Outfalls	17
13.	Soils Map	19
14.	Vegetation	21
15.	The Tualatin River	23
16.	Unmowed Lowlands	24
17.	Effluent Storage Pond	24
18.	Great Blue Heron in Mowed Lowland	25
19.	Ownership	26
20.	Urbanization	28
21.	Canada Geese in Wildlife Ponds	29
22.	Seasonal Storage Pond	32
23.	Effluent Treatment Pond	33
24.	Storm Runoff Wetlands	33
25.	River Access and Trail System	34
26.	Interpretive Center	35
27.	Concept Master Plan	39
28.	Phase I Concept Plan	43

Introduction



I. Introduction

Our Future Lies in Working Together

By mid-November taking a drive along Highway 219 through Jackson Bottom can be an exciting adventure. You may see a large flock of Canada geese swooping down out of the leaden sky, or catch a glimpse of some pintail ducks poking out from beneath a bush. If it's a really glorious day, you'll be serenaded by meadow lark as they dart about the Bottom.

But that's in November when it's as cold and wet for you as it is for your less domestic friends. What if it were August and you could bask in the warmth of the afternoon sun while watching a green heron daintily plucking a salamander for a midday snack. Or maybe enjoy the full orchestral sound of several varieties of song birds while watching the sun rise above the horizon. You'd be able to aim your fogless binoculars on a family of tundra swan yards away and clearly observe their escapades.

Then for a break, you hike back to the interpretive center to look for a guide book on the mating habits of red tail hawks. On the way you discover a trail which leads to the canoe launch and decide to take a quick tour by water before catching the light-rail train back to Portland.

All this is possible if we start now and work cooperatively to transform Jackson Bottom into a national model for wildlife preservation, water quality management, and recreational opportunities that will attract people from throughout the Northwest and beyond.



Figure 1: *Canada Geese Swooping over the Bottom*

Combining Resources

Serving Our Multiple Needs

For over ten years the City of Hillsboro, the Unified Sewerage Agency, the Oregon Department of Fish and Wildlife, the U.S. Soil Conservation Service, the Washington County Soil and Water Conservation District, and the Portland Audubon Society have been working together on preserving and enhancing the natural resources of Jackson Bottom, a lowland area within the floodplain of the Tualatin River. Their efforts until now have been directed primarily towards improving the area as a wildlife habitat and for recreational purposes. Now the coalition is broadening its efforts to include the improvement of water quality in the Tualatin River.

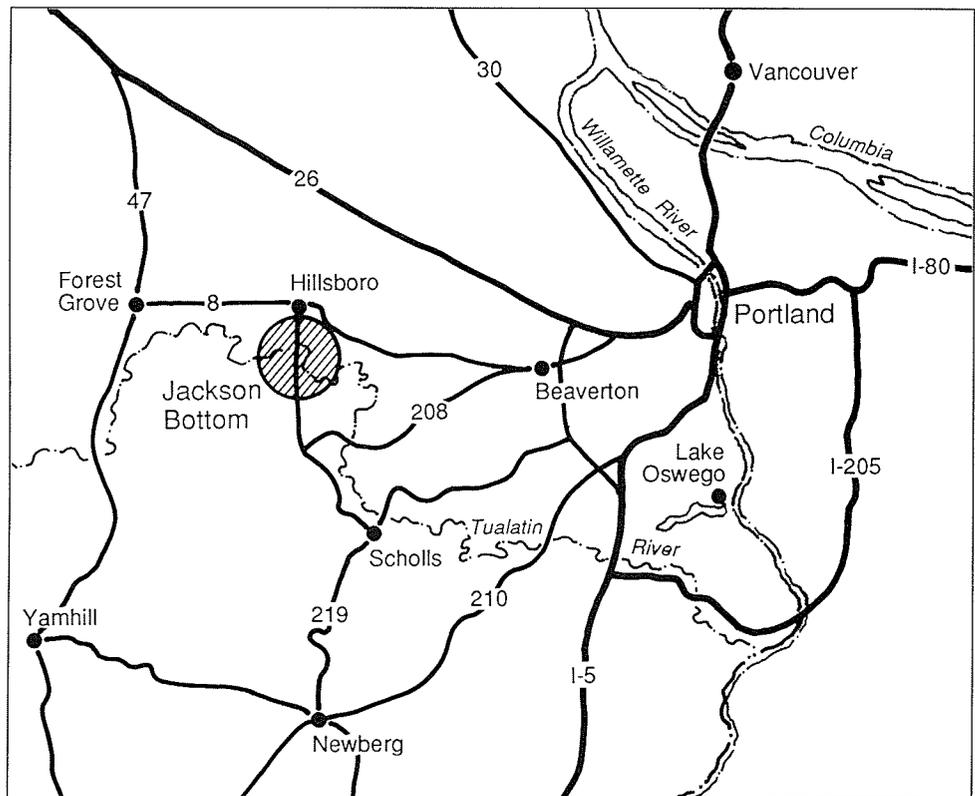


Figure 2: Vicinity Map

The wetlands of Jackson Bottom provide a unique opportunity for expanding the diversity of resident wildlife, improving water quality, attracting tourists, and offering passive and non-consumptive forms of recreation. In particular, the following goals can be achieved through an integrated master plan which is implemented in phases and through the cooperative activities of public and private entities.

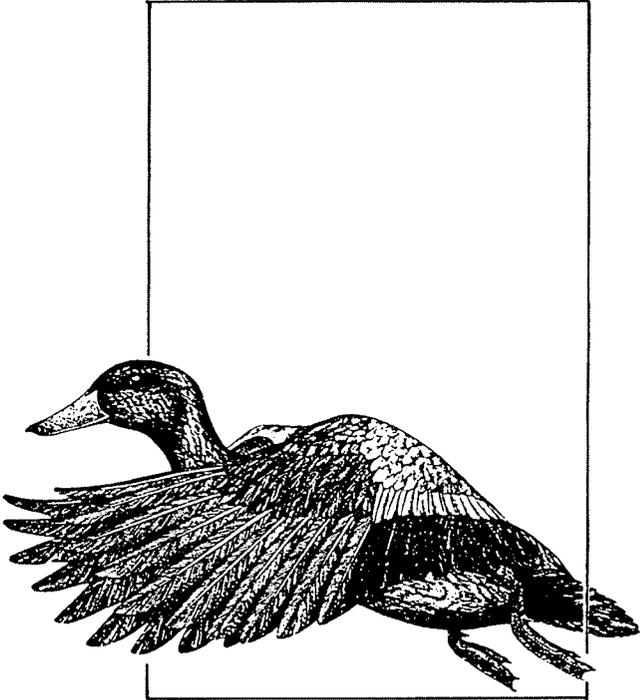
1. Attract a more diverse wildlife population by expanding the wetlands which provide food and shelter to a variety of birds and animals.
2. Preserve remaining blocks of undeveloped flood plain for open space and agricultural uses.
3. Encourage recreational use by expanding facilities for walking, bicycling, wildlife viewing, fishing, and boating.

4. Expand educational activities for youth and adults.
5. Store spring run-off water to augment Tualatin River flows through the late summer.
6. Explore the potential of developing commercial aquaculture.
7. Take advantage of the large amount of water available from the Unified Sewerage Agency for maintaining water levels in wetlands and ponds and for irrigating non-edible crops.
8. Create an exemplar of wetlands preservation and development which will serve as a model for other areas in the state and nation.
9. Utilize the wetlands for biofiltration treatment of wastewater.
10. Perform research to characterize existing conditions, monitor changes, and provide feedback for future activities.



Figure 3: Aerial View of Jackson Bottom

Executive Summary



II. Executive Summary

A Brief Overview

It is well known that wetlands provide habitat for many forms of wildlife, including shore birds, waterfowl, mammals, amphibians, and reptiles. Areas near wetlands, such as fields and forests, also support raccoons, opossums, coyotes, and deer. Wetlands have high recreational and educational value as well. They offer opportunities for wildlife viewing and research into the diverse plant and animal communities they support.

A convergence of interests is occurring with regard to Jackson Bottom. Public and private organizations are coming to the conclusion that expansion of the wetlands in Jackson Bottom may benefit their varied interests for natural resource management and water quality maintenance.

Benefits

The Rewards of Our Efforts

The following benefits are expected by enhancing the wetlands and lowlands of Jackson Bottom:

- Permanent preservation of open space and agricultural land.
- Augmentation of Tualatin River flows in late summer.
- Expanded wildlife population.
- Expanded recreational opportunities.
- Expanded educational opportunities.
- Lower capital and operational costs to meet water quality standards.

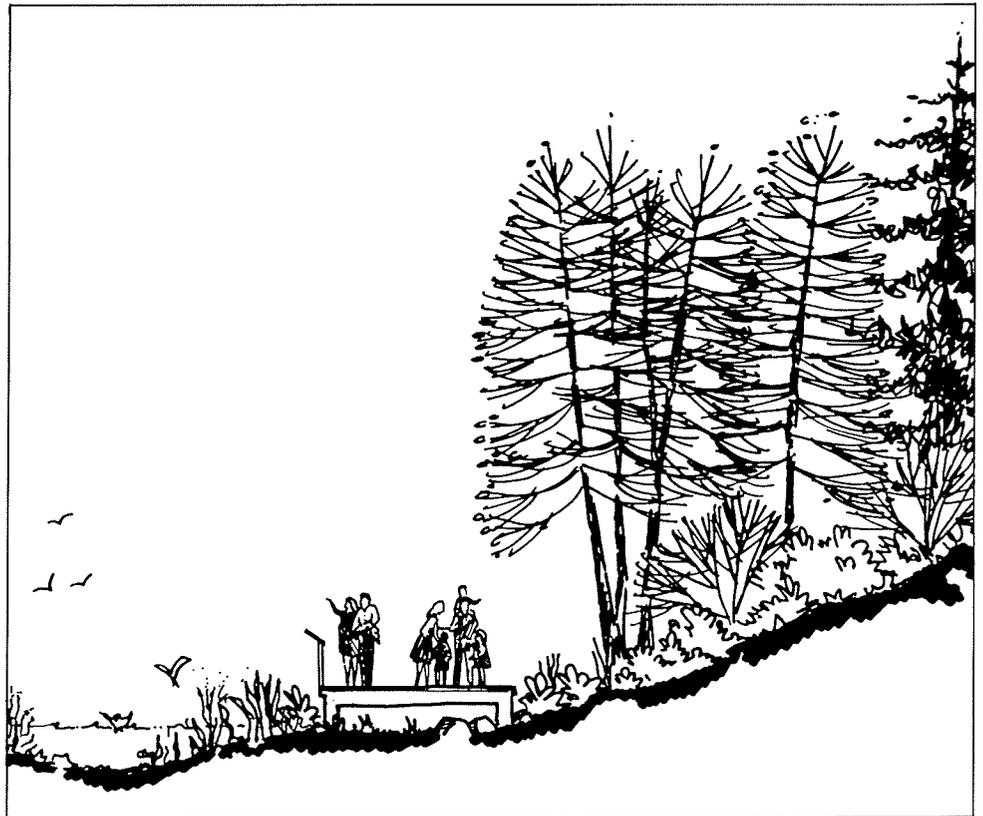


Figure 4: *Recreational & Educational Opportunities of Enhancing Wetlands*

The Master Plan

How It Can Happen

The concept master plan for Jackson Bottom is illustrated and described in Chapter V (page 29). The key elements of the plan include the following:

1. Wildlife habitat and forage areas will be created and expanded to encourage a more diverse wildlife population.
2. An education and interpretative center will be developed to accommodate the needs of children and adults.
3. Access to the Tualatin River will be expanded to encourage greater use of the river for recreational pursuits.
4. An extensive trail system will be developed to accommodate the recreational and educational desires of walkers, joggers, and bicyclists.

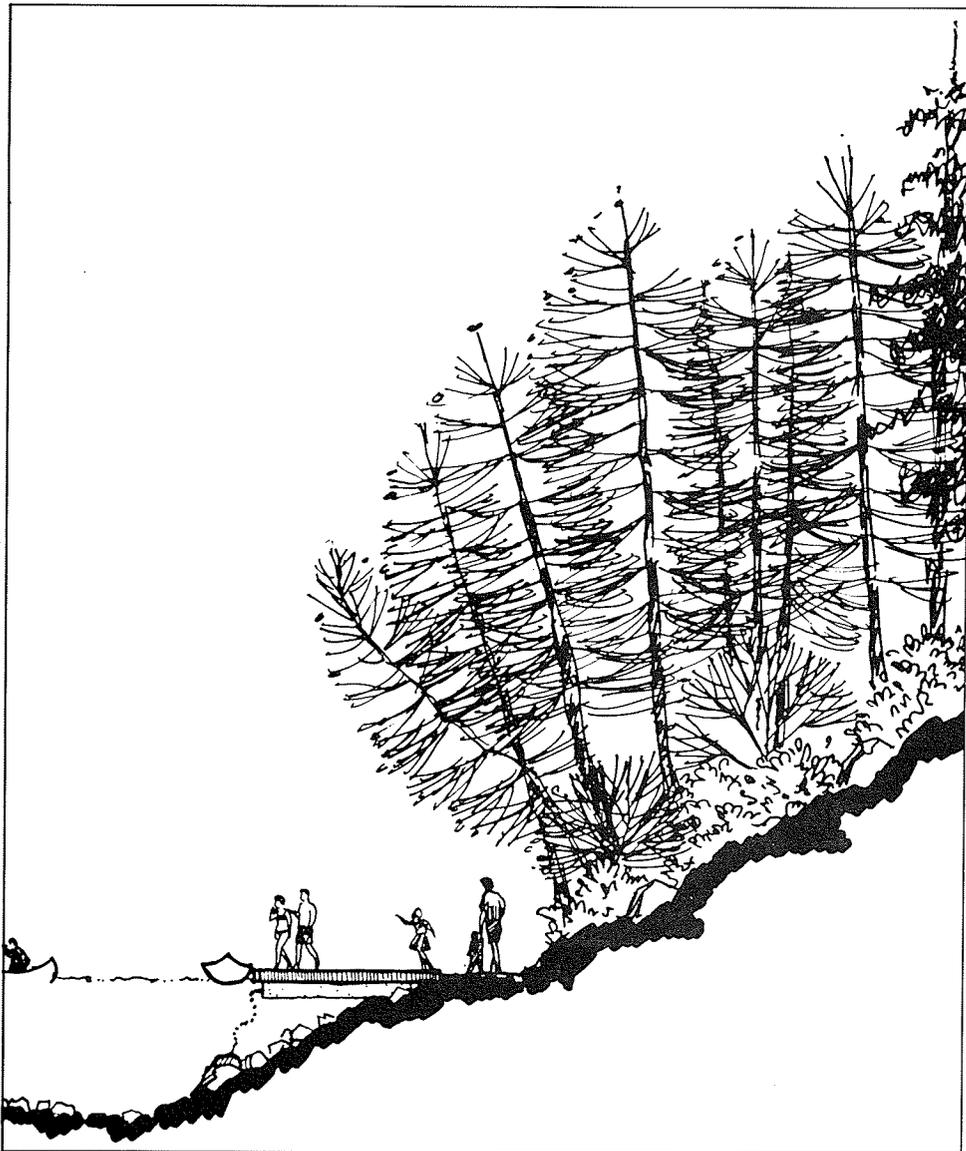


Figure 5: *Improving River Access*

5. The landfill site, after closure, should be redeveloped to accommodate active and passive recreational uses.
6. Seasonal storage ponds will store Tualatin River water during the spring for release during the dry summer months.
7. Wetlands will be constructed to intercept and filter storm runoff.
8. Wetlands will be constructed to "polish" treated wastewater before release to the Tualatin River.
9. Greater use of treated wastewater for irrigation purposes will be encouraged.

Phase One Project

The First Step

The phase one project includes the initial development of recreational and educational facilities. An unstaffed interpretive facility is proposed along Highway 219 on existing public land. Maps and other displays will encourage recreational use of the area and educate visitors about the value of wetlands. The beginning of a trail system is proposed to enable visitors to observe the wetlands and enjoy the river. To encourage greater recreational use of the Tualatin River, small boat access should be provided at bridge crossings and other locations where public property abuts the river.

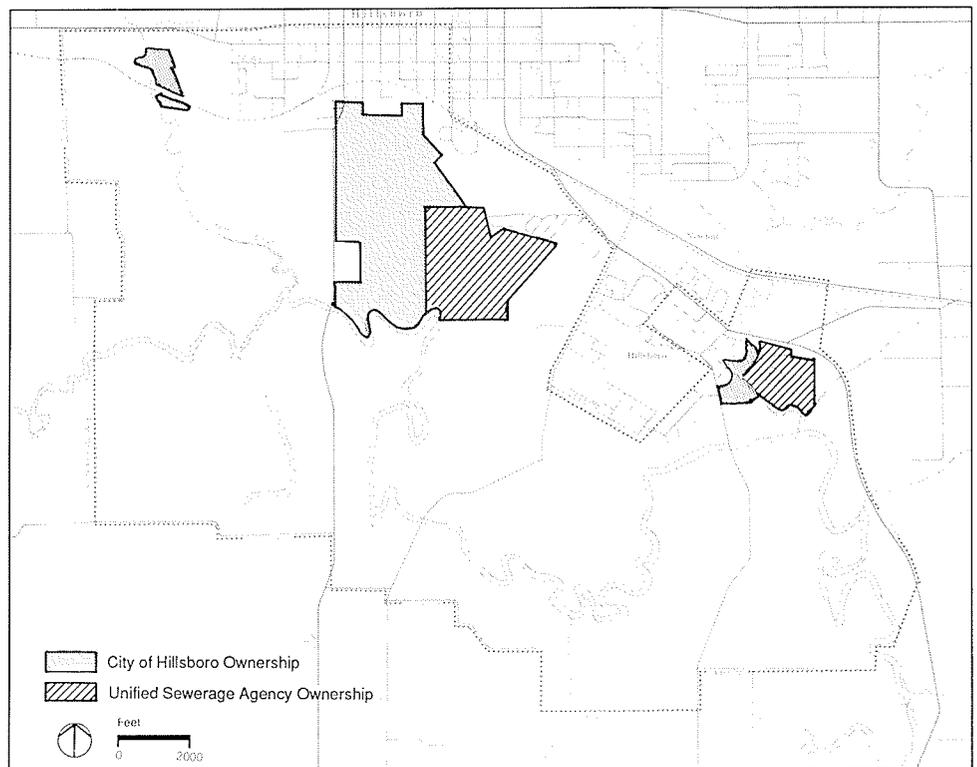


Figure 6: Ownership

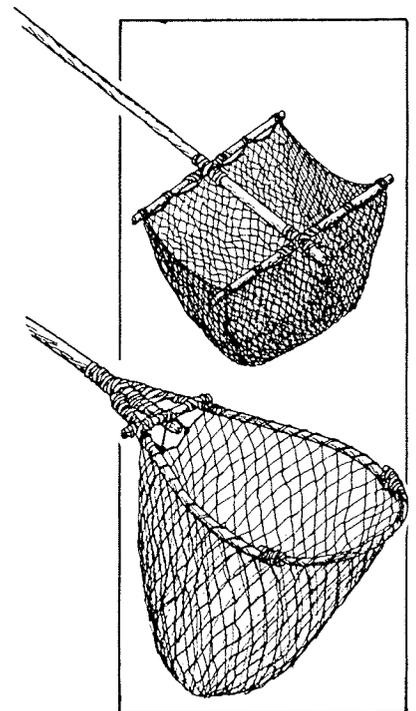
The phase one project area also includes test parcels spread throughout the 420 acres presently in public ownership. The purpose of this undertaking is to experiment with a number of different enhancement techniques to determine which work best in Jackson Bottom.

Phase One Costs

How Much Money We Need

The total phase one cost is estimated to be \$1,520,000. This figure includes construction, professional fees (design, survey, legal), the cost of wetland management for the first five years, and the cost of recommended research activities during the five-year period.

Area History



III. Area History *How Jackson Bottom Came to Be*

The formation of the Tualatin Valley can be traced back 10,500 years. At that time the first of several ice dams burst in western Montana. When they broke, torrents ripped through the entire Columbia River System. The floodwaters which resulted from these cataclysms deposited vast amounts of sediment in the lower Columbia, Willamette, and Tualatin River valleys. By 4,200 years ago the waters had receded from the Tualatin Valley, leaving behind a flat floor of rich soil.

The Land

The Geology of Jackson Bottom

The central portion of the Tualatin Valley is nearly level and covered with deep sedimentary deposits, which reach a thickness of over 1,300 feet near the city of Hillsboro. The middle and lower stretches of the Tualatin River, now a sluggish waterway, cross this level plain. Due to its flat gradient and minimal current, the river's course, and hence the surrounding area, has changed very slowly over the centuries. Except for changes to the numerous oxbows and bank scouring during occasional major floods, the valley has not been subjected to much erosion over the past 2,000 to 3,000 years.

This lack of erosion can be directly attributed to basalt formations which are located near the surface of the valley in several locations. The high erosion resistance of basalt means that the downward cutting power of the river has been effectively reduced. A basalt formation located just south of the Jackson Bottom study area, between Laurel Ridge and Bull Mountain, has greatly slowed the rate of erosion in the central portion of the valley and has kept the river gradient nearly flat.

Because so little sediment has been carried out of the valley by the river system, it can be assumed that present topographic conditions have existed at least since the end of the last ice age. Indeed, the upper portions of the Tualatin Valley have actually gained in sediment. Younger alluvium soils have been carried down from the coast range by floods, gradually building up the river bottoms. Other than these recent deposits, nearly the entire floor consists of older alluvium soils. Consequently, the soils of Jackson Bottom are similar to other wetlands in the Tualatin River system.

Early Inhabitants

Native American Indians

Members of the Atfalati tribe first occupied the land surrounding the Tualatin River. Primarily gatherers, the Atfalati were a band of the Kalyapuias who inhabited the Tualatin and Central Willamette River valleys. Known to journey to Tillamook Bay and the Columbia River for salmon, the Atfalati ranged widely throughout the area, though they remained centered in the mid-valley area.

The forays for Chinook salmon were undertaken because salmon did not run on the Tualatin. Upstream of Willamette Falls most salmon remained in the Willamette River, bypassing the western Willamette Valley tributaries completely. With the absence of salmon as a major food source, the Atfalati initiated burning to clear the Tualatin plains of its dense vegetation. The burned-over areas

revegetated as grasslands and yielded seasonal food sources such as tarweed seed, berries, and nuts. The grasslands also provided excellent habitat for deer and elk.

Initiated in pre-historic times, field burning continued until the arrival of the white settlers in the 1830's. By this time, much of the valley floor had been transformed into a grass-covered plain. Areas within the flood plain remained more or less in their natural state, although in particularly dry years sections of the lowlands were known to burn. Nevertheless, compared with the almost total destruction of the forests on the plains, the Jackson Bottom area remained fairly unchanged.

When the Atfalati used the bottom land, it was primarily for hunting small game and waterfowl and for root gathering. It is recorded that fishing was fairly poor, though some warm water fish and lamprey eel were caught. Smaller mammals were also found in the Bottom.

The mainstays of the Atfalati diet were waterfowl, bulbs of a flower called camas, and tubers of an arrow-leaved water plant call wapato. Conjecture also holds that the Atfalati ate insects, i.e., grasshoppers, caterpillars, and yellow jacket larvae, although this assumption is based on the knowledge that other Kalyapuia tribes did so. Nonetheless, the Bottom would have been a prime habitat for such creatures.

Several seasonal village sites have been discovered within the Jackson Bottom area, but no significant village finds have been recorded. Archaeologists have found simple utensils such as bowls, mortars, and pestles. In addition, several landowners have discovered arrowheads and other items. However, no actual camp-sites have been found below the 160-foot contour (most of the bottom land is below the 140-foot contour.) Below this level the soil was probably too wet for habitation, except for a short while in the summer season.

The summer camps would have consisted of a cluster of lean-tos. More permanent village sites were established at Wapato Lake. (This large lake bed near Gaston has been drained.) Here the Atfalati passed the winter months on a diet of smoked salmon and cakes of camas. The tribe constructed half-buried long-houses, usually located between the 160 and 180-foot contours around the lake. With the arrival of spring, the Atfalati would disperse, moving to auxiliary sites such as those found near Jackson Bottom.

The Settlement Era

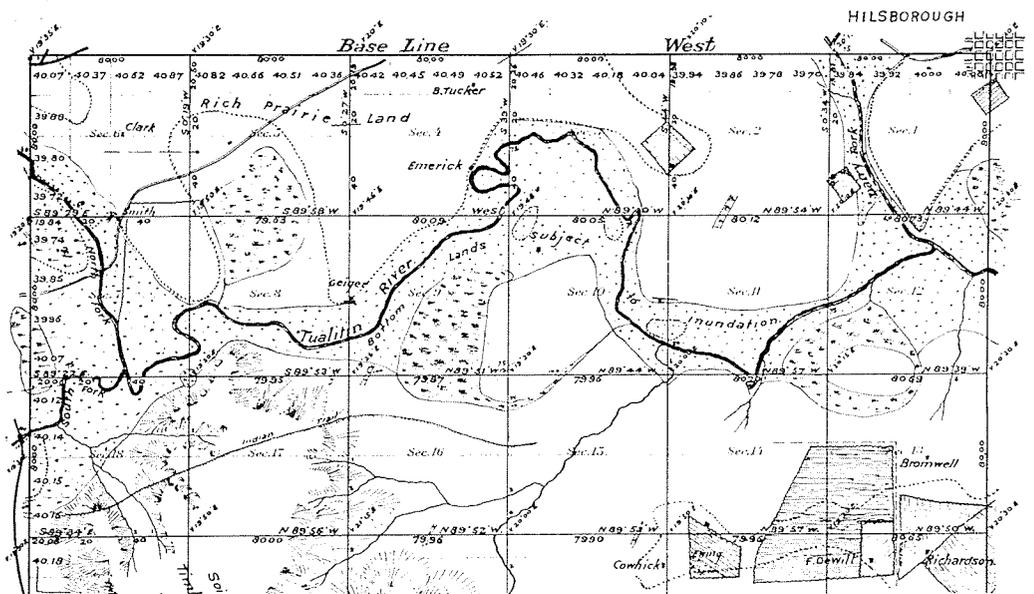
The Arrival of New Inhabitants

By the 1830's a majority of the Atfalatis had died of disease, possibly smallpox and malaria brought by the arrival of trappers. Virtually decimated, the Atfalati left an agricultural treasure as their legacy: the broad, fertile plains of the Tualatin Valley.

The first use of the Tualatin Valley by Caucasians was as summer pasture for the cattle of Fort Vancouver, presaging the agricultural value future settlers would place on the area. Soon after, retired trappers began to settle the valley and establish the markings of a permanent settlement. The first American settlers arrived in the 1840's.

The eastern Tualatin Valley was one of the first areas settled in the Oregon Territory after Fort Vancouver. Under the system of Donation Land Claims, a majority of the high quality agricultural lands had been claimed by 1852. Jackson Bottom was not one of these areas. The Tualatin River floodplain, including Jackson Bottom, hindered accessibility to the southern portion of the Tualatin Valley for several decades.

Among the early land claims in the Jackson Bottom area were the homesteads of Noah Job, David Hill, Michael Moore, and George Sigler to the north and, on the south side, those of Francis Dewitt, N.C. Richardson, and Horace Lindsay. As recorded on the 1852 Donation Land Claims maps, all except one of these men farmed areas well away from the Bottom. The exception, Noah Job, established a small plot which lay partly in the lowlands along Dairy Creek. As time passed, people began to edge closer to Jackson Bottom. After a time, much of the land in the bottom area was brought under cultivation. Nevertheless, it was clear that the bottom land was an area of last resort for farming and not claimed until better agricultural land had been settled.



Area Southwest of Hillsboro

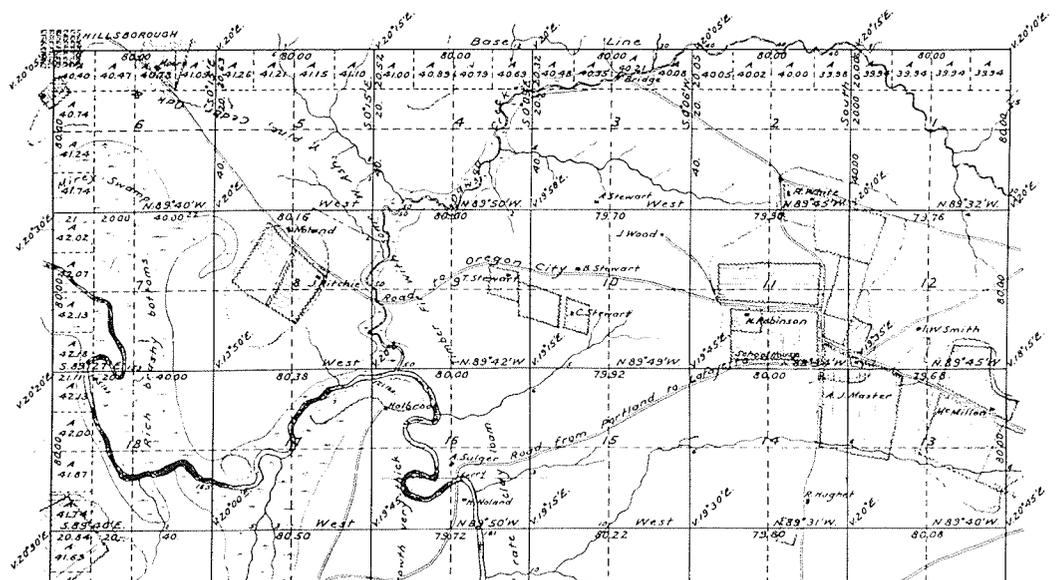


Figure 7: 1852 Surveys, Area Southeast of Hillsboro

With the land claims and growth of what is now the city of Hillsboro on David Hill's claim, industry began to develop. Early commercial activities, such as lumber production and transportation of farm products, centered on the river. By 1857 steamboats were plying the Tualatin River even though the journey up river was a difficult one. Snags had to be pulled from the river channel, a job which took years and eventually contributed to the demise of river transportation. As a further hindrance, low water in the summer months made river travel impossible. And yet, for several years riverboats remained an important mode of transportation, moving people and goods between Lake Oswego and what is now Cornelius.



Figure 8: Log Drive on the Tualatin River

Landings lined the length of the river, with several located in the Jackson Bottom area. Warehouses were located in Cornelius and at the site of the Jackson Bottom Bridge, which is now Highway 219. The warehouse at Jackson Bottom Bridge stood from 1865 until the mid-1890's. Other landings were located at Rood Bridge and Sulger Ferry, at the extreme southern edge of the Jackson Bottom area. Sulger's Ferry was the crossing point for the Portland-Lafayette Road, an important overland route in the 19th century.

Not far upstream from the ferry, Lewis Rood purchased the area near the mouth of Rock Creek, land which is now Meriwether Golf Course. Here he built a bridge and established a large sawmill, one of the many constructed to supply the needs of the growing valley population. Another river crossing was established with the opening of the Minter Bridge. Named for Jacob and Mary Minter, who settled in the area in 1854, the bridge spanned the center of Jackson Bottom.

The route which is now Highway 219 was established some time prior to 1865. Over the years this route was improved and enlarged several times, easing accessibility to the county seat for residents of the southern Tualatin Valley. According to one source, a bridge was standing in 1865 and collapsed in the 1890's. A photo caption from a private collection states that a wooden truss draw bridge was built in 1905 and stood until 1921. The present earth dike, which runs from the Hillsboro sewage treatment plant to the KUIK radio towers, is thought to have been constructed in the spring of 1920. Although all information on this route is

based on sketchy information, it appears likely that at least three bridges have crossed the Tualatin River along the Highway 219 alignment.

With the coming of the railroad, use of Jackson Bottom began to diminish. Steamer service on the river was halted, unable to compete with the speed and convenience of train service. The sawmills and their log drives continued for several more years, but eventually they, too, moved their operations to make use of rail transport.

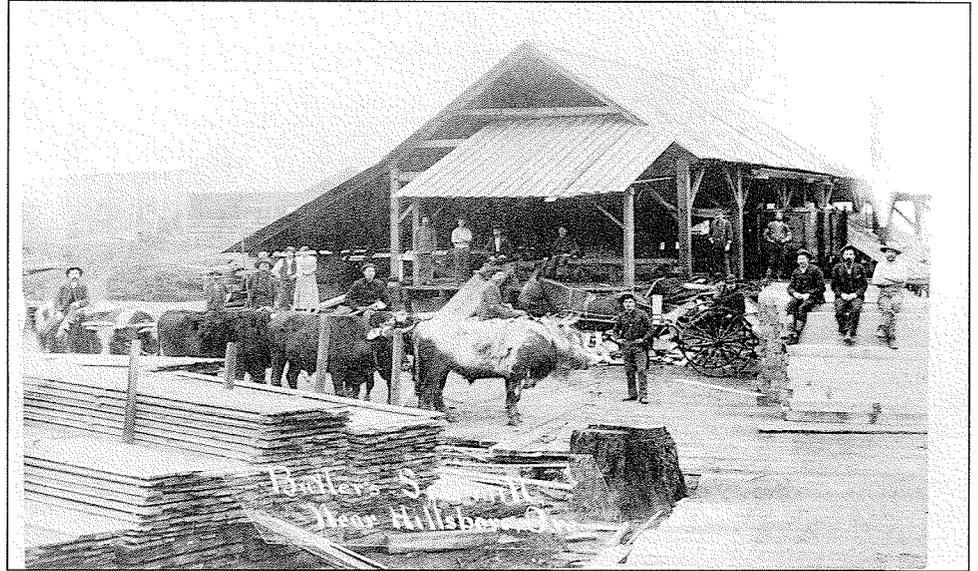


Figure 9: Sawmill on Rock Creek and Baseline Road



Figure 10: 1905 Bridge Across Jackson Bottom South of Hillsboro

Recent Times

Jackson Bottom Today

During the early part of this century farmers cleared most of the Jackson Bottom area for agricultural purposes. Reed canary grass was introduced along the river by dairy farmers and eventually spread, via flooding, to most areas of the Bottom.

In 1910 the City of Hillsboro installed sewers in the downtown. They were connected to a septic tank located at the end of Second Avenue, in Jackson Bottom. In 1935 the City constructed a sewage treatment plant along Highway 219 to replace the inadequate earlier system.

By the 1930's Hillsboro's population had reached approximately 3,500 people, and its economy was centered around cannery and lumbering activities. Cannery wastes were discharged directly into the Tualatin River, polluting the river to such an extent that the dairy farmers could no longer use river water for their herds.

Many farmers were incensed about river pollution and at least a few threatened to sue the City. With the effects of the Depression prevalent in Oregon, money was tight and the City leaders were hesitant to take action against the canneries. In 1939 the largest cannery, Maling & Company, purchased the 120-acre Trent farm to eliminate the most vocal opponent of river pollution. The farm was then resold to the City and became the first publicly owned property in Jackson Bottom.

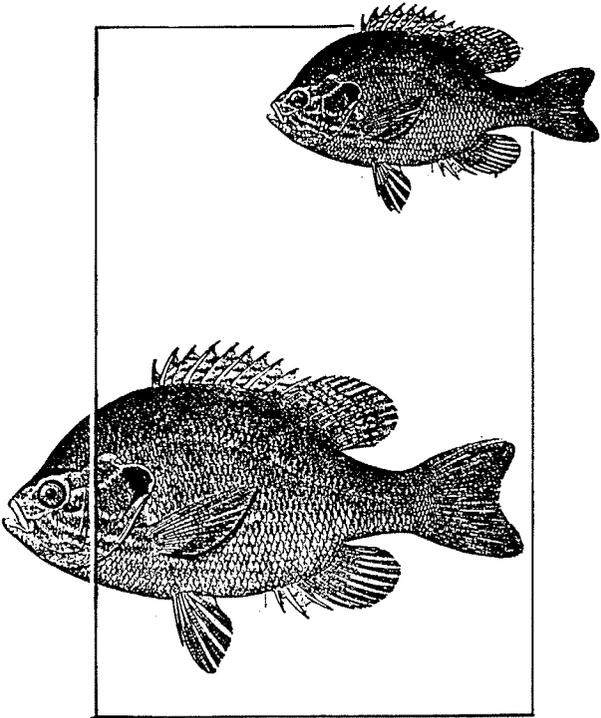
State and local pressure to clean up cannery waste increased and by 1945 the City of Hillsboro started experimenting with land disposal techniques. James Burns, the operator of the Hillsboro Sewer Farm from 1935 to 1969, returned from his World War II service in the U.S. Army Corps of Engineers with many innovative ideas about land disposal. He experimented with intermittent flooding, spray irrigation, crop production (beans, corn, broccoli, cauliflower, and squash), and pasture enhancement.

These activities proved successful and at one time the sewer farm employed over 200 people to grow, harvest, and process crops grown on the farm. At its peak, the project produced a \$36,000 profit for the City. Additional private properties were acquired over the years and by 1956 the City owned most of Jackson Bottom east of Highway 219.

The City continued to operate the sewer farm into the early 1970's. Intensive farming ceased and reed canary grass took over as the area was allowed to become pasture land.

In 1980 the Jackson Bottom Coordinated Resource Management Plan was developed. This plan encouraged the creation of ponds for wildlife enhancement in Jackson Bottom. Pond construction was commenced in 1980, supervised by Gene Herb of the Oregon Department of Fish and Wildlife. Pond development, plantings of forage and shelter vegetation, construction of nesting boxes, and placement of gabusia fish to control mosquitos continue to the present.

Existing Conditions



IV. Existing Conditions

What We Have to Work With

Jackson Bottom is a lowland area within the floodplain of the Tualatin River. It is located to the south of the city of Hillsboro. The study area includes approximately 3,000 acres.

Climate

The Weather at Jackson Bottom

The climate of the Tualatin River basin is mild due to the moderating influences of the Pacific Ocean and the Columbia River. Winter temperatures seldom fall below freezing and summer temperatures range in the 70's and 80's. The growing season is 220 days in length. Rainfall and stream flow are seasonal, tending to be high during the winter and low during the summer. Annual rainfall is approximately 40 inches.

Hydrology

Where the Water Comes From

Jackson Bottom sits in the middle of the Tualatin River basin, near mile 45 of the 83 miles of the Tualatin River. The Bottom is within the central plain of the basin, at the upper end of the middle segment of the Tualatin River.

The Tualatin River. The Tualatin River meanders through the Jackson Bottom study area, traversing a total of 9.5 river miles (river mile 36 to 45.5). The river is roughly 40 to 60 feet wide in the study area.

In the early 1920's fill was placed along the Highway 219 alignment to replace a bridge, creating a dike which causes higher flood elevations on the upstream side. In 1975 a dam was built on Scoggins Creek, a tributary of the Tualatin River. The resulting reservoir, called Hagg Lake, is used to store water for summer irrigation and to accommodate recreational pursuits. During 1987 the minimum daily discharge from the reservoir was 12 cubic feet per second (in March when the reservoir was being refilled) and the maximum was 170 cubic feet per second (in August when water was being released for irrigation and river flow augmentation).

River flow through the Jackson Bottom area is highly seasonal, with flooding occurring periodically during the winter and early spring (generally December through March). Ten-year floods (a level of flooding predicted to occur once every ten years) reach an elevation of 140 to 141 feet above sea level; 100-year floods reach an elevation of 146 feet. Consequently, the Bottom is periodically covered with up to ten feet of water during the winter and occasionally up to 20 feet.

Streams and Wetlands. There are five streams that empty into the Tualatin River within the project area: Dairy Creek, Rock Creek, Gordon Creek, Davis Creek, and Butternut Creek. Only the first two of these streams discharge significant amounts of water into the Tualatin River. There are an indeterminate number of spring-fed streams that also empty into the river. There are two small oxbow lakes that have been created by the Tualatin as well as a number of small embayments or backwaters.

Wetlands in Jackson Bottom are generally associated with riparian corridors. These areas are defined by the U. S. Fish and Wildlife Service as wetlands because their soils are inundated sufficiently long each year to provide habitat for wetland plants.

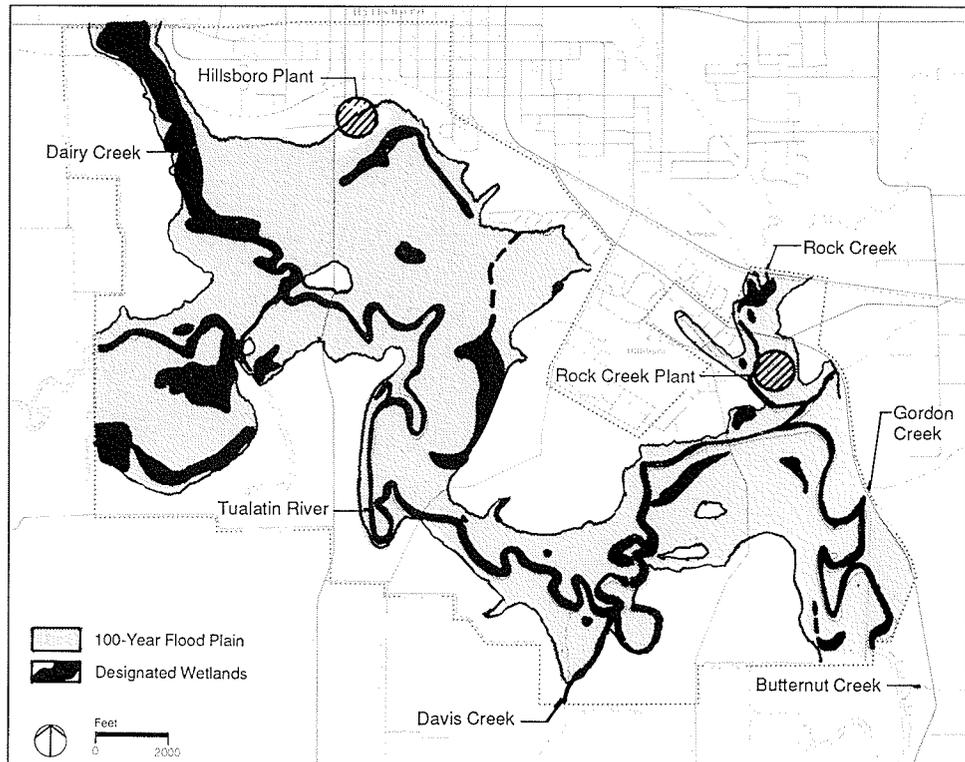


Figure 11: Hydrology

A circular wetland was identified on USA property east of the KUIK radio tower. Wetlands associated with old river oxbows occur in the southwest corner of the project area and along the north side of the golf course in the eastern portion of the project. A wide band of wetland was mapped along the lower reaches of Dairy Creek, and a band of wetland also exists at the base of and to the immediate south of the Hillsboro landfill. Wetlands have also been created on USA property, using effluent from the Hillsboro Treatment Plant to maintain water levels and encourage greater wildlife use.

The landfill operator has recently received approval to fill 10 acres of wetland south of the landfill and create, as a mitigation action, a similar amount of wetland acreage west of the landfill. In recent years, the landfill operator has created additional wetlands in the process of removing soil for use as landfill cover.

Water Withdrawals and Discharges. Water uses on the stretch of the Tualatin River within the study area range from irrigation to sewage treatment. A number of farms withdraw water from the river for irrigation purposes through the Tualatin Valley Irrigation District, which withdraws a total of 1600 gallons per minute during the irrigation season.

The Unified Sewerage Agency (USA) has two sewage treatment plants in the Jackson Bottom area. The Hillsboro plant provides secondary treatment for sewage. Treated effluent is spray irrigated on grass-covered areas within the Bottom or stored in a holding pond for release to the Tualatin River during the rainy

season. The Rock Creek plant provides tertiary treatment and discharges directly into the river. Some Rock Creek plant effluent is provided to others for irrigation use (e.g., plant nurseries, a high school, etc).

Neither groundwater movement nor quality has been characterized for the Hillsboro or Jackson Bottom area though site-specific investigations have been made at the Hillsboro landfill for phosphorus concentrations. Results indicate the need for reducing phosphorus loading of groundwater in the area.

Urban Drainage. Storm drainage from the urban area of Hillsboro discharges into Jackson Bottom through an estimated 42 drain pipes located at the edge of the Bottom as illustrated in Figure 12. The amount of runoff water, of course, varies from virtually none during summer months to major flows during winter storms.

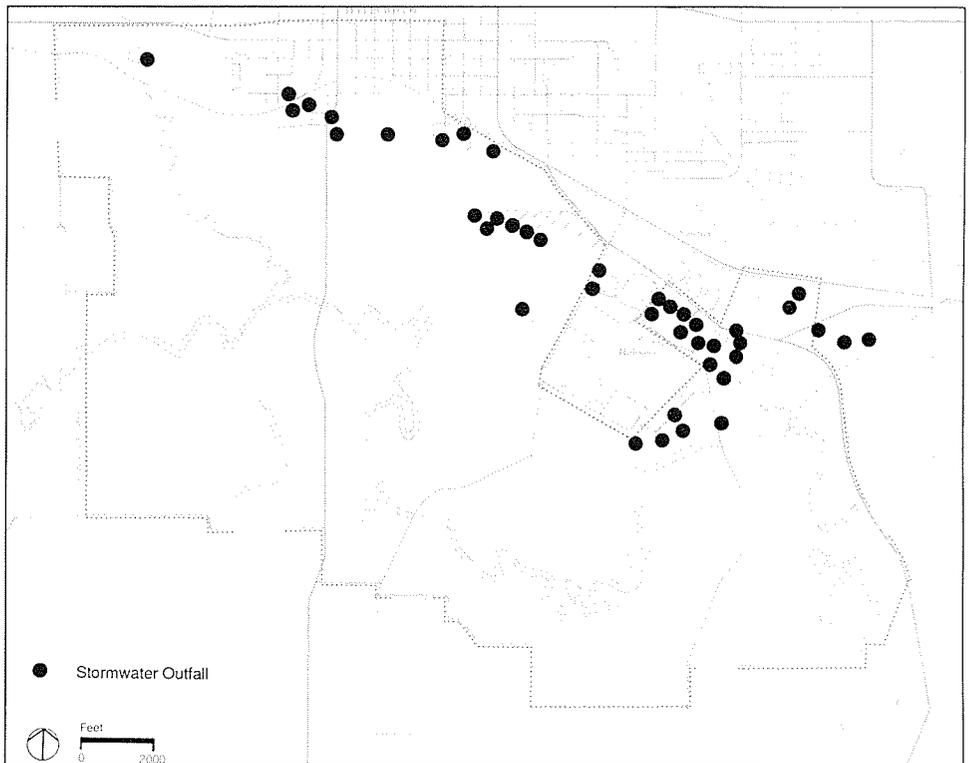


Figure 12: Stormwater Outfalls

Two major creeks, Rock Creek and Dairy Creek, collect urban and agricultural stormwater runoff as they flow through rural portions of the valley and then through urban areas of Hillsboro and into the Tualatin River. Washington County is gathering more in-depth information on urban storm drainage at this time. The study should be available in 1989.

Soils
The Composition of the Ground

A complex of soils exist within the Jackson Bottom. Of the four major soil associations in the area, two are well drained soils and two tend to be poorly drained.

The two fairly well drained soil associations are the Woodburn-Quatama-Wilamette association and the Aloha-Amity-Dayton association. These soils are located in upland areas away from the river and tend to be better farming soils because of their ability to drain water after inundation or heavy rainfall. These soils also tend to be older, having been formed prior to 4200 B.C. when Ice Age floods retreated from the Tualatin Valley.

The poorly drained soil associations are the McBee-Chehalis association and the Wapato-Verboort-Cove association. These soils were formed relatively recently and are located in lowland areas along the river. Because of the high content of both organic materials (peat) and fine grained inorganic soil (clay), these younger alluvial soils are slow draining. While these soils are fair for farming, their slow draining characteristic is ideal for the formation of ponds and wetlands. In fact, surface ponding is very common on these soils during rainy months.

Vegetation

The Plant Life of Jackson Bottom

Along the River. Recent aerial photographs of the central Tualatin River basin indicate narrow bands of riparian vegetation, with occasional expansion of these bands of shrubs and trees into larger wooded areas. The most common species of trees along the river in Jackson Bottom are Oregon ash, Pacific red willow, an occasional black cottonwood, and Douglas fir on the higher ground. Red-osier dogwood, hawthorne, Douglas spiraea, Columbia River sedge, cocklebur, and reed canary grass comprise the understory.

The wooded areas which frequently abut the Tualatin River riparian corridor are relatively small, a widespread pattern which continues in the Jackson Bottom area. There are three large "woodlots" adjacent to the Tualatin River near the east and west edges of the project boundary. The two on the east side are generally comprised of Douglas fir. The other woodlot at the edge of an isolated oxbow of the Tualatin River contains ash. There is an isolated woodlot north of the landfill which has mainly Oregon white oak.

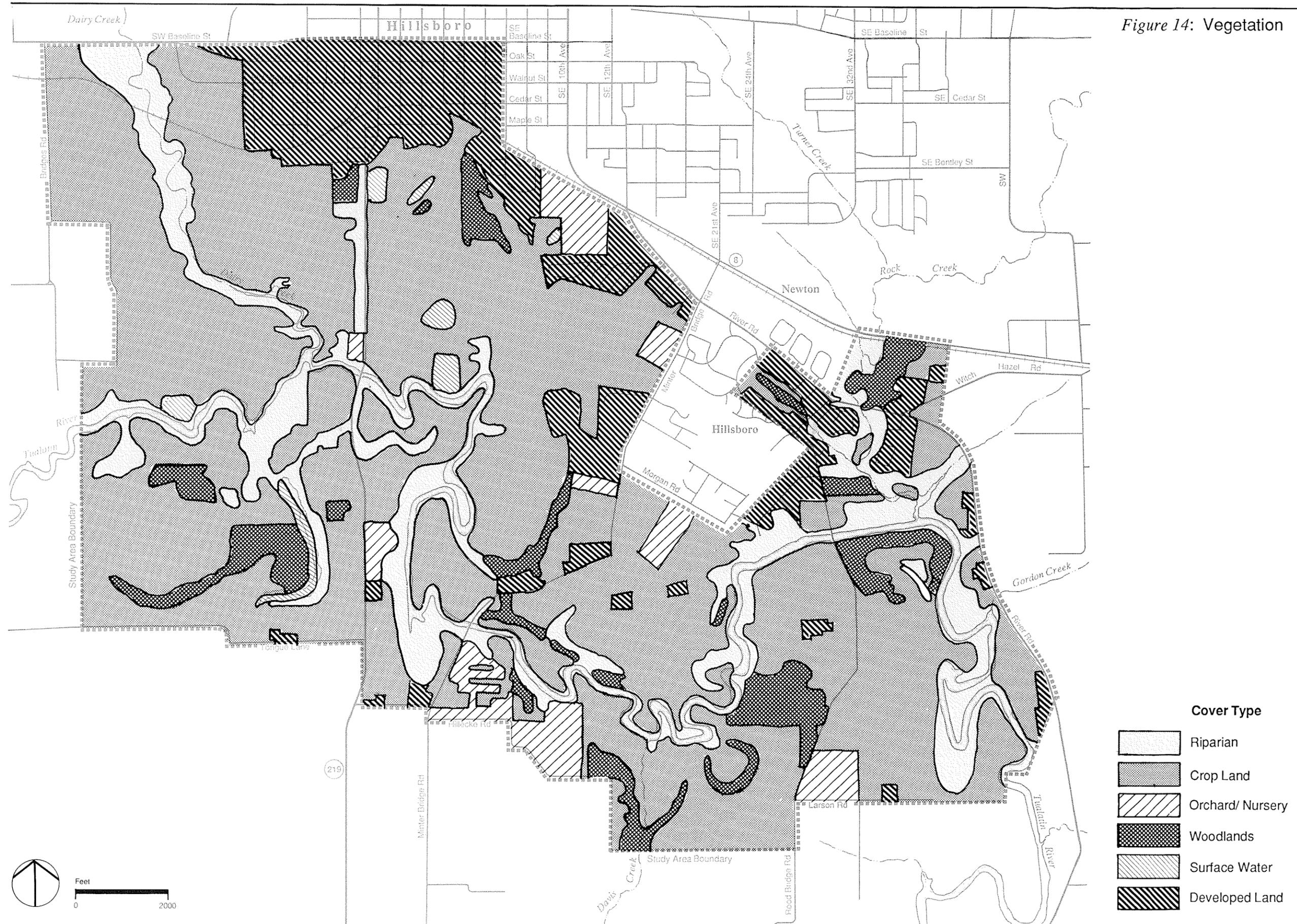
Bottom Land Adjacent to the River. The once extensive prairies and swamps mentioned by 19th century surveyors have been drastically reduced. Monoculture stands of reed canary grass have replaced the prairies and come to dominate lowland areas which are deeply flooded. Other grasses, such as meadow foxtail, cannot compete with reed canary grass under these conditions. Reed canary grass covers most of the publicly owned property adjacent to Highway 219, particularly the areas below the 140-ft. elevation. Though less desirable than some other grasses, the seeds of reed canary grass are a good source of wildlife food. On dry sites in summer, small birds and mammals are common.

Cropland. The most extensive vegetation in Jackson Bottom is crops: corn and a wide variety of row crops (e.g. broccoli) on lower-lying, more deeply flooded land; spring grain (e.g. oats) on higher, less deeply flooded ground. There are only a few orchards in the project area.

Figure 13: Soils Map



Figure 14: Vegetation



Wildlife

The Animals that Make Jackson Bottom Home

With its diversity of wildlife habitats, Jackson Bottom has been identified as a unique natural area of regional significance in the 1988 Regional Parks Study prepared for Metropolitan Service District. The sizeable amount of undeveloped land found in Jackson Bottom provides the City with the opportunity to enhance existing habitats as well as create additional wetland habitats for a wide range of species.

Annual migration of waterfowl through the Jackson Bottom Wetlands provide a spectacular wildlife viewing opportunity during the winter. However, spring and summer use by waterfowl and other wildlife is minimal because the area lacks sufficient surface water to support a diverse wildlife population.

Along the River. The meandering river, with its steep banks and logjams, provides habitat for such aquatic wildlife as beaver, nutria, and mink. Wood ducks, hooded mergansers, and great blue and green herons feed and rest along the shoreline. Green herons may nest locally.

The riparian forest adjacent to the river provides nesting habitat for herons, wood ducks, mergansers, woodpeckers, red-tailed hawks, owls, American kestrels, and a great diversity of songbirds, such as warblers, sparrows, finches, and flycatchers. A variety of reptiles and amphibians, including frogs, toads, garter snakes, newts, and salamanders, also inhabit the area. Raccoons, opossums, coyotes, and deer take cover and feed here as well as in adjacent fields and wetlands.



Figure 15: *The Tualatin River*

Unmowed Lowlands. The reed canary grass in the lowland areas support a much less diverse wildlife community than along the Tualatin River and adjacent forest areas. Large populations of voles live in the fields of tall grass during the dry season. Vole populations are large here because the dense, tall cover protects them from their predators, the great horned owl, northern harrier, red-tailed hawk, coyote, and great blue heron. Weasels, mice, and shrews are also present.

Coyotes, mink, and nutria travel in these areas but probably don't spend much time there. Birds such as the red-winged blackbird, common yellowthroat, marsh wren, and song sparrow may nest in the grassy fields and among the willows, spiraea, and other shrubs or small trees. When flooded, the reed canary grass also provides feeding and resting habitat for waterfowl and nutria. Garter snakes are probably common.



Figure 16: *Unmowed Lowlands*

The Forests. The patches of ash, oak, and Douglas fir forest located on the slightly drier sites provide nesting habitat for owls, hawks, songbirds, woodpeckers, and the other species which inhabit the areas along the Tualatin River and adjacent riparian forest. These patches of dry forest are quite limited in the study area and, as such, are very valuable in adding diversity and cover for wildlife.



Figure 17: *Effluent Storage Pond*

The Effluent Storage Pond. The effluent storage pond supports a very productive freshwater community rich in nutrients, algae, and aquatic invertebrates. Swallows feed extensively on emerging aquatic insects, and ducks and phalaropes

fringe of woody vegetation along the shoreline has limited habitat diversity to some extent there.

Other Areas. The landfill provides a potential forage area for a variety of opportunistic wildlife species, including crows, starlings, house sparrows, Brewer's blackbirds, gulls, raccoons, skunks, opossums, and coyotes. Adjacent water and forest cover provides other habitat requirements for these species.

The areas of mowed reed canary grass also make a good habitat for voles, but populations can be expected to be lower than the unmowed areas because of increased exposure to predators.

The row crops which dominate the privately owned lands in Jackson Bottom provide some seasonal food and cover for wildlife, depending on the crop and the requirements of the wildlife species. They do not, however, meet year-round habitat requirements for any wildlife species.



Figure 18: Great Blue Heron in Mowed Lowland

Orchards and nurseries provide some food and cover for wildlife though they are often actively discouraged from crop depredations by measures such as fencing and netting. These areas also do not meet the year-round habitat requirements for wildlife.

Fish

Life in the Water

Wild and hatchery stocks of winter steelhead and coho salmon are present in the Tualatin River. Spawning occurs primarily in the upper main stem and in Gales and Dairy Creeks. Hatchery steelhead smolt are released in the upper part of the system by the Oregon Department of Fish and Wildlife.

Migratory and resident cutthroat trout also inhabit the river system. The migratory cutthroats move upstream into tributaries to spawn during winter and early spring and move downstream to spend the late spring, summer, and early

fall in the lower parts of Dairy Creek and the Tualatin River. The resident cutthroats do not migrate from their native streams.

Rainbow trout are stocked in standing waters, primarily Hagg Lake, but are no longer stocked in the main stem Tualatin River because of the lack of public access. A variety of warmwater game fish, including yellow and brown bullheads, smallmouth and largemouth bass, and yellow perch have been illegally introduced into Hagg Lake and are now reproducing. Coarse scale suckers and red-sided shiners also exist in Hagg Lake.

Crayfish are abundant in Hagg Lake as well as the Tualatin system and are regularly harvested commercially and recreationally.

The Oregon Department of Fish and Wildlife is preparing a Tualatin River fish management plan to be completed by 1990.

Ownership and Current Uses

Who Owns the Land and How It's Used

The City of Hillsboro and the Unified Sewerage Agency (USA) control approximately 420 acres of Jackson Bottom. USA uses some of the Jackson Bottom property for aerial application of treated wastewater produced by the Hillsboro Treatment Plant. In addition, about seven to ten acres have been developed as wetlands wildlife habitat, with another five to ten acres undergoing habitat development during the summer of 1988. Also, in 1988 USA will implement a pilot project to assess alternative methods of treating sewage effluent in the natural environment. This pilot project may involve up to 45 additional acres of land.

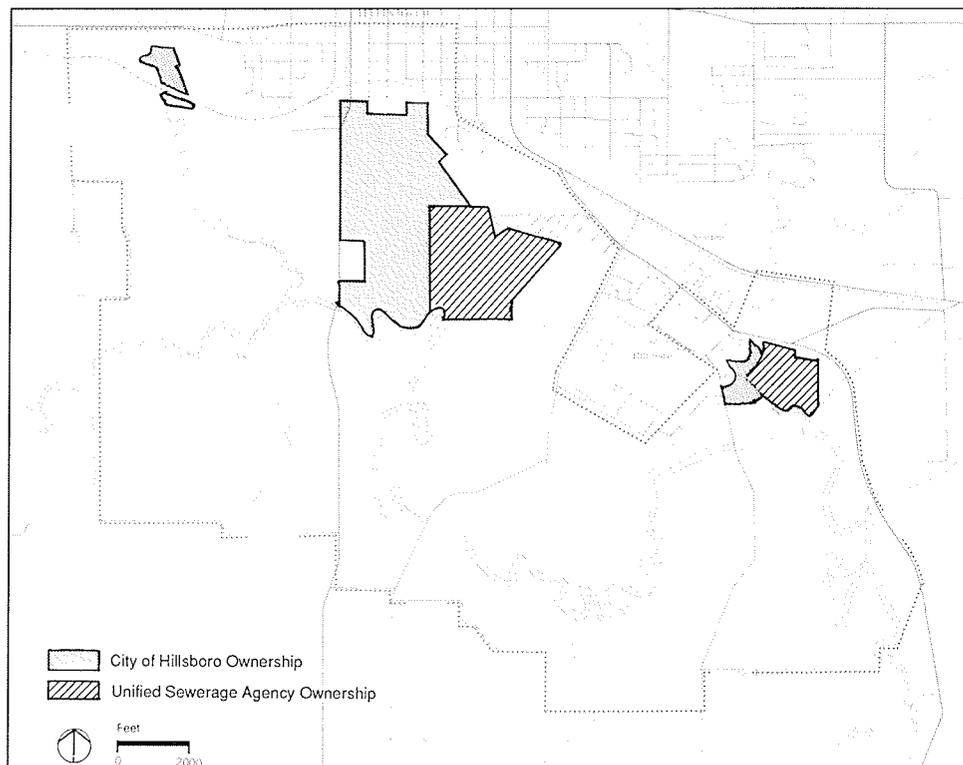


Figure 19: Ownership

USA is charged with providing adequate treatment of wastewater generated in the urban portions of Washington County. In addition, the agency is charged with meeting state standards for effluent discharged to the Tualatin River.

Wastewater irrigation methods used in the Jackson Bottom are designed to prevent direct flow of remaining pollutants into the Tualatin River. However, the aerial application of sewage effluent precludes use of the wetlands by the general public for health reasons.

The Department of Environmental Quality has recently promulgated new standards for effluent discharge into the Tualatin River and USA is studying possible courses of action. Among the approaches USA is considering are the following:

- Relocation of effluent discharge to the Columbia and/or Willamette Rivers.
- Removal of more phosphorus at treatment plants with discharge to the Tualatin River.
- Polishing of highly-treated effluent in wetlands with discharge to the Tualatin River.
- Dilution of highly treated effluent using low phosphorus water stored in seasonal ponds with discharge to the Tualatin River.
- Reuse of highly treated effluent to irrigate greenways, parks, school grounds, golf courses, plant nurseries, and farms.

Although it is unknown at this time which of these alternatives, or combination thereof, will ultimately be selected, the use of wetlands and lowlands is an attractive and feasible option. Wetlands not only enable effluent polishing and/or dilution, they also provide a very desirable habitat for wildlife. It is also anticipated that by using the pollution reduction capacity of wetlands, an effluent polishing system can be developed at significantly lower costs than constructing a pumped system. Appendix 'A' contains a complete discussion of the conditions and advantages of using wetland systems for water quality enhancement.

To find out how well an integrated system of wetlands and lowlands will work on the Tualatin River, it is necessary to test various approaches. The phase one project described later in this report recommends an integrated approach.

Urbanization

Where the People Live

The Jackson Bottom study area is partially under the jurisdiction of the City of Hillsboro and partially under the jurisdiction of Washington County.

Historically, Hillsboro's urban growth has occurred on upland areas and has been restrained on the south by the broad Tualatin River floodplain. In recent years, limited southerly expansion has occurred and several residential developments have been constructed up to the edge of the 100-year floodplain.

The economy of Hillsboro is in transition from a rural, farm-based economy to an urban-centered one, with the electronics industry playing an important role in that transition. As industrial growth continues, additional activity can be anticipated on remaining unsubdivided parcels above the 100-year flood elevation.

Development within the Jackson Bottom area is effectively limited by city and county comprehensive plans, the urban growth boundary, city and county zoning ordinances, the Federal Flood Insurance Program, and good judgement on the part of landowners. It is expected that, for the foreseeable future, land within Jackson Bottom will continue to be protected from urbanization by these measures and agencies.

Several land use assumptions have been made to provide a basis for projecting future development in the Jackson Bottom area. They are as follows:

1. The urbanized area will continue to expand to the south of Hillsboro and to the west of Beaverton, but only to the edge of the flood plain.
2. The urban growth boundary will remain at the edge of the flood plain.
3. The lowland area within the floodplain will continue to be limited to agricultural use, wildlife habitat, and certain recreational uses.
4. The area south and west of the flood plain will continue to be restricted to agricultural and certain other compatible uses.

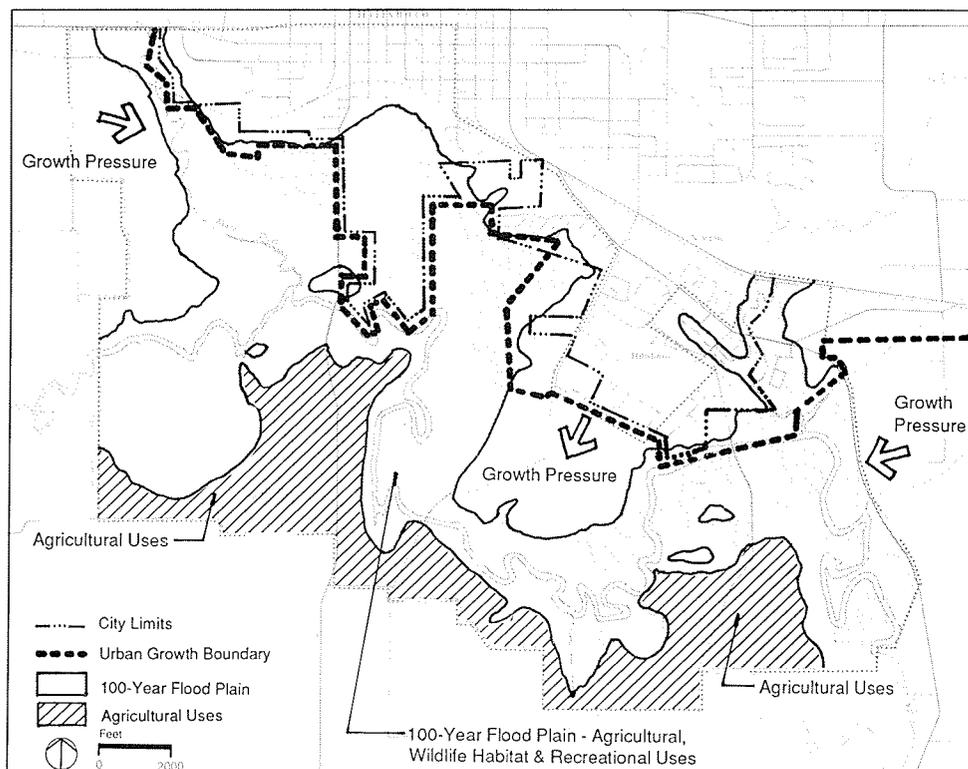
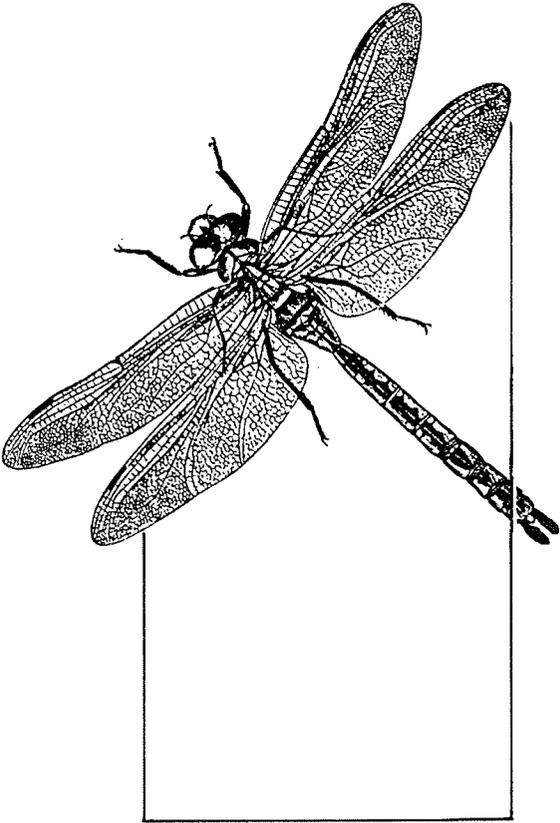


Figure 20: Urbanization

The Master Plan



V. The Master Plan

A Blueprint for Vitality

The master plan described below will transform Jackson Bottom into a rich and vital home for wildlife; provide unique educational and recreational opportunities for local, regional, and out-of-state visitors; improve the water quality in the Tualatin River; and offer a natural, unobtrusive method for polishing wastewater. If fully developed as proposed, the completed plan will serve as a model for other communities around the country. Jackson Bottom will become a showcase project for the enjoyment of people and the betterment of the natural environment.

Opportunities

What Jackson Bottom Can Become

Wildlife Habitat Enhancement. The proposed plan will preserve existing wetlands and construct additional wetlands to greatly increase the amount of wetland habitat in the Hillsboro area. Conversion of an area with seasonally flooded reed canary grass (a monoculture which supports limited needs of wildlife) to one containing deeper open water, shallow open water, and emergent vegetation interspersed with upland-riparian areas of trees and shrubs will provide habitat for a much greater diversity and quantity of fish and wildlife. Existing wooded areas will be preserved to maintain wildlife habitat and to provide a refuge during periods of construction. In addition, specific enhancement measures are proposed which will provide further benefits to fish and wildlife. These include installation of nest boxes and structures to encourage selected wildlife species; planting of selected trees, shrubs, and other vegetation to provide habitat diversity, thereby attracting more varied wildlife; and the planting of shade trees along water body edges to reduce water temperatures and provide cover and shade for fish.



Figure 21: Canada Geese in Wildlife Ponds

Ponds and wetlands will be constructed with variable edge and bottom configurations to increase shoreline length and provide a variety of edge conditions and varying water depths. The creation of variable shoreline conditions and water depths will increase habitat diversity and create "niches" that will be occupied in time by a wide range of plants and animals. In addition, small islands will be placed in many of the ponds to provide safe nesting areas for waterfowl.

Areas between ponds will be planted in a variety of patterns to provide food and shelter for wildlife and encourage a more diverse wildlife population. Trees will be planted in some areas to produce a thick forest cover. In other areas, only a few trees will be planted for nesting areas and perches. Shrubs will be planted in selected areas to serve as habitat for small animals. Other areas will be kept as open meadows.

Enhancement of the wildlife habitat is expected to lead to the following:

- greatly increased usage of the area by waterfowl
- attraction of shore birds, especially during periods when water storage ponds are being emptied to augment river flow
- attraction of more wading birds, including great blue and green heron
- potential attraction of osprey, if fish populations are large enough
- increase in warmwater fish populations
- increases in mammalian populations, including beaver, weasel, raccoon, fox, coyote, skunk, rabbit, vole, moles, mice, shrew, and deer
- increases in amphibians and reptile populations, including frogs, toads, newts, salamanders, and garter snakes
- year-round use of Jackson Bottom by more species

Recreational and Educational Features. The proposed wildlife habitat enhancement will lead to an increase in wildlife diversity which, in turn, will draw more people to Jackson Bottom in pursuit of recreational and educational activities.

An educational and interpretive center will serve as the "hub" of these activities at Jackson Bottom. This center can be expanded over time to accommodate the needs of casual visitors, school groups, serious researchers, adult education, and recreationists. The center should include:

- an interpretive exhibit which describes the Tualatin River system and the man-made and natural wetlands of Jackson Bottom,
- a library and/or bookstore,
- space to display rotating and special exhibits,
- classrooms and laboratories,
- research facilities, and
- an orientation area which contains information about the trails and other recreational features of the area.

A system of loop trails originating at the education/interpretive center is proposed. Both paved and unpaved trails will be included in the system. Paved trails are proposed in areas where a higher number of users are likely and to accommodate bicyclists. Unpaved trails (gravel, wood chips, dirt, or boardwalks) are proposed in other areas.

View points and wildlife observation blinds are proposed in selected locations along the trail system. To minimize disturbances of wildlife, trails should be separated by thick vegetation buffers from critical wildlife areas.

Access to the river for fishing and non-powered boating is proposed at each of the three bridges crossing the Tualatin within the study area. In addition, river access is proposed at other points wherever feasible.

The existing landfill has significant potential for development to accommodate active and passive recreational pursuits. Additional studies will be required to determine what type of activities can be accommodated and how much time must elapse after closure of the landfill before recreational use can commence.

One of the seasonal storage ponds is proposed to be maintained at full pool, at least until mid-September, for rowing and other water activities. An area could also be made available for storage and rental of non-motorized watercraft if a local organization or club is interested in sponsoring this amenity, or if the City's Park and Recreation Department chooses to operate and manage this activity as part of a recreation program.

Finally, development of storm drainage wetlands along Dairy and Rock Creeks and in Jackson Bottom along the base of the urbanized area is proposed. These wetlands will filter storm runoff and reduce or remove pollutants before the runoff enters the Tualatin River.

Local and Regional Access

How to Get There

The Jackson Bottom Interpretive Center will be within a mile of downtown Hillsboro, making it easily accessible to local residents. Trails will also be developed through the wetlands linking the educational and interpretive center with downtown. The trailhead will be a ten-minute walk from downtown. The plan also proposes selected trimming of vegetation along the shoulders of Highway 219 to encourage pedestrian use.

Because Hillsboro is located on the edge of the Portland metropolitan area, visitors to Jackson Bottom will be drawn from a large population area. When light-rail service is extended to Hillsboro, a pedestrian connection between the downtown stop and Jackson Bottom would make the Bottom easily accessible from the metropolitan area by mass transit.

Components of the Master Plan

The Parts that Make Up the Whole

The master plan concept for Jackson Bottom is illustrated in Figure 27. As can be seen, most of the proposed uses are centered around Highway 219. The key elements of the concept are briefly described below.

Seasonal Storage Ponds. Lowland areas near the Tualatin River will be developed as storage ponds, with a water depth averaging six to eight feet. River water will be stored during the spring when phosphorus levels tend to be low and released slowly during the dry summer months. Release of the water during the summer will dilute wastewater effluent, reduce phosphorus levels, and augment

river flows. The combination of reduced phosphorus levels and increased flow rate is expected to improve water quality in the river.

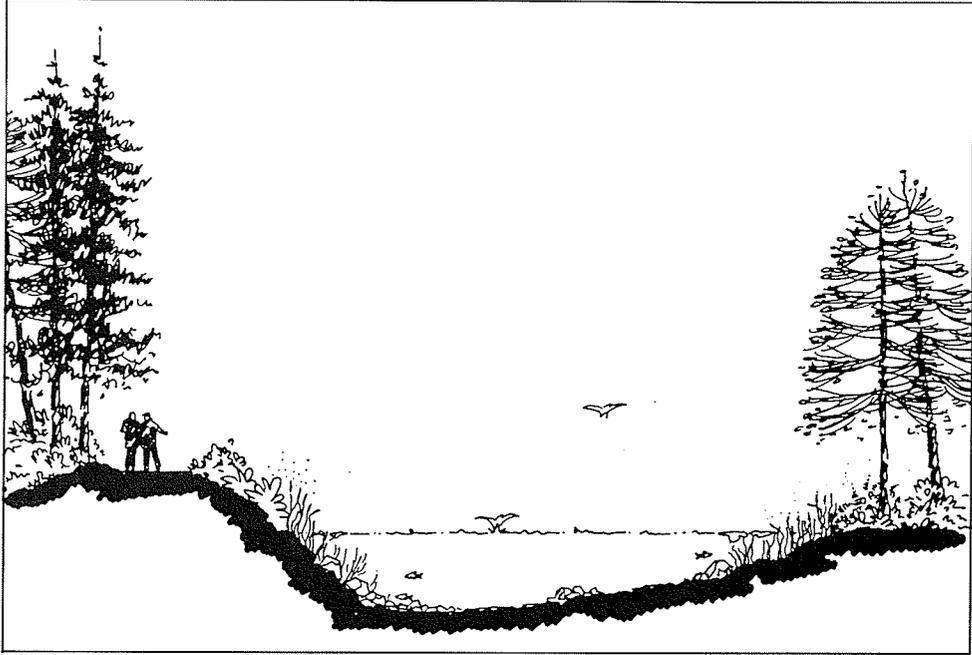


Figure 22: Seasonal Storage Pond

Shoreline trees and shrubs should be planted to enhance the character of pedestrian trails and increase habitat diversity. Pond bottoms should be contoured to provide some deeper holes as a refuge for fish during low water periods. Shorebirds will be attracted to mudflat areas during late summer and fall. Islands or floating platforms should be incorporated to provide night roosting and nesting areas for waterfowl and waterbirds. Nesting islands must be surrounded by water during the nesting season to prevent attacks from land predators, such as raccoons and coyotes. In addition, these ponds could be actively used for recreational boating and/or fishing as they will also provide habitat for warmwater game fish.

One of the storage ponds is proposed for maintenance at full capacity through mid-September and can be used for recreational activities such as rowing, canoeing, and fishing. A facility can be added for storing and renting non-motorized water craft. Classes in water craft use and safety, fishing, and other aquatic activities could be provided as part of a recreation program.

Effluent Treatment Ponds and Wetlands. It is proposed that low lying areas between the storm runoff wetlands and the seasonal storage ponds be developed as effluent treatment ponds and wetlands. Treated effluent from the Hillsboro West and Rock Creek treatment plants could be "polished" here to reduce pollutant loads before release into the river.

These ponds and wetlands will have stable water levels and, consequently, stable vegetation. They will be one to four feet deep and include alternating areas of open water and emergent wetlands. The bottom contours of the ponds should be somewhat variable to create different depths, which could be colonized by different emergent wetland plants. For example, deeper areas would likely support bulrush while shallower areas could have stands of cattails, burr-reed, and

wapato. These plants would increase the complexity of the habitat for wildlife. Pot holes in the ponds would provide refuge for fish during periods of low pool or hot weather.

Islands or floating platforms are desirable in the ponds to encourage nesting by waterfowl and waterbirds. Shoreline vegetation should include trees and shrubs to provide additional habitat diversity and cover for wildlife. An approximate 50-50 ratio of open water to emergent vegetation is optimal for waterfowl breeding. These ponds may have nutrient loads and vegetation that produce levels of dissolved oxygen too low for most fish species.

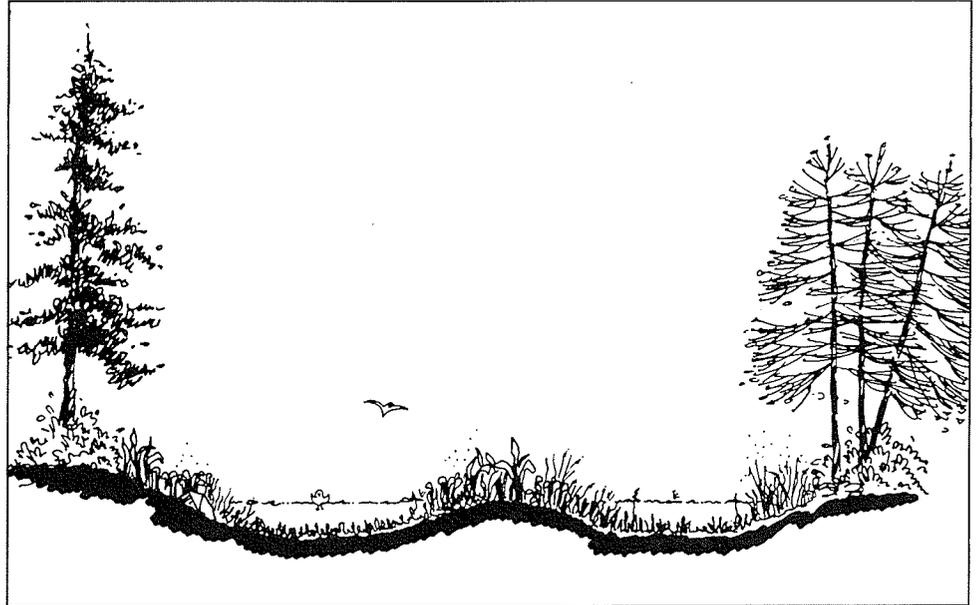


Figure 23: Effluent Treatment Ponds

Storm Runoff Wetlands. Land along the base of the upland areas and Dairy and Rock Creeks will be developed as wetlands designed to intercept and filter storm

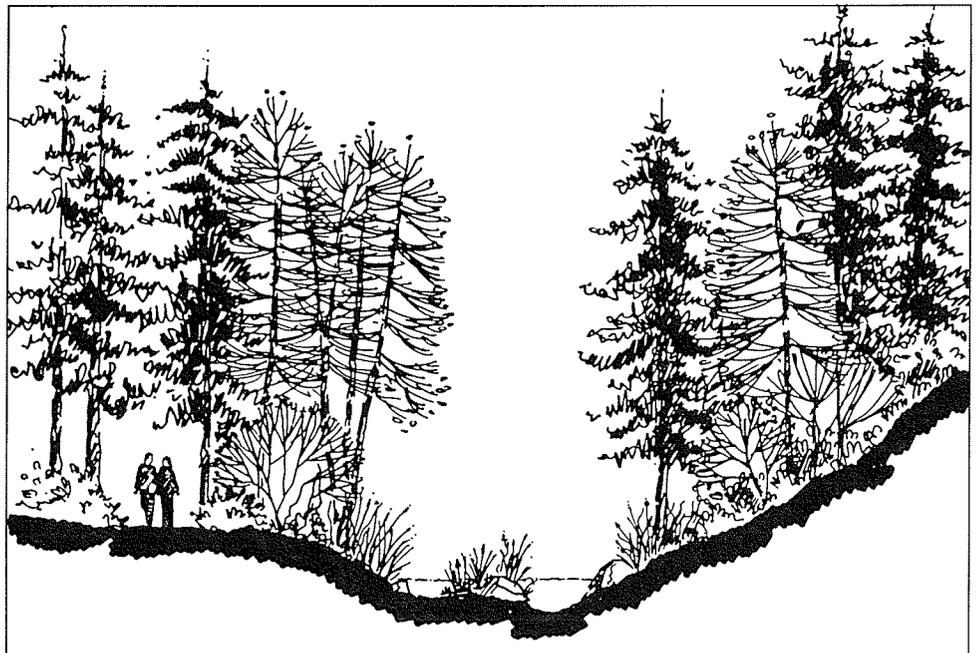


Figure 24: Storm Runoff Wetlands

runoff from urban areas. Storm drainage directly into the Tualatin River will be discontinued. Water depth will vary from two to four feet during major storms to no water during dry months.

A rich vegetative community more tolerant of seasonal inundation and drying will thrive in this environment. Shoreline trees and shrubs will provide additional habitat diversity for wildlife.

Wildlife Habitat around Ponds and Wetlands. Existing wildlife habitat will be preserved and additional habitat and forage areas will be developed around each pond and wetland. Some areas between the ponds and wetlands will be planted with food crops to encourage more wildlife. In other areas, trees and low shrubs will be planted to augment existing tree cover. In addition, shade, food, and appropriate substrate materials in deeper ponds are proposed to increase the numbers of fish and crustaceans.

Trail System. A hierarchy of trails for walkers, joggers, and bicyclists will be constructed through the area. Most of the trails will be "loops" leading out from the central education and interpretive center. Trail and road shoulder connections will also be added to link the education and interpretive center to downtown. In addition, trails along the Tualatin River would be developed where feasible.

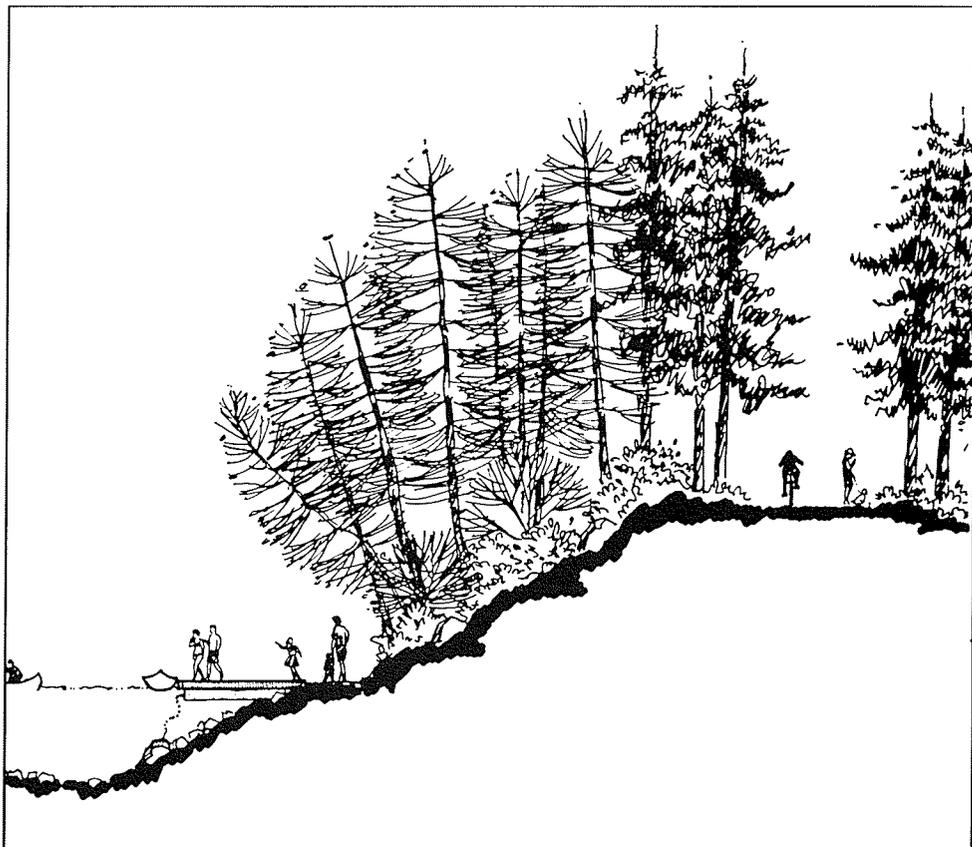


Figure 25: River Access & Trail System

River Access. Access to the Tualatin River for pedestrians, anglers, and non-motorized water craft will be provided at road crossings and other feasible locations, such as publicly owned land. Automobile parking should be provided near each access point. The Tualatin River through Jackson Bottom is slow moving and recalls earlier times when the pace of life was slower. Trails along the river

will allow for passive use, showcase the river as a pleasant place to be, and encourage further cleanup of other stretches of the Tualatin River.

Education and Interpretive Center. An education and interpretive center is proposed for development along Highway 219, north of the Tualatin River. Initially, this center could be a simple overlook with interpretive panels and, over time, expand into a comprehensive educational facility. The center should be designed to accommodate elementary school needs (such as the outdoor school program), provide simple laboratories and reading areas for high school programs, and contain more sophisticated laboratory facilities for wetland researchers. The center should also house lecture and meeting rooms for adult education programs.

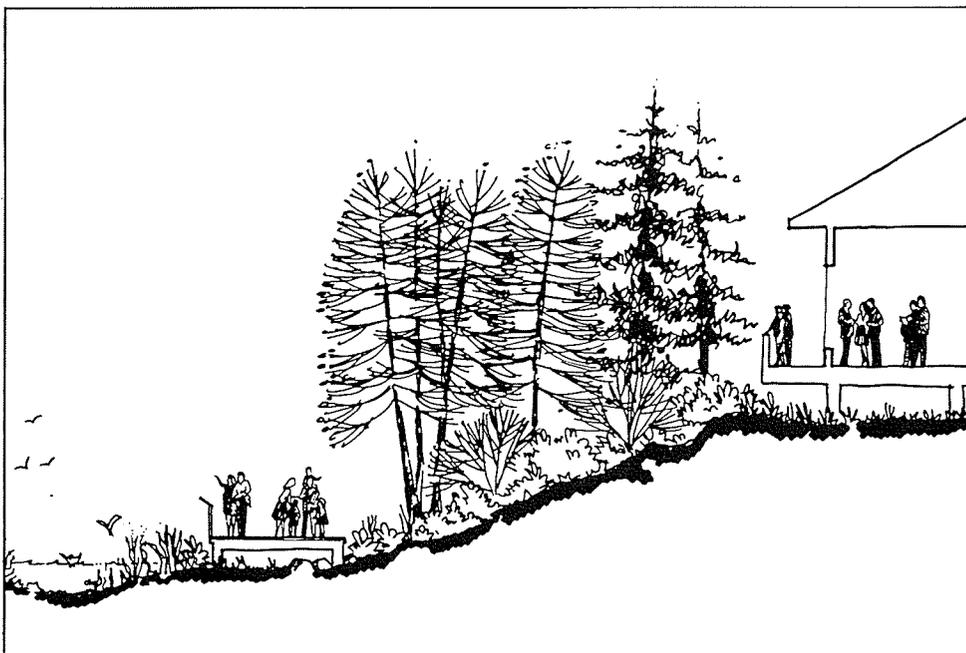


Figure 26: Interpretive Center

Irrigation With Treated Effluent. The use of effluent for irrigation of agricultural fields solves two problems: 1) it consumes treated effluent, thereby reducing the total quantity of water to be discharged into the Tualatin River, and 2) it conserves fresh water, which would otherwise be diverted from the river to irrigate fields.

The plan recommends that the agricultural area south of the river, which is level and owned by a few large land owners, be used for accepting treated effluent. Also, the Unified Sewerage Agency is encouraged to expand its program for marketing irrigation water to include the development of long-term leases or other contractual arrangements with agricultural and recreational property owners.

Plan Implementation

How to Put the Master Plan into Action

Commitment and energy are needed to bring this plan to fruition. The ideas presented here are desired goals. The next step is to establish an organization knowledgeable in long-range planning to implement this project. This organization must be broadly based to ensure that a wide constituency supports these ef-

forts. Political savvy is essential since many decisions will be made in the public arena and require the cooperation of local, county, state, and possibly federal governments. Fund raising skills will also be required.

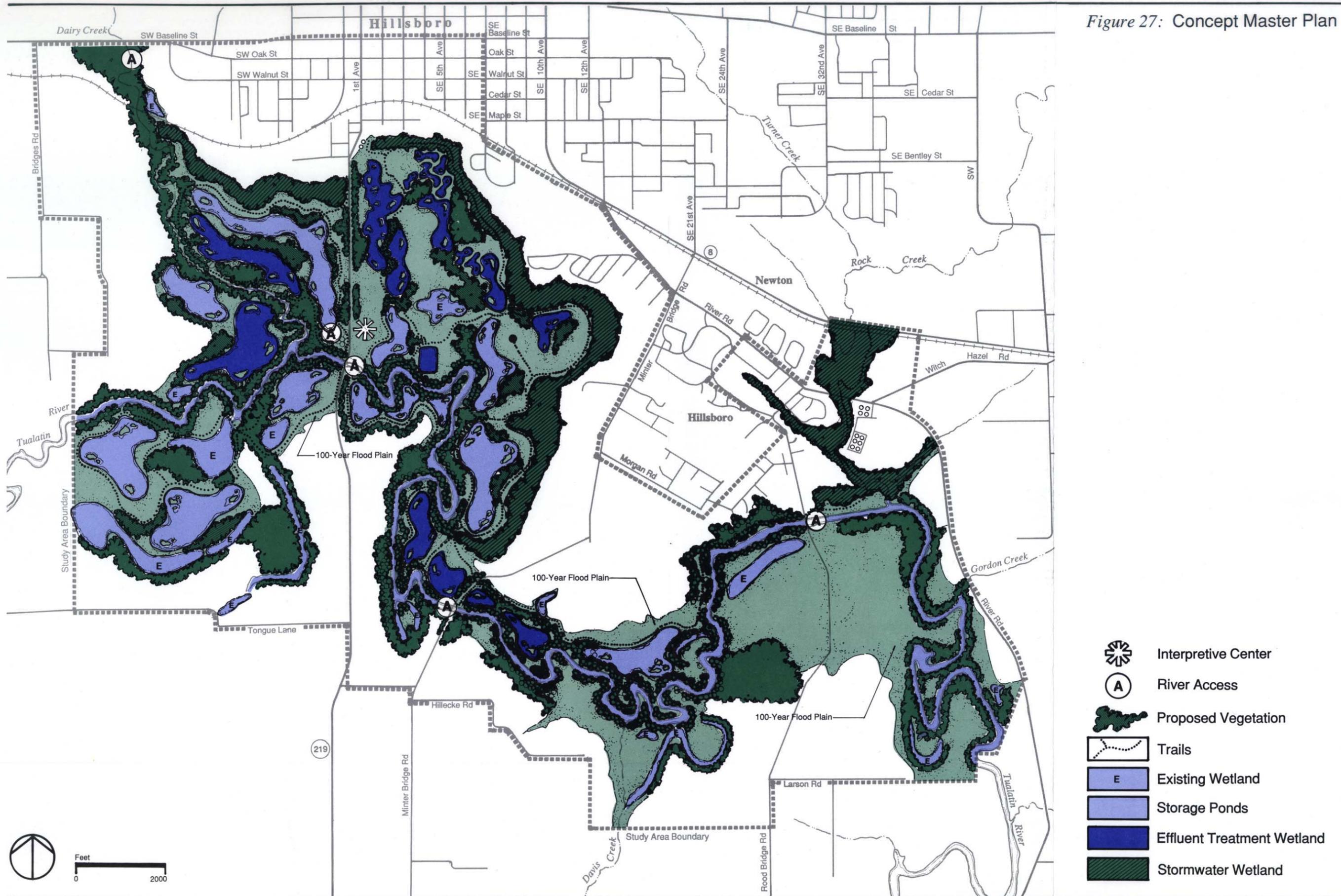
The Jackson Bottom Steering Committee may be the entity to assume implementation responsibility. Community discussion will help determine whether this committee is the appropriate vehicle or whether another organization should be established.

Actions. A number of actions by government and other organizations will be required to implement this master plan. The actions listed below are recommended to begin the plan implementation process. As time goes on, other interests and sources will be discovered and should be added to the list. These actions are not inclusive, but are simply a means of starting the process; they are listed according to convenience, not priority.

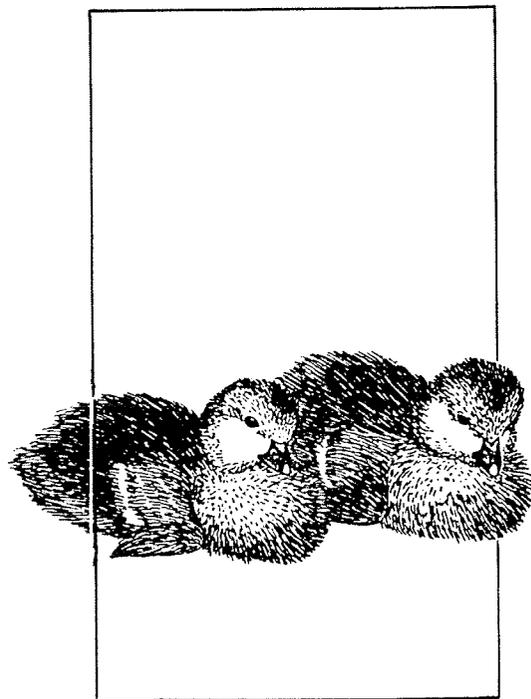
1. Obtain acceptance, concurrence, or approval (as appropriate) of the master plan concept from the following organizations:
 - City of Hillsboro
 - Washington County
 - Department of Environmental Quality
 - Unified Sewerage Agency
 - Division of State Lands
 - Department of Water Resources
 - U.S. Army Corps of Engineers
2. Continue and expand pilot studies with the objective of moving into full-scale projects.
3. Obtain approval of phase one projects and proceed with necessary approvals, design, fundraising, and construction.
4. Research the possibility of developing a wetland "mitigation bank" in Jackson Bottom, rights to which could be sold to area developers. Fees collected from urban area developments could be used to expand the wetlands system in Jackson Bottom.
5. Seek private and public funding to assist in the development of the Jackson Bottom Master Plan. Possible sources include:
 - Department of Environmental Quality (to fund research and monitoring)
 - Unified Sewerage Agency
 - State Marine Board (to fund river access improvements and snag removal)
 - State Department of Fish and Wildlife (to fund angler access trails and plant game fish)
 - Portland Audubon Society (to fund wildlife enhancement and educational improvements)
 - Nature Conservancy (to acquire and hold key parcels for repurchase by a public agency)

- Charitable foundations (such as the Fred Meyer, Chiles, Tektronix, and Vollum foundations)
 - Corporations (such as Fujitsu, NEC, Tektronix, and Intel)
 - Hillsboro landfill owner (for future dedication of land and cooperation in creating wetlands while removing soil for landfill cover)
7. Seek educational and research support from area colleges and universities (Pacific University, Portland Community College, Oregon Graduate Center, and Portland State University).
 8. Seek educational support from the Washington County Education Service District (for outdoor school programs).
 9. Seek recreational support from City of Hillsboro Park and Recreation Department and other appropriate agencies.

Figure 27: Concept Master Plan



Phase One Project



VI. Phase One Project

How to Proceed: A First Step

Several activities have already been undertaken in the study area, including expansion of wildlife ponds, construction of pilot wetlands, and spray irrigation of treated wastewater. Phase one is intended to add additional elements described in the master plan and to begin integrating all elements into a cohesive whole. Most phase one elements are proposed for areas accessible and/or visible from Highway 219. The reason for this is to create higher visibility for Jackson Bottom improvements and thereby encourage greater public use and support.

Objectives

The objectives of the phase one project are to:

1. Preserve existing wildlife habitat and continue expansion of additional habitat to encourage diversity and increase existing populations.
2. Improve access to the study area for recreationists; provide parking, trails, and wildlife view points; improve pedestrian links to downtown Hillsboro.
3. Encourage educational use by signing the area, developing interpretive materials for schools, providing site tours, and assisting educators with research projects.
4. Provide river access for anglers, walkers, and users of non-powered boats and improve general river appearance.
5. Develop pilot wetlands to evaluate the feasibility of using wetlands to remove pollutants from urban storm runoff.
6. Evaluate the feasibility of using wetlands to "polish" treated wastewater prior to release into the Tualatin River.
7. Construct a seasonal storage pond to evaluate the feasibility of diluting wetland "polished" wastewater to achieve DEQ phosphorus standards.
8. Research the potential of increasing fish populations in ponds and wetlands.
9. Experiment with different cover crops, irrigation techniques, and application rates to evaluate pollutant removal potential.
10. Commence an experimental silviculture program to evaluate the growth rate of trees planted in various soils, irrigated at different rates, and planted on varying elevations.
11. Develop a data bank containing land use, economic, and research information that can be utilized by others.

Components

<u>Sub Area</u>	<u>Acres</u>	<u>Comments</u>
Wildlife Habitat	12	Extend the pond system being developed along Highway 219.
Access/Parking/Trails	5	Develop parking, improve pedestrian links to downtown, construct recreational trails.
Non-powered Boating	20-30	Build river access ramps for small boats from the Highway 219 bridge to Rock Creek Sewage Treatment Plant; construct angler paths along the river.
Storm Runoff Wetland	23	Construct a band of wetlands in the Bottom adjacent to urban areas to filter urban storm runoff.
Wastewater Wetlands	48	Undertake pilot projects to evaluate wetland alternatives for treating effluent.
Seasonal Storage Pond	15	Construct a pond near the Tualatin River; develop wildlife habitat around the perimeter; develop a recreational trail around the pond.
Irrigated Fields	80	Experiment with various wastewater application rates on a variety of crops.
Silviculture	30	Experiment with tree plantings on different soils and varying elevations to study growth rates.
Offsite Irrigation	NA	Develop markets for irrigation water (plant nursery, pasture, golf course, Christmas tree farm).

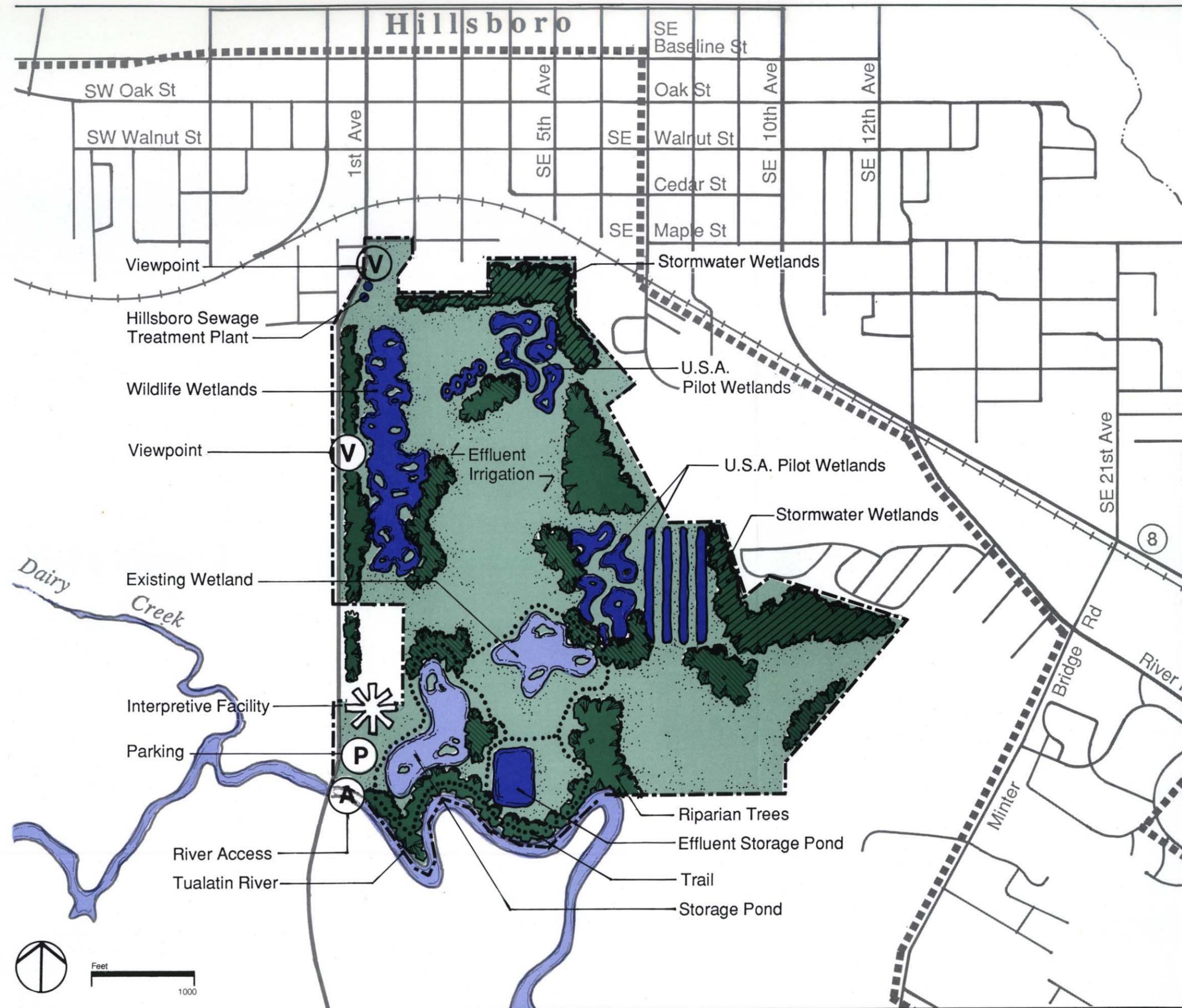
Design and Other Studies

To further the ideas presented in this concept master plan, it will be necessary to undertake more detailed, site specific studies. These studies should be completed before phase one improvements are undertaken. Major tasks required include:

- obtain a topographic map and a boundary survey
- prepare preliminary designs for physical improvements
- prepare more detailed cost estimates
- obtain necessary regulatory permits and approvals
- prepare construction documents

In addition to these tasks, it may be appropriate to develop visual materials (maps, model, slides, video, site signs, brochure) to help explain the concept and to activate interest in the project.

Figure 28: Phase I Concept Plan



Time Schedule for Improvements

The following time schedule is suggested for the phase one improvements and assumes timely funding and permit acquisition.

1. Expand wildlife habitat ponds: 1988-89
2. Develop wastewater treatment wetlands: 1988-89
3. Experiment with irrigation techniques and crops: 1988-90
4. Develop educational/interpretive materials: 1989
5. Develop storm runoff wetlands: 1989
6. Develop river access: 1989-90
7. Develop recreation trails, viewpoints, and parking: 1989-90
8. Silviculture plantings: 1989-90
9. Construct a seasonal storage pond: 1990
10. Research on fish populations: 1990-92

Project Management

Management of phase one activities is essential to the success of the Jackson Bottom Concept Master Plan. A wetland manager is proposed to oversee construction activities, recommend properties for acquisition, oversee research activities, and insure that the intent of the Concept Master Plan is followed. In addition, office space and necessary support staff assistance will need to be provided by the City of Hillsboro and/or the Unified Sewerage Agency

Research and Monitoring

A research and monitoring program should be developed to accompany the physical improvements. Many of the techniques proposed are experimental in nature and require adequate monitoring to insure that the desired results are, in fact, achieved. In some instances, it may be appropriate to conduct baseline studies prior to construction of the physical improvements. Pre-existing conditions can then be compared with post-improvement conditions to observe what changes actually occurred. The following costs assume that researchers are hired for the project. If cooperative programs can be developed with area colleges and universities, it may be possible to reduce some of these costs significantly.

- Monitor and map vegetation, wildlife activity, hydrologic changes, human use patterns, and fisheries.
Suggested research program length: 5 years
Estimated cost per year: \$25,000
- Analyze storm runoff in terms of water quality and load transport rates.
Suggested research program length: 2 years
Estimated cost per year: \$25,000
- Analyze growth rates of trees planted on different soils and at varying ground elevations when irrigated at various rates.
Suggested research program length: 5 years
Estimated cost per year: \$30,000
- Analyze the potential for aquaculture in ponds and in the river.
Suggested research program length: 2 years
Estimated cost per year: \$30,000

Cost Estimates

The following costs have been prepared to give an "order of magnitude" for the proposed improvements. The reader is cautioned that these costs are based on concept-level studies, not on engineered designs and are only expected to be accurate within a range of -25 percent to +50 percent of true costs.

Phase One Improvements

A. Expenditures to Date

ODFW	(\$25,000)*
USA	(\$60,000)*

B. Construction

• Extend the pond system being developed along Highway 219 (approximately 12 acres).	\$85,000
• Improve walking links to downtown, construct recreational trails, develop parking (4,500 feet of roadside vegetation thinning, 11,000' of gravel trail, 20 gravel parking spaces).	\$70,000
• Construct a river access ramp, insure boat passage, construct an angler path along the river (one access ramp, boat passage on six miles of river, 4,000' of lightly gravelled trail).	\$35,000
• Construct storm runoff wetlands adjacent to urban areas (approximately 23 acres).	\$175,000
• Construct pilot wastewater wetlands (approximately 48 acres).	Being constructed by USA.
• Construct a seasonal storage pond (approximately 15 acres).	\$325,000
• Install interpretive signing (allowance).	\$10,000
• Develop a viewpoint along Highway 219.	\$15,000
Estimated Construction Subtotal (1989)	\$715,000
Recommended Construction Contingency (20%)	\$143,000
Estimated Construction Cost	\$858,000

C. Design, Survey, Legal

• Professional fees (at 12 percent of estimated cost).	\$102,000
--	-----------

D. Wetland Management

• Salary, fringe benefits, and expenses for a full-time wetland manager for the first five years (at \$35,000 per year).	\$175,000
--	-----------

D. Research Activities

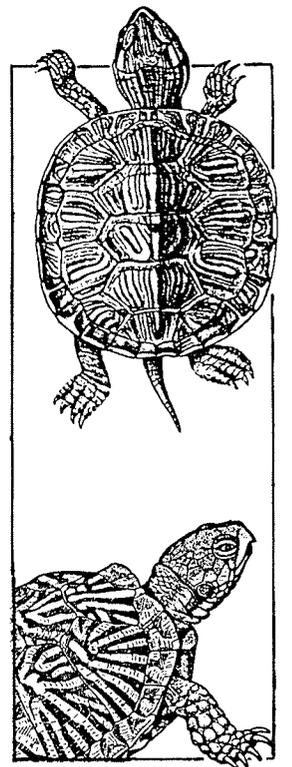
• Costs associated with research activities during first five years.	\$385,000
--	-----------

E. Total Phase One Costs

• Construction	\$858,000
• Design, Survey, Legal	102,000
• Wetland Management	\$175,000
• Research Activities	\$385,000
TOTAL PHASE ONE COST	\$1,520,000

*These costs are not included in the phase one improvement costs listed here.

Appendixes



APPENDIX 'A'

WETLAND WASTEWATER TREATMENT SYSTEMS

Introduction

In recent years, there has been an increasing need for the development of improved methods for wastewater treatment, specifically for those communities which could be categorized as small to medium in size. While the "progress" of our industrial society continues at a rapid rate, technological advances in treatment methods for the new variety of toxic chemicals, exotic organics, and general domestic sewage seems stymied. Initial construction cost and continuing operational costs of wastewater treatment plants are the most significant factors affecting technology selection process. The cost to small communities for reaching the same level of wastewater treatment as large communities using standard technology is disproportionately high. Although large sums of money have been made available by the Federal and State governments for pollution control systems, relatively few funds are being applied to advance research and development of improved treatment technology. Since present wastewater treatment systems are primarily designed after "natural" mechanisms for pollution abatement (trickling filters, activated sludge, oxidation ponds, etc.), it is ironic that practical, cost effective, and efficient treatment of wastewater utilizing controlled nutrient uptake by macrophytes in a marsh, is not in wider use and encouraged by regulatory and funding agencies.

Use of wetland wastewater treatment systems based on emergent plant species is more widespread than use of floating aquatic plant systems. This process involves the growth of rooted emergent plants such as reeds and bulrushes, in an artificial bed, and the passage of wastewater either across the surface of the wetland (Surface-flow Systems), or through the growing medium in which the wetland plants are rooted (Subsurface-flow or Root Zone Systems).

Surface-flow Wetlands

The Surface-flow wetland approach utilizes the stems of wetland plants as the main site for effluent treatment. In this method, beds of emergent wetland plants, such as reeds or bulrushes, are flooded with pretreated effluent which is retained within the wetland system for a predetermined period prior to discharge.

Surface-flow wetland plant stems provide a substratum for the micro-organisms which achieve the desired effluent treatment. Wetland processes result in an accumulation of organic material in the bottom of the system where micro-organisms also occur in high densities and further enhance effluent treatment, particularly in terms of nitrogen elimination (Bartlett, 1979). Figure 1 depicts the processes involved with this form of wetland treatment.

Subsurface-flow Wetlands

The principle behind the Subsurface-flow wetland treatment system involves passage of wastewater through a specially prepared soil, sand or gravel medium in which reeds or other emergent plants are grown. Wastewater treatment occurs in the growing medium, principally as a consequence of the growth of wetland plant rhizomes which are claimed to enhance the hydraulic conductivity of the growth medium, and introduce oxygen into adjacent areas of the growing medium.

Three general categories of subsurface-flow wetlands have been developed. These have been termed the Max Planck Institute Process, the Root Zone Method, and a modified Root Zone process based on research in California and Mississippi. These methods are each discussed separately in the following sections.

Max Planck Institute Process

The Max Planck Institute Process (MPIP) utilizes wetland plants growing in trenches to "treat" settled wastewater (Boon, 1986). In the MPIP process wastewater percolates vertically through the plants and growing medium to be collected in subsurface drainage systems. This is in contrast to other subsurface flow systems which involve horizontal percolation through the beds.

An example of the MPIP process is at Laguna Niguel, California (Pope, 1981). This system utilizes marsh plant species growing in a series of concrete basins lined with polythene and filled with gravel. The first basin in series serves to remove coarse suspended solids from the wastewater and the second basin serves as a "polishing" area to remove dissolved materials from the first basin effluent. In this process effluent is introduced to the surface of the basin and it percolates down through the gravel substratum where an underdrain collects treated effluent for passage to the next polishing basin or to the discharge point.

This process has been reported to result in operational problems with clogging, freezing, ponding in polishing basins and overflow in wet weather. The Laguna Niguel system was effective in terms of BOD and suspended solids reduction only at low application rates, and total nitrogen and phosphorus removal was not effectively achieved at all (Pope, 1981). The MPIP process is also used in sludge drying beds in other parts of the United States (Boon, 1987).

Root Zone Method

The most significant feature of the Root Zone Method (RZM) involves developing, in a constructed bed, a dense growth of reeds (normally Phragmites sp.), and the encouragement of the roots to grow vigorously throughout the growing medium of the constructed bed. This root system is claimed to provide the basis for effluent treatment.

Wastewater is fed into the developed RZM bed and flows horizontally below the surface of the bed through the root zone or "rhizosphere". In this "rhizosphere" the wastewater is mixed in a mosaic of aerobic and anaerobic spaces in the growing medium, which are inhabited by diverse species of bacteria. It is these bacteria which are claimed to result in the desired level of effluent treatment (Cooper, 1987; Ronsch, 1983).

The key features of the RZM process include the following:

- Emphasis is placed on the soil microorganisms in effluent treatment rather than the plants themselves.
- Particular attention is given to the soil used in the RZM beds to enhance ion-exchange, and the beds are undersealed to result in an enclosed system.
- The deeper rhizomes of Phragmites are encouraged to create a porous structure through the soil and in this way increase soil hydraulic conductivity. Wastewater flows along the living roots and through the pores created by old and decaying roots.
- The water table is maintained slightly below the surface of the RZM bed. This enables the aerobic composting of sludges and decomposing leaf litter.
- Passage of oxygen takes place through the stems of the reed plants into the root zone of the plants. This results in the development of patches or aerobic space within the anaerobic subsurface material. This complex pattern of aerobic and anaerobic spaces enhances both aerobic and anaerobic decomposition within the soil.
- Harvesting of reed plants is avoided to prevent damage to the rhizomes and to avoid compaction of the soil.
- The beds are engineered according to the wastewater characteristics, the nature of the soil and the desired effluent standards.

Modified Gravel Bed System

This system relies on wetland plants growing in a gravel bed or rock filter medium. The coarse substratum results in enhanced hydraulic conductivity, and the plants are claimed to provide additional treatment over that achieved in the gravel bed/rock filter alone.

The use of wetlands for wastewater treatment is an unusual field, in that it is the subject of active research but it is concurrently being promoted as an effective and proven treatment technology. In such circumstances it is essential that information on wetland

wastewater treatment is disseminated in an objective fashion, to enable balanced evaluation of the methodology. This approach would also assist in avoiding costly duplication of effort.

Surface Flow Wetlands

Natural Wetlands

Discharge of pretreated wastewater to natural wetlands has been a widespread practice for many years in the United States, where a number of sites have been identified as being the subject of ongoing discharge for more than 50 years (Hammer, 1983). Discharge sites have been reported from Florida to Canada's Northwest Territories (Nichols, 1983). Sites where discharge to natural wetlands presently occurs or is proposed include Michigan (Kadlec, 1980; Williams, 1980), New York, Massachusetts, New Jersey, Nevada (Hammer, 1983), South Carolina (CH2M Hill, 1986), Florida (CH2M Hill, 1985; Knight, 1985), California (Demgen, 1985), Wisconsin (Fetter, 1978), and Minnesota (Kappel, 1980).

In the United Kingdom, wetlands have been used for treatment of wastewater for more than 100 years at some sites (Cooper, 1987).

In general, few water quality problems have been observed with discharges to natural wetlands but the assimilative capacity of natural wetlands has only been monitored in detail since 1960 (Knight, 1985), and in the light of insufficient generalized long term data some workers advocate caution in the management of natural wetlands to which wastewater is discharged (Nelson, 1985).

Artificial Wetlands

The methodology of artificial wetlands, based on constructed basins planted with wetland species was pioneered by Dr. Kathe Siedel in the 1950s (Rossiter, 1984).

This methodology is presently utilized in the Netherlands where it was originally developed by the IJsselmeerpolders Development Authority in 1967. The original system involved a pond planted with bulrushes (Scirpus lacustris), which was designed to take a seasonal supply of sewage from a camping site. In 1969 additional ditches were constructed and planted with bulrushes, and reeds (Phragmites australis). The procedure continues to be utilized in the Netherlands where it is applied to intermittent flows such as campsites, or sewage disposal from small communities (DeJong, 1985).

Use of artificial wetlands for surface-flow effluent treatment in the United States and Canada is presently restricted to a series of pilot scale trials at Arcata northern California (Gearheart, 1982, 1983, 1985), Gustine in southern California (Crites, 1987), Orlando and Lakeland in Florida (Feeney, 1986); Listowel (Herskowitz, 1987) and Port Perry in Ontario, Canada. The Arcata, Gustine and Florida trials have been deemed successful and have been discontinued to enable

construction of larger scale systems which have been designed on the basis of trial results.

The use of artificial surface-flow wetlands is not presently a widespread effluent treatment technology in the United States or Canada. The larger scale systems have only recently been commissioned or are under construction, and thus the majority of the available monitoring information only relates to pilot scale systems. However, the general consensus in relation to use of trial-scale artificial wetlands for wastewater treatment is that the process is valid and effective, although at present there is insufficient long term operational data to derive construction and operation guidelines.

Subsurface-flow Wetland Systems

General

In this section all subsurface flow systems are discussed together, as they are all based on the same principle: that the passage of wastewater through the below-ground parts of wetland plant confers an increased treatment efficiency.

Operational subsurface-flow systems are not widely utilized in the United States at present with the MPIP process being used in sludge drying systems in New Jersey (Boon, 1986), sand gravel systems in Pennsylvania (Watson, 1987; SMC-Martin, 1985), and a limited number of small systems in Mississippi (Wolverton, 1987). A variety of subsurface flow systems have been experimentally evaluated in San Diego (Gersberg, 1983, 1984, 1986, 1987); Mississippi (Wolverton, 1987); and Pennsylvania (Watson, 1987).

WETLAND TREATMENT CHARACTERISTIC SURFACE FLOW AND SUBSURFACE FLOW SYSTEMS

Introduction

Recent research indicates that certain aquatic plants have a potential for the reduction and removal of water quality constituents in wastewater and storm runoff. These plants include both emergent and submergent vascular aquatic plants. The aquatic plants are able to extract and metabolize natural and man induced inorganic (nitrogen, phosphorus, calcium) and organic (phenols, heavy metals, herbicides) compounds present in water.

Wastewater treatment systems utilizing aquatic plants (i.e. biological filtration) are very reliable since the rooted marsh plants of these systems show a surprising ability to withstand extreme shock load from toxic materials. Seidel (1976) has attributed this capacity to a "root tent" (rhizosphere) which provides a protective area for benign bacteria that recolonize the plant surface when toxic materials have disappeared. Valiela et al. (1976) stress that the wastewater

treatment capacity of native wetlands in their concluding remarks as follows:

"Wetlands seem to be better processors of wastes than estuaries and coastal waters. It might be feasible to safely dispose of effluents under carefully controlled conditions on marshlands rather than deeper coastal areas where the elimination of contaminants is not as effective and dispersal of contaminants is more likely. We would like to emphasize, however, that the wetland properties outlined above, and the consequent effects on nutrients, heavy metals, hydrocarbons, and pathogens are features of wetlands as they function naturally. They are, in fact, providing free waste treatment for contaminated waters already. It seems imperative therefore to implement wetland conversion to maintain this subsidy intact."

Probably the most desirable function of aquatic plants is the removal of soluble inorganics. Large amounts of nitrates, phosphates, Na, K, Ca, Mg, and other macronutrients are incorporated into plant material during the summer growing season. The nutrients are removed from the marsh by harvesting the plants and flushing the marsh during the winter season. Eutrophication of the receiving waters is effectively reduced during the critical dry-weather months (Bristow, 1971).

The following sections present treatment data for a representative selection of surface-flow and subsurface-flow wetland systems. Information is presented for BOD, suspended solids, nitrogen and phosphorus.

In reviewing reported wetland treatment characteristics, it is apparent that site specific characteristics significantly control the effectiveness of particular wetland systems. This feature has been noted in relation to natural wetlands (Richardson, J. and J.A. Davis, 1987), and is relevant in evaluating the performance of artificial wetlands. The site specific nature of wetland performance leads to difficulties in extrapolating reported results to form generalized conclusions about treatment efficiency.

It is emphasized that wetland treatment results must be interpreted in relation to the particular characteristics of the wetland system for which the results have been derived. Accordingly, treatment data presented in this section should be interpreted in the light of associated data on wetland characteristics. The following results generally represent the level of treatment effectiveness reported for such systems and are not intended to comprise a definitive compilation of wetland treatment capabilities.

BOD

BOD (Biochemical Oxygen Demand) is a measure of the oxygen uptake in a given aquatic system principally as a result of the biochemical processes of the micro-organisms in that system. High levels of BOD in wastewater can result in dissolved oxygen depletion of the receiving waters to which wastewater is discharged. Therefore, it is desirable from a water quality management viewpoint to reduce BOD levels in wastewater, thereby protecting natural dissolved oxygen levels.

BOD in wastewater can arise from either dissolved material in solution, or it can be associated with settleable solids. A wetland reduces BOD levels either through physical sedimentation of solids within the wetland channel system, through direct physical filtration of solids by wetland plants, or through biological processes associated with micro-organisms in the wetland.

It is possible that certain wetland plants, e.g. Phragmites, have the capability to "pump" oxygen into the soil or growing medium adjacent to the plant's rhizomes. There is some debate concerning this (Lawson, 1985) but if it does occur, this process would provide a potential for subsurface-flow systems to reduce BOD levels in the soil or growing medium. This phenomenon has not yet been researched adequately to determine quantitative relationships between plant derived oxygen input and BOD reduction but the matter is presently under investigation.

In surface flow wetlands BOD reduction (or dissolved oxygen enhancement) may be achieved by provision of a central open area in the wetland within which wind induced reaeration can maintain dissolved oxygen levels.

The lowest BOD treatment efficiency value (37% reduction) was reported for a subsurface-flow wetland which was reported as not being operated effectively (Lienard, 1986). For remaining sites which were operating correctly, reported BOD reductions ranged from 97% reported for long term surface-flow wetlands in the Netherlands (Greiner, 1987), to 56% reduction reported as an overall average for a surface-flow system at Arcata, northern California (Gearheart, 1983). At Arcata, quarterly BOD reductions ranged from 1% to 88%, and reduction was found to be significantly influenced by temperature and flow rate.

- Ability to treat different wastewaters (septic tank effluent, screened and dewatered wastewater, settled wastewater, secondary effluent, and sludge liquors);
- The removal of faecal pollution indicator bacteria and pathogenic micro-organisms present in sewage under different conditions (type of matrix, flow pattern, species of hydrophyte etc.).

Detailed investigations have been undertaken into BOD removal through a gravel based subsurface-flow wetland at Santee, San Diego, United States (Gersberg, 1984). However, when a mixture of primary and secondary effluent was used, reported BOD removal efficiency over a 12 month period was 93% (influence BOD 49.16 mg/l; effluent BOD 3.24.0 mg/l).

Furthermore another study at this site (Gersberg, 1986) indicated that planted gravel beds were more effective at BOD treatment than unplanted gravel beds. BOD removal efficiencies were highest in the bulrush and reed beds, both of which were found to have mean effluent BOD levels significantly lower than BOD effluent levels from the unvegetated bed.

It is clear, therefore, that properly established and operated wetland treatment systems have the potential to significantly reduce BOD levels in wastewater, but that wastewater influent characteristics and wetland design will have a major influence on the level of BOD reduction.

Suspended Solids

The Suspended Solids (Non Filterable Residue or Settleable Solids) content of wastewater is of direct water quality significance in terms of turbidity in receiving waters, and indirectly in relation to the associated transport of other waste constituents such as nitrogen, phosphorus and BOD.

In wetlands, suspended solids are retained as a consequence of slow water velocities and long residence times. This contributes to sedimentation which has been identified as the primary method of suspended solids reduction (Tchobanoglous, 1979). Wetland vegetation causes surface waters to follow a tortuous path, around and through innumerable obstacles which provide sites where suspended solids may impact, lose momentum and settle (Hammer, 1983). Direct vegetative filtration also contributes to suspended solids reduction (Tchobanoglous, 1979), and it has been noted that suspended solids reduction improves in artificial surface flow systems as wetland plants mature (Gearheart, 1982). In subsurface-flow systems, suspended solids are filtered in the growing medium (soil, sand or gravel), in a manner similar to rock filter technology (Wolverton, 1987).

Reported suspended solids reduction in subsurface-flow systems range from 37% in a failed system; to greater than 90% in others. Removal data from surface flow systems range from 61% at Listowel when treating lagoon effluent, to 96% in a long term detention system in the Netherlands. An overall average of 83% reduction was noted for surface-flow systems among the selected records.

An important concept in relation to surface-flow wetlands relates to the nature of suspended solids in the influent in comparison with solids in the effluent. In wetlands, suspended solids and other

material constituting waste, are transformed from an initial "effluent-derived" form to an eventual "wetland-derived" form. Thus, although the absolute suspended solids levels may be very similar, material discharging from the wetland consists of plant detritus and natural wetland products. This characteristic has significant implications in terms of the requirements of discharge permits.

Nitrogen and Phosphorus

The Nitrogen component of wastewater is of water quality significance (along with Phosphorus) in relation to the potential enrichment of receiving waters which can lead to excessive algal growth and eutrophication. Nitrogen related processes in wetlands have been the subject of considerable research and are considered in some detail in this report.

In wetlands, nitrogen is removed by a number of mechanisms:

1. Uptake and subsequent harvesting of wetland plants;
2. Volatilization of ammonia;
3. Bacterial nitrification/denitrification;
4. Sedimentation.

Of these mechanisms, bacterial nitrification/denitrification has the greatest removal potential (Stowell, 1981). In this process ammonia-nitrogen in wastewater is converted to nitrate-nitrogen in the presence of oxygen by Nitrosomonas and Nitrobacter bacteria (this is known as Nitrification). Subsequently, in anaerobic conditions, nitrate nitrogen is converted to nitrogenous gases (nitrogen and nitric oxide) by anaerobic bacteria (denitrification). These nitrogenous gases are the main mechanism by which nitrogen is converted and exported from the system (Good, 1987; Griggs, 1987).

Nitrifying bacteria occur on the submerged portions of wetland plants and in wetland detritus (Matulewich, 1978), and denitrification occurs in the anaerobic areas of the wetland mainly in anaerobic soils (Stowell, 1981).

In wetland soils, nitrate diffuses to anaerobic layers as rapidly as it is formed and is denitrified. It has been found that 90-95% of nitrate nitrogen added to wetland soil-water suspensions is reduced to nitrogenous gases with little or no transfer of nitrate to ammonia or organic nitrogen (Bartlett, 1979). At present it is unclear whether wetland plants actually contribute to nitrogen removal, with some indications that the presence of plants can augment nitrification and denitrification (Zolteck, 1979) and other evidence that the presence of plants makes no significant difference to nitrogen removal (Gersberg, 1984).

The rate of nitrification is dependent on temperature and the oxygen availability in the wetland (Stowell, 1981), and the process is only possible where oxygen can readily diffuse to the reaction site

(Hammer, 1983). For this reason, anaerobic wetlands which may have been subject to high BOD loadings, and surface flow wetlands which for a number of reasons may have low dissolved oxygen levels, will not be effective as nitrification systems for example Arcata (Gearheart, 1983). Oxygen translocation by plant roots has been reported as potentially useful in this regard, particularly if the wetland plants are grown hydroponically (Stowell, 1981).

In general it appears that surface-flow wetlands are not effective nitrifiers as a consequence of low dissolved oxygen levels, but they are potentially effective denitrifying systems in view of the presence of anaerobic areas. Surface-flow wetlands would therefore potentially be very effective in nitrogen removal for highly nitrified effluents.

Subsurface flow systems have been found to be relatively poor at denitrification unless supplemental carbon is added (Gersberg, 1983, 1984). However, in view of the potential for oxygen translocation by the roots, subsurface flow systems are potentially valuable in nitrification.

Reported nitrogen removal efficiencies for wetlands vary for surface flow wetlands from around 26% as an average at Arcata (Gearheart, 1983), to 88% for a long term detention system in the Netherlands (Greiner, 1982); and for subsurface-flow systems 13% for an inefficient system at Kalo in Denmark (Brix H. and Schierup H-H, 1986) to 95% for a carbon supplemented system at San Diego (Gersberg, 1983, 1984).

It is concluded that nitrogen removal by surface-flow or subsurface-flow wetlands, is presently relatively inconsistent. However, wetlands have a number of important attributes which should lead to effective nitrogen removal, including wetland soil-water characteristics. Work with carbon supplementation (Gersberg, 1983, 1984) indicates that nitrogen removal mechanisms can be optimized and the means optimizing these nitrogen removal mechanisms is clearly an area for active research (Howard-Williams, 1985).

Phosphorus (along with nitrogen) is of potential concern from a water quality viewpoint in relation to potential enrichment and algal nuisance problems.

Research by Dymond (1948) showed that one aquatic plant, hyacinth, was capable of removing up to 75 percent of the nitrates and 61 percent of the phosphates from secondarily treated wastewater when a harvesting procedure was followed. If the hyacinth was not harvested, a reduction in the rate of nutrient removal was observed which paralleled the plant's attrition rate. However, nutrients which were sloughed off during the death phase remained in the marsh as bottom deposits and were not returned to solution. Dymond determined that each ton of hyacinth absorbed approximately 191 lbs. of nitrate and 36 lbs. of phosphate.

Cornwell et al. (1977) found that the nutrient removal capability of aquatic plants was directly proportional to marsh surface area. Marsh depth and hydraulic detention time could be set so that an optimum flow per unit of surface area was provided. This optimum hydraulic loading was found to be 0.2 mgd area of hyacinth. Under these conditions, 80 percent of the nitrate and 44 percent of the phosphate was removed from solution. As with the study by Dymond (1948), the rate of nutrient removal by the hyacinth was observed to reach a maximum, and then decline. Cornwell determined that this maximum occurred during the horizontal-vertical growth phase of hyacinth development.

The nutrient removal capabilities of hyacinth in standing versus flowing water was examined by Rogers and Davis (1976). Preparations of 10, 20, and 50 percent Hoagland's solution was used as growth media. Phosphate absorbed averaged 1.0, 2.1, and 3.1 mg/plant/day in the static media and 1.7, 2.3, and 3.3 mg/plant/day in the flowing media. Absorbed nitrate averaged 5.3, 11.4, and 19.8 in the static media and 9.9, 18.4, and 20.8 in the flowing media. It was concluded that under optimum flow rate and marsh depth, 25 acres of hyacinth could absorb the average nitrate and phosphate contribution of over 800 people.

Additional determinations of the nitrate and phosphate removal capability of hyacinth were made by Boyd et al. (1976). To achieve concentrations of nitrate and phosphate equivalent to those in eutrophic lakes, 2.35 lbs. of inorganic phosphate mixture and 1.75 lbs. of ammonium nitrate was broadcast over culture pond surfaces at two-week intervals. The average growth rate of the hyacinth in the ponds was 171 lbs./acre/day. The average rates of nitrate and phosphate removal was 18.8 and 2.4 lbs./acre/day respectively, with a general nitrate-phosphate absorption ratio of from 5:1 to 10:1.

To date, the most comprehensive study of the use of aquatic plants for wastewater treatment is that currently being conducted at the NASA NTSL research facility in Bay St. Louis, Mississippi (Wolverton, et al., 1976). Determinations of the potential for the removal of trace metals, hydrocarbons, and radioactive materials as well as the removal of nutrient salts have been studied. In addition, a total energy system has been devised wherein the by products of waste treatment (harvested plants) are converted to useful and marketable products. The wastewater filtration system utilized is made up of seven separate filtration pools planted in hyacinth, which comprise seven acres of a 40 acre pond. The nutrient and suspended solids concentrations of the effluent from the system is less than the U.S. drinking water standard. In addition to purification of the wastewater effluent, the plants are able to detoxify both industrial and chemical wastes in excess of the standards set by the NTSL.

Under optimum conditions, which are determined principally by climate, hydraulic detention time, and frequency of harvest, one acre of hyacinths was found to produce 534 lbs. of dry plant material per day. It was also determined that one acre of hyacinths can remove

3,500 lbs. of nitrate and 800 lbs. of phosphate, absorb and metabolize more than 150 lbs. of phenols every three days, and remove over 120 grams of trace heavy metal contaminants per day. In addition, one million cubic feet of biogas (a product similar to methane) can be produced from 70 tons of harvested plant material using an anaerobic decomposition process, with a residual 70 tons of high-grade fertilizer being yielded as a by-product. Since no heavy levels of heavy metals or other noxious substances have been detected in the Bay St. Louis effluent, harvested plants are also potential sources of animal food and human food supplements.

A wetland study in Florida utilizing trickling filter effluent proved to be efficient in removing total nitrogen and phosphorus in a wastewater stream (Boyt, 1977). The swamp ecosystem reduced ammonia concentrations from 20 mg/l in the dry season and 2.5 mg/l in the wet season to less than 1.0 mg/l under both conditions. Total phosphorus levels were reduced from 10 mg/l to less than 1.0 mg/l. Dilution may have accounted for some of the reduction in concentration since rainfall plus runoff averaged 95 percent of the water entering the swamp and evapotranspiration accounted for approximately 50 percent of the water loss from the swamp.

Elsewhere, an 18 month study in the Sacramento River delta was conducted which applied secondary treated wastewater to high rate algal ponds, marsh ponds, and pasture land (Cederquist, 1977). During summer months, the total inorganic nitrogen concentration in the system effluent averaged less than 2 mg/l. The dissolved oxygen levels in the system often dropped below 5 mg/l and were recorded as low as 2 mg/l. Problems associated with over-growth of a desirable algae and emergent vegetation were experienced and was thought to contribute to low dissolved oxygen concentrations. The ability to control water level over a depth of 1 to 5 feet was suggested as a means of controlling vegetation types. Alkali bullrush and watergrass was successfully germinated and grown in a media entirely made up of wastewater effluent from the City of Cordelia, California.

In an aquaculture project utilizing wastewater in various combinations with seawater at Woods Hole Oceanographic Institution, 90-95 percent nitrogen removal by unicellular algae has been achieved (Ryther, 1975). Only during periods of high predation by zooplankton was this removal rate reduced. Approximately 90 percent of the incoming nitrogen was removed on cloudy days and as much as 99.9 percent of the nitrogen was removed on clear sunny days. Algal yields and nitrogen removal capacity varied seasonally and were found to be controlled by solar radiation.

Areal requirements for adequate nitrogen removal at Woods Hole latitude was estimated to be approximately 26 acres/mgd in the summer and 77 acres/mgd in the winter. This areal loading produced algae at the rate of 3 grams/sq.m/day in the winter and 9 grams/sq.m/day in the summer. Algae uptake of nitrogen was estimated to be 1 gram/sq.m/day in the summer.

The removal of phosphorus from wetland systems is intermittent, and little is understood about the mechanisms involved in uptake. The principal phosphorus removal mechanisms are precipitation and adsorption to sediments, with secondary mechanisms including plant uptake and sedimentation (Tchobanoglous, 1987). Phosphorus is rapidly immobilized in organic soils, and thus saturation is reached relatively rapidly with the process being partially reversible (Hammer, 1983). Ultimate removal of phosphorus from wetland systems could be achieved by:

1. Harvesting of plants
2. Dredging of sediments
3. Resolubilizing of phosphorus stored in sediments and release to receiving waters when it would have least environmental impact (Stowell, 1981)

Phosphorus is commonly released during winter in wetland systems (Wile, 1981; Stowell, 1981) and this would be consistent with release during time of minimal environmental sensitivity.

Reported wetland removal results indicate a variable wetland performance with net phosphorus removal rates ranging from 0% in subsurface-flow systems (Phillips, 1987) and surface-flow systems (Gearheart, 1983) to 79% for a long term surface-flow system in the Netherlands (Greiner, 1982) and 83% in sand/soil based subsurface-flow systems in Denmark (Brix, 1986).

Pathogens-Bacteria Viruses

Bacterial and viral die off in wetlands is reported to be greatly enhanced over conventional wastewater treatment systems (Ives, in prep.) as a consequence of the development of a "higher", more complex microbiological community with increased diversity and abundance of bacterial and viral predators. However very little is known of the dynamics of viral reduction in wetlands although in most cases, wetlands can be anticipated to provide at least a 2 log reduction in bacterial levels with even a two day retention period (Gersberg pers comm).

In aquatic systems, concentrations of pathogenic organisms are reduced by prolonged exposure to physical, chemical and biological factors hostile to these organisms. The extent and reliability of reductions in pathogen concentrations in aquatic systems are unknown, but are considered primarily to be attributable to decomposition and natural dieoff, with other processes including possible root excretions (allelochemicals) of certain plants which are toxic to enterically derived pathogens (Stowell, 1981); filtration; adsorption; and biological inactivation and predation (Gersberg, 1987).

Little quantitative information is available on the specific efficiencies of wetlands in reducing pathogen levels, other than that

presented by Gersberg et al. in relation to subsurface-flow wetlands (Gersberg, 1987, 1986). These studies found a 99.1% reduction in total coliform levels in a vegetated (*Scirpus*) wetland bed compared with a 95.7% reduction in an unvegetated bed. The concentration of MS-2 bacteriophage virus was found to be reduced by 98.3% in a vegetated bed. Root allelochemicals of wetland plants such as *Scirpus lacustris* and *Phragmites communis* have been reported to be toxic to coliform and salmonella bacteria, and Gersberg et al. concluded that these chemicals may have resulted in the observed patterns of bacterial reduction. The root aeration ability of certain wetland plants could also contribute to reductions in pathogen numbers by enhancing soil bacterial populations (Gersberg, 1987).

A further study into the fate of viruses in surface flow wetlands was conducted at Arcata in northern California (Ives, in prep.). This study concluded that viral reduction in wetlands was related to temperature, dissolved oxygen, and suspended solids removal resulting from filtration by wetland plants. Methods of optimizing viral reduction in wetlands include rapid initial sedimentation, and provision of a non-vegetated area to enhance algal growth and augment aquatic temperatures.

It is concluded that artificial wetlands offer an attractive alternative to conventional land treatment systems for reducing the load of disease causing viruses and other pathogens to the aquatic environment.

Metals

In wetlands, metals are removed from wastewater by:

1. Plant uptake
2. Chemical precipitation
3. Ion exchange with and adsorption to settled clay and inorganic compounds.

However, it is likely that the potential capacity of wetlands to remove metals by plant uptake and harvesting will be small, and ultimate removal of metals from wetlands systems will probably be most effectively achieved by methods for the removal of phosphorus (Stowell, 1981).

Reported metals removal rates for subsurface flow wetlands include 99%, 97%, and 99% for Cu, Zn, and Cd respectively, where the primary removal mechanisms were attributed to precipitation/adsorption (Gersberg, 1984).

Engineering Approach

Wherever possible emphasis should be placed on a "low impact" engineering approach. This not only avoids unnecessary expense, but can enhance the natural processes involved in the use of wetlands. For

example, in creating cells consideration should be given wherever possible to leaving areas of existing vegetation intact. This assists colonization of wetland areas by naturally occurring plants and will lead to greater long term ecological stability of the system.

Water Depth

Initial establishment of emergent plants in surface-flow wetlands may require initial shallow water depths of 0.15m (Gearheart, 1982), after which depth should be increased to 0.3-0.6m. If Scirpus is the main desired species, initial water depths should be maintained as shallow as possible to prevent Typha domination. Scirpus does well in 0.05m to 3m depth whereas Typha dominates at depths >0.15m (Stephenson, 1982). Accordingly if available area permits, particularly in the establishment phase, it would be advisable to maintain only shallow water depths in the desired emergent plant areas.

Water level manipulation is an important vegetation management technique. There is evidence that survival of wetland plants is enhanced when water levels are varied, preferably on a seasonal basis. Reduction in water level termed drawdown is very important in relation to the maintenance of wetland plants at the proper successional status, and is important in nutrient recycling within the wetland (Fog, 1982). The required frequency and extent of drawdown will vary with each wetland application and will be difficult to predict. The presence of wide gently sloping margins will exaggerate the impact of water level fluctuations due to evapotranspiration and rainfall. It may therefore not be necessary to employ drawdown as a management tool. However, the need for water level management must be continually addressed through the period of use of the wetland.

Cell Construction

Bottom contours should be smooth, and abrupt bathymetric discontinuities should be avoided, to minimize potential problems with short circuiting, and to avoid formation of refuges for predators during periods of drawdown (Fog, 1982).

The height of embankments should be as small as practicable, consistent with providing for increases in water level due to rainfall, or for flow buffering. Minimizing the height of the embankment will maximize wind fetch, thus augmenting aeration and restricting problems with duckweed.

Drainage Points Within Cells

It will be important to provide for some means of enabling complete wetland drainage either for routine maintenance or, as a last resort, in the case of complete system failure. This could involve pumps or internal drainage points. If drainage points are used, it will be important to ensure that they are readily able to be located if required in the future.

In managing a wetland, it may be important to be able to take separate cells out of commission for maintenance, if necessary. Therefore, wherever practicable in final design, attention should be given to ensuring cells are self-contained, and that effluent bypasses will be able to be implemented.

Inlet Systems

Knight (1987) concluded that a point source discharge into a wetland would be preferable to a wide-front discharge (Knight, 1987). Nevertheless, on the basis of an overall review of available data, including discussions in the UK, it is concluded that the discharge should be made across a wide front to take advantage of initial BOD and SS reductions in the first 10-15m of a wetland. This should also avoid the rapid formation of a BOD or SS front which is referred to by Knight (1987).

Rhizome Planting

Rhizomes of most wetland plants are suitable for use in propagation. It is less resource intensive to spread rhizomes than to plant individual plants. However, rhizomes are themselves sensitive to desiccation and should be carefully managed to enhance the chances of suitable establishment of wetland plants.

When obtaining wetland plant rhizomes, or individuals for planting stocks should be obtained from the immediate vicinity if possible. This will increase the chance of successful establishment of plants which should at least be adapted to the general weather conditions of the planted area.

The advocated approach would be "plug-planting" with emergent wetland plants in early mid Autumn and allow approximately one year for suitable establishment of the plants. However, it is possible to plant at any time of the year provided that rhizomes and plants are kept constantly moist.

Soil Composition

At Listowel, the wetland soil was conditioned prior to planting (Herskowitz, 1987). In that case marsh basins were composed of compacted clay, filled to a depth of 0.15m with a combination of topsoil and peat (10% by volume). It might be advisable, for example, to utilize dewatered sewage sludge as a soil conditioner. This would be disked into the soil prior to planting. This soil conditioning will be required in particular, if soil is to be removed from the wetland area for construction of embankments.

Scale-up

It is advisable to adopt caution when extrapolating the results of small-scale trial wetlands to larger operational scale systems. If the wetland is to be utilized for effluent treatment, the system should be oversized to achieve greater detention times and minimal application rates than indicated in trial systems.

Temperature

Wetlands will operate best in situations of higher temperatures. This is related to plant physiology and the amount of litter deposited by plants during seasonal winter dieback. This would account for the apparent success of wetlands in Northland.

Herbivores

Local herbivores such as Pukeko and Rabbits have a tendency to eat newly shooting wetland plants. This may require pest control measures during wetland establishment.

Botanical Input

In designing wetlands, the engineering principles of cell construction, flow direction, depth, inlet and outlet structures, and application rates are relatively straight forward. However, the key to successfully establishing a wetland system lies in the installation and maintenance of the wetland plants. This is an area which must be given high priority from the initial stages of design of the system.

Plant Species Suitability

In terms of species suitability Typha (Raupo) is considered to be less suitable than Scirpus (Bulrush), for a number of reasons, including reduced capacity for oxygen translocation to the root system, greater degree of litterfall which can cause problems with anaerobic conditions, and problems with windthrow if the roots are not adequately deep in the soil.

Odors

Hydrogen sulphide generation and associated odors occur periodically at wetland outlets. The incidence of this problem is increased by use of plants which lead to anaerobic conditions (e.g. Typha), and in these cases odor problems are exacerbated when the outlet occurs as a cascade. Controlling the outlet can prevent hydrogen sulphide odor problems.

The odors identified most commonly in aquatic wetland treatment systems are associated with organic compounds containing sulphur, such as mercaptans and skatoles, and with hydrogen sulphide. Hydrogen sulphide is produced by obligate anaerobic organisms capable of

reducing sulphate (Tchobanoglous, 1979). In the absence of oxygen and nitrate, sulphate will serve as an electron acceptor and is reduced to hydrogen sulphide in the process. Thus the presence of sulphate in the wastewater can lead to the formation of hydrogen sulphide in the bottom sludge accumulations. The organic matter in the sludge accumulation serves as a carbon source for the anaerobic process. The incomplete oxidation of other organic materials containing sulphur will also lead to the development of odors.

Anaerobic conditions develop when the treatment process is overloaded organically. Most commonly, anaerobic conditions develop near the effluent end of an aquatic treatment system.

Strategies that can be used to control the development of odors include the following (Tchobanoglous, 1979):

1. More effective pretreatment to reduce the total organic loading on the aquatic treatment system.
2. More effective effluent distribution.
3. Step feed of influent waste stream.
4. Supplemental aeration.

For the Listowel trial, hydrogen sulphide levels in the wetland increase at the end of winter and in summer when oxygen and nitrate were unavailable to satisfy the requirements of heterotrophic bacterial metabolism (Herskowitz, 1987). Wetland effluent hydrogen sulphide levels remained at < 0.5 mg/l until early spring at which time concentrations rose to a maximum of 6 mg/l. Hydrogen sulphide production in summer occurred throughout the system and reached a maximum of 14.5 mg/l in one particular cell. There is clearly evidence therefore of a seasonal influence on hydrogen sulphide generation in this system.

In Arcata (April 1987), it was observed that hydrogen sulphide generation and odors occur periodically at wetland outlets. The incidence of this problem is increased by using plants which lead to anaerobic conditions (e.g. Typha), and in these cases odor problems are exacerbated when the outlet occurs as a cascade. Controlling the outlet can minimize hydrogen sulphide odor problems.

In constructing wetlands it will be necessary from the outset to consider whether the organic loading will be likely to cause odor problems. The most common approach is to estimate BOD loading in terms of kg/ha/day and compare with published BOD loading rates (e.g. as outlined in Knight 1987). Organic loadings at 166 kg/ha/day or less proved to be most effective in terms of not overloading the Arcata wetland system (Gearheart, 1983). Interestingly, loadings at Listowel (Herskowitz, 1987) were in the range 0.27-0.92 kg/ha/day and hydrogen sulphide generation was observed.

This indicates that the Listowel situation may have been atypical, possibly related to the reliance on Typha alone and possibly related to

the climatic situation at Listowel. This confirms the need to address each proposed wetland application in terms of its individual characteristics and illustrates the difficulties in deriving broad guidelines.

Final-Segment Polishing

The final segment of the wetland is of major significance in terms of final effluent polishing and retention of suspended solids. This final segment should be retained in as undisturbed a state as possible. If harvesting is selected as a management option (note that research has shown harvesting to be not necessary and even deleterious), then the final section of the wetland should be retained in this natural state at all times.

Wildlife

Provisions of wildlife habitat is an additional feature of wetland waste treatment systems, and in many cases wetland systems will be amenable to public viewing.

If a wetland is to provide a meaningful alternative wildlife habitat it will be necessary to determine which habitat type is to be provided and which species will be catered for. It will be a case of assessing habitat gaps and targeting wildlife management to fill these gaps.

For example, high quality nesting and brooding habitat may be sparse near built-up areas. Concentrating on these areas should encourage at least a seasonally resident population of waterfowl amenable to public viewing. There may also be a significant amount of incidental use by waterfowl outside of the breeding season and also species such as Bittern, Rails, Crakes, Tius, etc.

Careful selection of plant type, site location and aspect will be necessary to account for security, shelter, preening, nesting, moulting sites, and predators. All these requirements are identifiable in terms of practical management, if the optimum value to wildlife is to be achieved (Fog, 1982).

The following comments address particular wildlife management techniques of relevance to wetland waste treatment systems (Fog, 1982).

Shelter

Emergent grasses, sedges and rushes provide the cover needed by waterfowl for protection. To optimize these vegetation types it may be necessary to include seasonal drawdown in the management regime. This drawdown will expose seeds to the air and will encourage germination.

Nesting

As nesting sites, islands have a number of advantages, with accessibility being of primary concern. Most duck species avoid nesting on islands covered with trees and shrubs.

Breeding

In impounded lakes, food is a key feature in determining the breeding density of breeding pairs of birds, as well as their production of fledged young.

Feeding

It is the naturally generated aquatic plant and invertebrate communities which will dominate the food of waterfowl, and determine the area's success as a breeding and duckling survival habitat.

Drawdown is important short dry spells give seeds the opportunity to germinate and maintains an early successional status which is attractive to wildlife. It will be important to encourage the development of emergent grasses.

Waste straw is a valuable means of encouraging the buildup of bottom dwelling invertebrate communities which are valuable as food for wildlife. Experience to date indicates that this method does not work in waterbodies with an established invertebrate fauna. However, it does seem to be worthwhile in new areas. A recommended application rate is about 10 tons per hectare.

Bird Species Diversity

When trying to optimize the density of breeding pairs and production of fledged young, it is better to create two or more small water bodies than one large one. When species diversity is the main objective, it is preferable to make the water body as large as possible.

For high production of birds and high species diversity it is important to consider the final shape of the water body and the structure and diversity of the habitat. The edges should be irregular with spits and bays which would increase the productive edge zone and provide increased courting and brood rearing territories. Islands are also valuable in this respect.

Rejuvenation

The best way of rejuvenating a man-made lake is to provide for a complete drawdown for a term of one or more years. This releases nutrients from aquatic plants and the bottom substrate, permits colonization by terrestrial plants, and drastically reduces populations

of invertebrate predators and fish. It is recommended that such a drawdown be implemented every 5-10 years from a wildlife viewpoint.

General

Other aspects of significance from a wildlife management viewpoint are the gradient of the littoral areas it will be important to ensure that the nearshore submerged areas are not too steep. It will also be important to maintain an optimal ratio of vegetative edge: open water, while at the same time avoiding immobile backwaters liable to result in water quality problems.

Eutrophication

This term refers to algal enrichment of the waters in the proposed wetland area. Algal blooms occur in waters high in nutrients and the mechanisms driving blooms are often very complex. From a dissolved oxygen viewpoint, algal enrichment can increase dissolved oxygen levels as a consequence of diurnal photosynthesis. However, the same algal enrichment can lead to dissolved oxygen depletion at particular times, e.g. following dieoff or during the night and early morning when algal respiration can result in a net dissolved oxygen deficit. This, in turn, can have a marked influence on hydrogen sulphide generation through the creation of anaerobic conditions, and thus can contribute to odor generation.

It is therefore seen as important to address management strategies to control eutrophication or plankton over-enrichment.

References

Armstrong, W. (1986)

Bartlet, M.S., Brown, L.C., Hanes, N.B. and N.H. Nickerson, "Denitrification in Freshwater Wetland Soil", Journal of Environmental Quality", pp. 460-464, V. 8, No. 4, Oct.-Dec. 1979.

Boon, A.G., Report of a visit by A. G. Boon to Canada and the USA to Investigate the Use of Wetlands for the Treatment of Wastewater (8-28th March 1986), WRC Report 425-S, June 1986.

Boon, A.G., Proposal for Participation in Research and Development Programme in the field of the Environment (1986-1990). Submitted to European Community February 1987.

Boyd, C.E., et al., "Accumulation of Dry Matter, Nitrogen, and Phosphate by Cultivated Water Hyacinth," Economic Botany, 30: 51-56, 1976.

Boyt, R.L., S.E. Bayley, and J. Zoltek, Jr., "Removal of Nutrients From Treated Municipal Wastewater by Wetland Vegetation," J. of Water Pollution Control Federation, 49: 780, 1977.

Bristow, J.M., and M. Whitcombe, "The Role of Roots in The Nutrition of Aquatic Vascular Plants," American J. Ret., 58: 8-13, 1971.
Brix, H. and Schierup H-H (1986)

Cederquist, N., "Waste-Water Reclamation and Reuse Pilot Demonstration Program For The Suisun Marsh-Progress Report March 1977," Bureau of Reclamation, Mid-Pacific Region, Sacramento, California, 1977.

CH2M Hill, "Wetland Treatment and Landscape Irrigation for Wastewater Reuse at the South County Regional Park, Palm Beach County, Florida". Report for Palm Beach County Utilities West Palm Beach, Florida, May 1985.

CH2M Hill, "Boggy Gut Wetland Treated Effluent Disposal System Hilton Head, South Carolina Final Status Report November 1986". Report for Sea Pines Public Service District.

Cooper, P.G. and Boon A.G., "Use of Phragmites for Wastewater Treatment by the Root Zone Method". Paper presented to NE Branch of IWPC February 25, 1987.

Cornwell, D.A., J. Zolteck Jr., D.D. Patriuels, T. de S. Furmau, and J.I. Kim, "Nutrient Removal by Water Hyacinths," J. of Water Pollution Control Federation, 49(1): 57-65, 1977.

Crites, R.W. and Mingee, T.J., "Economics of Aquatic Wastewater Treatment Systems", pp. 879-888 In: Aquatic Plants for Water Treatment

and Resource Recovery K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc., 1987.

DeJong, J., Kok, T., and Koridon, A.H., "The Purification of Wastewater and Effluents Using Marsh Vegetations and Soils", Proc. EWRS 5th Symp. on Aquatic Weeds, 1985.

Demgen, F.C., "An Overview of Four New Wastewater Wetlands Projects", pp. 579-595 in: Future of Water Reuse Vol. 2, Proc. Water Reuse Symp. III, Aug. 26-31 San Diego, California, AWWA Research Foundation, 1985.

Dent, D., A Practical Guide to the Reclamation of Mangrove Swamps and Salt Marsh. Internal Report to Soil Bureau, DSIR Auckland.

Dymond, G.C., "The Water Hyacinth-A Cinderella of Plant World," Soil Fertility and Sewage, Dover Pub., New York, 1948.

Feeney, P., Morrel, B., Click D., Jackson, J.A., "Wetlands Wastewater Disposal A Simple Environmentally Safe Solution", Report to Florida Section AWWA, Florida PCA, Florida Water and Pollution Control Operators Association. West Palm Beach, Florida, Nov. 11-14, 1986.

Fetter, C.W. Jr., Sloey, W.E., Spangler, F.L., "Use of A Natural Marsh for Wastewater Polishing", pp. 290-307, Journal WPCF, Feb. 1978.

Fog, J., Lampio, T., Rooth, J., and Smart, M., "Managing Wetlands and their Birds A Manual of Wetland and Waterfowl Management", Proc. 3rd Technical Meeting on Western Palearctic Migratory Bird Management, held at the Biologische Station Rieselfelder Munster, FRG 12 15, Oct. 1982, Publ. Int. Waterfowl Research Bureau.

Gearheart, R.A., Wilbur S., Williams, J., Hull, D., et al., City of Arcata Marsh Pilot Project Second Annual Progress Report, Sept. 1981. Report to California State Water Resources Control Board, August 1982.

Gearheart, R.A., Wilbur, S., Williams, J., Hull, D., Finney, B., et al., Final Report City of Arcata Marsh Pilot Project, City of Arcata Department of Public Works, Arcata, California, April 1983.

Gearheart, R.A., Williams, J., Holbrook, H., and Ives, M., City of Arcata Marsh Pilot Project Wetland Bacteria Speciation and Harvesting Effects on Effluent Quality. Environmental Resources Engineering Department, Humboldt State University, Arcata, California, 1985.

Gersberg, R.M., Elkins, B.V., and C.R. Goldman, "Nitrogen Removal in Artificial Wetlands", Water Research Vol. 17, No. 9, pp. 1009-1014, 1983.

Gersberg, R.M., Lyon, S.R., Elkins, B.V. and Goldman, C.R., "The Removal of Heavy Metals by Artificial Wetlands", pp. 639-648 in: Future

of Water Reuse Vol. 2, Proc. Water Reuse Symp. III, Aug. 26-31 San Diego, California, AWWA Research Foundation, 1984.

Gersberg, R.M., Elkins, B.V. and C.R. Goldman, "Use of Artificial Wetlands to Remove Nitrogen from Wastewater", Journal WPCF Vol. 56, No. 2, Feb. 1984.

Gersberg, R.M., Elkins, B.V., and Goldman, C.R., "Wastewater Treatment by Artificial Wetlands", Water Science and Technology Vol. 17, pp. 443-450, 1984.

Gersberg, R.M., R. Brenner, S.R. Lyon and B.V. Elkins, "Survival of Bacteria and Viruses in Municipal Wastewaters Applied to Artificial Wetlands", pp. 237-247 in: Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc. 1987.

Gersberg, R.M., Elkins, V.G., Lyon, S.R., and Goldman, C.R., "Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands", Water Research Vol. 20, No. 3, pp. 363-368, 1986.

Gersberg, R.M., Lyon, S.R., Brenner, R., and Elkins, B.V., "Fate of Viruses in Artificial Wetlands", Applied and Environmental Microbiology Vol. 53, No. 4, April 1987.

Good, B.J. and W.H. Patrick Jr., "Root-Water-Sediment Interface Processes", pp. 359-381 in: Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc., 1987.

Greiner, R.W. and J. DeJong, "The Use of Marsh Plants for the Treatment of Wastewater in Areas Designated for Recreation and Tourism", Flevovericht No. 225, Introductory paper presented at 35th International Symposium (Cebedeau) 24-26 May, 1982 at Liege.

Griggs, J., Statement of Evidence by Jeff Griggs concerning application by Franklin County Council for a right to discharge treated sewage effluent to Drury Creek. Auckland Regional Water Board, October 12, 1987.

Hammer, D. and Kadlec, R.H., Design Principles for Wetland Treatment Systems, EPA 600/S2-83-026, May 1983.

Herskowitz, J., Black S., Lewandowski, W., Listowel Artificial Marsh Treatment Project, pp. 237-246 in: Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc. 1987.

Howard-Williams, C., Cycling and Retention of Nitrogen and Phosphorus in Wetlands: a theoretical and applied perspective, Freshwater Biology (1985) 15, 391-431.

Ives, M.A., "The Fate of Natural Virus in An Artificial Marsh Wastewater Treatment System Utilizing a Coliphage Model", in prep.

Kadlec, R.H., "Wetland Tertiary Treatment at Houghton Lake Michigan", pp. 101-139 in: Bastian, R.k. and Reed, S.C. (1979) Aquaculture Systems for Wastewater Treatment: Seminar proceedings and Engineering Assessment EPA 430/9-80-006.

An Experimental Trial, pp. 83-90, in: Bastian, R.K. and Reed, S.C. (1979) Aquaculture Systems for Wastewater Treatment: Seminar proceedings and Engineering Assessment EPA 430/9-80-006.

Knight, R.L., Lake Coral Treated Effluent Disposal System, Monitoring Report. Cited in: CH2M Hill (1985) Wetland treatment and Landscape Irrigation for Wastewater Reuse a the South County Regional Park, Palm Beach County, Florida. Report for Palm Beach County Utilities West Palm Beach, Florida, May 1985.

Knight, R.L., Wetlands: An Alternative for Effluent Disposal, Treatment, and Reuse, pp. 6-9, Florida Water Resources Journal, Nov-Dec 1985.

Knight, R.L, Effluent Distribution and Basin Design for Enhanced Pollutant Assimilation by Freshwater Wetlands, pp. 913-921 in: Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Ic. 1987.

Lawson, G.J., Cultivating Reeds (Phragmites australis) for Root Zone Treatment of Sewage. Institute of Terrestrial Ecology (Natural Environment Research Council). Contract Report to WRCITE Project 965, October 1985.

Lienard, A., Study of the Sewage Purification Works using Beds of Macrophytes at Logis a St. Bohaire, French Ministry of Agriculture, Department of Water Quality, Fishing and Fish Farming, LYON, October 1986.

Matulewich, V.A. and Finstein, M.A., Distribution of Autotrophic Nitrifying Bacteris in a Polluted River (the Passaic). Applied and Environmental Microbiology 1978 35(1):67-71.

Nelson, R.W. and Weller, E.C., A Better Rationale for Wetland Management, Environmental Management Vol. 8, No. 4, pp. 295-308, 1985.

Nichols, D.S., Capacity of Natural Wetlands to Remove Nutrients from Wastewater, Journal WPCF Vol. 55, No. 5, May 1983.

Phillips G.L., Ayling, B., Clarke, C., and C. Thomas (1987). Pope, P.R., Wastewater Treatment by Rooted Aquatic Plants in Sand and Gravel Trenches-Laguna Niguel, California, EPA 600/2-81-091.

Richardson, C.J. and J. A. Davis, Natural and Artificial Wetland Ecosystems: Ecological Opportunities and Limitations, pp. 819-854 in:

Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc. 1987.

Rogers, H.H., and D.E. Davis, "Nutrient Removal by Water Hyacinth," *Weed Science*, 20: 423-427, 1976.

Ronsch, R., *Root Zone-Sewage Treatment Plants after Kickuth Spenge-Wallenbruch 2 Verbesserte Auflage*, 1983.

Rossiter, J.A. and Crawford, R.D., *Evaluation of Artificial Wetlands in North Dakota: Recommendations for Future Design and Construction*, Transportation Research Record 948, 1984

Ryther, J.H., "Preliminary Results With A Pilot Plant Waste Recycling-Marine Aquaculture System," International Conference on The Renovation and Reuse of Wastewater Through Aquatic and Terrestrial Systems, Bellagio, Italy, July 15-21, 1975.

SMC- Martin Inc., *Marsh-Pond-Meadow Sewage Treatment Facility*. Vilalge of Neshaminy Falls, Montgomery Township, Montgomery County, Pennsylvania, SMC-Martin, Valley Forge, Pennsylvania, 1985.

Stephenson, M., Turner, G., Pope, P., Colt, J., Knight, A., Tchobanoglous, G., Publication No. 65 *The Use and Potential of Aquatic Species for Wastewater Treatment Appendix A: Environmental Requirements of Aquatic Plants*, California State Water Resources Control Board, Sacramento, California, 1982.

Stowell, R., Ludwig, R., Colt, J., Tchobanoglous, G., *Concepts in Aquatic Treatment System Design*, pp. 16555-16569, Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 107, No. EE5, October 1981.

Tchobanoglous, G., *Aquatic Plant Systems for Wastewater Treatment: Engineering Considerations*, pp. 27-48 in: *Aquatic Plants for Water Treatment and Resource Recovery*, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc. 1987.

Tchobanoglous, G., Stowell, R., Ludwig, R., Colt, J. and Knight, A., *Aquaculture Systems for Wastewater Treatment: Seminar proceedings and Engineering Assessment*, EPA 430/9-80-006, pp. 35-55 in: Bastian, R.K. and Reed, S.C., 1979.

Valiela, I., S. Vince, and J.M. Teal, "Assimilation of Sewage by Wetlands," in Estuarine Processes, Vol. I, edited by M. Wiley, Academic Press, 234-253, 1976.

Watson, J.T., Diodato, F.D., and Launch, M., *Design and Performance of the Artificial Wetlands Wastewater Treatment Plant at Iselin*, Pennsylvania, pp. 263-271 In: *Aquatic Plants for Water Treatment and Resource Recovery*, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc., 1987.

Wile, I., Palmateer, G. and G. Miller, Use of Artificial Wetlands for Wastewater Treatment, pp. 255-271 in: Proceedings of the Midwest Conference on Wetland Values and Management, Richardson, B. (ed), St. Paul Minn. June 1981.

Williams, T.C. and Sutherland, J.C., Engineering, Energy and Effectiveness. Features of Michigan Wetland Tertiary Wastewater Treatment Systems, pp. 141-173 in: Bastian, R.K. and Reed, S.C. (1979) Aquaculture Systems for Wastewater Treatment: Seminar proceedings and Engineering Assessment EPA 430/9-80-006.

Wolverton, B.C., Aquatic Plants for Wastewater Treatment: An Overview, pp. 3-15 in: Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc. 1987.

Wolverton, B.C., Artificial Marshes for Wastewater Treatment, pp. 141-152 in: Aquatic Plants for Water Treatment and Resource Recovery, K.R. Reddy and W.H. Smith (eds), Magnolia Publishing Inc. 1987.

Zolteck, J., Bayler, S.E., Herman, A.J., Tortora, L.R., Dolan, T.J., Graetz, D.A. and Erickson, N.L, Removal of Nutrients from Treated Municipal Wastewater by Freshwater Marshes Final Report to City of Clermont. Florida Centre for Wetlands, University of Florida, 1979, 325 pp.

APPENDIX 'B'

WILDLIFE HABITAT

The following sections describe the anticipated habitats in each of the three pond-wetland system concepts, and provide some recommendations on how they can be managed to provide maximum benefits to fish and wildlife.

Treatment Ponds for PO4

These ponds and wetlands will have stable water levels and as a consequence, stable vegetation. They will be 3-4 ft deep overall, and include alternating areas of open water and emergent wetlands. If possible, the bottom contours should be somewhat variable to create different depths which would be colonized by different wetland emergent plants. For example, deeper areas would likely support bulrush while shallower areas would have stands of cattails, burr-reed, and wapato. This would increase habitat complexity for wildlife. Islands would be desirable for nesting by waterfowl and waterbirds. Shoreline vegetation should include trees and shrubs to provide additional habitat diversity and cover for wildlife. An approximate 50:50 ratio of open water:emergent vegetation is optimal for waterfowl breeding use. These ponds may have nutrient loads and vegetation that produce levels of Dissolved Oxygen too low to be tolerated by most fish species.

Stormwater Treatment Ponds

These ponds will also be about 3-4 ft deep, and be variable in depth over time. They are likely to be full for much of the winter months and possibly dry during the late summer and early fall. This type of hydrological regime will probably create a different vegetative community of wetland species more tolerant of seasonal inundation and drying. Shoreline trees and shrubs would also provide additional habitat diversity for wildlife. Providing some areas of gently sloping shoreline for mudflat development would attract shorebirds and other waterbirds. These areas could provide seasonal habitat for fish.

Dilution Water Storage Ponds

These ponds will be 6-7 ft deep, will be filled during winter floods, and gradually drawn down during the summer months. Owing to the draw downs and greater depth, these areas will also probably support different vegetation from the above two types of ponds. These ponds will provide good habitat for warmwater game fish. These ponds are likely to be the focus of potentially active recreational activities such as boating and/or fishing. Shoreline vegetation of trees and shrubs should also be provided here. Variable bottom contours could create pools as fish refugia during low water periods, and mudflat areas to attract shorebirds during late summer and fall.

If islands are possible, they would provide night roosting areas and potential nesting areas for waterfowl and waterbirds. Nesting islands should only be constructed if they are certain to remain protected by water during the nesting season, rather than drying out and being accessible to land predators such as raccoons and coyotes.

General Recommendations and Comments

The following general recommendations are offered that would be applicable throughout the Jackson Bottom area.

1. It may be necessary to trap nutria and/or beaver to give newly planted herbaceous and woody vegetation a chance to become established.
2. Place a number of nest boxes of different sizes in existing wooded areas and in newly planted areas as they are established. These should range from swallow boxes to kestrel boxes to wood duck/merganser size to larger ones suitable for owls.
3. A walking trail or trails could include a footbridge spanning one or more ponded areas, and the underside of the bridge could be designed to be suitable for use by nesting swallows and/or bats, to control mosquitos.
4. Establish mosquitofish populations and/or other small fish in all ponds to aid in controlling mosquitos. These fish will also attract kingfishers, mergansers, grebes, etc.
5. Construct one or more observation blinds providing viewing of ponds designated as secluded rather than open to unrestricted human disturbance.
6. Mow reed canary grass areas adjacent to shrub and tree plantings to aid in controlling vole populations (shorter mowed grass makes the voles more vulnerable to predation by owls, coyotes, crows, great blue herons). Strips or islands of unmowed grass could be left to provide some cover for mice and nesting birds. The new green shoots in mowed areas may be palatable to geese and ducks. Trial plantings of bentgrass in moist areas would also attract geese and ducks. If possible, occasional burning would remove excess thatch from reed canary grass areas.
7. Encourage local high-school or college biology classes to trap voles in shrub and tree establishment areas. These voles might be usable as food for raptors at the Audubon Society's wildlife rehabilitation center, or the zoo, for example.
8. Establish at least one forest area that is secluded enough to provide potential heron rookery habitat. The best area would be a fairly large block of forest within a river oxbow.

9. Include some fast-growing hybrid poplars in the tree-shrub planting areas to provide larger trees quickly. If these fast-maturing trees are similar to cottonwoods, they will also provide cavities and dead branches for wildlife use much more rapidly than the slower-growing ash, alder, and oaks.
10. Plant a diversity of wetland plants to enhance wildlife habitat: cattail, bulrush, burr-reed, wapato, willow, spiraea, sedge, wild millet (Polygonum), pond lily, sago pondweed and other pondweeds.
11. If fish populations are sufficiently large in the area, place an osprey nesting platform along the Tualatin River.

REFERENCES

- Murase Associates. 1988. Regional Parks Study. Prepared for Metropolitan Service District. in prep.
- Oregon Department of Fish and Wildlife (ODFW). 1987. Tualatin River Basin Fish and Water Quality. 15 p. mimeo report.
- Taitt, M.J., J.H.W. Gipps, C.J. Krebs, and Z. Dundjerski. 1981. The effect of extra food and cover on declining populations of Microtus townsendi. Can. J. Zool. 59: 1593-1599.
- Taitt, M.J. and C.J. Krebs. 1981. The effect of extra food on small rodent populations: II. Voles (Microtus townsendi). J. Animal Ecol. 50: 125-137.
- Taitt, M.J. and C.J. Krebs. 1983. Predation, cover, and food manipulations during a spring decline of Microtus townsendi. J. Animal Ecol. 52: 837-848.

JACKSON BOTTOM WILDLIFE LIST - 1988

BIRDS

Grebes

Western Grebe
Pied-billed Grebe

Bitterns, Herons and Egrets

American Bittern
Green Heron
Great Blue Heron
Common Egret

Waterfowl

Tundra Swan (Whistling)
Snow Goose
Canada Goose
Cackling Goose
Wood Duck (nests locally)
Blue-winged Teal
Cinnamon Teal (nests locally)
Mallard (nests locally)
Pintail
Northern Shoveler
Gadwall
American Widgeon
Canvasback
Ring-necked Duck
Lesser Scaup
Common Goldeneye
Buffle Head
Common Merganser
Hooded Merganser
Ruddy Duck

Vultures

Turkey Vulture

Osprey, Kites, Eagles and Hawks

Osprey
Bald Eagle
Northern Harrier
Sharp-shinned Hawk
Rough-legged Hawk
Red-tailed Hawk
Cooper's Hawk

Falcons

American Kestrel
Peregrine Falcon

Gallinaceous Birds
Ring-necked Pheasant
California Quail

Rails
Virginia Rail

Plovers
Black-bellied Plover
Killdeer

Shorebirds
Solitary Sandpiper
Spotted Sandpiper
Least Sandpiper
Yellowlegs
Sanderling
Long-billed Dowitcher
Common Snipe
Northern Phalarope

Gulls
California Gull
Ring-billed Gull

Doves
Mourning Dove
Band-tailed Pigeon

Owls
Great Horned Owl
Screech Owl

Goatsuckers
Common Nighthawk

Hummingbirds
Rufous Hummingbird

Kingfishers
Belted Kingfisher

Woodpeckers
Northern Flicker
Yellow-bellied Sapsucker
Downy Woodpecker

Flycatchers
Olive-sided Flycatcher
Traill's Flycatcher
Western Flycatcher
Western Wood-Pewee

Larks

Horned Lark

Swallows

Cliff Swallow
Violet-green Swallow
Tree Swallow
Barn Swallow
Rough-winged Swallow

Jays and Crows

Steller's Jay
Scrub Jay
Common Crow

Chickadees, Bushtits and Nuthatches

Black-capped Chickadee
Chestnut-breasted Chickadee
Common Bushtit
Red-breasted Nuthatch
White-breasted Nuthatch

Wrens

Winter Wren
Bewick's Wren
House Wren

Thrushes

Varied Thrush
Swainson's Thrush
American Robin
Ruby-crowned Kinglet
Golden-crowned Kinglet

Waxwings

Cedar Waxwing

Starlings

Starling

Vireos

Warbling Vireo

Warblers

Yellow Warbler
Black-throated Warbler
Mac Gillivray's Warbler
Orange-crowned Warbler
Yellow-rumped Warbler
Common Yellowthroat

Grosbeaks and Buntings

Black-headed Grosbeak
Evening Grosbeak
Lazuli Bunting

Towhees and Sparrows
Rufous-sided Towhee
House Sparrow
Chipping Sparrow
White-crowned Sparrow
Golden-crowned Sparrow
Song Sparrow
Fox Sparrow

Blackbirds, Meadowlarks and Orioles
Red-winged Blackbird
Western Meadowlark
Brown-headed Cowbird

Finches
Purple Finch
House Finch
American Goldfinch

MAMMALS

Chickoree
California Ground Squirrel
Raccoon
Shrew
Deer Mouse
House Mouse
Townsend's Vole
Striped Skunk
Nutria
Virginia Opossum
Brush Rabbit
Little Brown Bat
Muskrat
Mink
Weasel
Black-tailed Deer
Coyote
Red Fox
Pocket Gopher
Gray Fox

REPTILES

Alligator Lizard
Rubber Snake
Garter Snake
Western Painted Turtle

AMPHIBIANS

Rough Skinned Newt
Salamander
Western Toad
Red-legged Frog
Tailed Frog
Pacific Tree Frog
Bullfrog

FISH

Coho Salmon
Fall Chinook (occasional)
Winter Steelhead
Cutthroat Trout
Rainbow Trout
Largemouth Bass
Warmouth Bass (rare)
Bluegill
Crappie
Brown Bullhead
Carp
Redside Shiner
Northern Squawfish
Cottid
Dace
Pacific Lamprey
Pumpkinseed (rare)
Channel Catfish (rare)