Putrajaya Wetlands is the first man-made wetlands in Malaysia, and one of the largest constructed freshwater wetlands in the tropics

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The construction of Putrajaya Wetlands has attracted several species of migratory birds such as cattle egrets (above) to the area

FOREWORD

from the President of Perbadanan Putrajaya

The setting up of Putrajaya, Malaysia's new Federal Government Administrative Centre, is another milestone in the development of Malaysia as an independent and sovereign nation. Putrajaya is being developed as an intelligent city and a city in a garden.

Central to this concept of the city in a garden is the 600 hectare man-made lake created by the damming of Sungai Chuau and Sungai Bisa. The resulting Putrajaya Lake forms the centrepiece of the new city giving it a distinctive character and identity.

In order to ensure that the water entering the lake would remain clean and suitable for body contact recreational activities, the Perbadanan took great pains to institute various measures to achieve the required water quality standard. Towards this end, the Perbadanan adopted the environmentally-friendly approach of constructing a series of wetlands to treat the water before it enters the lake. This is the first such project undertaken in Malaysia. We look on this project as an innovative attempt to harness nature and the eco-system to develop an attractive and viable lake.

The wetlands covers an area of 197 hectares and was built in a record time of seventeen and a half months.

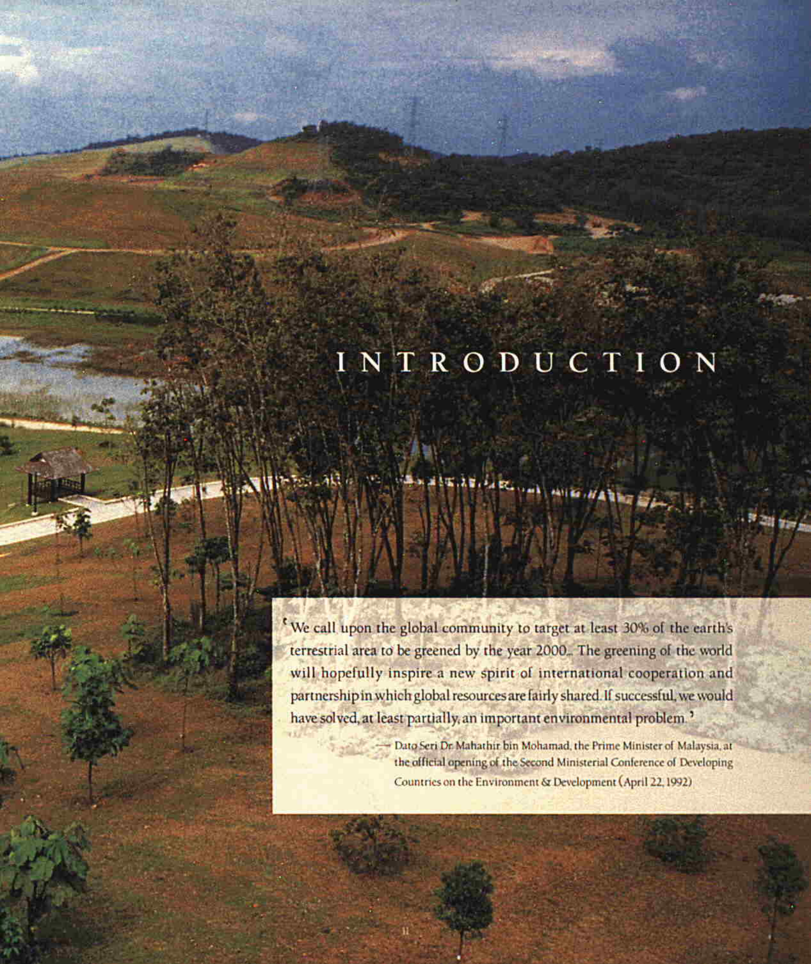
This achievement is all the more meaningful for us as it is the product of Malaysian scientists in various disciplines working together to provide an acceptable solution to meet the need for a system to keep the lake water clean. I take this opportunity to extend my heartiest congratulations to the parties involved.

The Perbadanan is ever conscious that the wetlands need to be closely monitored and managed. A comprehensive programme has been drawn up for this purpose. The success of the wetlands and their ability to fulfil their functions depend on the cooperation and concerted efforts of all concerned, including the general public. Together we can make the wetlands serve as a retreat and the means to interact with and enjoy nature.

Tan Sri Datuk Seri Azizan Zainul Abidin
President, Perbadanan Putrajaya

Taman Wetland, which overlooks Putrajaya Wetlands, is designed for public use and exposure to the wetlands environment

C O N T E N T S



INTRODUCTION

'We call upon the global community to target at least 30% of the earth's terrestrial area to be greened by the year 2000... The greening of the world will hopefully inspire a new spirit of international cooperation and partnership in which global resources are fairly shared. If successful, we would have solved, at least partially, an important environmental problem.'

— Dato Seri Dr. Mahathir bin Mohamad, the Prime Minister of Malaysia, at the official opening of the Second Ministerial Conference of Developing Countries on the Environment & Development (April 22, 1992)

Almost 40% of Putrajaya is designated as "green area"

Chapter 1

PUTRAJAYA
The Model of Sustainable Development

Putrajaya is a city planned and built to meet the challenges of the new millennium. It is A City In A Garden that turns to nature for inspiration, resulting in a landscape dominated by the picturesque Putrajaya Lake. A high standard of lake water quality is one of the most important factors for the success of this scenic centrepiece, and the solution was found in simulating yet another gift of nature — with the construction of Putrajaya Wetlands.

Background

Malaysia's new Federal Government Administrative Centre of Putrajaya is not just a new city. It also represents the coming-of-age of Malaysia as a dynamic and progressive member of the global community committed to the concept of sustainable development.

The development of Putrajaya is firmly grounded on reconciling opposite concepts: between constructed endeavours and the natural environment; economic/social needs and ecological/spiritual needs of the nation; conserving tradition and pursuing high technology. This holistic approach is clearly reflected in the duality of the project theme: A City In A Garden, An Intelligent City.

The country's largest urban development project sets out to be the model city of sustainable development. The objectives for the development of Putrajaya are:

- to build a well-planned modern city based on the concept of sustainable development;
- to build a city that reflects the rich cultural and natural heritage of the country;
- to develop a federal government administrative centre with the capacity and amenities to meet the challenges of the next millennium;
- to develop a conducive residential, commercial and recreational environment where people can enjoy a high quality of life;
- to showcase Malaysia's expertise in the management, planning, design, construction and maintenance of a large scale urban development project;
- to use predominantly local resources and materials in the development of Putrajaya.

Built 39 years after Malaysia achieved independence, the development of Putrajaya is phased over 15 years, beginning 1996. The city is named after the country's first prime minister, Tunku Abdul Rahman Putra Al-Haj.

The idea of relocating the federal government administration to another area outside of Kuala Lumpur dates back to the late 1970s. There had been much discussion since then, with the relocation impulse gaining momentum in the early nineties. There were two reasons for this:

- There was increasing pressure on the resources of the federal capital of Kuala Lumpur, which also serves as the country's principal commercial and financial centre. The rapid growth of the capital city had imposed a severe strain on infrastructure, housing and other urban amenities. This resulted in spiralling real estate prices. The move was thus viewed as a cost-saving strategy.
- By centralising the federal administrative function in one location, the government sought to provide a more conducive and integrated working environment.

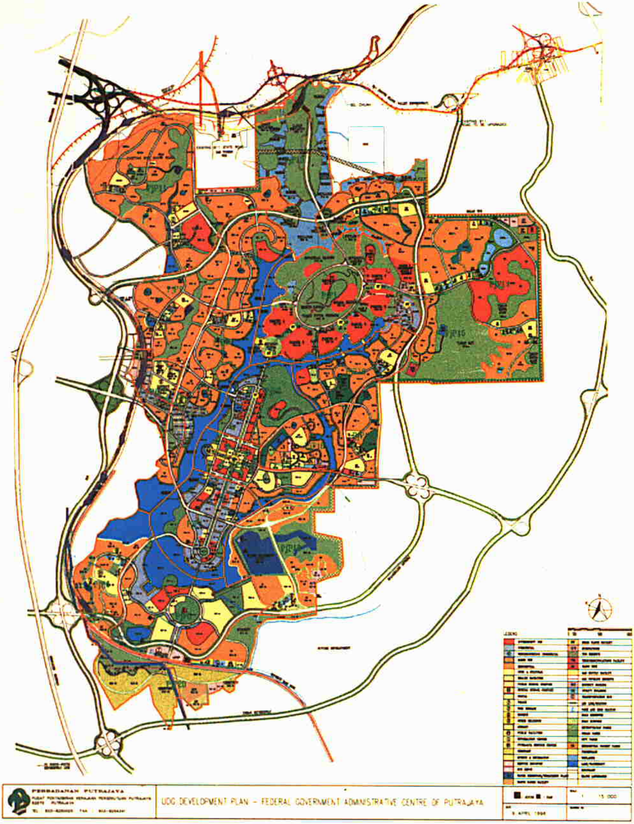
Site Selection

Several sites were proposed including Janda Baik in Pahang, but eventually the government decided on a 4,581-hectare oil palm plantation site in Prang Besar, Selangor. Key considerations for site selection were the availability of a large green field site that could sustain long term urban development and the relative proximity to the federal capital and other major developments. Prang Besar is located in the centre of the Multimedia Super Corridor (MSC) which contains other synergistic infrastructural developments undertaken in the 1990s, which include KL International Airport and Cyberjaya. The northern end of the MSC is anchored by the federal capital of Kuala Lumpur.

Prang Besar, in the district of Sepang, was thus identified as the strategic site for the federal government administrative centre.

The Prime Minister's office complex rises on a mound overlooking Putrajaya Lake

Putrajaya is located at the hub of the Multimedia Super Corridor, Malaysia's electronic superhighway



Putrajaya's masterplan details the land use of the city and its environs.
Note the generous allocation to the 'green area', a reflection of "A City in a Garden" concept.

The Masterplan

The masterplan for the development of Putrajaya covered the core area, peripheral residential areas and parklands. It incorporated a comprehensive set of policies and guidelines for land use planning, transportation systems, utilities and infrastructure, residential areas, public amenities, information technology, parks, gardens and landscaped areas for an estimated 330,000 residents.

The area has been divided into 20 precincts, with five main precincts : government, mixed development, civic & cultural, commercial and sports & recreational. The remaining area was designated for residential development.

The city is to be developed in two phases over a period of 15 years. Phase One, which is scheduled for completion in the year 2000, involves the construction of government offices, commercial offices, residential units, public amenities (parks, main transport terminals), Putra Mosque, the Promenade and Putrajaya Lake. Phase Two is scheduled for completion in 2010.

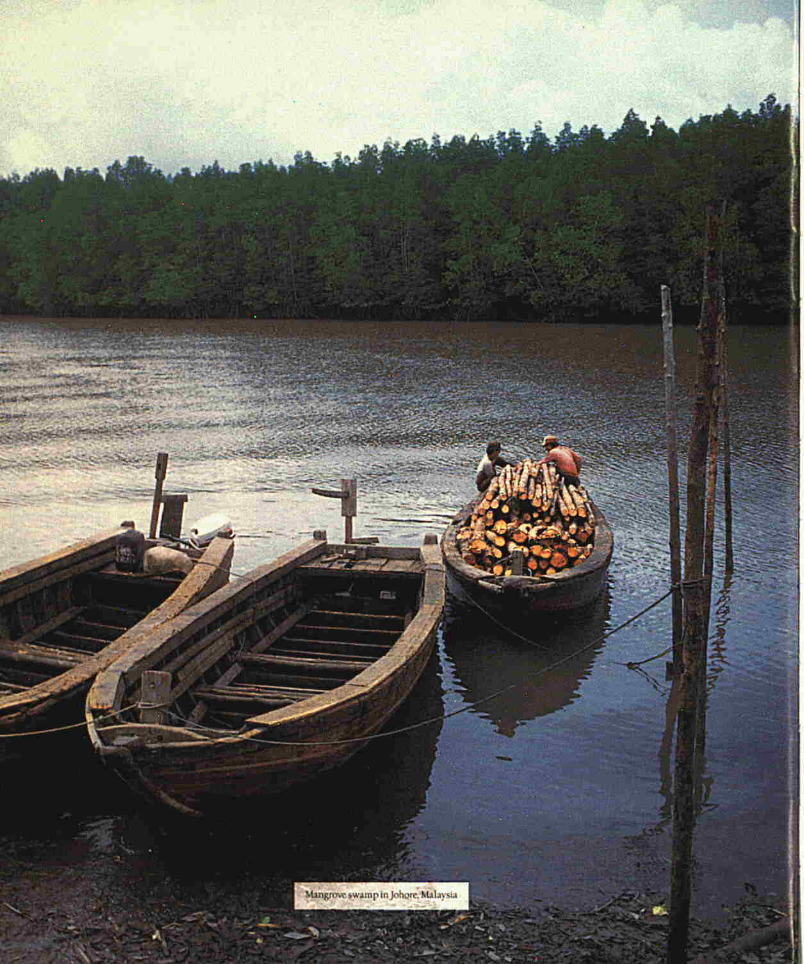
A critical component of the project is Putrajaya Lake, which is located in the heart of the city. The quality of the lake water is of paramount importance to the development of Putrajaya. To achieve a high standard of lake water quality, the masterplan proposed the construction of wetlands to remove pollutants and cleanse catchment run-off before it enters the lake.

PUTRAJAYA FACT FILE

Name	Putrajaya, the Federal Government Administrative Centre	
Location	25 km south of Kuala Lumpur, 20 km north of Kuala Lumpur International Airport (KLIA)	
Population	330,000 people	
Total Acreage	4,581 hectares	
Land Use (%)	Government	5.3%
	Commercial	2.9%
	Residential	25.8%
	Civic & Cultural	0.2%
	Public Facilities	10.1%
	Utility & Infrastructure	18.2%
	Green Area	37.5%
Development Components	Core Area	1,069.1 ha
	Government Precinct	*236.2 ha*
	Mixed Development Precinct	*155.2 ha*
	Civic & Cultural Precinct	*135.3 ha*
	Commercial Precinct	*213.3 ha*
	Sports & Recreational	*329.1 ha*
	Water Bodies, Wetlands & Lake	585.6 ha
	Periphery Area	2,925.3 ha
	Putrajaya Boulevard	100 m wide and 4.2 km long
Transportation Systems	Intra city — light rail transit, taxi, buses Inter city — Express Rail Link, North-South Link KL-Putrajaya-KLIA dedicated highway KL-Seremban Highway	
Phases of Development	Phase 1 : 1996 - 2000	Phase 2 : 2000 - 2010
Implementation	**Statutory Authority : Perbadanan Putrajaya** It was incorporated on March 1, 1996 under the Perbadanan Putrajaya Act as the body corporate to administer and manage Putrajaya. As local planning authority, Perbadanan Putrajaya is responsible for formulating and implementing planning and development control policies and urban design guidelines to fulfil the vision and objectives of Putrajaya. **Developer : Putrajaya Holdings Sdn Bhd** Putrajaya Holdings Sdn Bhd is the company entrusted to develop the Putrajaya project. Incorporated on October 19, 1995, its shareholders are Petroliam Nasional Berhad (PETRONAS), the national petroleum company, Khazanah Nasional Berhad, the government investment arm, and Kumpulan Wang Amanah Negara, the national trust fund group.	

THE IMPORTANCE OF WETLANDS

Increasing research and knowledge of the role of natural wetlands in controlling water pollution have led to the trend to construct wetlands that replicate the environmentally-friendly benefits of this unique ecosystem.



Mangrove swamp in Johore, Malaysia

Chapter 2

THE IMPORTANCE OF WETLANDS

Natural wetlands have been found to be a source of inspiration in modern urban planning. As a result, there is a trend to construct wetlands in built-up areas for water resource management.

Definition

Wetlands are defined by the Convention of Wetlands of International Importance (the Ramsar Convention 1971) as "Land inundated with temporary or permanent water that is usually slow moving or stationary, shallow, either fresh, brackish or saline, where the inundation determines the type and productivity of soils and the plant and animal communities".

Natural wetlands

Essentially wetlands are transitional areas between terrestrial environments and deep water aquatic systems. They are open systems, strongly influenced by external forces such as precipitation, solar radiation, energy and nutrient inputs and surface and ground water flows.

One factor that governs the ecology of wetlands is its relationship with other adjoining ecosystems, that is, its place in the total regional landscape. As a result, a high diversity of habitats is possible in these transitional environments, from mangrove and salt marsh swamps to estuarine lakes and inland floodplain lakes.

Unlike other habitats, wetlands are dynamic, transitional and dependent upon natural disturbances. The most significant and visible disturbance is periodic flooding and drying. Both states are important for the maintenance of wetland health and functionality. Changing water depths strongly influence the composition of plant species and breeding cycles of some waterbirds, fish and animal species.

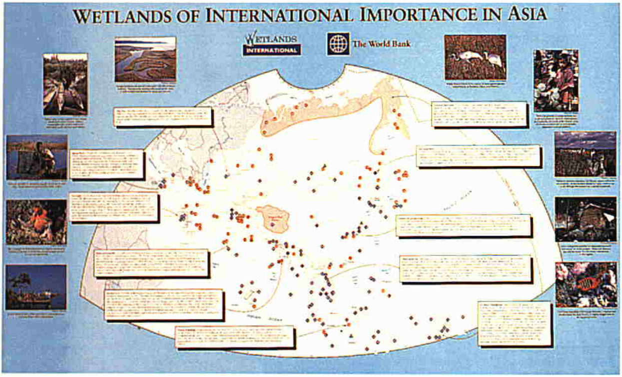
The most well-documented role of natural wetlands is its biodiversity, which includes not only diversity within species but also between species and of ecosystems.

Constructed wetlands

The role of wetlands in water resource management is fast gaining ground resulting in the construction of wetlands in many developed countries. Constructed wetlands are man-made systems that involve altering the existing terrain to simulate wetland conditions. They primarily attempt to replicate the treatment that has been observed to occur when polluted water enters natural wetlands. These wetlands have been seen to purify water by removing organic compounds and oxidising ammonia, reducing nitrates and removing phosphorus. The mechanisms are complex and involve bacterial oxidation, filtration, sedimentation and chemical precipitation.

Most constructed wetlands attempt to imitate the ecosystem's biochemical function as filtration and cleansing agents, followed closely by the hydrological function that is centred on flood mitigation.

The biological biodiversity and ecological complexity of wetlands have led to extensive scientific research



Biochemical Function

The use of constructed wetlands to treat urban waste water and remove nutrients from diverse sources in rural catchments has received much attention lately. Industrial waste water, landfill leachate and effluents from agricultural industries can be treated through wetland systems. An American study of riparian wetlands showed that up to 90% of sediment, 89% of total nitrogen and 80% of total phosphorus were removed from in-flowing water (*Keunzler, 1989*). Not all wetlands, however, perform as well as there is considerable variability in their performance depending on the type of contaminant and circumstances at the time of measurement.

Thus, wetlands are essentially the filtering area, the 'kidneys' of the catchment, intercepting water flow, trapping sediment and pollutants, removing toxic substances (pesticides, herbicides, metals) and assimilating nutrients and energy derived from the upstream catchment area.

Sediment is often the major water pollutant in many river streams. It has a strong tendency to absorb nutrients, pesticides, heavy metals and other toxins such as chlorinated and petroleum hydrocarbons (*Williams, 1990*). The natural function of wetlands as sediment sinks (by the slowing of water flow and entrapment by vegetation) is very important. Toxic residues from pesticides and herbicides as well as heavy metals from water can be removed in the wetlands by cation exchange and absorption by organic and clay sediment and plant uptake.

The cleansing agents here are plants. Different plants absorb different pollutants and at varying intensities. Species selection thus determines the success level of the wetlands.

The capacity of the wetlands to perform this function is also contingent upon the overall health and distribution of the wetlands. As a result the design and maintenance of the wetlands and their relationship with the surrounding areas are critical.

A spin-off benefit of the bio-chemical function is the trapping of carbon, sulphur and metallic ions in the long term storage reservoir. By eliminating the impact of these greenhouse gases on the atmosphere, wetlands are beneficial to the microclimate of the area.

Glimpses of Malaysia's Mangroves IPT - Asian Wetland Bureau

Local communities have for centuries depended on mangrove swamps for timber, fuel, food, medicinal herbs and other forest products

Hydrological Function

It is generally accepted that wetlands have the potential to attenuate flooding *(eg Carter et alia, 1978; Pressey, 1986; Gippel, 1992)*. Wetlands provide retention storage for storm water by spreading the water over a wide flat area. The effect is to de-synchronise tributary and main channel flood peaks, decrease the velocity of storm flow and attenuate the flood peak *(Gippel, 1992)*. This is particularly so in wetlands and lakes with restricted outflows. Wetland vegetation retards surface water flow to varying extents depending on the type, density and water depth *(Carter et alia, 1978)*.

The importance of this function will vary with wetland type and location in the catchment. Generally, the percentage of flow is related to the percentage of wetlands or lakes in a catchment.

Ecological Function

Wetlands have often been cited as being among the most productive ecosystems in the world. Their ability to filter nutrients from inflowing waters is the key to understanding this function. These nutrients represent the base of many food chains that not only start and finish within the wetlands but extend beyond the wetlands complex itself.

Where there is food there is life, and hence wetlands act as breeding grounds, nurseries and homes to numerous plants, invertebrates, frogs, reptiles, fish and waterbirds. In fact, wetlands are best known as habitats for fish and waterbirds.

Social and Recreational Functions

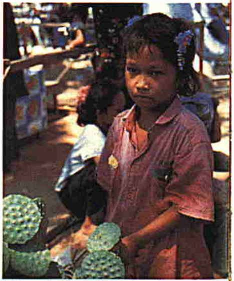
Wetlands are becoming increasingly popular as ecotourist destinations. Their biodiversity, open space, aesthetics and the development of public amenities make them attractive propositions for recreational activities and social pursuits.

The public, however, must be mindful of the fact that wetlands are fragile ecosystems and should be treated with care.

Several native communities rely on peat swamp forests for their food, medicine, fuel and timber

Glimpses of Malaysia's Mangroves, JPT · Asian Wetland Bureau

Ecotourism in Pulau Langkawi



In Kampuchea, the seeds of the sacred lotus *(Belumbo nucifera)* are an economically important wetland food product

Education and Research Functions

Wetlands are a fertile ground for scientific study and research. In fact, there is also a growing interest in wetlands among school children who are beginning to embark on a voyage of discovery of their environment by being introduced to this dynamic ecosystem. This may well be the first step in public education of wetlands, which are the collective responsibility of all users.

Meanwhile, there is a trend to establish partnerships between educational institutions, universities and the wetland management to undertake scientific research into this complex ecosystem.

Geomorphological Function

Many natural wetlands play a prominent role in protecting the coast from premature weathering by storms, winds and tides. Wetland vegetation also helps protect soil erosion and stabilise the land. Extensive landscaping efforts in constructed wetlands retard soil erosion in undulating areas while plantings in the Zone of Intermittent Inundation, particularly of creepers, have helped stabilise the slopes.

The above functions are all played out in varying degrees of intensity in Putrajaya Wetlands, with the bio-chemical function of cleansing and filtering catchment water superseding all other functions. It is the singlemost reason for the existence of Putrajaya Wetlands, the life support system of Putrajaya Lake.

An Overview of the World's Ramsar Sites. Wetlands International.

Waituna Lagoon, New Zealand is one of 770 wetlands designated as Ramsar sites that cover more than 52 million hectares across the world

SUMMARY OF THE FUNCTIONS OF WETLANDS

Biochemical

- net carbon sinks
- sediment trapping
- pollution trapping
- removal of toxic substances (eg heavy metals, radioactive isotopes, pesticides, herbicides)
- nutrient removal
- water processing
- net oxygen production
- geochemical storage (eg high storage of organic matter and carbon dioxide sink)
- biogeochemical cycle (many biogeochemical cycles are closed by reducing N, C, S, Fe etc in anaerobic muds)
- influence atmospheric and climatic fluctuations

Ecological

- habitats and nursery grounds for wildlife including commercial and recreational fisheries, bird rookeries and refuges for terrestrial animals, pests and predators
- gene banks for plant and animal species
- reference wetlands (also seed source for creation of new compensatory wetlands or purpose-built wetlands)
- maintenance of biodiversity
- wildlife corridors
- primary productivity and biomass production
- secondary productivity – export to adjacent ecosystems of organic foods (eg commercial and sports fisheries)

Hydrological

- flood mitigation
- storm and flood storage
- base flow and estuarine flow modification (eg prevention of intrusion of saline waters)
- recharging aquifers and groundwater storage and discharge

Social/Recreational/Education

- commercial use (eg timber, agriculture, fishing, peat extraction, solid waste disposal)
- recreational value
- open space and aesthetics
- scientific and research opportunities

Geomorphological

- erosion protection
- coastal protection from storms, tides and wind

Compiled from sources including Lugo and Brinson, 1978; James, 1991; Cox, 1993

The Thames Water Barnes reservoirs in the heart of London were transformed into a wetland nature reserve in an ambitious project spearheaded by Sir Peter Scott. Called the WWT Wetland Centre, it has been described as the most exciting and complex habitat creation project in Europe

THE PROJECT

Detailing the key elements of planning, design and construction that have reshaped the terrain to create a unique tropical freshwater wetlands habitat that reflects Putrajaya's Vision: "to create a self-sustaining and balanced ecosystem".

Chapter 3

GENERAL INFORMATION

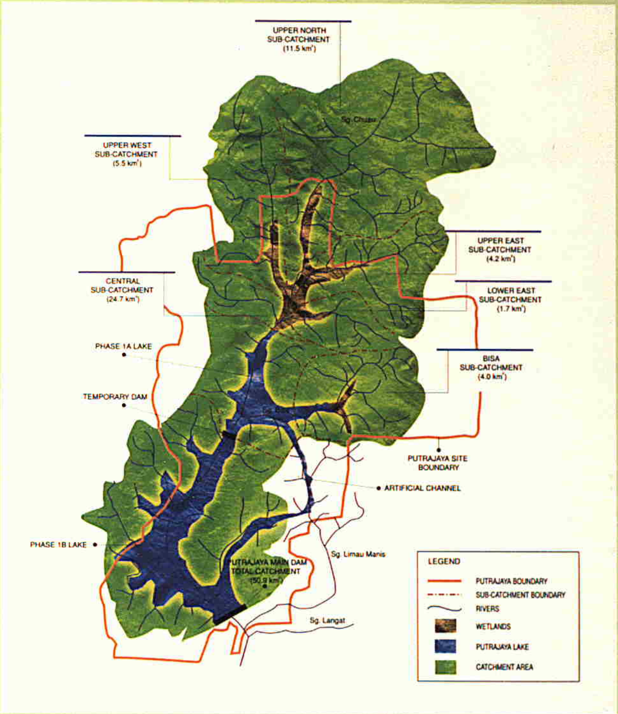
Putrajaya Wetlands was constructed by damming the upper reaches of Sungai Chuau. Its primary function is to treat 60% of catchment run-off before it enters the lake. The remaining run-off is filtered by gross pollutant traps and riparian parks. Together, they ensure that water entering the lake meets the Putrajaya Lake Water Quality Standard.

The humble Sungai Chuau and its tributaries help fill the lake, which has a storage capacity of 26.5 million cubic metres

Putrajaya Lake

The 400 hectare Putrajaya Lake was created by inundating the valleys of Sungai Chuau and Sungai Bisa. Construction was undertaken in two phases. The first phase of approximately 110 hectares involved the construction of a temporary dam across Sungai Chuau.

The dam was completed in May 1998 and the impoundment of the Phase 1A Lake commenced in September 1998 and was fully inundated in January 1999.



Putrajaya Lake and the Sungai Chuau catchment

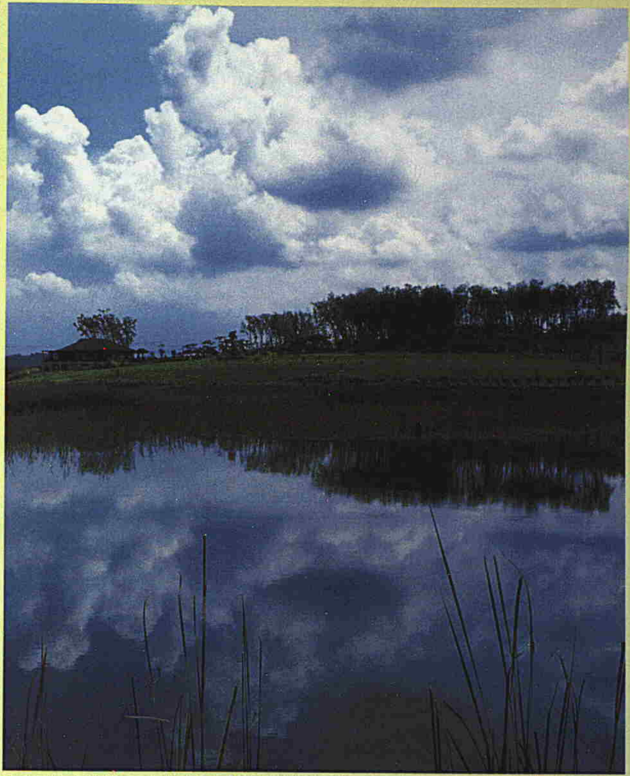
The 400 hectare Putrajaya Lake is one of the main tourist attractions

The lake has been primarily designed to enhance the aesthetic appeal of Putrajaya. It is also to be used for recreation and as a tourist attraction.

Studies of the Putrajaya catchment, however, showed that the water carried elevated levels of pollutants derived from upstream sources and outside of the Putrajaya development boundary. The quality of the major inflows was found to be below the standard set by Perbadanan Putrajaya.

Future development of the Sungai Chuau catchment is expected to increase run-off and pollutant concentration will either be maintained or increased.

This is expected to result in increased pollutant loadings in Sungai Chuau and Sungai Bisa which drain into Putrajaya Lake. As a result, the use of constructed wetlands as a natural treatment system was recommended to treat primary upstream inflow to the lake. The wetlands is to be complemented by riparian parks and gross pollutant traps.



Putrajaya Wetlands is the life support system of Putrajaya Lake. It is the filtration and cleansing system that makes the lake a viable recreational attraction

Putrajaya Wetlands

Putrajaya Wetlands is the first man-made wetlands in Malaysia and one of the largest fully constructed freshwater wetlands in the tropics. The 197 hectare project resulted in transforming an oil palm site into a wetland ecosystem with the help of modern technology and stringent environmental management methods in design and construction.

The wetlands straddle the water courses of Sungai Chuau, Sungai Bisa and three tributaries. Their primary function is to ensure that the water entering the lake meets the standard set by Perbadanan Putrajaya.

To achieve this, the wetlands have been planted with a variety of aquatic plants that act as a natural filtration system, removing nutrients and pollutants from the catchment water. They treat natural run-off from the 50.9 sq km Sungai Chuau catchment.

In addition to being a water cleansing and filtration system, the wetlands also help in flood mitigation, nature conservation, ecotourism, recreation, research and education and protection against soil erosion. Construction of Putrajaya Wetlands began in March 1997 and was completed in August 1998.

The maintenance of the environmental quality of the lake underpins the quality of life in Putrajaya. To achieve this, Putrajaya Wetlands was constructed to remove pollutants and cleanse water from the catchment before it enters the lake.

Principal Features of Putrajaya Lake

Catchment Area	Water Level	Surface Area	Storage Volume	Average Depth	Average Catchment Inflow	Average Retention Time
50.9 square kilometres	RL 21 metres	400 hectares	26.5 million cubic metres	6.6 metres	200 million litres per day	132 days

Principal Features of Putrajaya Wetlands (Area in hectares)

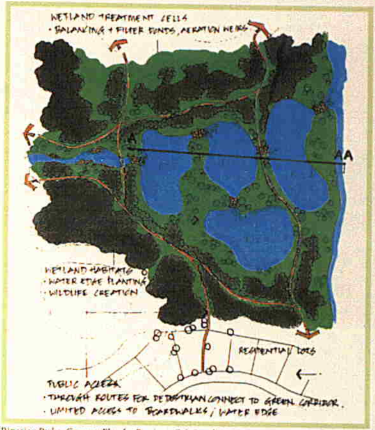
Total Area	Planted Area	Open Water	Weirs & Islands	Zone of Intermittent Inundation	Maintenance Tracks
197.2	77.7	76.8	9.6	23.7	9.4

Riparian Parks

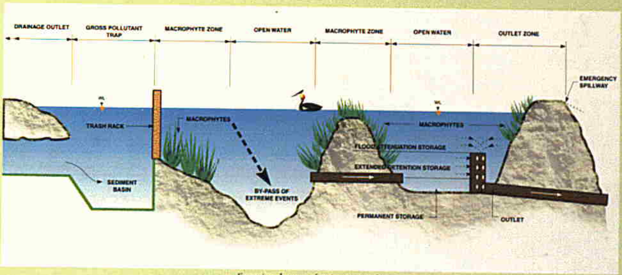
Riparian parks are located at the edge of Putrajaya Lake and downstream of major stormwater outlets. Their primary function is to complement the wetlands by cleansing surface run-off before it drains into the lake. They also act as balancing ponds preventing water from entering directly into the lake.

Gross Pollutant Traps

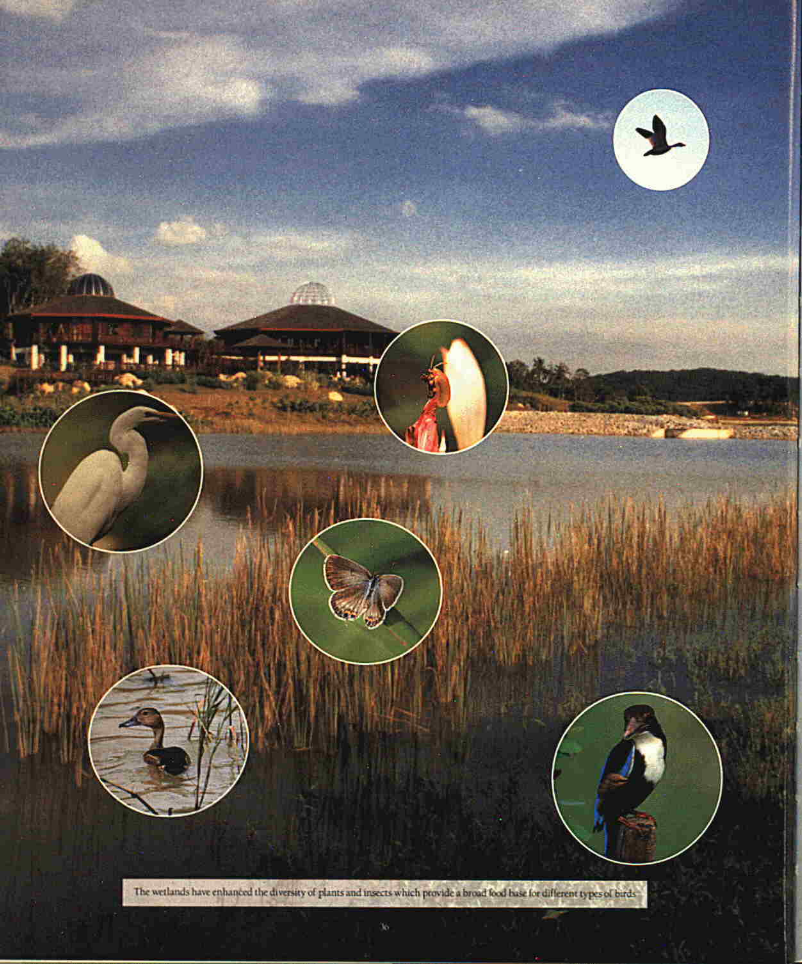
Gross pollutant traps for the removal of rubbish, debris and sediment have been constructed immediately downstream of the stormwater outlets. They are built in the outlets of wetland cells, especially those in the upper catchment.



Riparian Parks : Concept Plan for Precincts 7, 8, 9 and 10



Functional zones of a riparian park



The wetlands have enhanced the diversity of plants and insects which provide a broad food base for different types of birds

Chapter 4

FROM VISION TO COMMITMENT

Putrajaya Wetlands is a national statement of pride and commitment to the environment and the ingenuity of Malaysians to pioneer with projects that will enhance the quality of life in the country.

The Vision

One of many developments in Putrajaya, the wetlands share the city's vision :

"To create a self-sustaining and balanced ecosystem in Putrajaya".

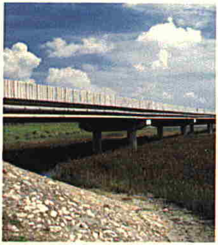
The Goals

Putrajaya Wetlands has a set of well-defined goals. They are:

- to construct a self-sustaining and balanced lake and tropical wetland ecosystem that is unique to this part of the world;
- to guarantee a high quality of lake water that complies with the standard set by the local authority and permits body contact recreation;
- to develop a natural habitat for public conservation of indigenous wetland flora and fauna;
- to establish an environment suitable for public education and scientific research on wetlands;
- to develop an aesthetically pleasant environment that enhances the quality of life in Putrajaya and makes the city an attractive destination for domestic and international tourism.

Plants of Putrajaya Wetlands

The large catchment has a high pollutant load, some derived from orchards upstream



Interfacing with other developments proved to be a tremendous challenge

Key Challenges

Challenge 1: Experience

Putrajaya Wetlands is the first constructed wetlands project ever undertaken in the country. There was, therefore, limited knowledge of this type of development available locally. To meet the challenges of the wetland project, an experienced team of consultants and contractors, comprising botanists, ecologists, engineers, environmental scientists, landscape architects and project managers was assembled. Innovative concepts, design and construction techniques were established to meet the desired goals of the project.

Challenge 2: Size and Interfacing

The sheer size of the wetlands and difficult construction conditions were overwhelming. This project was one of several in the development of Putrajaya, and the challenge of having to interface with other construction activities required strong project management skills.

Challenge 3: Time

As with the rest of Putrajaya, the development of the wetlands was a fast-track project. Having to build something that is altogether new to the country, on a large scale, together with other ongoing projects, and on record time posed an incredible strain on resources and manpower.

Challenge 4: Catchment Management

The task of design and construction had to take into account the high pollutant load from the large catchment area upstream of Putrajaya Lake. Furthermore, the pollutant loading rate is likely to accelerate as the catchment area continues to urbanise. The catchment extended beyond the boundary of Putrajaya territory and this required liaison and collaboration with other government and statutory authorities.

Challenge 5: Lake Design

Numerous inlets in the lake rendered the construction of the wetlands extremely difficult.

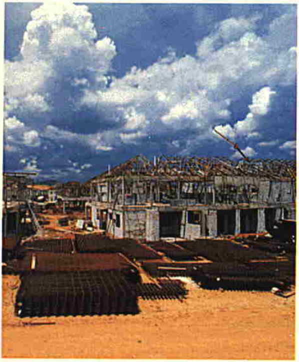
Putrajaya Wetlands is a project that had to overcome several challenges

The Strategies

Some constructed wetlands had not resolved these complex development issues, and consequently have not been able to function effectively. In an attempt to address these problems, Putrajaya Wetlands adopted the following strategies:

- The establishment of a comprehensive and integrated water quality management plan;
- The design of a strategic and innovative wetland layout to maximise flood detention and pollutant capture at critical stormwater outlets;
- The management of pollutant sources in the catchment for the control of wastewater and solid waste, chemicals such as fertilisers and pesticides, and erosion as a result of construction activities;
- The selection of plant species that have good pollutant removal ability and are adaptable to the Putrajaya site.

Construction debris is one of the pollutants that occurred during the development



The development strategy took into account the change in land use, from agricultural to urban

It was critical to select and propagate wetland plants that could adapt to the Putrajaya site

Wetland vegetation consists of indigenous species, which enhance the natural heritage of Putrajaya.

A clean and healthy lake suitable for recreational activities is the driving force behind the construction of Putrajaya Wetlands

PUTRAJAYA LAKE WATER QUALITY STANDARD

Putrajaya Wetlands is the cleansing agent of Putrajaya Lake, which must be kept clean and healthy for recreational activities. Its effectiveness as the "kidneys" of the lake is determined by the Putrajaya Lake Water Quality Standard.

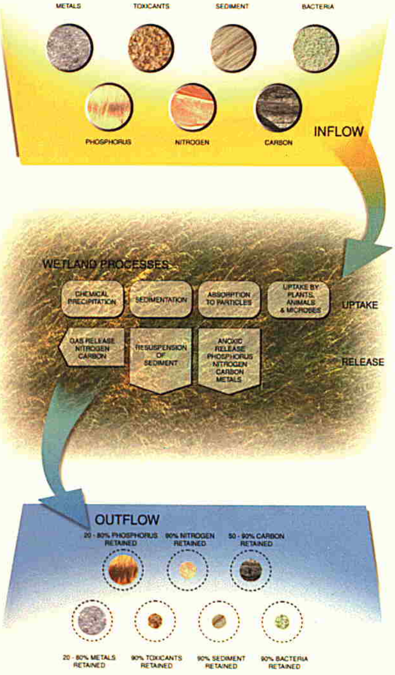
Water used for body contact activities such as swimming, bathing and other water sports should be sufficiently free from faecal contamination, pathogenic organisms and other hazards (eg poor visibility or toxic chemicals) to protect the health and safety of the users.

Physically stable, fresh and brackish water bodies receiving excessive amounts of nutrients (both nitrogen and phosphorus) are often found to have algae blooms. Eutrophication (i.e. high levels of phytoplankton growth) leads to serious deterioration of water quality, depletion of oxygen in bottom waters, significantly reducing the aesthetic appeal and reduction in other uses. Eutrophication problems in lakes and reservoirs typically occur when the concentration of total phosphorous (TP), total nitrogen (TN) range from 0.005 to 0.05 mg/l TP, 0.1 - 0.5 mg/l TN respectively and chlorophyll-a of 2-10 ug/l (ANZECC 1992).

Common management practice is to limit the concentration and loads of nitrogen and phosphorus entering a water body on the assumption that there is a direct causal relationship between these nutrients and phytoplankton biomass.

Perbadanan Putrajaya had thus drafted the Putrajaya Ambient Lake Water Quality Standard to control pollution. Table 5.1 (on page 46) summarises the water quality standard for recreational use.

Wetland vegetation filters and removes pollutants in the water



Pollutant capture in constructed wetlands

Fishing is permitted only during special events. This is part of the maintenance activity when an overpopulation of fish requires harvesting to be carried out

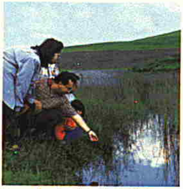
The visual clarity of the water enhances the aesthetic appeal of Putrajaya Lake

The table below shows the limit for the various types of pollutants in the Putrajaya Lake Water Quality Standard.

PUTRAJAYA AMBIENT LAKE WATER QUALITY STANDARD

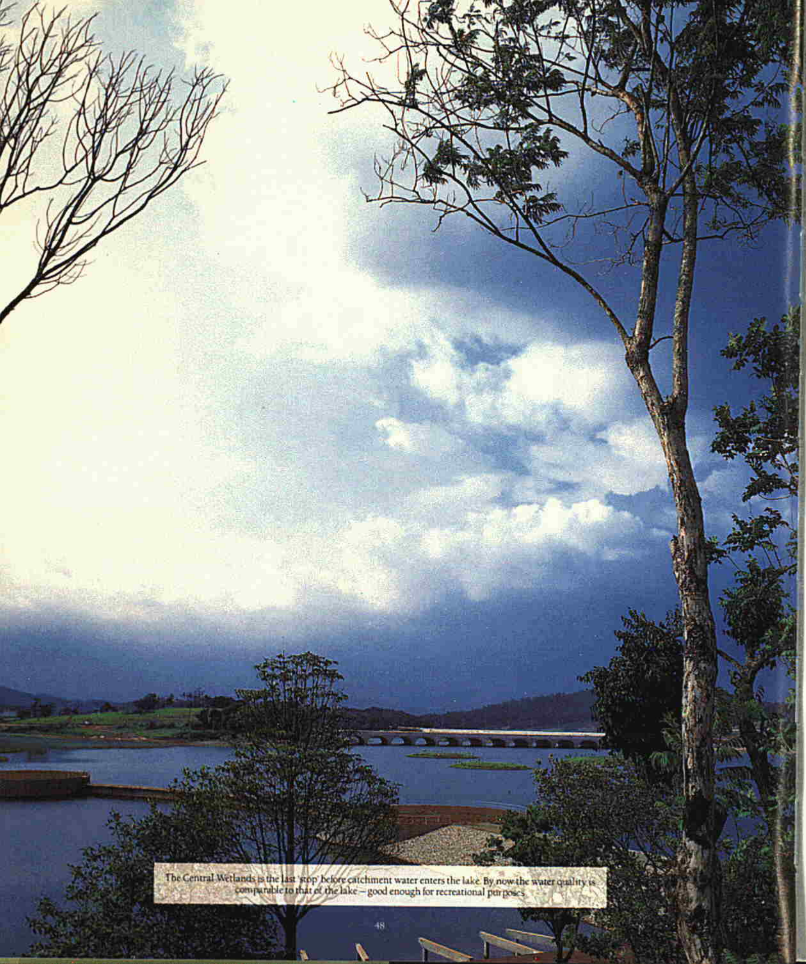
Lake Water Quality Parameter	Unit	Putrajaya Ambient Lake Water Quality Standard
Aluminium	mg/l	<0.05 if pH<6.5* <0.01 if pH>6.5
Ammoniacal Nitrogen	mg/l	0.3
Ammonia	mg/l	0.02 - 0.03
Arsenic	mg/l	0.05
Antimony	mg/l	0.03
Barium	mg/l	1
Beryllium	mg/l	0.004
Boron	mg/l	1
Cadmium	mg/l	0.002
Free Chlorine	mg/l	1.5
Total Chromium	mg/l	0.05
Copper	mg/l	0.02
Cyanide	mg/l	0.02
Fluorine	mg/l	1.5
Iron	mg/l	1
Lead	mg/l	0.05
Manganese	mg/l	0.1
Mercury	mg/l	0.0001
Nickel	mg/l	0.02
Nitrate (NO3-N)	mg/l	7
Nitrate (NO2-N)	mg/l	0.04
Total Phosphorus	mg/l	0.05
Silica	mg/l	50
Selenium	mg/l	0.01
Silver	mg/l	0.05
Sulphur	mg/l	0.05
Sulphate	mg/l	250
Zinc	mg/l	5
BOD	mg/l	3
COD	mg/l	25
Colour	TUC	150
Conductivity	US/cm	1000
Salinity	ppt	1
Total Suspended Solids	mg/l	50
Turbidity	NTU	50
Transparency (Secchi)	m	0.6
Hardness	mg/l	250
Taste		No Objectionable Taste
Dissolved Oxygen	mg/l	5 - 7
Odour		No Objectionable Odour
pH		6.5 - 9.0
Temperature	°C	Normal + 2
Oil & Grease	mg/l	1.5
Chlorophyll-a	mg/l	0.7
Floatables		No Visible Floatables
Microbiological Constituents		
Faecal Coliform	Count/100 ml	100
Total Coliform	Count/100 ml	5000
Salmonella	Count/l	0
Enteroviruses	PFU/l	0
Radioactivity		
Gross-alpha	Bq/l	0.1
Gross-beta	Bq/l	1
Radium-226	Bq/l	<0.1
Strontium-90	Bq/l	<1
Organics		
Carbon Chloroform Extract	mg/l	500
MBAS/BAS	mg/l	500
Oil & Grease (mineral)	mg/l	40; NF
Oil & Grease (emulsified edibles)	mg/l	7000; NF
PCB	mg/l	0.1
Phenol	mg/l	10
Aldrin/Dieldrin	mg/l	0.02
BHC	mg/l	2
Chlordane	mg/l	0.08
t-DDT	mg/l	0.1
Endosulfan	mg/l	10
Heptachlor/Epoxide	mg/l	0.05
Lindane	mg/l	2
2, 4-D	mg/l	70
2, 4, 5 - T	mg/l	10
2, 4, 5 - TP	mg/l	4
Paraquat	mg/l	10

Source: Putrajaya Lake Management Guide (1998)



A young family sights a shoal of fish in the wetlands

Only environmentally-friendly water-based activities are permitted on Putrajaya Lake



The Central Wetlands is the last 'stop' before catchment water enters the lake. By now the water quality is comparable to that of the lake – good enough for recreational purposes.

Chapter 6

THE DESIGN

The development of Putrajaya Wetlands involved extensive research into tropical freshwater wetlands for stormwater management. The adoption of the multi-cell, multi-stage design approach sought to overcome some of the problems faced by similar projects elsewhere, namely in flood detention during extreme flow conditions.

Current Practices

Current practices in the design of constructed wetlands for stormwater pollution control are generally based on design guidelines adapted from experience in wetlands used for the treatment of wastewater. In many cases, the wetlands used for treatment of urban run-off are inadequate due to the large fluctuation of hydraulic and pollutant loading rates.

The technology for the design and construction of artificial wetlands is a relatively new field and the techniques are still evolving. In the design of Putrajaya Wetlands, an extensive literature research was carried out to compile the latest local and international research findings on the design of man-made wetlands.

A constructed wetland system generally comprises a combination of vegetated area and open water. Ponds are open water bodies with fringing vegetation and submerged macrophytes while the vegetated or macrophyte zones (often referred to as the wetlands) often consist of shallow permanent pools with extensive emergent macrophytes. The function of wetlands is to trap pollutants attached to fine suspended particles by enhanced sedimentation and filtration. The main function of the open water zone, on the other hand, is to facilitate the sedimentation of coarse materials and to enhance water disinfection through ultra violet radiation.

A combination of wetland morphology, available storage, hydrologic and hydraulic controls, and wetland vegetation layout determine the overall performance of the wetlands. The proportion of open water area to the macrophyte zone will vary depending on the nature of the inflow, particularly the suspended sediment particle size distribution. The storage volume of the wetland system is a key design parameter which, in combination with the hydrologic control, defines the detention period of stormwater in wetlands and the percentage of overall run-off volume treated by the wetlands. Wetland morphology and vegetation layout promote the appropriate flow pattern within wetlands so that the various treatment processes can be optimised.

Design Criteria

Putrajaya Wetlands' design criteria is based on the following parameters:

- to meet the minimum lake design standards for phosphorus (0.05 mg/l), nitrogen (0.5 gm/l), suspended solids (50 mg/l) and bacteria (400 counts/100 ml)
- to achieve maximum flow routing through macrophyte areas
- to stabilise sediment deposition areas from wind, wave or current resuspension through:
  - sufficient water depth (sediment basins only)
  - physical barriers (energy dissipaters, protective berms)
  - sufficient density of macrophyte planting
- to minimise potential for deoxygenation of surface sediment through:
  - minimising areas deeper than three metres
  - regularly maintaining sedimentation basins
  - providing *in situ* aeration devices
  - recirculating aerated water
  - providing stands by chemical treatment
- to incorporate flood detention capacity – not less than three days and not more than seven days to return to design water level after the peak of an Average Recurrent Interval (ARI) one year event
- to ensure integrity of all structures and bank areas – to withstand design flood without structural damage or significant change of vegetation
- to ensure no significant litter entering main wetland from 95% of flows
- to shape and landscape wetlands by integrating them with surrounding topography and parkland through:
  - wall structures contoured and planted with compatible trees, shrubs and ground cover
  - minimum practical lengths for walls and use of horizontal and vertical variations to soften structural lines
  - rock cascade features at level changes to improve oxygenation and provide landscape interest
  - varied subsurface topography and shape to encourage some diversity in macrophyte species and variation in vegetation height
  - soft edges with aquatic and semi-aquatic vegetation above and below the shoreline
- to plant indigenous wetland species
- to incorporate plantings of sub-aquatic species in ephemerally wet areas (generally within 1.5 m above the normal operating level)
- to ensure ease of maintenance:
  - access for sediment dredging equipment
  - access for weed removal and macrophyte harvesting
  - access for regular and contingency dredging
  - simple to maintain or automated litter and sediment traps
- to minimise mosquito potential
  - eliminate potentially stagnant areas
  - provide for fish movement across weirs
  - prevent build-up of sediment which may create isolated ponds
- to provide artificial habitats for fish refuge and breeding

Source: Putrajaya Lake Phase I Concept Design Report – Wetland Component 1996

The Design Strategy

Putrajaya Wetlands adopted the multi-cell and multi-stage design strategy. This approach would yield the following advantages:

- ensure better distribution of flow across the wetlands;
- maximise shallow areas required for the successful growth of macrophytes, the main agents in the filtration and cleansing function;
- permit cost-effective maintenance including the management of weeds and pests.

Low maintenance plant species have been favoured for the wetlands

The Multi-Cell Approach

The multi-cell layout is an innovative design comprising six defined wetland arms with a total of 24 cells. The cells are separated by weirs (or bunds), each 200 metres in width and two - three metres in height.

The names of the wetlands and cell annotations are as follows:

- Upper North Wetlands (Eight cells: UN1 to UN8)
- Upper West Wetlands (Eight cells: UW1 to UW8)
- Upper East Wetlands (Three cells: UE1 to UE3)
- Lower East Wetlands (Two cells: LE1 and LE2)
- Upper Bisa Wetlands (Two cells: UB1 and UB2)
- Central Wetlands (One cell: CW)

The masterplan site for 20 wetland cells was later enlarged for the system to function more effectively. This required further land acquisition and the construction of cells UN7 and UN8, UW7 and UW8.

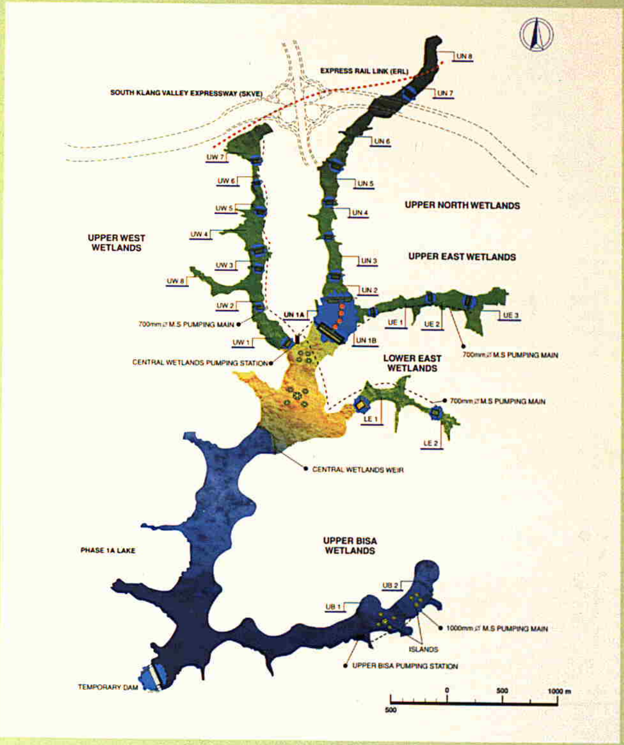
BREAKDOWN IN LAND USE OF THE PUTRAJAYA WETLANDS (AREA IN HECTARES)

WETLAND	TOTAL AREA	PLANTED AREA	OPEN WATER	WEIR & ISLANDS	ZII	MAINTENANCE TRACKS
UPPER NORTH	54.1	27.3	11.0	3.6	7.7	4.5
UPPER WEST	38.5	23.0	4.0	2.6	6.6	2.3
UPPER EAST	15.8	8.7	2.1	1.1	2.8	1.1
LOWER EAST	14.3	5.0	4.5	0.8	3.0	1.0
BISA	23.6	4.0	16.6	0.5	2.0	0.5
CENTRAL	50.9	9.7	38.6	1.0	1.6	0
TOTAL	**197.2**	**77.7**	**76.8**	**9.6**	**23.7**	**9.4**

Note : ZII denotes Zone of Intermittent Inundation.

AREA AND STORAGE CAPACITY OF THE WETLAND SYSTEM

	Upper West	Upper North	Upper East	Lower East	Upper Bisa	Central Wetlands
Catchment Area (square kilometres)	5.53	11.54	3.34	1.73	4.03	2.47
Wetland Inundated Area (hectares)	27.0	38.3	10.8	9.5	20.6	48.3
Volume (million litres)	230	310	130	150	430	1200
% of Catchment Area	4.9	3.5	3.2	5.5	5.1	2.0



Layout of the wetlands and the lake in Putrajaya

Upper North Wetlands is the second largest wetland, with 54.1 hectares and eight cells (Cell UN5 above)

The Upper West Wetlands occupies 38.5 hectares and has eight cells (Cell UW2 above)

Upper East Wetlands, with three cells, is relatively small with an area of 15.8 hectares (Cell UE3 above)

The two cells of Upper Bisa occupy a total of 23.6 hectares. They are south of the lake and discharge water directly into Putrajaya Lake

The Lower East Wetlands consists of two cells, and is the smallest wetland with an area of 14.3 hectares

The Central Wetlands is one large 50.9 hectare cell, where water from the four wetlands (Upper Bisa excluded) is collected before being discharged into the lake

Cell Characteristics

Within each cell the water depth varies between 0.5 metres and three metres, with the cell depth in each wetland increasing in a downstream direction. Within each wetland, the uppermost cell, which is the deepest, acts as a sedimentation basin, while the downstream cell, which is the shallowest, aids macrophyte growth.

Each cell in the wetlands is planted with both emergent and submerged aquatic macrophytes. These plants perform the primary role of the wetlands as a filtration system by intercepting pollutants. Bacteria and micro-organisms flourish in the root zone, further assisting in the removal of nutrients and pollutants from the water. Figure 6.3 (page 57) illustrates the major pollutant uptake and release pathways in a wetland system.

To enhance pollutant removal efficiency, each wetland cell is carefully shaped to create zones of varying depths. There are two primary zones: a Wetland Zone and a Zone of Intermittent Inundation (ZII).

Wetland Zone

The wetland zone is permanently flooded and includes:

- The macrophytic area where macrophytes (plants growing in water) are located in the shallower part;
- Open ponds in deeper parts; and
- Ornamental ponds in some cells.

Only emergent aquatic plant species are grown in the wetlands, with different plants grown to suit the different depths of water. The macrophytic area is further subdivided into three zones – Zones 1, 2 and 3 – depending on the depth of the water (see Figure 6.4 on page 57).

Zone of Intermittent Inundation (ZII)

The ZII is the lower slope or bank rising from the inundated area. It is flooded only during high flows, and is planted with species adaptable to intermittent flood conditions. The ZII is subdivided into:

- Zone F1, which is the fringing or littoral marsh/swamp in the lower areas;
- Zone F2, which is the swamp forest on the higher areas.

Fields of *Lepironia* are found in the macrophytic zone

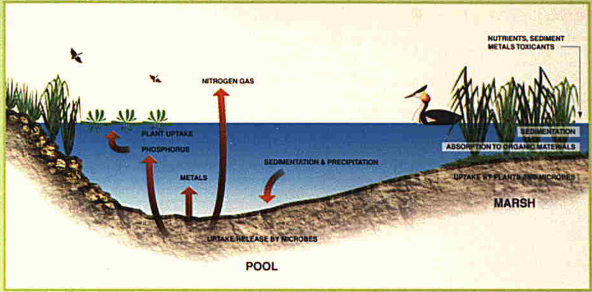


Figure 6.3 Major pollutant uptake and release pathways in a wetland system

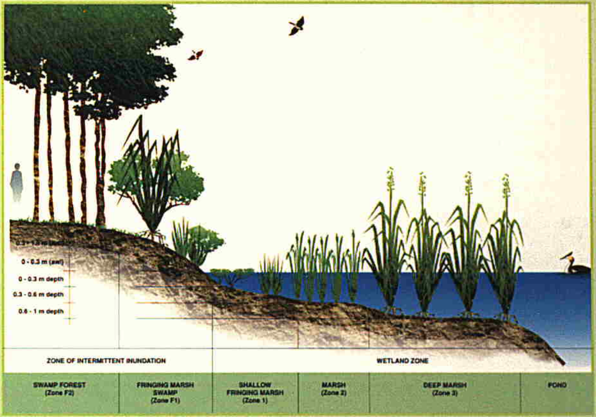
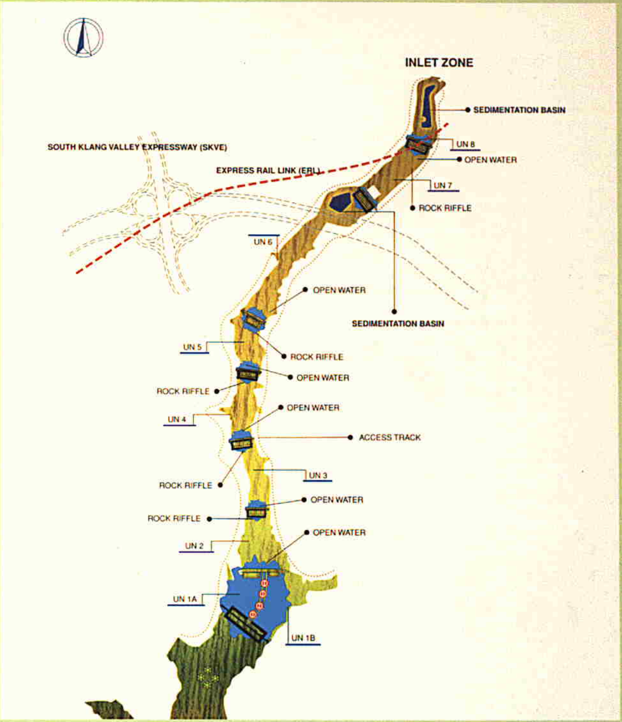


Figure 6.4 Longitudinal section of a typical wetland cell showing (in water entry order) the Zone of Intermittent Inundation (F2 and F1), Wetland Zone (Zones 1, 2 and 3) and the Open Pond

Summary of a Wetland Cell Structure and its Functions

Zone	Component	Function
Inlet Zone	• inlet	• provides passage of water by gravity to wetlands
	• energy dissipater	• provides protection for the bed of channels and the inlet of the wetland by reducing the energy of the water and preventing soil erosion. May be applicable to any part of the wetland where there are potential erosion problems
Macrophyte Zone	• reed bed	• provides support for microbial biofilms that facilitate nutrient transformation; organic flocculation, filtration of pollutants, enhancement of sedimentation, and provision of oxygen to sediment to enhance bacterial decomposition of organic matter • increases biodiversity • provides a range of habitats for macro and micro fauna • provides visual contrast through different textures, sizes, shapes and colours
	• sedimentation forebays	• enhances settling of finer soil and sediment particles (that would pass through a GPT) and associated pollutants such as heavy metals, nutrients and pesticides • reduces sediment loads to reed bed zones ensuring higher clarity for effective plant growth • improves water quality both within and downstream of wetlands which in turn improves health of ecosystem
Open Water Zone	• open water	• allows UV (sunlight) penetration for disinfection • enhances mixing of water column and reduces short circuiting • provides deep water habitat for bird, fish, invertebrates, frogs, turtles, creates a refuge during droughts or dry times, provides landing and secure areas for waterfowls. Contacts with planted areas enhance visual attraction of the wetlands
	• islands	• provides isolated habitat for bird shelter, refuge and nesting • provides a visually appealing focus to the wetlands
ZII	• edge water plants	• creates habitat diversity along the shoreline for invertebrates and wading birds • provides water quality improvement • prevents access
	• water level control structures	• allows capture of highly polluted flows for retrieval or recycling • allows water level control for a range of purposes including - operations and maintenance - predetermined water regimes to be implemented for greater habitat diversity or to specifically encourage particular species - manipulation of water level for water plant establishment
	• trash racks	• prevents litter and debris from entering wetlands and degrading water quality, aesthetics and health of ecosystem • impounds stream flows to create a pool
	• weirs	• sets normal operating water levels in wetlands

A cell in the Upper Wetlands, with an extensive macrophytic zone. Note the ZII encircling the submerged area, which is divided by a weir that regulates water flow



The layout of the Upper North Wetlands

The Multi-Stage Approach

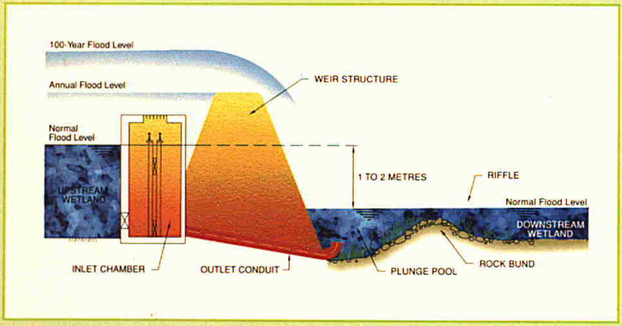
The performance of the wetlands depends on the effective control of the water level in each of the wetland cells. There are three control levels in Putrajaya Wetlands:

- Normal Water Level (NWL) - controlled by orifice flow;
- Weir Overflow Level (WOL) - storage for the annual flood;
- Major Flood Level (MFL) - regulates the flood level over the weir during the once in 100 years Average Recurrence Interval (ARI) flood.

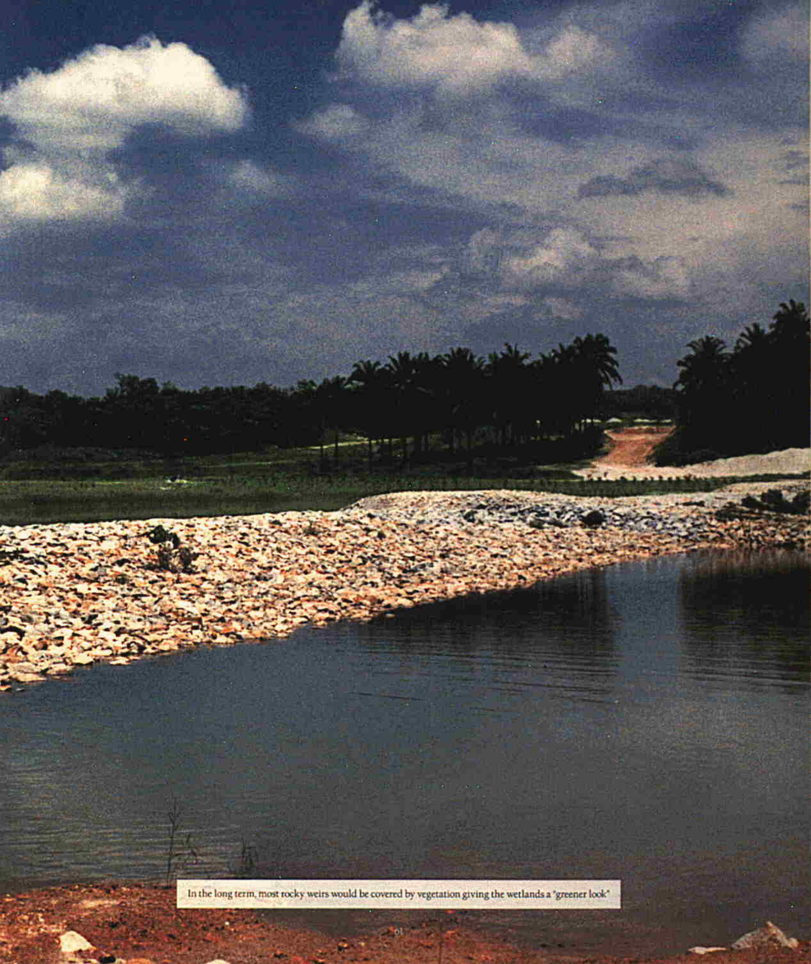
The multi-stage approach provides flood detention storage between the NWL and the WOL.

The figures on pages 62 and 63 show the schematic layout of the longitudinal profile of Sungai Chuau from the Upper North Wetlands to the Central Wetlands and Phase IA Lake. The three control levels for each cell and the average depth are shown in these figures.

The proposed outlet structure for each weir is shown below. Basically, the arrangement is based on orifice and weir control. Orifice control is used to control the release of floodwater during a flood event. The criterion adopted is to discharge the annual flood in 72 hours. The advantage of having an orifice system is that it increases the wetland retention time.

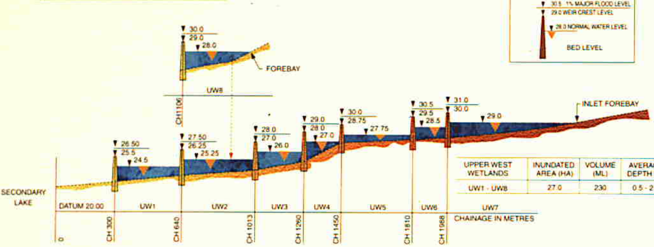


An arrangement of wetland outlet structure and weir



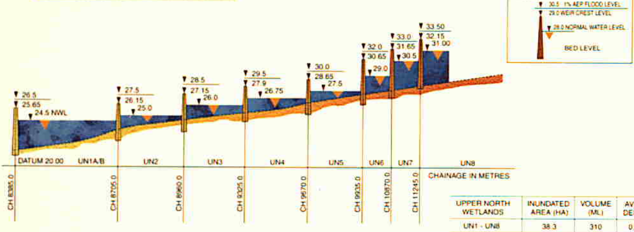
In the long term, most rocky weirs would be covered by vegetation giving the wetlands a "greener look"

UPPER WEST WETLANDS



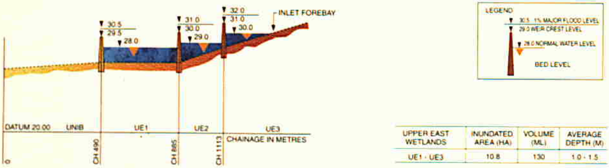
UPPER WEST WETLANDS	INUNDATED AREA (HA)	VOLUME (ML)	AVERAGE DEPTH (M)
UW1 - UW8	27.0	230	0.5 - 2.0

UPPER NORTH WETLANDS



UPPER NORTH WETLANDS	INUNDATED AREA (HA)	VOLUME (ML)	AVERAGE DEPTH (M)
UN1 - UN8	38.3	310	0.5 - 2.5

UPPER EAST WETLANDS



UPPER EAST WETLANDS	INUNDATED AREA (HA)	VOLUME (ML)	AVERAGE DEPTH (M)
UE1 - UE3	10.8	130	1.0 - 1.5

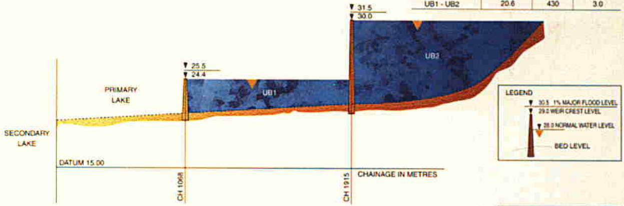
Schematic layout of the longitudinal profile of the wetlands showing lake/wetland design water levels

LOWER EAST WETLANDS

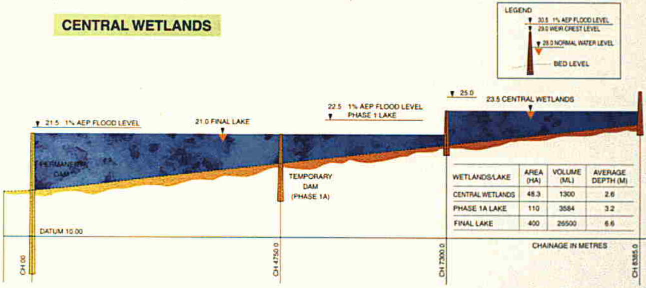
LOWER EAST WETLANDS	INUNDATED AREA (HA)	VOLUME (ML)	AVERAGE DEPTH (M)
LE1 - LE2	9.5	150	2.0 - 2.2

UPPER BISA WETLANDS

UPPER BISA WETLANDS	INUNDATED AREA (HA)	VOLUME (ML)	AVERAGE DEPTH (M)
UB1 - UB2	20.6	430	3.0



CENTRAL WETLANDS



WETLANDS/LAKE	AREA (HA)	VOLUME (ML)	AVERAGE DEPTH (M)
CENTRAL WETLANDS	48.3	1300	2.6
PHASE 1A LAKE	110	3584	3.2
FINAL LAKE	400	26500	6.6

The water from the Central Wetlands cascades into Putrajaya Lake

Chapter 7

ENVIRONMENTAL DESIGN PARAMETERS

The design of Putrajaya Wetlands involves converting the existing land use from a plantation landscape to a unique submerged wetland ecosystem in an urban environment. Designing the wetlands involved a thorough study of the catchment conditions to establish the environmental design parameters.

The wetland site was originally occupied by oil palm and rubber estates

The design of the lake and wetland system is based on the following catchment conditions:

- Terrain
- Drainage
- Land Use Changes
- Geology and Soils
- Meteorology
- Hydrology
- Water Quality

Land use in the Putrajaya catchment changed from a predominantly agricultural landscape to an urban environment

Terrain

Before the wetlands, the site was predominantly agricultural land utilised mainly for oil palm and rubber cultivation. The area had an undulating topography interspersed with steep sided hills. The valley floors were flat resulting in significant floodplain storage during floods. The main rivers – Sungai Chuau, Sungai Bisa and Sungai Limau Manis – were found to flow southward to Sungai Langat.

Drainage

Sungai Chuau is a small, narrow river draining in a southerly direction over a distance of 14.8 km. It is fed by a number of smaller tributaries, with Sungai Bisa as the largest within the catchment boundary.


Construction activity resulted in increased run-off that had to be mitigated

Land Use Changes

The effect of altered land use – from agricultural to urban – is expected to increase peak run-off volumes and rates. Run-off entering the lake will be significantly attenuated by the large volume of lake water. However, run-off directed off site from external catchments will require detention basins to offset the increase in run-off rates. There will also be an increase in pollution loads entering the lake. As the bulk of run-off enters the lake, water quality treatment measures will be required to prevent pollution of the lake. Off-site run-off should be passed through water pollution control ponds contained in retention basins to return pollution rates to pre-development levels.

Geology and Soils

The geological plan of the site indicated:

- Hawthorden Schist throughout the reservoir area

  This rock is the oldest rock type in the area and underlies the majority of the area.

- Kenny Hill Formation sandstone and shale about 500 metres south of the temporary dam and west of the storage area

  This type of rock is predominantly phyllites with minor quartzite and mica. Together with Hawthorden, it forms the bedrock of the project site.

- Alluvium on the valley floor

  Alluvium occurs in the low-lying, almost flat swampy ground of the Sungai Chuau valley. The thickness varies between 0.3 metre and 10 metres. It is generally much thicker in the middle of the river valley and thinner adjacent to the rounded sedimentary rock hills. The alluvium consists of very soft humic clays and silts with minor very loose sands and peat. Generally they have no bearing strength. Groundwater occurs from 0.3 to 2.2 metres below the surface of alluvial deposits.

- Residual soil

  Residual soil is the result of weathering of underlying rocks, and thus overlies the schist and phyllites in the area. It occurs on hill slopes and sometimes below the alluvium. On rare occasions, it overlies alluvium as a result of deposition of excavated materials from hill cuts and slope wash. Generally, the soil consists of clay silts with minor sand and a trace of angular rock fragments made up of highly weathered veined quartz materials. The thickness of residual soil ranges from three metres to 12 metres.

Meteorology

Climate

The site is located about 25 kilometres south of Kuala Lumpur along the west coast of Peninsular Malaysia. The climate in this region is characterised by warm humid tropical weather with moderate rainfall, mild wind conditions, uniformly high temperatures and high relative humidity throughout the year. The climate is influenced by:

- the north-east monsoon from December to March, and
- the south-west monsoon from June to September.

The periods between April/May and October/November are transitional periods.

Rainfall

The mean annual rainfall recorded at Putrajaya is approximately 2,000 millimetres based on the rainfall records at Ladang Prang Besar which is situated within the catchment area. The rainfall pattern reflects the annual monsoon cycles with the highest rainfall recorded around November/December and the lowest around June/July.

Air Temperature

The mean annual air temperature is 27.1 °C based on data recorded at the nearest meteorological station at Sultan Abdul Aziz Shah Airport (Subang), with monthly mean air temperatures ranging between 26.3 °C in December and 27.7 °C in May. The mean monthly minimum and maximum air temperatures range from about 20 to 36 °C in February to about 22 to 35 °C in May.

Evaporation

The average annual evaporation depth over open water recorded at Sultan Abdul Aziz Shah Airport (Subang) is 1,705 millimetres. There is no significant variation in evaporation throughout the year.

Relative Humidity

Consistently high relative humidity is recorded throughout the year ranging from 81% in February to 86% in November.

Surface Winds

Wind data collected at Sultan Abdul Aziz Shah Airport (Subang) shows mild wind conditions with calm periods occurring more than one third of the time, with no dominant wind direction. The average wind speed is low, at about 2.5 metres per second.

Sunshine

The average daily duration of sunshine averages about six hours, from a low of four hours in November to 7.5 hours in February.

Hydrology

Catchment

Most of the Putrajaya area of approximately 46 square kilometres lies within the Sungai Chuau catchment, which extends about 12 kilometres from north to south, and about 4.5 kilometres from east to west.

About 80% of the catchment was originally cultivated with oil palm and rubber. The remaining 20% was used for institutional, residential or commercial purposes. Prior to the development of Putrajaya, the drains and rivers generally were found to follow their natural courses with the drainage system in the area.

There are a few rainfall measuring stations operated by the Department of Irrigation and Drainage in the catchment area of Sungai Chuau.

Existing River Flows

Flows of Sungai Chuau and its tributaries have been estimated based on the results of the run-off routing model. In the absence of long term stream flow records, simulated run-off data have been derived for the sizing of the wetlands. This approach is described in Chapter 8 on *Hydrologic and Water Quality Modelling*.

Putrajaya attempts to restore some of the vegetation that was earlier removed for settlement

Design River Flows

The development of the Sungai Chuau catchment, both within and outside of the Putrajaya development boundary, will result in substantially increased pollutants as a result of the removal of catchment vegetation for the development of roads, perimeter areas, buildings and parking areas. The design of the wetlands must be based on the future catchment conditions with the anticipated increase in run-off. Estimated future flows in each of the major tributaries of Sungai Chuau are described in the next chapter on *Hydrologic and Water Quality Modelling*.

Water Quality: Existing Catchment vs Design

Existing Catchment

Physical and chemical characteristics

The physical and chemical characteristics of the water from the catchment area that was monitored include temperature, conductivity, pH, colour, turbidity and suspended solids. These criteria provide baseline data on the quality of water in the rivers, lake and wetlands.

Nutrients

The degree of biological productivity, or trophic status, of a water body is one of the most important aspects of water quality. Nutrient concentrations (phosphorus and nitrogen) are the most significant factors accounting for variability in biological productivity, especially in standing water bodies such as lakes. High productivity systems, or eutrophic systems, are prone to problems associated with excessive biomass production and decay, and consequent deoxygenation of the water column and sediment.

Total nutrient concentrations include nutrients in both dissolved and particulate forms. Dissolved inorganic nutrients (phosphate and dissolved inorganic nitrogen which is the sum of ammoniacal nitrogen and nitrate and nitrite nitrogen) are in forms which are immediately available for biological uptake. Nutrients found in particulate form may be deposited as bed sediment and stored in an inaccessible form or undergo decomposition into bio-available form.

For the Putrajaya Wetlands site, known nutrient sources include fertilisers from golf courses and detergents from households.

Run-off from golf courses in the Putrajaya catchment contains a significant amount of pesticides and fertilisers

Biological Oxygen Demand

Biological Oxygen Demand (BOD) is a reliable indicator of water quality. BOD measures the capacity for consumption of oxygen by biological constituents of water. BOD levels play a significant role in the acceptance criteria for disposal of effluents, especially into inland water bodies. Adequate dissolved oxygen level in a water body is vital for the health of the ecosystem.

Bacteriological Characteristics

The presence of faecal coliform bacteria which originates from faecal sources indicates the presence of harmful pathogens such as Salmonella, Shigella, Pseudomonas sp., Protosoan cysts, Giardia cysts, enteric viruses, etc.

Metals

Metal concentrations in the water entering the wetlands and the lake may affect the health of the ecosystem including plant species and biota in the lake, and the bio-accumulation of edible species in the lake.

Insecticides and Pesticides

The occurrence of insecticides and pesticides may be relevant in Putrajaya given the presence of golf courses, orchards and other related users upstream.

Other Parameters

Other parameters included are the flow rate and water level measurements. Mosquito larvae count is included to prevent the breeding of mosquitoes in the wetland cells.

Orchards upstream are another source of pollution – fertilisers and pesticides used here affect the water quality of catchment run-off

The Putrajaya Wetlands site has always attracted several species of birds and fishes

Design Catchment Water Quality

The proposed water quality standard for Putrajaya is based principally on DOE Class IIB standard and other international standards applicable to inland water bodies such as Putrajaya Lake.

To determine the existing water quality from the upstream catchment area, an extensive water quality sampling and testing programme was carried out before the commencement of construction activity in Putrajaya.

The results of the water quality analysis for Total Phosphorus, Total Nitrogen, Ammonia Nitrogen, BOD5, Total Coliform, Faecal Coliform and Total Iron exceeded the limits imposed by the standard. The high levels of these pollutants indicate pollution associated with the use of detergents and fertilisers.

To address these issues, hydrologic and water quality modelling were undertaken to ensure Putrajaya Wetlands met the lake water quality standard.

The macrophytic zone with a luxuriant growth of *Lepironia articulata* which also provides shelter and food for water birds

Chapter 8

HYDROLOGIC AND WATER QUALITY MODELLING

Hydrologic and water quality modelling to quantify the pollutant load for the purpose of determining the size and shape of the wetlands involved simulating conditions likely to occur after construction to ascertain that the wetlands met the desired lake water quality standard.

Two innovative techniques undertaken in the design of the Putrajaya Wetland cells were the study of hydrologic and water quality parameters using modern technology. Hydrologic parameters are associated with the routing of flood hydrographs through the wetland cells and spillways. Water quality parameters are associated with the removal efficiencies of the wetland cells for different types of pollutants.

The Hydrologic Model

A flood hydrology study was carried out for the proposed Putrajaya Lake and Wetlands. The wetland cells and lake, which are distributed spatially throughout the entire catchment area, are to provide storage for flood flows as well as attenuation of flood peaks. In the routing of flows through the catchment, the hydrographs were routed through these storages using a storage routing procedure.

In the study, the catchment was divided into 43 sub-catchments and the flows were routed through a total of 23 storages, with outlets controlled by a combination of weir structures and/or low flow pipe outlets. The modelling of these storages presented a unique challenge due to the large number of storages involved.

The model was calibrated using a storm hydrograph from a nearby rainfall station and a stage hydrograph recording at a gauging station in Sungai Chuau. Both stations were operated by the Drainage and Irrigation Department. After calibration, the model was applied to compute the design of floods for the existing (undeveloped) and future (developed) conditions of the catchment. The model was also applied to compute the flood hydrographs for the sizing of the dam spillway and diversion works.

The URBS model *(Carroll, 1996)* was applied for the run-off routing study. The URBS run-off routing model is based on a network of sub-catchments whose centroidal inflows are routed along a prescribed routing path to generate run-off. Figure 8.2 (page 75) shows the system configuration of the URBS run-off routing model. Figure 8.1 (page 74) shows the flood routing through the dam spillway for an example of a 10,000 year flood with a six hour duration. The reduction in peak flow as the flood passes through the wetland system and phase 1A lake is about 42%.

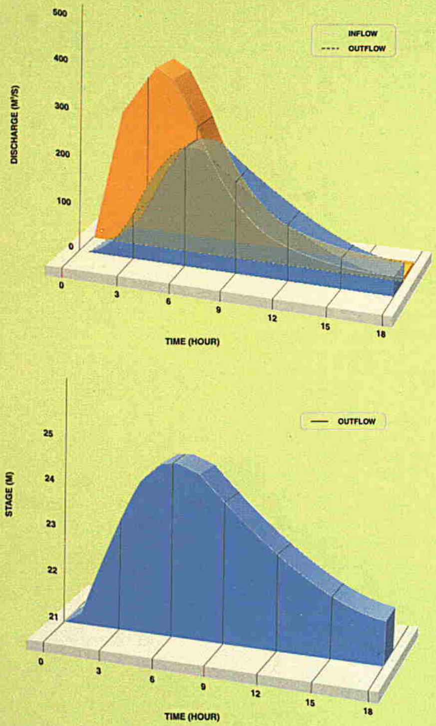


Figure 8.1 Flood routing through a 25 metre-wide spillway (10,000 year flood, six hour duration) in the wetland system and Phase 1A of Putrajaya Lake

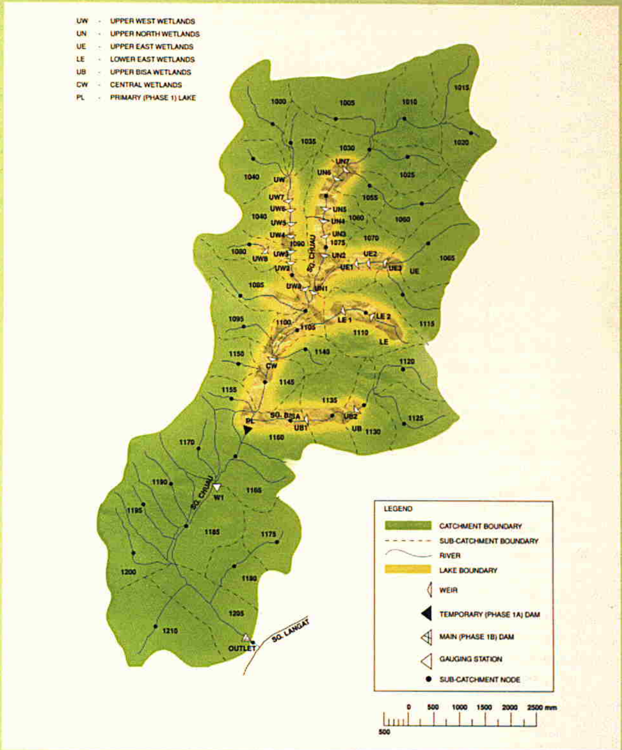


Figure 8.2 The URBS Run-off Routing Model

The Water Quality Model

A study of the water quality of the Putrajaya Wetlands and Lake was carried out using computer modelling techniques. The objectives of the modelling were as follows:

- To assess the retention of the pollutants under 'normal' urban loading conditions (assuming little or no catchment management);
- To estimate the maximum average influent pollutant concentrations which enable the primary lake to attain the Putrajaya Water Quality Standard;
- To assess the likely eutrophication potential of the proposed lake and wetland system.

The AQUALM model (page 77) was chosen to model water quality in the wetlands and the primary lake. AQUALM is an integrated rainfall run-off and water quality model which simulates long term pollutant export and retention using a daily time step. The model requires rainfall, evaporation and catchment data as well as estimates of export rates from various land use types. The pollutants selected for the analysis were Total Phosphorus (TP), Total Nitrogen (TN) and Suspended Solids (SS).

The model uses pollutant retention curves (based on hydraulic residence time) to estimate daily pollutant removal rates. Eutrophication potential is assessed using the Vollenweider analysis which requires estimates of hydraulic and pollutant loading rates.

Data for Water Quality Modelling

Pollutant Retention Curves

The pollutant retention curves from other wetlands in the region and around the world were used in the water quality modelling. These were applied to the Putrajaya Wetlands to study the pollutant removal efficiency.

Water Balance Model Parameters

The model required estimates of the upper soil and groundwater store depths as well as recession and store run-off coefficients. Local parameters were used whenever possible. The run-off coefficient for non-urban areas was estimated to be 0.35 and for fully urbanised areas 0.7.

Rainfall Data

Rainfall data were provided by the Department of Irrigation and Drainage (DID) for the Prang Besar rainfall measuring station. Daily values from 1981 to 1994 (inclusive) are available. A total of 13 out of the 14 years of data were found suitable for analysis. These rainfall data were used by the model to generate 13 years of run-off data from which the pollutant levels and loads were calculated.

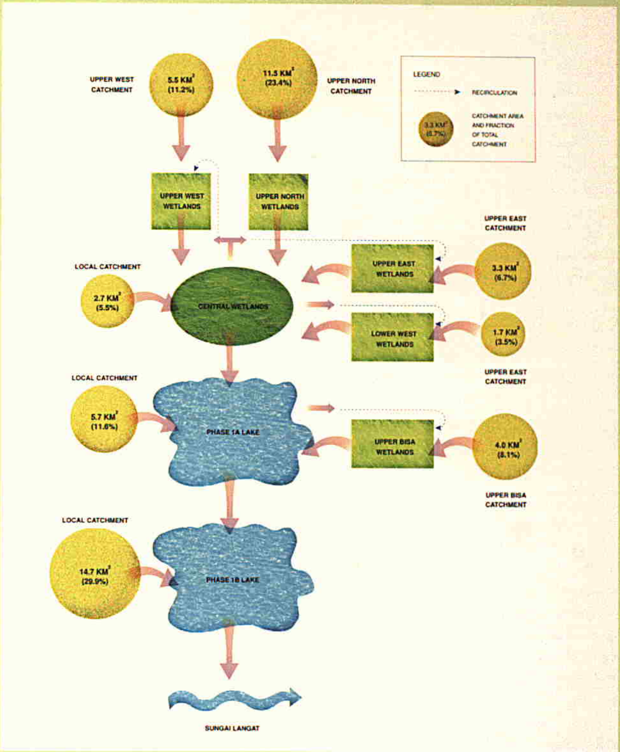


Figure 8.3 A schematic of the Putrajaya Wetlands/Lake Water Quality Model

Evaporation Data

Evaporation data were based on average monthly values provided by the DID. These figures were based on Class A pan records for Sultan Abdul Aziz Shah Airport (Subang). The annual evaporation rate is 1700 millimetres. A pan evaporation factor of 0.7 was used to estimate evapo-transpiration from rural areas, and for open water surfaces a factor of one was used.

Pollutant Export Loads and Rates

The loading rates adopted for established urban conditions were based on calibrated loads from two established urban catchments outside Putrajaya. Calibrations were performed for Total Phosphorus, Total Nitrogen and Suspended Solids.

Eutrophication Potential Data

As mentioned earlier the eutrophication potential was assessed using the Vollenweider analysis assuming phosphorus is the limiting nutrient. The model required an assessment of the fraction of phosphorus that is bio-available for various land uses and sources. The recommended values of 0.3 for urban areas, 0.1 for rural areas and 0.9 for sewage sources were used for this study.

Wetland and Lake Stage-Area-Volume Relationships

To simplify the analysis, the cells for each wetland were modelled as a single cell by referencing the storage and area values to the normal water level (NWL) for each cell. The Stage-Area-Volume relationships for each wetland were then prepared.

Model Structure

The model schema is shown in Figure 8.3 (page 77). The schema shows the Upper West, Upper North, Upper East and Lower East Wetlands contributing to the Central Wetlands. The Central and Bisa Wetlands, together with untreated catchment run-off, contribute to Phase 1A lake catchment.

The percentage of each catchment's contribution to the Phase 1 lake catchment is also shown on Figure 8.3. It has been noted that 25% of the catchment entering the Phase 1 Lake is untreated.

Model Results and Discussion

The long term pollutant export and retention for the Putrajaya Wetlands and Lake were simulated using the AQUALM model for thirteen years of data. Figure 8.3 (page 77) shows the model configuration for the Putrajaya Lake-Wetlands system. Modelling was carried out to assist in the sizing of the wetlands and assessing the eutrophication potential of the lake subject to the design pollutant loading rates.

HYDRAULIC LOADING RATE

	Upper West	Upper North	Upper East	Lower East	Upper Bisa	Central Wetlands
Design Inflow Rate (million litres per day)	18.8	37.6	11.4	5.9	13.7	79.5
Mean Residence Time (day)	12.2	8.2	11.4	25.4	31.4	15.1
Hydraulic Loading Rate (centimetres per day)	7.3	11.1	8.9	6.2	6.7	15.1

Hydraulic loading rates directly influence the performance of the wetland system although there is no simple correlation between this parameter with pollutant removal.

Hydraulic Loading Rate

Design inflow rates for each of the primary wetland sub-catchments were estimated based on future conditions after catchment development. In this exercise, thirteen years of daily rainfall records at Prang Besar rainfall measuring station from the period 1981 to 1994 were used. Thirteen years of daily run-off data for each sub-catchments were generated using a rainfall run-off simulation model. The design inflow rates and hydraulic loading rates (HLR) for each wetland system are shown in the table above.

Hydrologic and water quality modelling are computer techniques used in wetland design

Wetland Pollutant Loading Rates

Current in-flowing pollutant concentrations in the Putrajaya catchment are moderately high in phosphorus, nitrogen, BOD and some heavy metals. Bacteriological contamination and total suspended solids are extreme in many samples analysed. The current mean annual inflow rates (6,862 ML per year) and average total phosphorus concentrations recorded at sampling sites at Sungai Chuau are within the loading rate of one to five grammes per square metre per year to achieve 60 - 90% removal of phosphorus within the wetlands.

Projections of future loadings in Putrajaya will have to take into account the final land use and population density. Phosphorus is a critical parameter as it is the most difficult chemical to retain in wetland systems and will result in eutrophication of the lake if excess amounts are not successfully removed from the water. The long term efficiency and sustainability of the wetlands are governed by phosphorus inputs over time. Based on the projected pollutant loading rates for developed catchment conditions, the future mean TP mass loading rates estimated are shown in the table below.

POLLUTANT LOADING RATE

	Upper West	Upper North	Upper East	Lower East	Upper Bisa	Central Wetlands
Mean TP Load (tonnes per year)	2.6	5.1	1.6	0.8	1.9	4.7
Mean TP Loading Rate (grammes per square metre per year)	10.1	15.0	12.5	8.4	9.3	9.8

The layout of Putrajaya Wetlands follows the original contours of the terrain

Chapter 9

DESIGN FEATURES

Unlike most constructed wetlands, Putrajaya Wetlands is built into the main river, by damming Sungai Chuau and regulating the water flow over an extensive catchment. This approach necessitated a wide spectrum of design features that work in concert to control pollution and water velocity particularly during floods.

Layout

Putrajaya Wetlands' layout has been constrained by the long linear configuration and the steep sided slopes of Sungai Chuau and Sungai Bisa. The wetland design attempts to follow the natural contours of the terrain, with cut and fill techniques used wherever necessary to create the required shallows, sedimentation ponds and overflow marshes.

Main Design Features

Cascading Water Levels

The design water levels of the wetland cells generally vary from RL 32 metres in the upstream cell to RL 23.5 metres in the downstream cell. The design water levels create a cascading effect and enhance aeration of water as the flow passes through the wetlands.

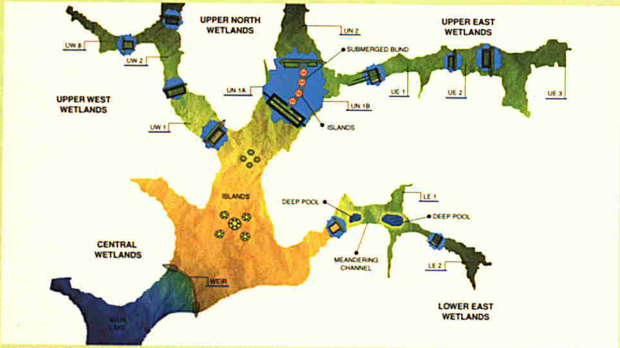
The design of the water levels in the wetland cells is an iterative process taking into account the existing topography, water depth of the functional zones, surface required and the extent of earthworks needed to achieve an optimum design layout.

Central Wetlands Layout

The figure below shows the layout of the Central Wetlands where the design water level is RL 23.5 metres. This is required to maintain a staged drop in water level between the primary constructed wetlands and the main lake at RL 21 metres.

The Central Wetlands, which occupies 48 hectares, receives flows from all the four upstream wetlands, namely, the Upper North, Upper West, Upper East and Lower East. Concentration of flows from the four arms of Sungai Chuau will take place here leading to the short-circuiting of flows.

To overcome this, nine small islands were created in the Central Wetlands to distribute flows coming from the four wetlands. These in turn create a more varied landscape, enhancing the aesthetic appeal of the environment as well as providing natural habitats for water fowl and birds.

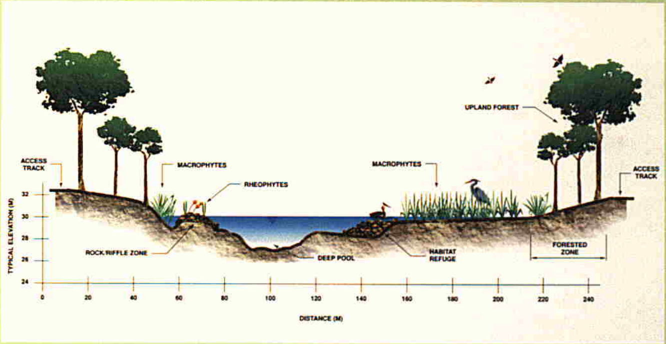


The layout of the Central Wetlands

Wetland Treatment Zones

Each of the wetlands is serially constructed and incorporates primary settling basins for sedimentation and initial pollutant removal, flowing on to the main wetlands comprising several cells separated by rock weirs. The figure below shows a diagrammatic representation of the functional zones. The intermittent flooded zone is important for the control of soil erosion and sedimentation. It is also an important landscape that links to the development and land uses adjacent to the wetlands.

The shallow macrophytic zone is a relatively tranquil part of constructed wetlands within which particle settling and adhesion to vegetation occur. This zone has been planted with rooted emergent macrophytes and is to be the primary nutrient uptake zone. The vegetation here also reduces flow velocity and prevents sediment resuspension. Given sufficient retention time, wetland vegetation can achieve efficient removal of both particulate and dissolved pollutants.



A diagrammatic representation of wetland functional zones

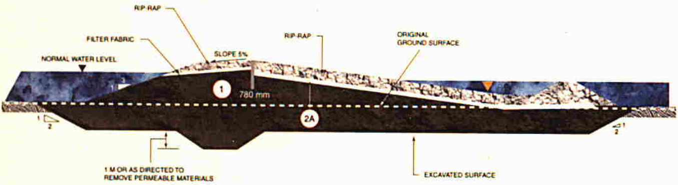
Inlet Zones and Primary Sedimentation Basins

Each of the wetlands is fed by one of the major upstream arms of the river. A river inlet zone is constructed at the head of the wetland feeding directly into the primary sedimentation basin. This is lined with limestone rock armour to intercept incoming flow, dissipate energy, reduce flow velocity and distribute flow laterally over the sedimentation basin.

Primary sedimentation basins are provided to allow settling of larger size fractions of inflowing suspended sediment. This is critical as a high percentage of inflowing pollutants would be expected to be bound to sediment that settle within these basins, thereby allowing physical removal.

Overtoppable Embankments (Weirs)

Each wetlands cell is bounded by two or more earth-filled embankments protected with armour rocks. The embankments have been designed as water retaining structures and also function as spillways during high flows. The proper detail design of the structure to overcome the risk of piping failure and damage by floods is critical. The figure below shows a typical section of an overtoppable embankment.



A typical section of an overtoppable embankment (or weir)

Outlet Works

Each overtoppable rockfilled weir separating the wetland cells is provided with an outlet conduit and inlet structure to control the flow of water from one cell to another.

An inlet structure with trash racks for the trapping of gross pollutants and the facility to vary the water levels of the wetland cell using stop logs is provided at each outlet work. The ability to vary the water levels of each cell is critical during the plant establishment stage. It has been designed to pass the floodwater of a one year Average Recurrent Interval (ARI) event flow in 72 hours. The wetland retention time is increased during event flows with the flood retention storage provided in each cell between the normal water level and the crest of the weir.

The outlet conduit tends to concentrate inflows into downstream wetlands. This is overcome by the construction of a downstream pool and a rock riffle system to dissipate energy and redistribute flow across the wetlands. The outlet design has a significant impact on the hydrologic effectiveness of the wetlands. Also, the outlet configuration governs the distribution of water levels, which in turn is fundamental to controlling the distribution of wetland plants.

Cell Morphology

Detailed shaping of the wetland cells is needed to achieve a wetland morphology conducive for plant establishment and hydraulic performance. The approach to the shaping of the ground surface is to create a well vegetated flow path with a high diversity of plant surfaces to enhance particle sedimentation and filtration while minimising short-circuiting of flow. Stagnant areas and deep pools which can lead to anaerobic conditions and low dissolved oxygen conditions were minimised to prevent the release of phosphorus from sediment. Extensive soil samplings and testings were carried out to ensure that the plant species are suited to the substrate prevailing at the site.

Hydraulic Efficiency

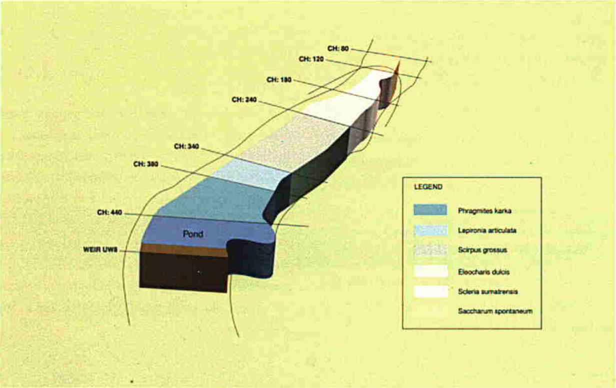
The design layout of the wetlands, morphologic design and vegetation layout are prepared to enhance the hydraulic efficiency of the wetlands. Inputs from ecologists, aquatic biologists, hydrologists, hydraulic and soil engineers were sought to achieve a design that optimises the wetland treatment processes.

The hydraulic design is aimed to create a well vegetated flow path, with a diversity of plant surfaces to enhance particle sedimentation, filtration and absorption, while optimising detention time and minimising short-circuiting of flows.

Vegetation Layout

The figure below shows a typical layout of the wetland vegetation. The plant zones are arranged in a series across the notional flow path. The vegetation structures were designed taking into account the functional processes associated with energy dissipation, flow distribution, sedimentation and filtration. The plants in these treatment zones need to have suitable morphologies to enhance the treatment processes as well as being ecologically adaptable to the water regime. The topography in the Putrajaya site frequently interferes and the cells were each individually designed to accommodate the particular terrain and the local drainage system.

Planting sometimes required the use of rafts



Vegetation planting layout in Cell UW8

Hydraulic Constraints

The overtoppable rockfilled weirs are designed to withstand flood flows of up to 1000 year ARI. The outlet conduit has been provided in each weir to control the flow of water from one cell to the downstream cell.

The weir has been designed to control the flow such that for an event flow of 100 year ARI, the flow velocity across the wetlands is below 0.5 metre per second. In natural environments many aquatic plants can tolerate periods of quite high water velocity exceeding two metres per second.

In most constructed wetlands, however, it is desirable to limit peak water velocity to less than 0.5 metre per second.

Many wetland quality treatment processes will be limited at high flow velocities which also pose the risk of sediment resuspension. To achieve optimal treatment performance, flow velocities through the wetlands should be kept below 0.1 metre per second for the period of normal inflows.

Habitat Islands

There are 22 small islands created in the Central Wetlands (nine), Upper North (four) and Upper Bisa (nine).

The small artificial islands will improve the hydraulic performance of the wetlands, create a more varied landscape to enhance the aesthetics of the environment as well as provide birds and water fowl with breeding sites away from predators.

Habitat islands in the Central Wetlands

Wetland cells can be accessed by a network of maintenance tracks

Maintenance Access and Trash Control

An extensive network of access tracks is provided along some 22 kilometres of the wetland perimeter to gain access for the maintenance of the wetlands and passive recreational activities. The tracks also provide a buffer to control weeds from spreading into the wetlands. Some 50 culverts with trash racks and energy dissipators have been provided at all the inlets into the wetlands to prevent rubbish from entering the ecosystem.

Water Circulating System

There are four water circulating systems which prevent the drying out of reed bed zones during drought and help maintain the ecology of the wetlands. The circulation of water is also necessary to prevent mosquito breeding in stagnant water. In times of poor water quality, the water in the lake and Central Wetlands can be pumped upstream for further treatment in the wetlands.

Mosquito Control

The construction of the wetlands may lead to excessive mosquito breeding, a common occurrence in many unmanaged swamps in Malaysia. The use of indigenous larvivorous fish in the control of mosquito larvae is favoured over the use of pesticides due to the growing resistance of pests and vectors to chemicals.

Wetland Planting Zones

The wetland cells, which average about four hectares each, are designed with the depth increasing from one end to the other. Each cell consists of two planting zones - a Wetland Zone and a Zone of Intermittent Inundation (ZII) - which are further divided into sub-zones.

The Wetland Zone

The Wetland Zone is permanently flooded, or inundated. It is basically a shallow body of water, comprising the Macrophytic Zone, and at the deepest end, the pond.

The macrophytic zone comprises three zones:

- Zone 1 (0 - 0.3 metre in depth): the water entry end with shallow marsh
- Zone 2 (0.3 - 0.6 metre): the water deepens into marsh
- Zone 3 (0.6 - 1.0 metre): deep marsh

These sub-zones are shallow enough for macrophytes (emergent plants that grow permanently in submerged land) and are, collectively, known as the Macrophytic Zone.

The pond is too deep for macrophytic growth and so remains an open body of water. Floating plants may occasionally occur but they would not have been intentionally introduced and, as weeds, would be removed.

The lush macrophytic zone has a depth of up to one metre of water

There are a host of macrophytes but generally individual plants are used to colonise the different depths of the macrophytic zone. There are some exceptions, however, like the *Phragmites*, which thrives in a range of depths as well as on uninundated soils. Wetland species planted in the different zones are listed in the table below. All the species were planted for their water cleansing ability, although their efficacy and ability to reduce specific pollutants may differ.

SPECIES PLANTED IN THE WETLAND ZONES

Shallow Marsh (water depth 0 - 0.3 m)	
Botanical Name	**Common Name**
Eleocharis variegata	*purun*, spike rush
Eriocaulon longifolium	*rumput butang*, Asiatic pipewort
Fimbristylis globulosa	*rumput sadang*, globular Fimbristylis
Fimbristylis miliacea	*rumput tahi kerbau*, lesser Fimbristylis
Hanguana malayana	*bakong*, common Hanguana
Ludwigia adscendens	*inai pasir*, water primrose
Ludwigia octovalvis	*naleh*, hairy Malayan willow herb
Monochoria hastata	*keladi agas*, hastate-leafed pond weed
Philydrum lanuginosum	*rumput kipas*, fan grass
Polygonum barbatum	*tebuk seludang*, knot grass
Saccharum spontaneum	*tebu salah*, swamp sugar cane
Scleria sumatrensis	*rumput sendayan*, Sumatran Scleria
Marsh (water depth 0.3 - 0.6 m)	
Eleocharis dulcis	*ubi purun*, spike rush
Fuirena umbellata	*rumput kelulut*, hairy blue sedge
Lepironia articulata	*purun*, tube sedge
Philydrum lanuginosum	*rumput kipas*, fan grass
Scirpus grossus	*rumput menderong*, greater club rush
Scirpus mucronatus	*rumput kercut*, bog bulrush
Scleria sumatrensis	*rumput sendayan*, Sumatran Scleria
Typha augustifolia	*banat*, cat-tail
Deep Marsh (water depth 0.6 - 1.0 m)	
Lepironia articulata	*purun*, tube sedge
Phragmites karka	*rumput gedabong*, common reed
Scirpus grossus	*rumput menderong*, greater club rush
Scirpus mucronatus	*rumput kercut*, bog bulrush
Typha angustifolia	*banat*, cat-tail

The open pond has been incorporated into the overall wetland design to enhance the water cleansing ability of the system — it allows sunlight, with its ultra violet radiation, to reach and sterilise the water, and wind swirl to mix and polish it. The tranquillity of the open water is also of great aesthetic value, and the deep water provides a habitat for fish and other aquatic life, and a refuge for them during a drought when the shallower parts of the cell dry up.

Zone of Intermittent Inundation (ZII)

As implied by its name, the ZII is sometimes flooded and sometimes not. It is the bank rising from the flooded cell. The flood retention capacity of the cell determines how much and how long the ZII is flooded. The zone is divided into two sub-zones:

- Immediately arising from the water is Zone F1, or the fringing or littoral marsh/swamp (0 – 0.3 metre above normal water level).
- Above it is Zone F2, or the swamp forest (0.3 – 1.5 metre above normal water level).

Because of the different conditions in Zones F1 and F2, different species adapted to the respective conditions were planted (Refer to the tables below).

SPECIES PLANTED IN THE ZII FRINGING MARSH/SWAMP (ZONE F1)

Fringing Marsh/Swamp (0 - 0.3 m above normal water level)

Botanical Name	Common Name	Botanical Name	Common Name
Alocasia macrorrhiza	*senteh*, elephant's ear	*Eugenia longifolia*	common *kelat*
Alstonia spathulata	*pulai paya*, marsh pulai	*Eriocaulon longifolium*	*rumput butang*, Asiatic pipewort
Colocasia gigantea/esculenta	*keladi*, coco-yam	*Fimbristylis miliacea*	*rumput tahi kerbau*, lesser Fimbristylis
Commelina nudiflora	*rumput aur*, common spiderwort	*Ludwigia octovalvis*	*naleh*, hairy Malayan willow herb
Crinum asiaticum	*bakong*, sea-shore Crinum	*Pandanus immersus*	*rasau*, riverine Pandanus
Dillenia suffritcosa	*simpoh air*, shrubby simpoh	*Ploiarium alternifolium*	*riang-riang*, cicada tree
Cyperus halpan	*rumput sumbu*, sheathed Cyperus	*Polygonum barbatum*	*tebuk seludang*, knot grass
Cyperus compactus	*para-para*, swamp Mariscus	*Rhynchospora corymbosa*	*rumput sendayan*, golden beak sedge
Cyperus digitatus	*rumput bunga satuan*, digitate Cyperus	*Saraca thaipingiensis*	*gapis*
Eleocharis variegata	*purun*, spike rush	*Scirpus juncoides*	*rumput bulat*, upright club rush

SPECIES PLANTED IN THE ZII SWAMP FOREST (ZONE F2)

Swamp Forest (0.3 - 1.5 m above normal water level)

Botanical Name	Common Name	Botanical Name	Common Name
Alstonia spathulata	*pulai paya*, marsh pulai	*Ficus microcarpa*	*jejawi*, Malayan banyan
Artocarpus heterophyllus	*nangka*, jack-fruit	*Flagellaria indica*	*rotan tikus*, common Flagellaria
Arundina graminifolia	Tapah weed	*Garcinia mangostana*	*mangis*, mangosteen
Caryota mitis	*rabok*, fish-tail palm	*Hibiscus tiliaceus*	*baru-baru*, sea hibiscus
Centella asiatica	*pegaga*, Indian pennywort	*Ixora javanica*	Javanese Ixora
Commelina nudiflora	*rumput aur*, common spiderwort	*Ixora umbellata*	Malayan white Ixora
Cerbera odollam	*pong-pong*, yellow-eyed Cerbera	*Koompassia malaccensis*	*kempas*
Cratoxylon arborescens	*geronggong*	*Lansium domesticum*	*langsat*
Cyrtostachys renda	*pinang raja*, sealing-wax palm	*Licuala spinosa*	*palas*
Dillenia suffruticosa	*simpoh air*, shrubby simpoh	*Litsea teysmanni*	*medang kelor*
Elaeocarpus nitidus	*jiremong*, walnut oil fruit	*Melaleuca cajuputi*	*gelam*, paper-bark tree
Eugenia aquea	*jambu air*, wax apple	*Nepenthes gracilis*	*periok kera*, slender pitcher plant
Eugenia longifolia	common *kelat*	*Pometia pinnata*	*kasai*
Fagraea fagrans	*tembusu*,	*Santiria rubiginosa*	*kerantai*
Ficus benjamina	*waringin*	*Saraca thaipingiensis*	*gapis*
		Shorea parvifolia	*meranti sarang punai*

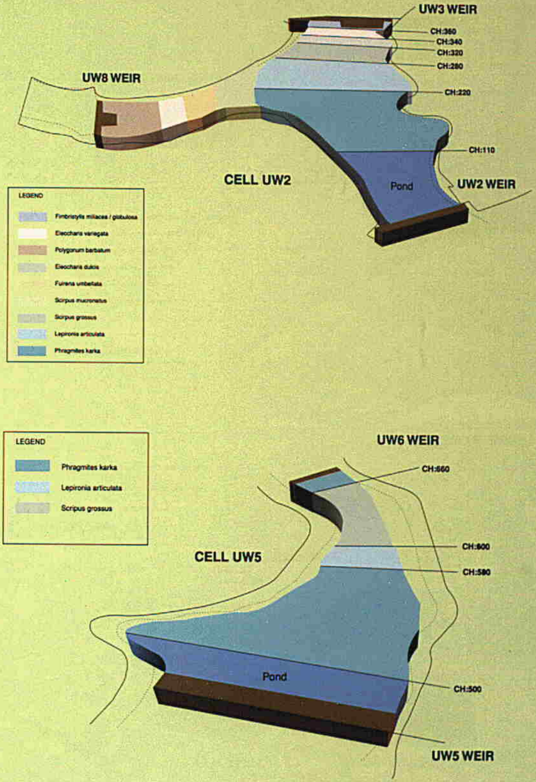
Vegetation Layout

As each cell is unique in its shape, configuration and depth, the plant species combination/composition and area planted differ between the cells. It would be unnecessary to describe the vegetation layout for all the 24 cells, so only two examples - UW2 and UW5 - are illustrated to give the reader an understanding of the concept and system used (Refer to figures on page 93).

In both figures, the species composition and location of each species planted in the macrophytic zone (Zones 1, 2 and 3) are illustrated. However, the species planted along the fringe or edge of the wetlands (Zone F1) are not included.

The combination of different species within a cell ensures efficient cleansing of the water by the different cleansing ability of each species of each and every pollutant.

A combination of different wetland species was planted for an effective filtration and cleansing system



The vegetation layout of Cell UW2 (top) and Cell UW5

The focal point during construction was the nursery, which consists of a three hectare covered nursery (above) and a four hectare open nursery

Chapter 10

THE CONSTRUCTION

The 197 hectare wetlands was built using predominantly local resources – machines, materials and men. The scale and the speed of civil works may well rank as a record in wetland construction. But the high point of the entire exercise must surely belong to plant sourcing and propagation, which involved entering the uncharted territory of growing large numbers of native wetland species. Putrajaya Wetlands braved through this experience and came away successfully planting a total of 12.3 million plants belonging to 70 species in 17 and a half months!

As with the rest of Putrajaya, the wetlands distinguished itself for its local content, using more than 90% of materials, labour, professional and technical expertise from Malaysia.

The Main Components

Putrajaya Wetlands involved the following major construction works:

- Construction of 24 wetland cells over a total of about 200 hectares involving 2.5 million cubic metres of earthworks for reshaping the terrain;
- Construction of 21 earthfilled weirs across Sungai Chuau and four of its tributaries. Total length of earthfilled weirs is 3.114 km;
- Construction of three reinforced concrete weirs with a total length of 177 metres and 160,000 cubic metres of concrete;
- Construction of some 22 km of maintenance access tracks, 50 culverts and gross pollutant traps;
- Construction of two water pumping stations and the laying of a pipe network for the recycling of water;
- Planting of about 12.3 million wetland plants involving 70 species;
- Stocking of fish in the wetlands for the control of mosquitoes;
- Construction of a nursery approximately 7.0 hectares in size;
- Construction of a laboratory and an administration building.

The Construction Process

The biggest challenge in the project stemmed from the sheer size of the project and the tight construction schedule. The construction process for the main component of works and the issues associated with the works are briefly described below.

Erosion Control Measures

The construction of Putrajaya Wetlands required the clearing of vegetation from some 200 hectares of land. Land clearing and construction can cause significant soil erosion and siltation as exposed surfaces are subject to erosion by surface run-off. The sediment washed off would pollute and block waterways, damage habitats and fauna in the valley downstream. An environmental management plan for the control of erosion and sedimentation was thus formulated.

Erosion control was achieved by minimising the exposure time of cleared land, protecting the exposed surface during rains and retarding surface flow velocity to a non-eroding velocity. Sedimentation was minimised with the construction of silt traps and sedimentation ponds to prevent sediment from escaping to the water course downstream of the construction site.

Construction of Wetland Cells

A total of 24 wetland cells were built with the design water levels decreasing from the upstream to downstream cell. This created a cascading water effect as the water flowed through the wetlands.

The construction of the cells involved 21 earthfilled weirs across Sungai Chuau and its four tributaries. Altogether 3.114 kilometres of earthfilled weirs were constructed. These weirs were designed as water retaining structures and spillways for flow to overspill the weir during heavy rain. For each weir to withstand the eroding force of flowing water, it is protected with a reinforced concrete cut-off wall and covered with armoured rocks. The foundation of the weir was stripped of all loose, compressible material and highly organic soil to avoid subsidence.

Porous materials especially sandy alluvial deposits on the floodplain was removed to prevent seepage and potential soil erosion. Each earth-filled weir was provided with an outlet conduit for the passage of normal weather flows. An inlet structure was constructed with trash racks to remove rubbish and stoplogs to control water levels in the cells. At the outlet of the conduit, energy dissipaters and sills spread the flow evenly across the cell. The pool at the outlet of the conduit was deepened to minimise the risk of shortcircuiting the flow.

Reshaping the terrain

Reshaping of the valleys was required to create an area suitable for wetland plantings and areas of open water. The extent of reshaping was governed by the water depth required in each wetland cell and the volume of earth required for construction of the earthfilled weirs. Earthworks was aimed at achieving a balance of cut and fill. This was to avoid the need to dispose excess earth from the cut operations or the need to import earth for the construction of weirs. Top soil which contained organic materials was stripped during the shaping of wetland cells and stockpiled for reuse.

The shaping of cells and construction of weirs required the working area to be kept dry. The control of water by river diversion works such as channel, bunds and cofferdams had to be planned and constructed carefully to minimise the risk of flooding in the work areas.

The construction of the weirs and the shaping of cells were undertaken in stages so that land disturbances at any one time could be confined to a manageable size. Erosion control and slope stabilising measures were implemented progressively as each area was opened up. These measures included construction of silt fences, catch drains, bunds and geotextile blanket covers. Where possible, earthworks on steep slopes was undertaken during the dry season.

Earthworks was aimed at achieving a balance of cut and fill

Top Soil Placing

In excavated areas, the ground was shaped along the contours to a depth of about 150 millimetres to break-up any hard pan. Gypsum was applied, where required. Top soil was placed in two layers of 150 millimetres each using full swivelling tracked excavators to avoid over-compaction. A sand layer about 50 millimetres thick was spread over the top soil to hold the loose top soil in place. The wetland cell was then flooded to about 100 millimetres of water to facilitate the planting of wetland species.

Access Tracks and Haul Roads

An extensive network of temporary haul roads was constructed over 200 hectares of land. These roads were aligned with the terrain to minimise erosion. Some 22 kilometres of permanent tracks covered with gravel were constructed along the perimeter of the wetlands for maintenance access. Some 50 culverts equipped with trash racks and energy dissipators were provided at the inlets to prevent rubbish from entering the wetlands. Regular maintenance of the trash racks is required to minimise the accumulation of gross pollutants in the wetlands.

The construction of the Express Rail Link was interfaced with the wetland development

Interfacing of Construction Activities

During the construction of Putrajaya Wetlands, there were several other construction projects taking place in adjacent areas. Interfacing was inevitable, particularly with the construction of the Express Rail Link (ERL), the South Klang Valley Expressway (SKVE), Taman Wetland, Taman Botani, Precinct 16, the Government Precinct, roads and bridges.

The Nursery Complex

An integrated approach was adopted in the construction of the nursery complex, which comprises the nursery, laboratory and administrative centre. The nursery complex produces plants as well as provides supportive research and development activities, especially producing plants for post-project use and research on improvements to conventional nursery practices.

The Nursery

The nursery consists of a covered nursery (three hectares) and an open nursery (four hectares). The covered nursery has a rain sheltered shade house with a roof made of ultra violet resistant PVC sheets with 50% shade. It has an automatic mist irrigation system, which provides electrically controlled pressure regulating valve and humidity sensor to monitor and control the release of irrigation water. There is also a netted shade house covered with 50% PE shade netting only. It is also provided with an automatic micro-sprinkler irrigation system. The open nursery is adjacent to the rain sheltered nursery and is used to harden plants before planting them in the wetlands and ZII. The nursery service building is used for the storage of potting mixture, receiving and preparing plants and transplanting seedlings/plants into compressed fibre pots.

Propagated plants were carefully tended in the covered nursery

The Laboratory

The laboratory undertakes analytical studies on soil and water quality monitoring and has the capacity to carry out tissue culture nutrient preparation. The laboratory's tissue culture section is capable of producing tissue culture plant materials from plant species that have a low population. It can also undertake R & D on technique development on tissue culture of new plant materials.

Quality Assurance and Control

Quality assurance and control measures were adopted in the propagation and production of plants in the nursery. Seeds and plants were collected from the healthy natural population. They were then screened for their vigour, with weak and old materials excluded from the plant propagation programme. As an additional quality assurance and control measure, a pest and disease specialist examined all plant materials collected for propagation. The materials were also treated to ensure no accidental introduction of pest or disease into the nursery. Upon arrival at the nursery, seeds were cleaned, dried and stored in airtight containers at five degrees Centigrade, and properly labeled to ensure there was no mix-up. In addition, sandy loam soil used as potting mixture was not collected from other aquatic areas to ensure that there was no introduction of aquatic weed seeds into Putrajaya Wetlands.

Plant Production

The blueprint for the wetlands called for the planting of 12.3 million plants using 70 species within 17.5 months. This period also included the sourcing of plants from the wild and constructing a three hectare nursery with irrigation facilities. As it was logistically impossible to get all the plants directly from the wild, most had to be propagated *in situ*. Direct transplanting from the wild is also not desirable because of the risk of introducing pests and diseases. By propagating in the nursery, all planting materials brought in were first "quarantined" for pests and diseases, which were literally "nipped in the bud".

Plant production involved three stages: sourcing, propagation and establishment.

Plant Sourcing

One of the requirements of Putrajaya Wetlands was the planting of exclusively indigenous species. Since large numbers were required and they were not commercially available (they are generally found growing wild in natural wetlands), these species had to be propagated *in situ*, in Putrajaya itself. The plants had to be first collected from the wild, which required a countrywide reconnaissance, with an emphasis on Selangor State (figure on page 101). When found and harvested, no more than 20% of its population were removed to minimise damage to the area and to allow quick regeneration of the stand.

Dried herbarium samples were made of all species collected, to confirm their identity and for future reference.

The services of Orang Asli were sought in sourcing wetland species from across the country

Several sites mainly in Selangor, Perak and Pahang were sourced for wetland plants

Plant Propagation

Vegetative propagation was preferred over regeneration from seed. This was simply because of the time constraint and accelerated speed of plant growth. Several novel techniques were developed for vegetative propagation, with materials taken from as many places as possible to increase genetic diversity.

For plants impossible or difficult to propagate vegetatively, seeds were used. Seeds were collected, germinated in the nursery and the young plants nurtured to transplanting age.

Depending on the species, plastic trays or biodegradable Jiffy pots were used to grow the wetland plants. The planting medium was a soil, sand and compost mixture of 70:15:15 by weight. The pots and trays were arranged in rows on benches in the covered nursery and irrigated by overhead and mist sprinklers two to four times a day. For wetland plants, slow release P-coated fertilisers (8:12:8:4 NPKMg) were used and for ZII plants slow release organic nuggets (5:5:5:1 NPKMg).

Establishment

The target for propagation was quick rooting and establishment - within a week, if possible. For this the propagated materials had to be kept in a prime state of health. This was done by shading (placed in the covered nursery), regular and adequate watering (by overhead and mist sprinklers) and fertilising. In addition to basal fertilisers, the plants were boosted with weekly sprays of a 1% dilution foliar fertiliser containing micronutrients.

One of the main problems to plant establishment in the nursery was attack by pests and diseases. Daily checks were carried out for any untoward symptoms indicative of the attacks and the problems quickly identified and resolved. Pests encountered included mites (which caused leaf yellowing and defoliation), lepidopteran stem borers (die-back), leaf-rolling and leaf eating caterpillars (defoliation), scale insects (leaf yellowing and defoliation) and rats (nibbling the young shoots).

Disease was less of a problem, and included fungal leaf spots and bacterial soft rot. In general, most of these problems were overcome by early detection and quickly spraying with the appropriate pesticides.

Plants of Putrajaya Wetlands

Plants of Putrajaya Wetlands

Sprinklers have been installed for watering, eg in the ZII (top). Pests and diseases (middle) had to be kept in check during plant establishment (bottom).

Field Planting

Precise coordination between plant production and field planting is of prime importance to ensure the success of the whole operation, especially for a constructed wetlands of this magnitude. Ideally, the plants should be transplanted as soon as they are ready. Plants that are too young are harder to establish and more prone to transplanting shocks than older plants.

To ensure that the plants do well, care was taken to preserve the topsoil. The first part of the construction of the wetland cells was to scrape off the topsoil and set it aside. After the cells were constructed, the topsoil was replaced to ensure that the plants were established in rich soil. In the field, the top soil had to be properly prepared to a fine tilth, and irrigated to the optimal "wetness" before the planting. Ready plants were taken from the nursery and planted manually. Early attempts to use a mechanical transplanter had to be abandoned because of the soggy and sticky soil conditions. As the plants established and grew taller, the water depth was slowly raised until the final *normal* water level. Once planting had begun, the cell was quickly completed so that it could be closed for manipulating the water level.

Slow-release fertiliser was added to boost initial growth, and whenever deemed necessary for the plants to be healthy.

After the plants had been established, they were monitored fortnightly for health, pests and diseases so that any problem could be quickly addressed and resolved. Field problems encountered included pest attacks (from lepidopteran stem borers, leaf-miners, leaf rollers and leaf-eaters, army worms, cockchafer leaf-eaters and aphids), disease (basal stem rot), nitrogen deficiency, siltation from soil-wash and oil contamination. As a point in conservation, pesticides were rarely used and, if required, only narrow spectrum pesticides or biopesticides such as Bt (*Bacillus thuringiensis*) were applied on specific targets in localised areas.

Plants were transplanted as soon as they were ready and were monitored for diseases and pests

Cyperus halpan, or *rumput sumbu*, is grown on the fringes of the wetlands and lake. Besides its wetland cleansing function, it is a food source for birds and fish, which eat its small nuts

Chapter 11

T H E F L O R A

Transforming the land from an undulating plantation site to a waterlogged wetland ecosystem resulted in a radical change in the flora of the area. The propagated wetland vegetation comprises exclusively indigenous species, some classified as endangered, which highlight the rich natural heritage of the country. It also helps enhance Putrajaya's potential as an ecotourist attraction.

Ludwigia octovalvis are attractive plants grown to protect the banks from soil erosion

One of the dominant species in Putrajaya Wetlands, the *Phragmites karka* aids filtration and sedimentation

Pre-wetland vegetation

Before the Wetlands

The site acquired for Putrajaya Wetlands was an oil palm and rubber plantation between 12 and 15 years old, on undulating land (predominantly Serdang and Prang Besar Series soils). The vegetation was typical of an old inland oil palm/rubber estate, a few years prior to replanting. The main vegetation was oil palm/rubber, with *Nephrolepis* and *Stenochlaena ferns* (mainly), and a host of other under-storey plants such as *Clidemia hirta, Dillenia suffruticosa, Borreria latifolia, Alstonia angustiloba* etc. There were miscellaneous plants growing from the attached old frond bases on the oil palm trunks, viz. *Ficus spp.* and various ferns.

Being old, the canopy of the oil palm had mostly closed, and only 10 - 20% of sunlight transmitted to the ground. Therefore, the ground vegetation was mostly shade-tolerant species – mainly ferns and bracken and soft grasses like *Paspalum conjugatum, Ottochloa nodosa, Ischaemum muticum* and *Centotheca lappacea*. In the more open areas, for example, where some palms had died, there were remnants of leguminous cover crops – *Pueraria, Centrosema* – planted with the oil palm/rubber. But most of them would have died years ago with the heavy shading from the closing of the oil palm/rubber canopy (at about 10 years old).

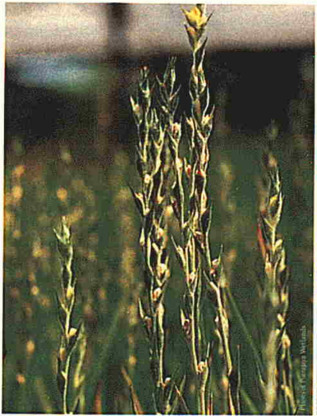
Some other shade tolerant species were also found, for example, creepers like *Mikania scandens* and *Passiflora foetida*, scramblers like *Asystasia intrusa*, woody shrubs like *Melastoma malabathricum* and, where the soil is damp, *Cyperus*. However, they were not extensive because under standard estate management practice, they are considered weeds and eradicated.

The original rivers and tributaries that flow through the area – Sungai Chuau, Sungai Bisa and their tributaries – were generally small streams, between two and four metres wide and 0.3 - 1.5 metres deep. Aquatic flora in the system included submergent plants such as *Hydrilla verticillata, Ceratophyllum sp., Najas sp.* and *Utricularia aurea*, and emergent species, such as *Limnocharis flava, Typha angustifolia, Monochoria hastata* and *Ludwigia hyssopifolia*. Also observed were algae and floating plants such as *Lemna sp.* (duckweed).

After Wetlands Construction

With the construction of the wetlands and planting of emergent aquatic plants, the riverine system was altered from a narrow, swift river into a slow flowing "marsh" (somewhat like the Everglades in Florida, U.S.A.) with a diversity of wetland plants and open water areas covering a full 80 hectares. Constructing the wetlands not only involved widening the river basin, but also clearing, cutting, levelling, sloping and, finally, flooding the large oil palm/rubber area straddling the basin. The ecology of the area was altered from a terrestrial plantation into a marsh of aquatic plants (in the wetlands itself) and banks of riparian and littoral vegetation (in the Zone of Intermittent Inundation).

The planted flora of the wetlands comprises only plants indigenous to Peninsular Malaysia. Large tracts of aquatic plants, mainly of *Eleocharis variegata*, *Eleocharis dulcis*, *Scleria sumatrensis*, *Scirpus grossus*, *Scirpus mucronatus*, *Phragmites karka*, and *Lepironia articulata*, now form the primary vegetation of the area. Other species planted along the littoral zone and in niche areas, such as *Polygonum barbatum*, *Typha angustifolia*, *Cyperus* spp., *Eriocaulon longifolium*, *Ludwigia* spp., *Monochoria hastata*, *Rhynchospora corymbosa*, *Fimbristylis* spp., *Phylidrum lanuginosum* and *Hanguana malayana* provide diversity and naturalness to the wetlands.



Phylidrum lanuginosum or *rumput kapas* are ornamental plants that remove chemical pollutants and suspended solids and biodegrade organic pollutants in the water

In addition to wetland cleansing, the *Hanguana malayana* or *bakong* is a shelter for water and arboreal birds

The ornamental *Monochoria hastata* or *keladi agas* are used for bank protection

Arundina graminofolia or tapah weed is used for slope protection

Eugenia aquea or *jambu air* is another slope protecting tree

The covers, herbs, shrubs and trees in the littoral zone not only protect the slope but also create a cool and natural environment for visitors. Fast growing trees planted include *Alstonia spathulata*, *Cerbera odollam*, *Saraca thaipingiensis*, *Eugenia* spp., *Melaleuca cajupute*, *Pometia pinnata* and others. To add a touch of colour and beauty to the area, an orchid (*Arundina graminifolia*), sealing wax palm (*Cyrtostachys renda*) and *Ixora* spp., all plants from damp areas, were planted along the ZII.

The *Ixora* enhances the beauty of the wetlands. Its flowers produce nectar which attracts bees and butterflies

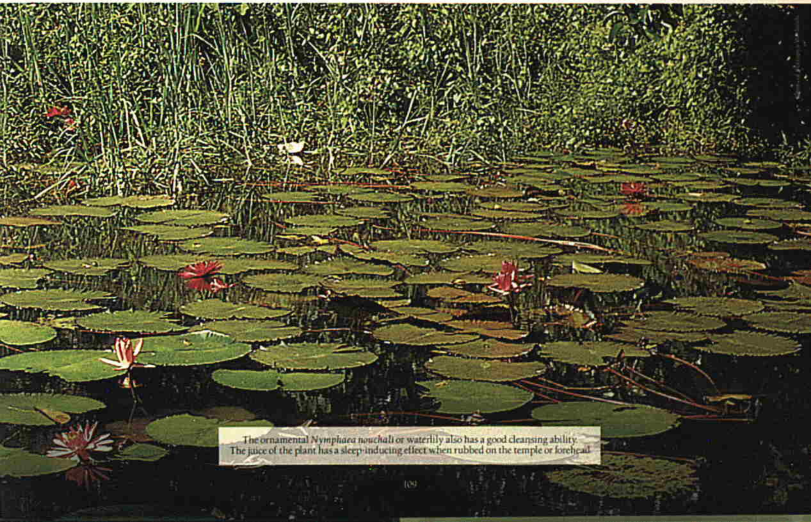
Melaleuca cajuputi or *gelam* is a slope protecting plant that is attractive to birds and other wildlife

The popular sealing wax palm is a landscape and slope protecting plant

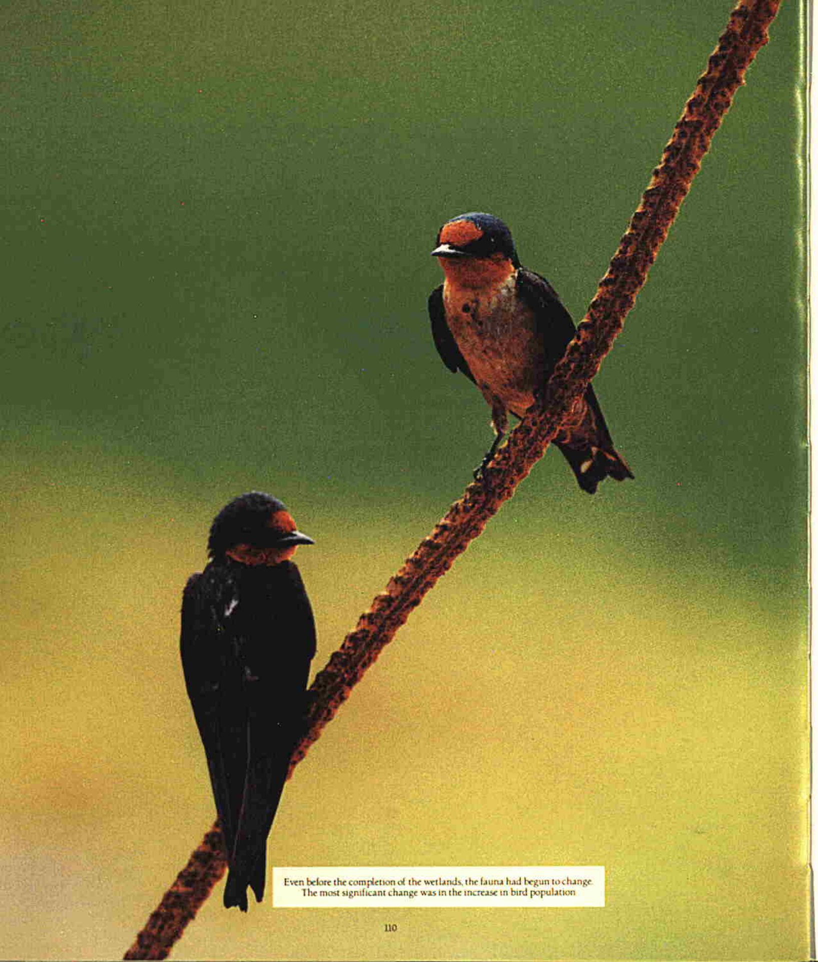
Vanda hookeriana or the Kinta weed is an endangered species

Plants of Putrajaya Wetlands

Four cells — LE1, UB1, UB2 and the Central Wetlands — have parts of their indented shoreline developed into ornamental ponds. The plants there add colour and form to the wetland area. They include the water lily (*Nymphaea* spp.), orchid (*Vanda hookeriana*) and the sisal-like *Hanguana malayana*.



The ornamental *Nymphaea nouchali* or waterlily also has a good cleansing ability. The juice of the plant has a sleep-inducing effect when rubbed on the temple or forehead.



Even before the completion of the wetlands, the fauna had begun to change. The most significant change was in the increase in bird population

Chapter 12

THE FAUNA

Wetlands are noted for their biodiversity. With the construction of Putrajaya Wetlands several species of migratory birds and other fauna have been attracted to the area. Like its unique flora, wetland fauna is at the heart of the success of Putrajaya as an ecotourist destination.

Before the Wetlands

The fauna was typical of an oil palm and rubber plantation, comprising mainly small mammals, some reptiles, amphibians and resident birds. However, as the area is adjacent to a stretch of primary jungle, some larger mammals, such as sambar deer and honey bears may have occasionally forayed into it.

Rats, mainly *Rattus rattus*, *R. tiomanicus* and *R. diardii* are common in oil palm plantations, feeding off the fruits. Other common mammals are squirrels (*Callosciurus* spp.), shrews (*Suncus* spp.), porcupines (*Hystrix brachyura*), scaly ant-eaters (*Manis javanica*), bats (*Cynopterus* sp. and *Macroglossus* sp.), long-tail macaques or *kera* (*Macaca fascicularis*), short-tail macaques or *beruk* (*Macaca nemestrina*) and dusky leaf-monkeys or *lontong chengkong* (*Prebytis obscura*), otters, civet cats (*musang*) and leopard cats. Wild pigs (*Sus scrofa*) occasionally forage on roots and fallen fruits. A recent survey by the Jabatan Perlindungan Hidupan Liar dan Taman Negara (PERHILITAN, 1998) confirmed the presence of four large mammals (long-tail macaques, short-tail macaques, dusky-leaf monkeys and wild pigs) and 62 species of small mammals.

From the resident estate population, a menagerie of domesticated animals was present — cattle, sheep, goats, dogs, cats and poultry.

Before construction

The python which preys on small mammals

The red jungle fowl

Snakes were common feeding on the rats. Mostly, they were the common cobra (*Naja naja*) and the occasional king cobra (*Ophiophagus hannah*) preying on other snakes and the python (*Python reticulatus*) on small mammals.

The birds were mainly residents of oil palm and rubber areas, such as the sparrow, mynah, swift, magpie, robin, weaver bird, sun-bird, eagle, kite, pigeon and dove, parrot, cuckoo and coucal, kingfisher, bee-eater, swallow, bulbul, night jar and the jungle fowl. The barn owl often preyed on rats, especially if nesting boxes had been put up by the estate. The greater coucal (*Centropus sinensis*) was frequently seen flying in the plantation and the moor hen (*Gallinula chloropus*) appeared from the riverine areas. A recent study by the Jabatan Perlindungan Hidupan Liar dan Taman Negara (PERHILITAN, 1998) recorded 81 species of birds, seven of which are migratory.

The site has a diversity of insects such as butterflies and bees (top), riverine creatures such as monitor lizards (middle) and birds such as woodpeckers (bottom).

In the riverine areas, monitor lizards, frogs, toads, tortoises and other herpetofauna were found. However, the original rivers flowing were small and did not contain many large fishes, except for the snake-head (*ikan haruan*) and the cultured carp (*grass and big-head*) which had escaped from rearing ponds upstream. A survey of fish in the rivers showed a relatively high population of *tilapia* (*Oreochromis* spp.) of various sizes, also believed to have spilled from upstream ponds and which subsequently bred in their new environment. Indigenous fish in reasonable numbers included the *seluang* (*Rasbora sumatrana*), *sepat ronggeng* (*Trichogaster trichopterus*), *terbul* (*Osteochilus hasseltii*), *ikan putih* (*Puntius binotatus*), *pelampung jaring* (*Puntius tetrazona partipentazona*), *keli* (*Clarias* spp.) and *haruan* (*Channa striatus*).

Because of the abundant and varied vegetation, a diversity of insects, comprising butterflies, moths, bees, crickets, grass-hoppers, tettigonids, praying mantis, beetles, flies and others, also abound in the area. Due to the abundance of oil palm in the area, several beetle species, common pests of the palm, such as *Oryctes rhinoceros* (rhinoceros beetle), *Rhynchophorus schach* (palm weevil) and *Apogonia spp.* (cockchafers) are present in large numbers. The survey by Jabatan Perlindungan Hidupan Liar dan Taman Negara (PERHILITAN, 1998) recorded 21 species of butterflies, five species of moths, three species of dragonflies and three species of hymenopterans (bees and wasps).

Wild ducks

After Wetland Construction

The wetlands, with their large expanse of diverse aquatic plants, and trees and bushes lining the littoral zone, form a crucial and important part of the "green corridor" linking the parks in Putrajaya (Taman Wetland, Taman Botani, Taman Jati, Taman Putra Perdana) to the surrounding forest reserves. Development of the "green corridor" is important to the sustainability of wildlife, especially birds, in Putrajaya. The large diversity of plants and insects provide a broad food base for the different birds, from insectivorous to frugivorous, granivorous and nectarivorous.

Insects such as the praying mantis (left) and butterfly (right) provide a broad food base for a variety of birds

The migratory egret is one of the newcomers to the area

Birds: A Photographic Guide to the Birds of Peninsular Malaysia and Singapore. A Sun Tree Notebook

The predatory Brahminy kite

Even before the completion of the wetlands, the fauna had begun to change. This was not unexpected, given the drastic modification of the environment. The most noticeable changes were in the increase in the population of dragonflies and birds such as swifts, moor hens, water hens, wild ducks and kingfishers. The normally airborne black-shouldered kite (*Elanus caeruleus*) and brahminy kite (*Haliastur indus*) are sometimes seen swooping on their prey. Migratory birds such as the cattle egret (*Bubulcus ibis*), little egret (*Egretta garzetta*) and purple heron (*Ardea purpurea*) have appeared, attracted by the shelter of the vegetation and abundance of food (fish). The migratory birds are believed to have come from their traditional feeding grounds – the natural wetlands and abandoned mining ponds in nearby Puchong

There has been a sharp rise in the dragonfly population

Meanwhile, the clean water of the wetlands has changed the habit of the long-tailed macaque — from aerial acrobats to swimmers.

Indigenous fishes, including those that feed on mosquito larvae, such as *pelaga* (*Beta pugnax*) and *sepat siam* (*Trichogaster pectoralis*), were introduced into the wetland cells. In the larger and deeper Central Wetlands and Putrajaya Lake, sport and "table" fishes, such as *patin* (*Pangasius pangasius*), *baung* (*Mystus spp.*), *tengalan* (*Puntius bulu*), *sebarau* (*Hampala macrolepidota*) and *temoleh* (*Probarbus jullieni*) were introduced. The introduced fishes represent the full spectrum in the food chain — from plankton (including algae) feeders to herbivores, omnivores and carnivores. Observation of the introduced fishes so far suggests that they are thriving in their new home. They are thus expected to breed and sustain their populations in conducive and clean conditions. Monitoring the fish and mosquito larvae populations will be carried out regularly to ensure that the fishes are able to control the breeding of mosquitoes.

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Anabantidae or *ikan sepilai* was introduced into Putrajaya Wetlands

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Ikan-Ikan Asli di Taman Pertanian Malaysia

Cyprinidae or *ikan putih* (left) and *Anabantidae* or *sepat ronggeng* (right) are Putrajaya natives

Ikan-Ikan Asli di Taman Pertanian Malaysia

Ikan-Ikan Asli di Taman Pertanian Malaysia

Cyprinidae or *ikan sebarau* (left) and *Ophicephalidae* or *ikan bujok* (right) are introduced species. Fishes help keep in check the mosquito population and maintain good water quality

POST-CONSTRUCTION

Even more daunting than constructing is the task of maintaining the wetlands to permit them to effectively play out their multiple roles which range from pollution control to public education, research and ecotourism.

The good health of wetland vegetation determines the effectiveness of its filtration and cleansing function

Chapter 13

WETLAND MANAGEMENT

Man-made wetlands are designed to be self-sustaining ecological systems. They are, however, also a dynamic environment requiring best practice management. As a result, Perbadanan Putrajaya developed a Wetland Management Plan to help meet its design objectives.

Wetland Management

The management of constructed wetlands comprises four primary tasks:

- **Monitoring** - of water quality, the habitat, flora and fauna;
- **Operational Control** - by varying the water levels and recirculating the water;
- **Inspection** - of physical structures such as dams & weirs, outlet control pipes, instrumentation, trash racks and stop logs;
- **Maintenance** - by repairing damage to structures, replanting and harvesting, and control of weeds and other sources of pollution.

Water quality analysis is undertaken regularly as part of the maintenance activity

Putrajaya Wetlands Management

Putrajaya Wetlands is managed by Perbadanan Putrajaya. The management primarily involves substantial scientific and biological monitoring, vegetation harvesting and replanting, water level management and water quality monitoring.

The Putrajaya catchment includes and extends beyond the jurisdiction of Perbadanan Putrajaya. As transitional ecosystems, the health of the wetlands can be affected by occurrences in the catchment such as excessive siltation and other pollution-inducing activities.

For an effective and integrated wetland management, Perbadanan Putrajaya has adopted a two-pronged approach :

- Intra-agency catchment management, which monitors and manages wetland functions; coordinates and controls water pollution through the planning and control of activities likely to affect catchment conditions within Putrajaya; and
- Inter-agency catchment management, which involves liaison and cooperation with agencies and local authorities operating outside of the Putrajaya boundary. The Putrajaya Lake Management Committee, under the purview of the Ministry of Agriculture, has been established for this purpose. The committee seeks to ensure that activities undertaken do not have a negative impact on the Putrajaya catchment.

Plants of Putrajaya Wetlands

Constructed wetlands are low maintenance and self-sustaining ecosystems. Nonetheless, regular maintenance is necessary to ensure good plant and water quality.

Gross pollutant traps have to be cleaned regularly so that they can capture debris and other litter effectively

Operations and Maintenance Manual (O & M Manual)

The management of the wetlands is securely anchored on the O & M Manual, the document detailing accurate, current and structure-oriented operating instructions for Putrajaya Wetlands.

The O & M Manual aims to achieve the following:

- to ensure that the wetlands meet their design objectives;
- to ensure the sustainability of the wetlands;
- to allow operational staff to make informed decisions;
- to ensure effective management of the wetlands.

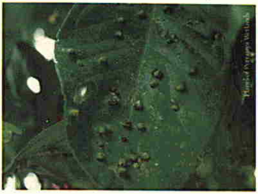
Riparian parks are regularly mowed and weeded

Key Maintenance Activities

Plant Management

Plants provide several mechanisms vital to the improvement of water quality in constructed wetlands. Plant management is thus very much at the heart of the matter of operations and maintenance, which aim at sustaining a dense stand of desirable vegetation within the wetlands cells. Plant inspection, harvesting and replanting, therefore, have to be undertaken as and when required.

Diseased plants (top), weeds (middle pictures) and pests (bottom) have to be kept under control to safeguard plant health



Plant health

Visible signs of plant distress should be investigated promptly. Senescence of plant species is part of the natural cycle of wetland vegetation, resulting in browning and possibly plants appearing to be dead. To check for senescence, it is necessary to examine new shoots and the plant root system. Familiarity with wetland species will eventually lead to a rapid identification of senescence.

Plant health can also suffer from many agents such as pest attacks, disease, nutrient deficiency, poor substrate and wrong water depth. The manual identifies likely problems and gives a detailed guide to dealing with them.

Weed Control

Weed invasion can dramatically reduce the ability of the wetlands to meet their design objectives. The manual identifies undesirable wetlands plants and methods of elimination.

Erosion

Erosion can occur within all zones of wetland zones, with the ZII being most vulnerable. Erosion should be repaired as soon as it is discovered because few plants can be expected to grow where the topsoil has been washed away.

Chemical Spills

There may be times when the wetlands becomes contaminated, for example, by chemical or oil spills on roads traversing the site. The management should aim to capture the spill in the individual wetland cell to prevent contamination of other cells. The spill can then be isolated and treated.

Litter Management

Litter screens are present in the outlet of each wetland cell. They trap significant amounts of litter entering the wetlands, particularly into cells in the upper catchment. Cleaning should be undertaken every month and after high flows. There is evidence to suggest breakdown products from decomposing litter may re-enter the water column within 10 days of entrapment. Frequent maintenance is thus imperative.

Debris may also accumulate and have to be removed periodically and after storms to ensure optimum performance of the wetlands.

Sediment Removal

Sediment forebays are the primary sediment removal mechanism for Putrajaya Wetlands. They ensure that sediment is not continually resuspended during high flows into the main wetland system where removal is more difficult and can smother the vegetation.

Excessive sediment in the main wetlands should be removed. This may only be required every five years.

Mosquito control

An increase in the mosquito population can pose a serious health hazard. It is essential to monitor the cells for mosquito larvae and undertake preventative and/or control measures.

Fish stocking

Fishes in the wetlands help achieve a balanced and sustainable aquatic system. Important considerations in fish stocking include maintenance of good water quality, mosquito larvae control, opportunities for sport fishing and aesthetic and ornamental appeal. Only indigenous species are to be introduced, with some invasive varieties classified as 'undesirable'. A quarterly fish sampling programme to monitor fish numbers and species is recommended.

Sediment accumulates during high flows

Fishes control mosquito breeding and maintain good water quality

Monitoring Stations

Biological, sediment and water quality monitoring stations are located within the wetlands. The manual details the frequency and size of sampling to be undertaken at each of these sites.

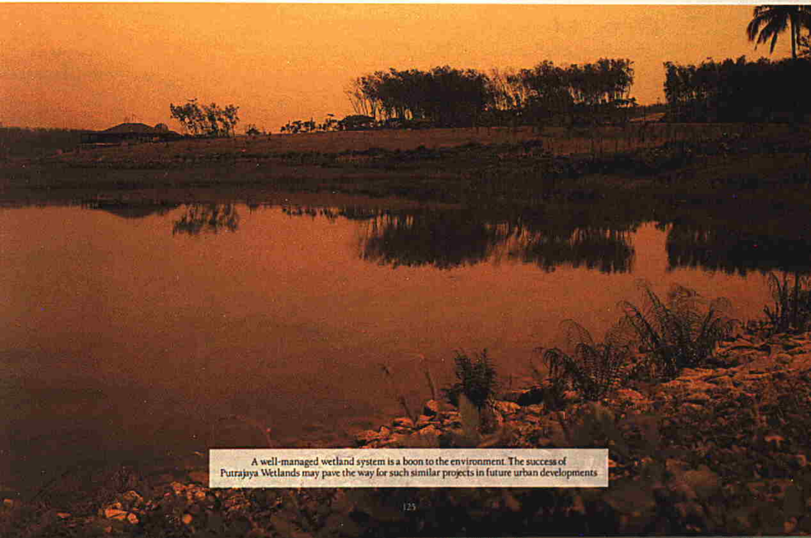
Roads and Tracks

There is a network of 22 kilometres of roads and tracks traversing the wetlands. They provide access to the wetlands by operations and maintenance staff as well as the public.

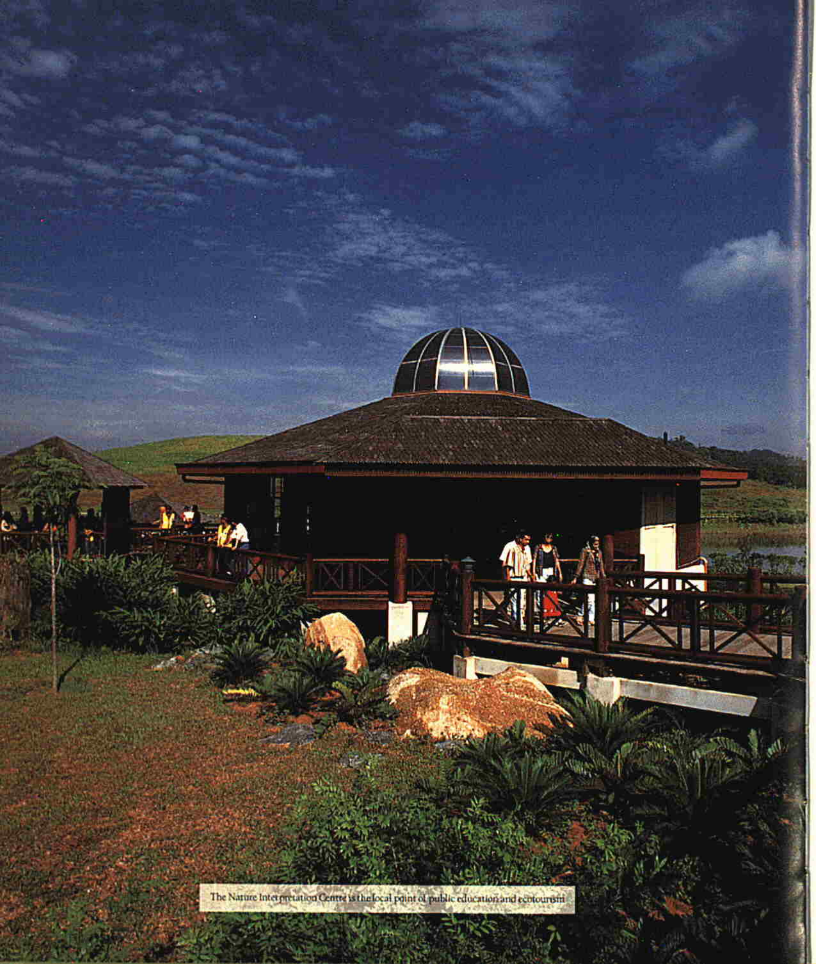
Long Term Sustainability

Perbadanan Putrajaya aims to ensure that the wetlands is managed to meet their design objectives. An integral part of long term management are action plans, which are expected to:

- assess the need for the wetlands to examine new objectives;
- review the Operations and Maintenance Manual; and
- implement new policies given greater experience acquired over time and the relevant conditions of the day.



A well-managed wetland system is a boon to the environment. The success of Putrajaya Wetlands may pave the way for such similar projects in future urban developments



The Nature Interpretation Centre is the focal point of public education and ecotourism

Chapter 14

PUBLIC EDUCATION & RESEARCH

As the first constructed freshwater wetlands in the tropics, Putrajaya Wetlands is a fertile ground for public education and research. And as a recently built environment, it has the amenities to help facilitate public understanding of wetlands and for specialists to undertake research into several yet-to-be-understood processes that are exclusive to this type of purpose-built system.

Public Education

The success of Putrajaya Wetlands is not exclusively the responsibility of the management alone. Very much also depends on how the public treats this fragile ecosystem which is the life support system of the city's centrepiece, Putrajaya Lake. There is thus a need to foster greater awareness and understanding of wetlands so that everyone – especially residents – can play their respective roles in conserving and preserving this 'nature reserve'.

Meanwhile, Putrajaya Wetlands management has embarked on a public education programme that is centred around the Nature Interpretation Centre.

How we can help

The care and maintenance of wetlands is the collective responsibility of all, not least, members of the public. Indeed, what we do in the Putrajaya environment can negatively impact on the wetlands, which treats surface run-off.

Here, we offer a few "Do's" to help us share and care for the long term sustainability of Putrajaya Wetlands.

- Do ensure litter and grass clippings are disposed off correctly because it will reduce the amount of floating debris in the receiving waters. Mulch grass clipping or place them in garbage bins for collection;
- Do wash cars in areas such as the lawn where nutrients can be absorbed by plants before being washed away;
- Do sweep paved areas with a broom rather than hosing debris into the stormwater system;
- Do dispose of unwanted oils (motor oil, cooking oil etc) and liquids through the appropriate waste disposal system and not onto the ground;
- Do ensure there is no sewage seepage in the garden;
- Do maintain good vegetation as ground cover because this reduces siltation in run-off;
- Do minimise the amount of fertilisers used on the lawn and garden. They seep into the ground and pollute the water;
- Do remove rubbish when visiting the wetlands;
- Do keep to marked roads and tracks to avoid erosion in the wetlands;
- Do leave plant life and wildlife alone;
- Do leash your pets or non-native animals and do not set them 'free' in the wetlands.

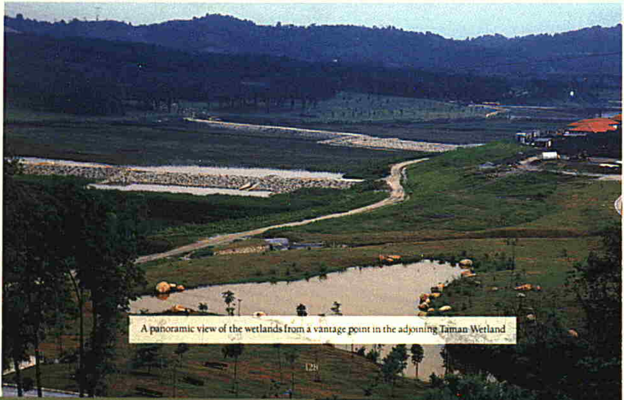
The Nature Interpretation Centre is located in the adjoining Taman Wetland, which overlooks the submerged ecosystem. The centre provides information primarily on the development of Putrajaya Wetlands, whilst highlighting environmental issues related to wetlands. It also has a catalogue and computer corner, a souvenir shop, a cafe and houses the wetlands administrative offices.

Visitors are encouraged to walk through the park and on boardwalks leading to the wetlands where they can commune with the bounties of this ecosystem. The variety of water forms, land forms, plant and animal life provide a stimulating sensory experience, and visitors are likely to return recharged and enriched by the visit. Guided tours by park wardens make the experience all the more meaningful.

For those with a serious interest in wetland plants and wildlife, there is a museum and herbarium. The collections here are registered, documented and endorsed, and are useful for wetland enthusiasts, researchers and other interested parties.

The look-out tower in Taman Wetland (in the background)

Furthermore, there is a look-out tower rising 18 metres on the highest point of Taman Wetland with sweeping vistas of the wetlands. There are also several other vantage points offering panoramic wetland views. For public convenience, there is a carpark for 57 cars and eight buses, and designated picnic areas and toilets.



A panoramic view of the wetlands from a vantage point in the adjoining Taman Wetland

Scientific Research

As a pioneering constructed wetlands project, Putrajaya Wetlands offers innumerable research opportunities. Much research and study was undertaken during the project, from studies of catchment conditions to plant sourcing and propagation. But there is so much more that can be done, which have the potential to make Putrajaya Wetlands the regional centre for research in constructed tropical wetlands.

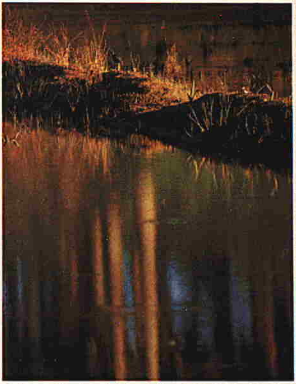
This function becomes even more significant given the location of several tertiary institutions in the vicinity. Putrajaya Wetlands is within a five kilometre radius of Universiti Putra Malaysia which, among others, specialises in agriculture, Universiti Tenaga, the Malaysian Agricultural Research and Development Institute (MARDI) and the Palm Oil Research Institute of Malaysia (PORIM). Also within proximity are several other bodies with a likely peripheral interest in wetlands. They are the Department of Agriculture in Serdang and the analytical laboratory of the Rubber Industry Smallholders Development Authority (RISDA) in Bandar Baru Bangi.

Several scientists from these institutions have already contributed to the project. Further research has the potential to raise the standing of these institutions as leaders on this specialised body of work which has a growing following.

Studies that can be undertaken include the physical and chemical processes that occur in the ecosystem — pollutant uptake by plants, their interaction with each other, sedimentation, pests and diseases, indigenous flora and fauna and the general workings of constructed wetlands.

By constructing Putrajaya Wetlands, a unique wildlife habitat has been created. Yet another branch of the sciences can undertake studies on the change of flora and fauna, their behaviour and habits. Migratory birds, even mammals, can be tagged to study their movements. It would be interesting and useful to study the succession of wetland plant species and the mosaic pattern of the flora.

The research will help improve our understanding of the factors that govern the performance of man-made wetlands in tropical conditions. It will also help in the long term operation and maintenance of Putrajaya Wetlands.



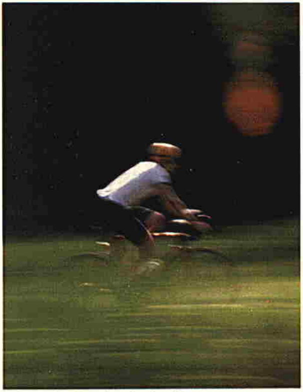
Much research can be undertaken on the environmental science of wetlands

Bird watching in the "green corridor" of Putrajaya which includes Putrajaya Wetlands, Taman Wetland, Taman Botani, Taman Putra Perdana, the Nursery and the Promenade

Chapter 15

THE ECOTOURIST DESTINATION

Putrajaya has been planned and built to reflect the concept of A City In A Garden. Much space has thus been dedicated to public parks, gardens and water bodies — oases of tranquillity for those seeking refuge from the pressures of modern urban living. These nature spots are all within a five kilometre radius of the Putrajaya city centre and 25 kilometres from Kuala Lumpur, making Malaysia's new Federal Government Administrative Centre a highly accessible and desirable ecotourist destination.



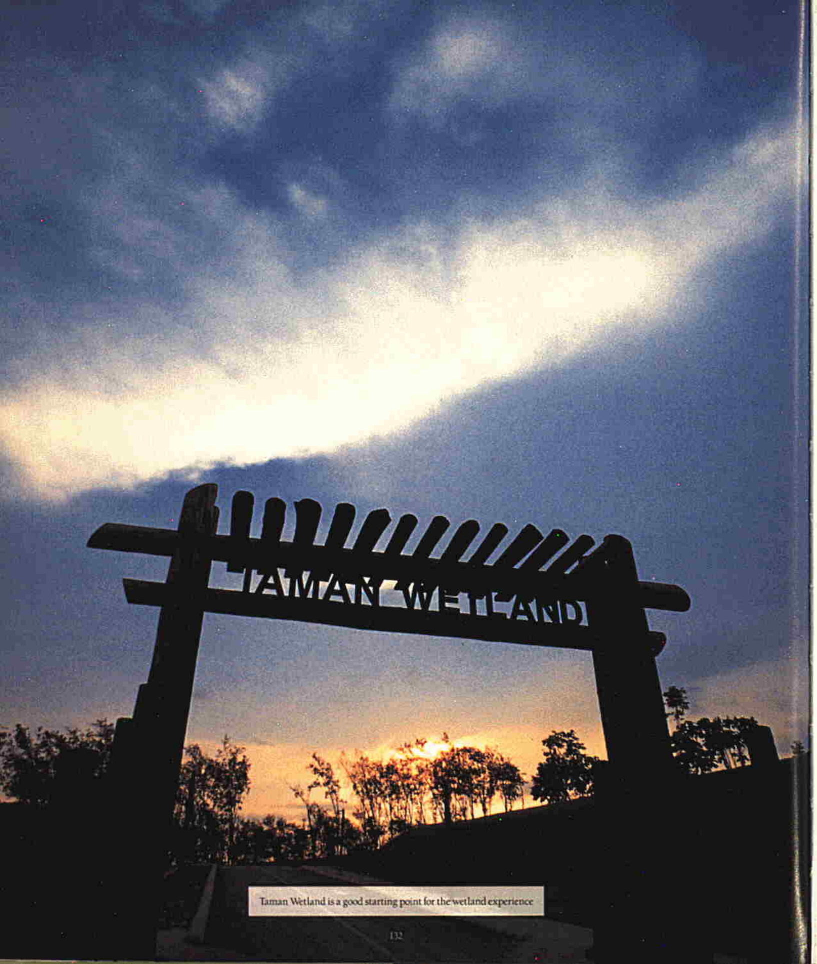
Cycling in the public parks and gardens of Putrajaya

The ecotourism appeal of Putrajaya lies in the development of a series of parks and gardens that have merged to form a unique ecosystem, which is a vibrant corridor of wildlife and vegetation.

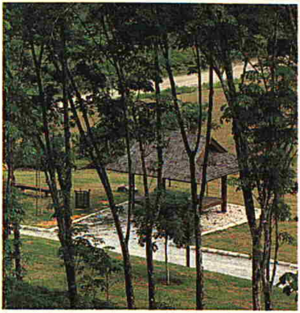
The centrepoint here may well be Putrajaya Wetlands, the transit area occurring between terrestrial and deepwater environments, and offering visitors the best of both worlds. However, the wetlands is best enjoyed and understood when seen in the context of adjoining natural attractions that complement one another and meld into a seamless area of "green".

These "green" attractions are:

- Putrajaya Wetlands
- Taman Wetland
- Putrajaya Lake
- Riparian Parks
- The Nursery
- Taman Putra Perdana
- Taman Botani
- The Promenade



Taman Wetland is a good starting point for the wetland experience



Taman Wetland has several rest areas and walking tracks

Putrajaya Wetlands

The starting point of any visit to the wetlands must surely be the Taman Wetland Nature Interpretation Centre, which traces the development of Putrajaya Wetlands, highlighting the importance of this constructed environment. There are also guided tours to the wetlands from the centre.

Visitors can also gain access to the wetlands along boardwalks, nature trails and cycling treks, to partake in recreational activities such as nature appreciation tours, bird hikes, fitness walking, cycling, canoeing and picnicking.

Taman Wetland

Taman Wetland is very much the public face of the wetlands. It occupies an undulating ridge offering panoramic views of the wetlands from several constructed vantage points. It also has a network of footpaths that encourage a walking tour of the park to enjoy a diversity of indigenous Malaysian flora.

Essentially, Taman Wetland serves as a green buffer to the wetlands. It is designed to perform the following functions:

- to act as a catchment area for the wetlands;
- to reinstate and rehabilitate the natural environment of the area;
- to complement the total development of Putrajaya as A City In A Garden.

Given this role, Taman Wetland is a landscaped park with a variety of flora. It contains pockets of rubber trees, oil palm and emerging secondary forest that were once part of the cultivated site of Putrajaya. This helps keep the soil intact (prevent soil erosion) and protect the habitat of flora and fauna found in the former plantation land. The remaining areas have been revegetated with diverse plant species to encourage biodiversity on previous land use which was essentially monoculture.

Much effort was expended in restoring damaged ecosystems and reinstating the land into a park for controlled and limited usage, namely passive recreation and educational pursuits.

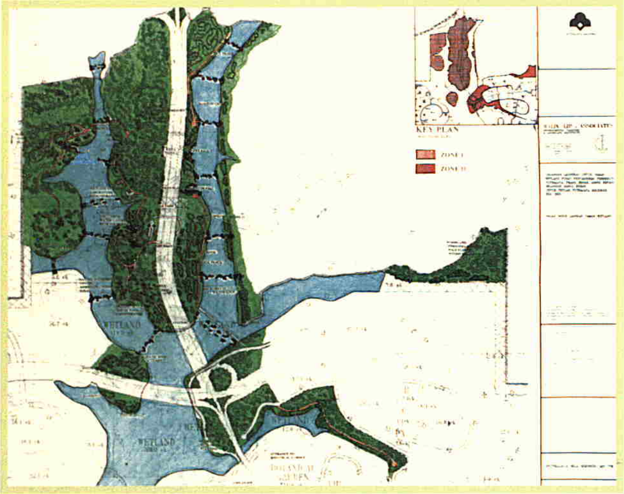
The initial attempt to restore biodiversity involved the planting of a range of plant species. Selection was based on four groupings: forest species, ecological plantings, rare fruit trees and a bambooreatum.

Groves of indigenous fruits have been planted in Taman Wetland

Each of these groupings have taken into account the topography of Taman Wetland. Up in the hilly ridge, forest species dominate, while creeks and streams are ideal for fruit trees. Bamboo groves occur where the land slopes towards the wetlands. Associated species such as *pulai paya (Alsonia spatulata)* and *gelam (Melaleuca lucadendron)* are used as an interfacing buffer with wetland plantings.

More importantly, Taman Wetland has the makings of a research centre, particularly in fruit tree cultivation. The possibility of research and development in fruit species will help popularise rare fruits and also lead to the development of commercially viable strains. This is a natural resource that merits greater study.

Bamboo cultivation in Taman Wetland is another area for further research. Bamboo is planted on the hilly terrain in the upper reaches of the Upper North Wetlands to control soil erosion and for research & development purposes. There is an estimated 29 varieties of bamboo planted in Taman Wetland, from small variety species such as *Bambusa multiplex (buluh cina)* to tall varieties such as *Dendrocalamus asper (buluh betong)*. Extensive collections and propagation need to be undertaken to further enrich what is currently available in the bambooreatum.



The layout of Taman Wetland

The beautifully landscaped Taman Wetland has several amenities and facilities for family outings

Putrajaya Lake

Putrajaya Lake is the centre of eco-friendly recreational activities, which are expected to invigorate the atmosphere of the city and enhance its potential as an ecotourist destination.

Water-based activities permitted on the lake include kayaking, rowing, swimming, dinghy sailing and windsurfing. Swimming, snorkelling, fishing and water cruises, however, are permitted only in designated areas while jet-skiing, parasailing and the use of diesel engine boats are strictly off-limits.

Among other things, the lake shore is ideal for bushwalking, birdwatching, jogging, cycling and relaxing. Waterfront facilities include picnic and barbecue sites, timber boardwalks, jetties, look-out points, restaurants, shops, parking lots and restrooms. For residents and visitors to enjoy the lake to the fullest, there are information centres to provide assistance.

A view from the look-out tower

Only environmentally-friendly water-based activities are permitted on the lake. Electric-powered boats are to be used for water cruises.



The parks and gardens of Putrajaya showcase a variety of plant and animal life

Riparian Parks

Putrajaya has several riparian parks, which function as mini wetlands in residential areas along the lake front. Riparian parks are low-lying with a variety of water depths, making them an ideal habitat for some flora and fauna.

Access to the riparian park is by boardwalks extending into the wetlands. The parks also have informal educational facilities explaining the ecological necessity of riparian parks.

Landscaping here focuses on simple structures, construction techniques and materials.

There are close to 20 riparian parks in the residential areas

COLLECTIVE RESPONSIBILITY

The ecotourist attractions in Putrajaya are public areas designed to provide visitors with an enriching experience of a variety of natural habitats. It is therefore important that users take care of the places visited so others can enjoy them as well. Eventually they must be a worthwhile legacy for posterity.

Acts of courtesy and civic duty will go a long way to make Putrajaya a truly sustainable development. Some environmentally-friendly suggestions are:

- Walk on designated tracks and boardwalks;
- Picnic in designated areas;
- Use proper toilet facilities;
- Do not trample on vegetation;
- Do not feed animals (unless permitted);
- Do not blare music (especially where fishing enthusiasts and bird lovers gather);
- Do not litter (tie up garbage and place inside appropriate bins);
- Do not pick flowers or/and plants;
- Do not bring your pets (unless permitted);
- Please observe warning and other cautionary signs.

The environment is fragile and must be treated with respect and handled with care.

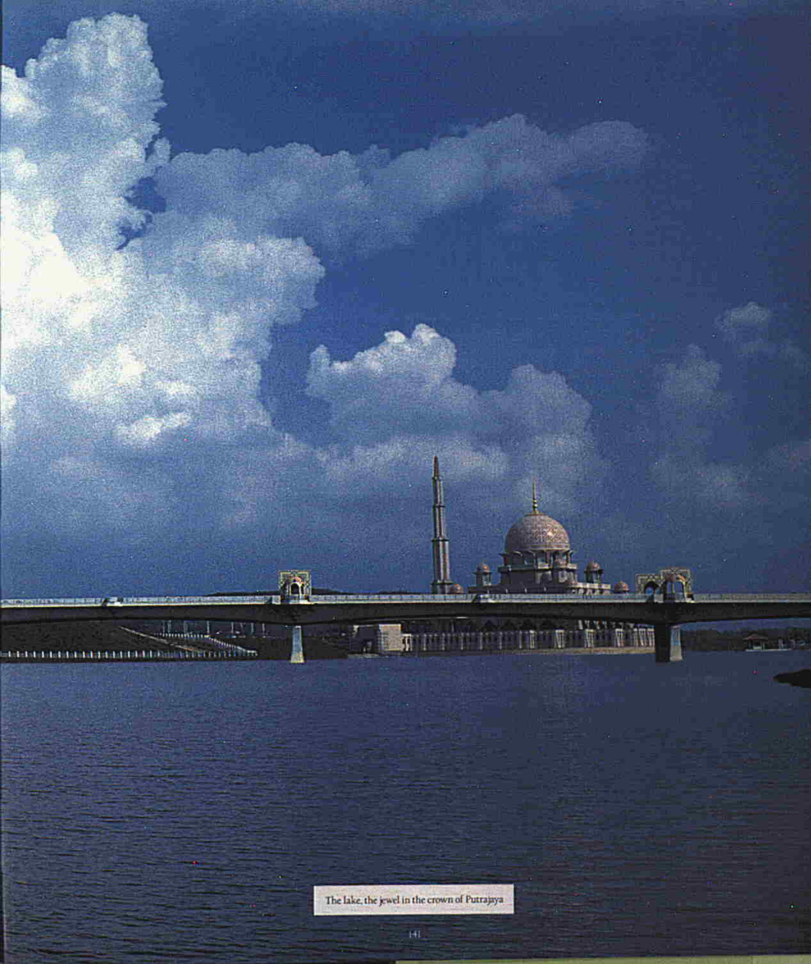
CONCLUSION

The construction of Putrajaya Wetlands is a statement of sustainable development; an attempt to demonstrate the harmonious co-existence of Man, Nature and the Environment. Herein, lies the challenge...

The wetlands must stir a sense of ownership and pride for the city's residents. A successful symbiotic relationship between people and wetlands augurs well for the future of similar projects.

Man-made wetlands for water resource management in towns and residential areas will spell an end to odorous waterbodies and open drains. Instead, dense population centres will be relieved by tranquil wetlands in their midst. Meanwhile, riverine basins in urban, industrial and agricultural areas that have been sculpted by man-made wetlands will have cleaner water draining into the rivers and seas.

Constructed wetlands have thus become a viable option for urban water resource management.



The lake, the jewel in the crown of Putrajaya

GLOSSARY

Absorption The taking up of one substance at the surface of another

Anaerobe Any organism that can live in the absence of free oxygen

Aquaculture The management and use of water environment for the raising and harvesting of plant and animal food products

Aquifer A water bearing formation capable of yielding useful quantities of water to bores or other extraction facilities

Base flow The flow of water in a stream that is derived from ground water that has been recharged by water infiltrating soil. Springs are a common source of base flow

Biodegradable Broken down naturally by micro-organisms

Biodiversity The variety of life forms, the different plants, animals and micro-organisms, the genus they contain and the ecosystem they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity

Biomass Total mass (usually measured as dry weight) of all living organisms in a particular area

Brackish Slightly saline water, with a salt concentration between that of salt water and freshwater

Canopy Crown portion of a tree, including leaves and branches

Compost Decomposed organic matter

Denitrification The loss of nitrate from the soil through the action of various denitrifying bacteria, which use nitrate as the terminal election acceptor during anaerobic respiration

Emergent plants Aquatic plants that emerge above water

Ephemeral Not permanent

Eutrophication The degree of biological productivity of a water body is one of the most important aspects of water quality. Eutrophic water has high levels of phytoplankton growth that leads to serious deterioration of its water quality, depletion of oxygen in bottom waters, significantly reduced aesthetic appeal and the reduction in other uses

Evapotranspiration Transfer of water to the earth's atmosphere as a result of evaporation from the land and transpiration from animals and plants

Fauna Assemblage of animal species, including insects, etc

Flora Assemblage of vegetable species, including plants, algae, fungi, etc

Frugivorous Feeding on fruits

Geomorphological Deals with the branch of geology that is concerned with the structure, origin and development of the topographical features of the earth's crust

Granivorous	Feeding on grains
Herpetofauna	Members of the reptilian and amphibian group
Hydrological	An adjective that refers to the movement or study of water
Hymenopterans	Insects belonging to the Order Hymenoptera, for example, bees and wasps
Inorganic	Chemical elements and their compounds, other than the compounds of carbon; however, the oxides and sulphides of carbon and metallic carbides are generally included as inorganic
In situ	At the site
Insectivorous	Feeding on insects
Leachate	Soluble nutrients or organic or mineral matter originally stored in soil or vegetation which are washed downwards through the soil by rainwater
Leguminous	Belonging to the legume (bean) family
Littoral	Strip of land along the water's edge
Macrophytes	Emergent plants that grow permanently on submerged land
Microbial biomass	Total dry weight of all living organisms in a given area which requires a microscope to be seen. They include algae, plankton, bacteria, fungi, micro crustaceans and micro invertebrates
Nectarivorous	Feeding on nectar
Nitrification	The oxidation of ammonia to nitrite and nitrate by chemautotrophic bacteria whose energy requirements come from these exergonic reactions
Nitrogen Cycle	The circulation of nitrogen between living organisms and the environment
Organic	Compounds of carbon. Owing to the ability of carbon atoms to combine in long chains, these compounds are far more numerous than those of other elements. They are the basis of living matter
Peat	A black or dark brown mass of partially decomposed plant material formed under anaerobic conditions in a waterlogged environment
Riparian	Inhabiting bank of river, pond or lake
Submergent plants	Plants that grow below the water level
Substratum	The substance to which an organism is attached or over which it travels or grows
Tributary	A stream that runs into another
Under-storey	Growing in shade
Weeds	Undesirable plants

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