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MARD/MDS PROJECTS

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A WETLAND ASSESSMENT OF ZONES 1 & 5

MAHAWELI AGRICULTURE AND RURAL DEVELOPMENT PROJECT

by

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MARD/MDS PROJECTS
PIMBURATTAWA

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EXECUTIVE SUMMARY

1.0 Purpose and Scope of Wetland Assessment

This assessment was carried out from June 5 to August 5, 1992 to: (1) inventory wetlands remaining in Zones 1 and 5, assess their quality, and make recommendations for their conservation; (2) assess the potential for incorporating natural or constructed wetlands into developed areas in Zones 1 and 5 and provide general design criteria for constructed wetlands; (3) examine and assess wetland conditions in Block 503 and make recommendations for conserving natural wetlands as the Block is developed; (4) provide recommendations and design criteria for incorporating constructed wetlands into the irrigation development for Block 503; (5) provide a general assessment of the villu wetlands adjacent to Zone 1; (6) provide a plan for management and monitoring of constructed wetlands to be installed; and (7) assess the state of forest green belts along the Kuda and Maduru Oyas and make recommendations for protection and/or renovation.

2.0 Definition of Wetlands and Criteria for Wetland Delineation

Wetland ecosystems are transitional between uplands and aquatic ecosystems. All wetlands share three characteristics that are are used by the U.S. government to delineate jurisdictional wetlands that are protected under U.S. Law: Wetlands are (1) **dominated by hydrophytic vegetation**, (2) **underlain by hydric soils**, and (3) **occupy sites having a wetland hydrology.**

3.0 Role of Wetlands in the Landscape

In recent years there has been a growing realization that wetlands are valuable components of the landscape. Wetlands are among the most productive ecosystems on earth; serve as important water storage areas; and act as filters by removing pollutants from waters passing through them--indeed, wetlands have been called the "kidneys of the landscape." Natural and constructed wetlands are used for treating municipal sewage, acid mine drainage, industrial effluent, effluent from animal confinement operations, and show particular promise for treating non-point sources of pollution such as runoff from agricultural fields. Wetlands also serve as vital wildlife habitat and nurseries for fish and shrimp, watering and bathing sites for cattle and buffalo, and sources of food and fiber.

4.0 Current Wetland Conditions in Zones 1 and 5

1. **Climate and Hydrology:** Much of the project area exhibits typical wetland hydrology, especially during Maha. Added irrigation flows result in saturated soil conditions even during the Yala.

2. **Soils:** Lowland areas in the project area are dominated by poorly drained alluvial soils. Such soils are particularly abundant in Zone 5 and cover 88% of Block 503. These soils exhibit well developed gley layers and are, therefore, <u>hydric</u>.

3. **Vegetation:** Hydrophytic vegetation, comprising plant species that are specially adapted to living in areas where the substrate is saturated, is common throughout Zones 1 and 5. It is most evident in villus, in shallow areas in and on the margins of tanks, in shallow stream beds, on the banks of larger streams, and in impounded areas along roads and dikes, all areas recognized as marshy or swampy and "officially" classified as wetland.

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4. **General Wetland Conditions in Zones 1 and 5:** Much of the project area is a "wetland waiting to happen." All conditions exist for the natural succession of wetland vegetation on any site where natural or man-made factors lead to the saturation of the soil for an extended period of time. Prior to extensive human habitation and cultivation, this area undoubtedly functioned as a giant sponge, capturing water during Maha and releasing it gradually during the dry months. This storage and release would have moderated flood conditions and increased stream flows during the dry months. Scattered wetlands occupying flood plains and low areas in the landscape, would have filtered and purified waters draining through them. Human intervention has altered this landscape dramatically in areas such as Zones 1 and 5.

5. **Villus:** Villus are freshwater marshes and lakes that occupy low areas in river flood plain. The Handipan, Bendiya and Gengala Villus lie in the Mahaweli Ganga flood plain adjacent to Zone 1. These riparian wetlands have been deprived of much of their flood water input because interbasin diversions have lowered the flow of the Mahaweli Ganga. There is concern about the impact that this might have on Yala grazing and villu fisheries. There is also concern about water quality of drainage flowing from Zone 1 into these villus, especially the possible impact that pesticides in these waters might have on cattle, fish, and ultimately humans. In spite of reduced flood inputs, these villus supported healthy wetland vegetation in shallow areas and appear to be adjusting to the new hydrologic conditions. No information is available about water quality of drainages from Zone 1.

6. **Tanks:** In Zones 1 and 5, 43 tanks occupy a total of 1,739.36 hectares. Wetland conditions occur in most of these tanks where water depth is less than 1 meter. Many of these palustrine wetlands are of high quality and are contributing to water purification, providing habitat and nursery areas for wildlife, and serving the needs of local human communities.

7. **Impoundments:** In Zones 1 and 5, any natural or man-made obstruction is likely to result in the creation of wetlands. Artificial and natural impoundments on the Kuda Oya and Narana Ela have created ponds that support hydrophytic vegetation at least along their banks, roads and broken culverts have stimulated the development of marshy areas, and seepage under tank dams also creates wetlands. Some of these wetlands are of low quality and should be drained. Others, however, are high quality wetlands, so situated in the landscape that they provide water storage and purification, water sources and bathing areas for livestock and humans, and other services and amenities. These wetlands should be preserved.

8. **Drainage Water Quality:** Little information is available on the water quality of agricultural drainage waters in Sri Lanka, including the project area. There is serious concern about probable high concentrations of pesticides and herbicides in these waters, and nitrate and phosphate levels in drainage and runoff are also probably high. Strategically placed wetlands might remove many of these pollutants.

9. **Habitat and Wildlife:** There has been an overall increase in waterfowl and possibly crocodile habitat as a result of development activities in Zones 1 and 5. Elephant habitat, however, has been seriously diminished and will be diminished further by development of Block 503, with a concommitent increase in elephant-human conflict.

10. **Wetland Conditions in and Adjacent to Block 503:** Natural wetlands occur on the small stream draining Block 503, in the channels of the Narana Ela and Kuda Oya, and on the riparian flood plain of the Kuda Oya. All of these wetlands are providing water storage and purification and should be conserved. A few shoreline wetlands occur along the bank of the Maduru Oya, but these are neither extensive nor well developed.

11. **Riparian Forests Adjacent to Block 503:** Riparian forests along the Kuda Oya are in poor condition and those along the Maduru Oya and Narana Ela are in even worse condition. Bank erosion is a serious problem, and reforestation is a critical need. Similar conditions exist in the riparian forests along the braids of the Kuda Oya, but erosion here is less because the current is slower.

5.0 Impacts of Block 503 Development

Irrigation development in Block 503 could eliminate wetland areas along the central drainage, and improvement of the Kuda Oya adjacent to 503 could have catastrophic impact on riverine wetlands in the main channel of the Kuda Oya, riparian wetlands occupying its braids and flood plain, and riparian forests along both banks. Development activities should be designed to conserve these resources. A No Development strategy will not halt development in Block 503. Second generation farmers are already encroaching in the Block and this trend will continue. Plus, cancellation of development will adversely impact areas in Block 502 and Zone 2 that will continue to be flooded by the Kuda Oya. Rational development is preferred. Measures such the construction of wetlands in Block 503, setting Kuda Oya flood dikes outside the river braids and the riparian forests, and appropriate reforestation will eliminate or mitigate undue damage to natural systems.

6.0 Retrofitting Wetlands into Zones 1 and 5

Volunteer wetlands abound in Zones 1 and 5. Guidelines are provided for identifying which of these wetlands should be conserved and which can be drained without undue impact on drainage water quality, wildlife habitat, or other wetland benefit. Guidelines are also provided for identifying sites for future retrofitting with constructed wetlands. Examples are provided. It is recommended that extensive retrofitting with constructed wetlands be deferred until information becomes available from monitoring studies on constructed wetlands in Block 503.

7.0 Recommendations

1. Drainage gradients in Block 503 should be established so that the deeper areas along the braided stream draining the center of the Block and which hold standing water into the summer are conserved.

2. Constructed wetlands should be installed at three locations in Block 503 strategically placed and designed to capture and filter water in Drainages A, B, and C.

3. Channelization of the Kuda Oya basin should be limited to removing anticuts and logs from the main channel, and dikes should be located well outside the wetlands occupying the small braids of the Kuda Oya and the riparian forests along both banks. No living trees should be removed from the channel or banks.

4. A tree planting program should be initiated to restore native riparian forests in bands at least 40 meters wide along both banks of the Kuda Oya and Narana Ela and on the left bank of the Maduru Oya adjacent to Block 503. Trees should also be planted on islands that lie between the main channel of the Kuda Oya and its small braids.

5. Effort should be made to stimulate the development of fuel wood plantations in the area to relieve fuel wood gathering pressure on riparian forests.

6. A program should be initiated to monitor water quality at the control structures on the constructed wetlands in Block 503, on a major drainage system in Zone 1, and on an impounded wetland in Zone 5.

7. Careful consideration should be given to minimizing the draining of impounded wetlands in the developed Blocks of Zones 1 and 5, but extensive retrofitting with constructed wetlands is not recommended at this time.

8. MARD extension specialists should work with local farmers and their families, especially those adjacent to any wetlands being protected and monitored, to inform them of the value of the wetlands. Extension specialists might also offer wetlands workshops for school teachers. Local wetlands could serve as teaching laboratories for biology classes.

9. A demonstration project should be undertaken to examine the use of constructed microwetlands for human sewage treatment at the farm or hamlet level.

10. US AID should provide support for the development of programs for short-term training and long-term education of wetland managers.

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FIGURE CAPTIONS

Figure 1. System B: Mahaweli Agriculture and Rural Development (MARD) project area showing Zones 1 and 5, including Block 503.

Figure 2. Main drains in Zones 1 and 5. Proposed water quality monitoring station is located at point "A" on MARD Road in Zone 1. Natural Narana Ela wetland is located at site "B" and the D4/502 saturated cropland area is located at point "C."

Figure 3. Natural drainages in Block 503, System B. Deeper wetland areas are indicated by cross hatching.

Figure 4. Portion of Zone 5. (A) Natural wetland that has developed behind a weir on the Narana Ela (cross hatch) and its drainage basin. (B) The D4/502 saturated cropland area and potential wetland site (cross hatch). (C) Divergence of the Narana Ela from the Kuda Oya at the southern tip of Block 503.

Figure 5. Preliminary infrastructure design for Block 503 development including the main supply canal system and dikes on the Kuda and Maduru Oyas and Narana Ela. (A) Dike to redirect Narana Ela flows through the central channel of Block 503. (B) Dike to cut off the southern end of this major braid of the Kuda Oya, converting it into a drainage channel from Block 503. (C) Dikes to prevent Kuda Oya flood waters from flooding cropland in Zone 2. (D) Dikes to prevent Maduru Oya waters from flowing into the central channel of Block 503.

Figure 6. Principal drainage basins associated with Block 503 development. (A) Drains approximately 200 ha. (B) Drains approximately 550 ha through the central channel. (C) Drains approximately 250 ha.

Figure 7. Map showing the braids of the Kuda Oya and proposed riparian forest zones associated with Block 503. Riparian forests on the Kuda and Maduru Oyas should be 40 meters wide and those on the Narana Ela should be 20 meters wide. Flood control dikes should be located outside the riparian forest zones.

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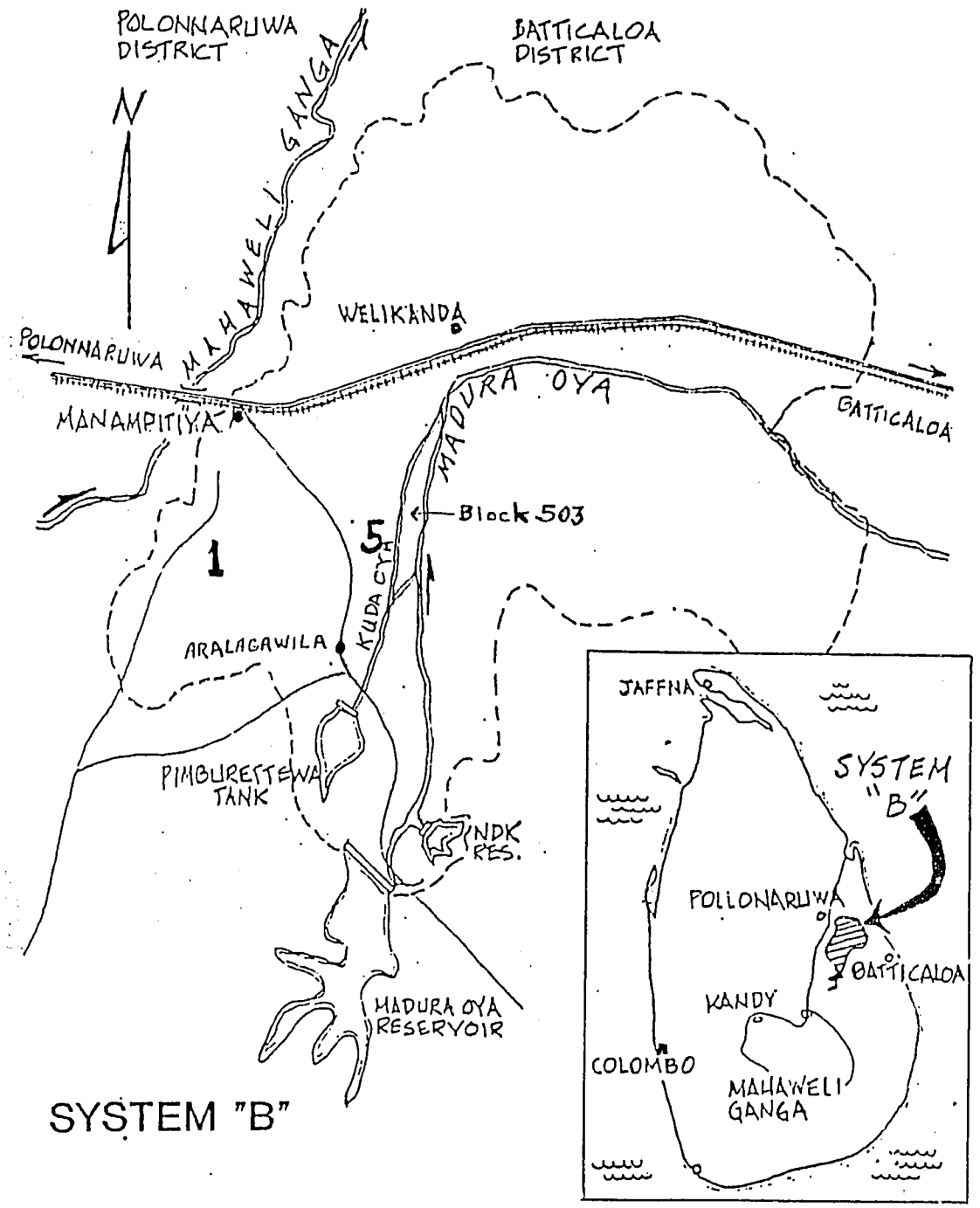
POLONNARUWA DISTRICT
BATTICALOA DISTRICT
N
MAHAWELI GANGA
WELIKANDA
POLONNARUWA
MANAMPITIYA
MADURA OYA
BATTICALOA
Block 503
5
1
KUDA OYA
ARALAGAWILA
PIMBURETTEWA TANK
NDK RES.
MADURA OYA RESERVOIR
SYSTEM "B"
JAFFNA
SYSTEM "B"
POLLONARUWA
BATTICALOA
KANDY
COLOMBO
MAHAWELI GANGA

FIGURE 1

10

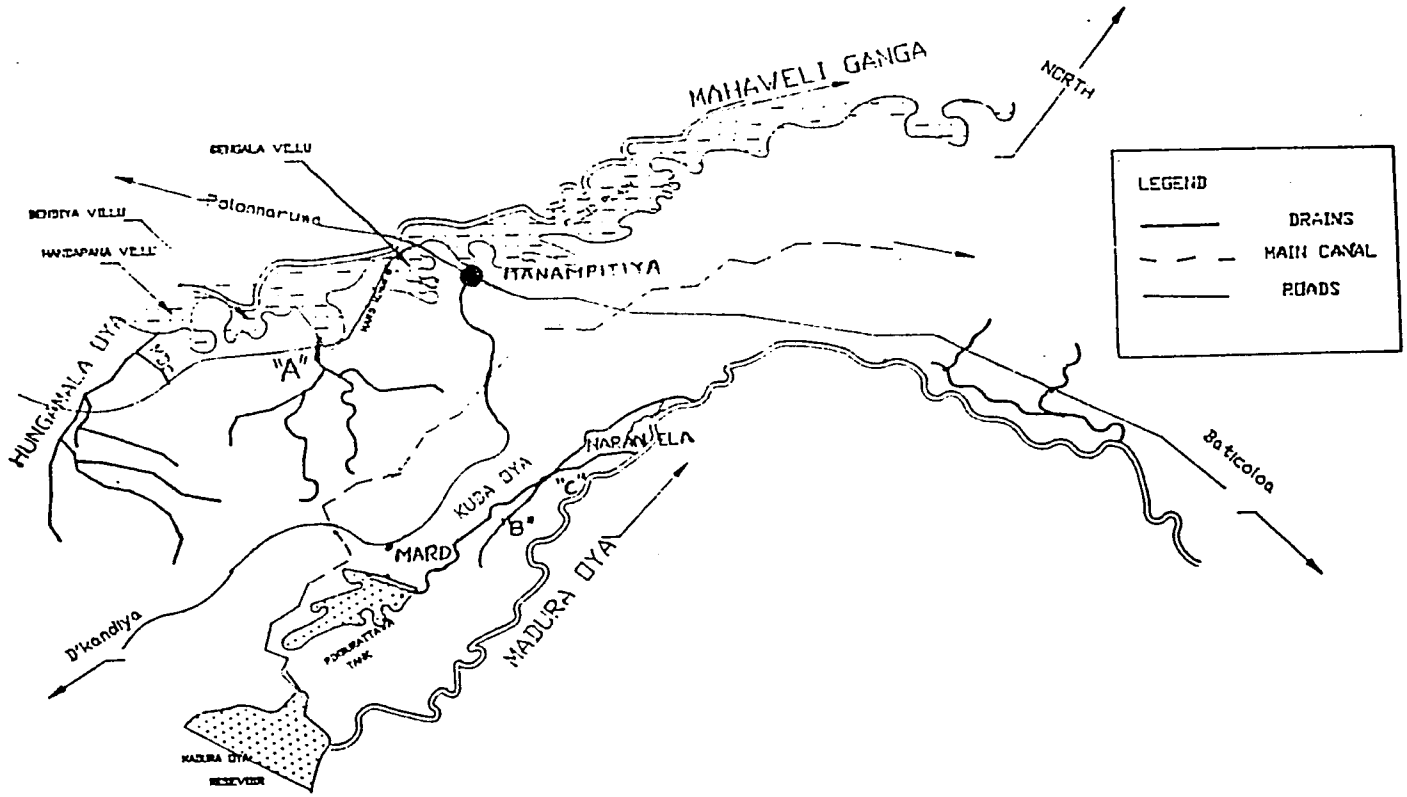
MAHAVELI GANGA
NORTH
LEGEND
DRAINS
MAIN CANAL
ROADS
SEMGALA VELLU
Polonnaruwa
MANAMPITIYA
"A"
HUNGANALA OYA
KUDA OYA
NARAN ELA
"C"
"B"
MARD
MADURA OYA
Batticaloa
D'kandiya
POOLBATTANA TANK
MADURA OYA RESERVOIR

FIGURE 2

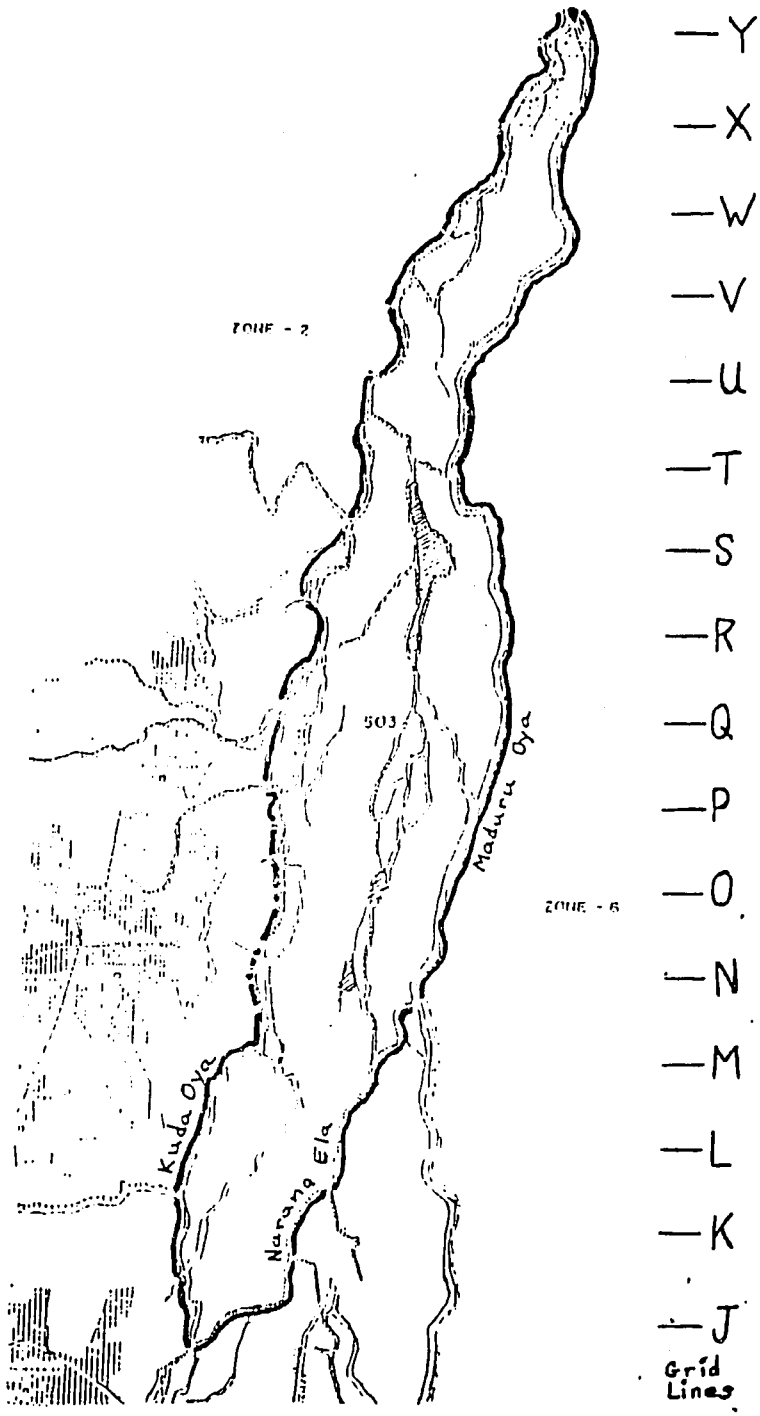
ZONE - 2
503
Madurk Oya
ZONE - 6
Kuda Oya
Narang Ela
Y
X
W
V
U
T
S
R
Q
P
O
N
M
L
K
J
Grid Lines

FIGURE 3

x

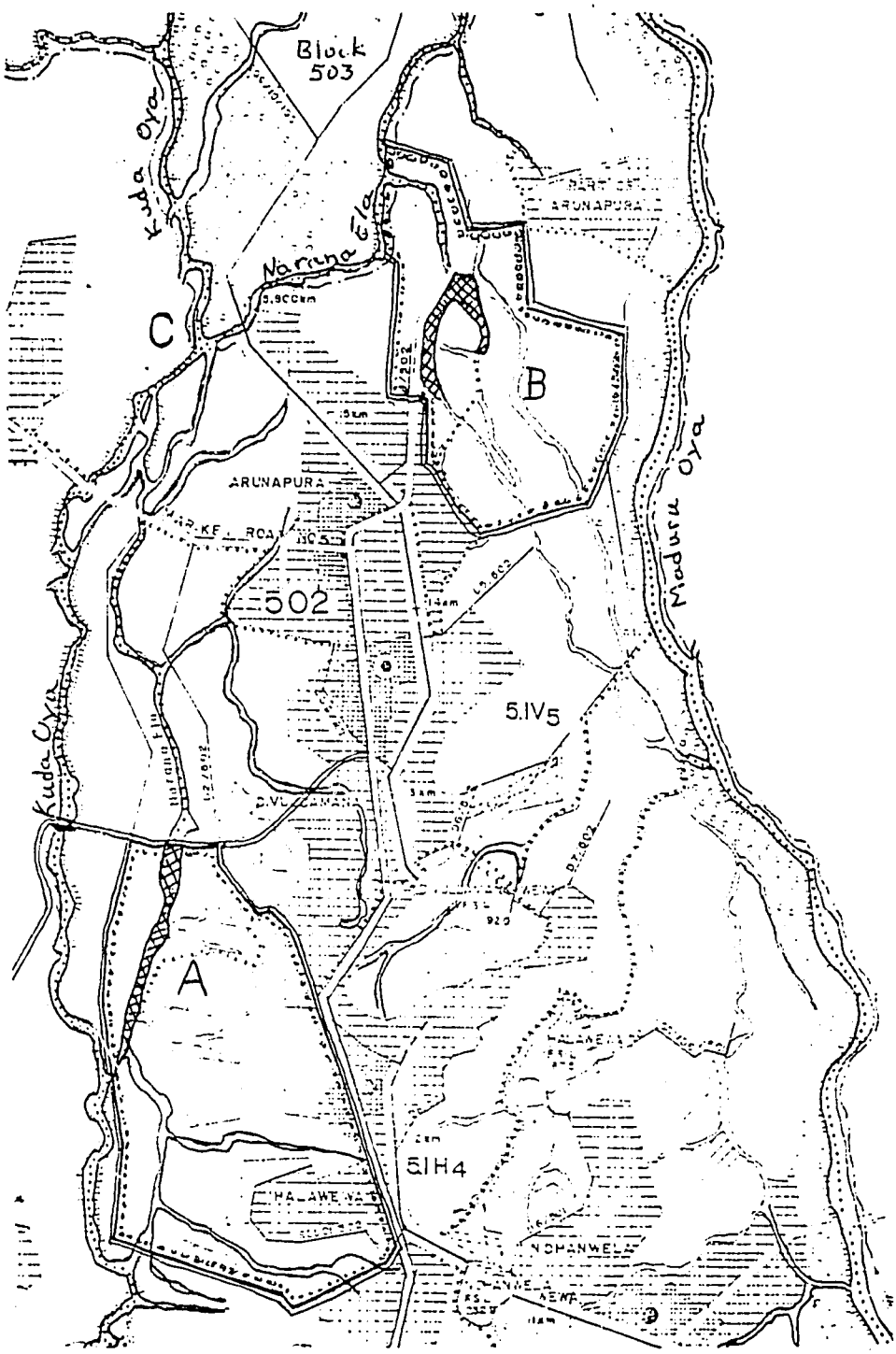
Block
503
Kuda Oya
Narana Ela
C
B
ARUNAPURA
ARUNAPURA
502
5.IV5
Madura Oya
Kuda Oya
A
5.IH4
NOHANWELA

FIGURE 4

13

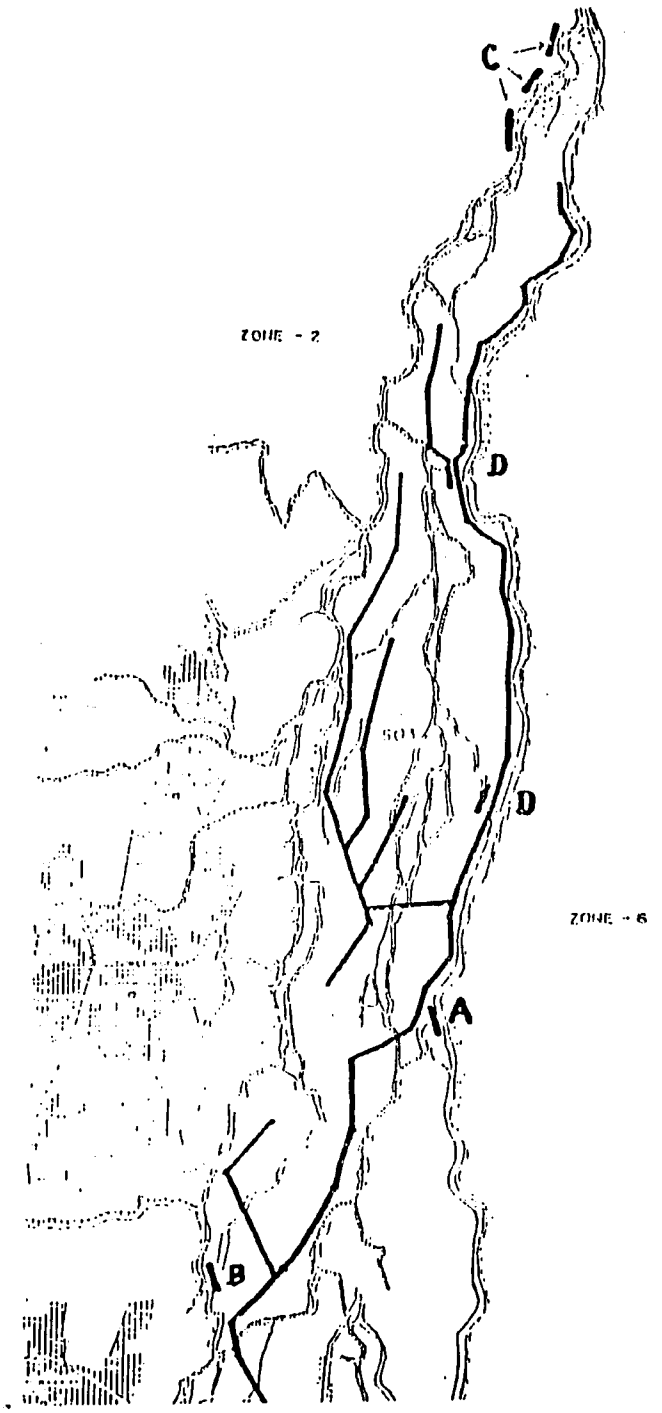

FIGURE 5

14

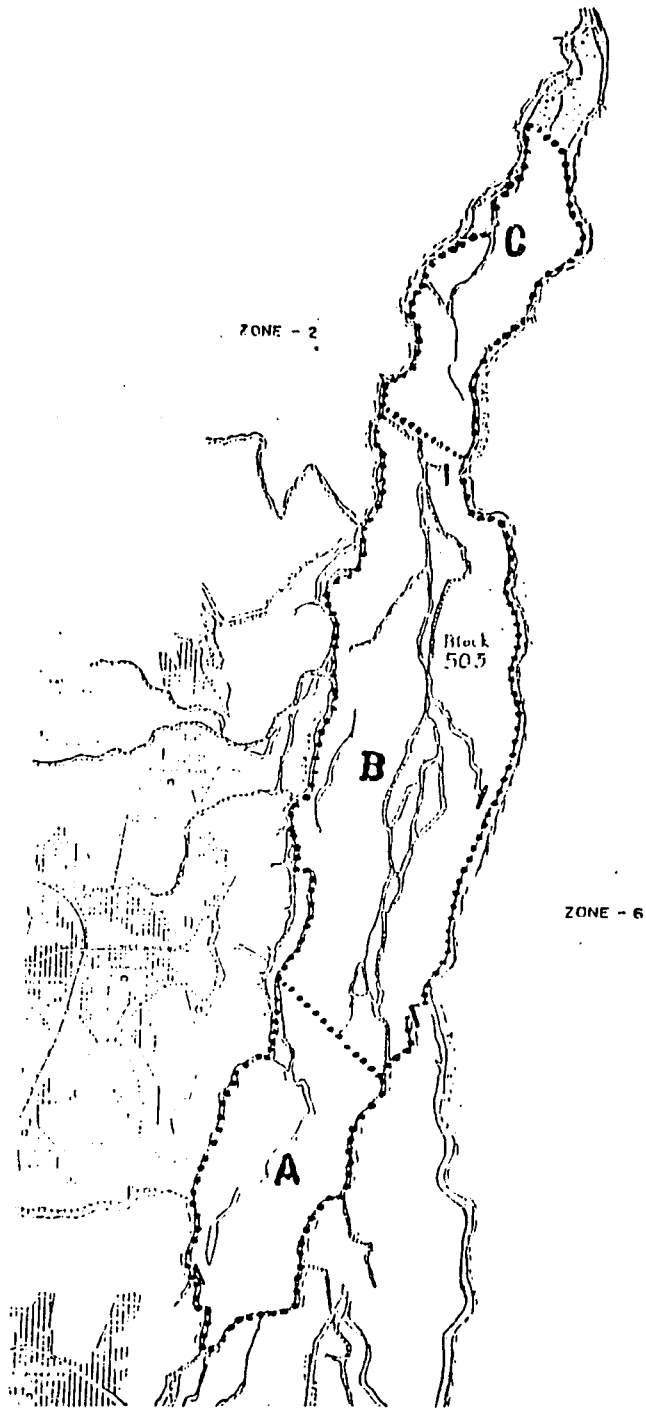

FIGURE 6

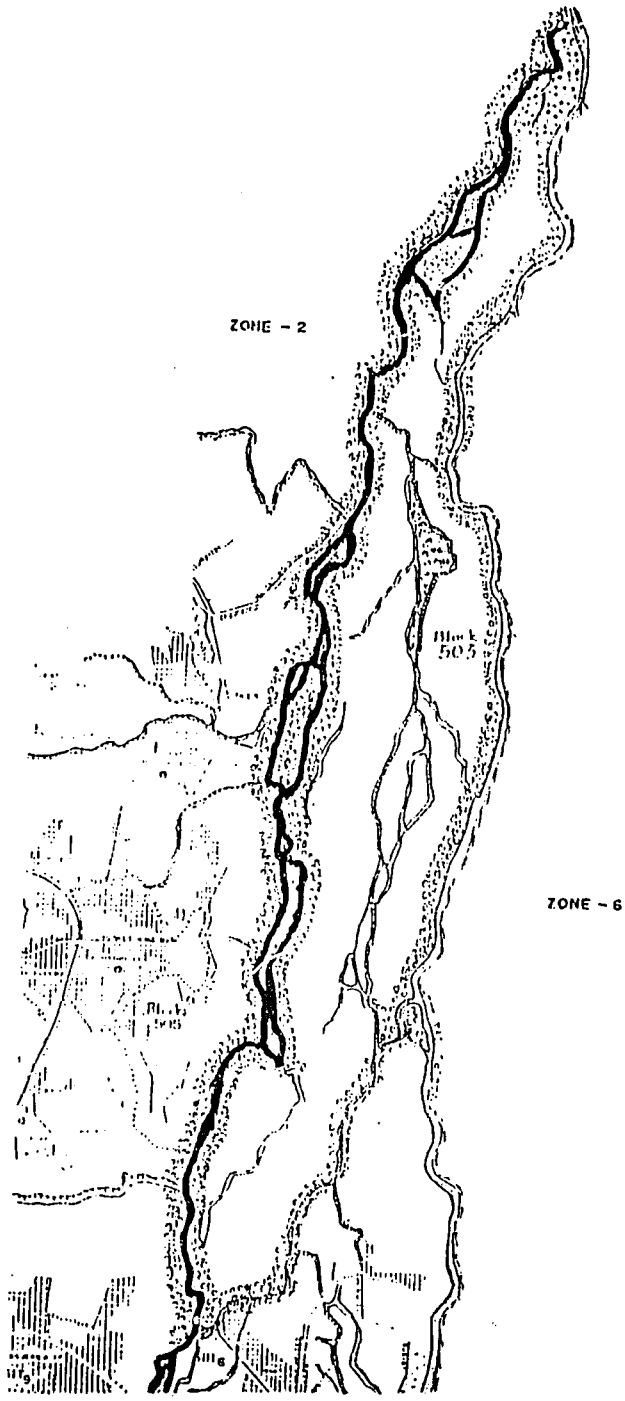

FIGURE 7

16

1.0 Introduction

1.1 Purpose and Scope of Wetland Assessment

An environmental assessment (EA) of a proposed amendment to USAID's Mahaweli Agriculture and Rural Development Project (MARD) was carried out from February 18 through March 15, 1992. This amendment calls for the creation of 1,000 hectares of irrigated land by expanding irrigation and drainage infrastructure to Block 503 of System B (MARD/MDS, 1991) and the improvement of irrigation and drainage in Zones 1 and 5 of System B.

The EA noted that while activities under the proposed amendment would result in an overall improvement of environmental conditions in the project area, there are concerns about potential adverse impacts on existing wetland ecosystems, riparian forests, and water quality of drainage effluent. Special concern was experessed for potential adverse impacts associated with proposed development in Block 503. The EA recommended that MARD contract the services of a wetland ecologist to assess the status of existing wetlands in Zones 1 and 5, recommend measures for conserving remaining wetlands, determine the feasibility of constructing new wetlands to promote filtration of waste water and enhance wildlife habitat, provide construction designs for constructed wetlands, and provide extension training for farmer organizations and regional agricultural extensionists. Further, the EA recommended that "wherever possible, the proposed drainage improvements can be designed in a manner that facilitates artificial wetland development." Finally, the EA recommended that "land development measures, particularly those to occur in Block 503, must not result in the removal of stream side vegetation," and that wherever possible stream side vegetation should be restored along the Kuda Oya and Maduru Oya.

This Wetland Assessment was undertaken in response to these EA recommendations. The assessment was carried out in System B from June 5 to August 5, 1992. The following scope of work was established by MARD and USAID:

1. Conduct an inventory of wetlands remaining in Zones 1 and 5, assess the current quality of these wetlands, and make recommendations for their conservation.

2. Assess the potential for incorporating natural and constructed wetlands into existing irrigation and drainage systems in Zones 1 and 5, make recommendations for retrofitting with constructed wetlands to enhance effluent water quality, and provide general design criteria for such wetlands.[1]

3. Examine and assess wetland conditions in Block 503 and make recommendations for conserving and/or enhancing extant natural wetlands as the Block is developed.

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[1]Design criteria for constructed wetlands are site dependent. Therefore, detailed design specifications must await the identification of precise locations for such construction and assessments of hydrologic and soil conditions on the selected site. General wetland design criteria should be used in project planning to insure that appropriate locations are selected for wetland construction.

4. Provide recommendations for incorporating constructed wetlands into the irrigation development for Block 503, provide general wetland design criteria, and work with MARD engineers on preliminary plans for incorporating constructed wetlands into Block 503 development[2].

5. Provide a general assessment of the villu wetlands adjacent to Zone 1 and make recommendations regarding their protection, conservation, and possible use in the treatment of effluent waters from Zone 1 and of waters from the Hungamala Oya and Mahaweli Ganga.

6. Provide a plan for management and monitoring of constructed wetlands to be installed.

7. Assess the state of forest green belts along the Kuda and Maduru Oyas and make recommendations for protection and/or renovation.

1.2 Assessment Procedures

A general field survey of wetlands and aquatic areas in Zones 1 and 5 was carried out, with special attention to wet areas in and associated with Block 503. Structure Plans were used to locate existing wetlands associated with Wewas (reservoirs and tanks), villus (flood plain wetlands), Oyas (larger rivers), elas (small streams), irrigation supply canals, drainage canals, and impoundments (roads, berms, dikes, etc.). A detailed soil survey (Dimantha, 1992), 4 chains to 1 inch engineering survey sheets, and the preliminary engineering design for infrastructure development facilitated assessment of current conditions and opportunities for wetland and riparian zone conservation and enhancement in block 503.

Wetland delineations in Block 503 were made according to the MANDATORY TECHNICAL CRITERIA FOR WETLAND IDENTIFICATION set forth in the Federal Manual for Identifying and Delineating Jurisdictional Wetlands (Federal Interagency Committee for Wetland Delineation, 1989; See APPENDIX B). Field surveys carried out during six east-west traverses in Block 503 revealed that drainage channels supported a distinctly hydric vegetation and that deeper areas along the drainage were dominated by hydrophytic plants. Based on these survey results and the availability of studies that show that these areas exhibit wetland hydrology and hydric soils, wetland delineation was considered to be "routine." However, to verify the presence of hydric soils on sites supporting hydrophytic vegetation, soil pits were excavated at selected locations in the drainage basins and adjacent uplands. Plant identifications were verified at the National Botanical Gardens Herbarium at Peradeniya.

Twenty nine interviews were carried out in the field with farmers, fishermen, and reed gatherers to determine the location, use, and value of local wetlands.

2.0 Definition of Wetlands and Criteria for Wetland Delineation

Ecologists define wetlands as ecosystems that are transitional areas between uplands and open water ecosystems such as lakes, ponds, rivers, and oceans. Wetland ecosystems include swamps, marshes, bogs, mires, springs, fens, mud flats, and rocky shores, depending upon local climatic and soil conditions and vegetation. Wetlands can be large or small, fresh or saline, vegetated or nonvegetated. All wetlands share three

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[2]Engineers preparing the final engineering designs for Block 503 must understand the general criteria for constructed wetlands so they can position such wetlands appropriately in the landscape.

characteristics that are so consistent that they are used by the U.S. government to delineate jurisdictional wetlands that are protected under U.S. Law (Federal Interagency Committee for Wetland Delineation, 1989).

1. Wetlands are **dominated by hydrophytic vegetation**, plant species that are adapted to living in water or saturated soils where oxygen is often deficient in the substrate. These include emergent species such as cattails, rushes, and sedges; floating-leaves species such as lotus, water lilies, and Salvinia; and submersed species such as Potamogeton, Myriophyllum, and Ceratophyllum. These species are often considered to be "aquatic weeds," a label that denies their value to human society and to the landscape.

2. Wetlands are underlain by **hydric soils**, soils that are sufficiently waterlogged during the year that they develop anaerobic conditions in their profile, and

3. Wetlands occupy sites having a **wetland hydrology**, permanently or periodically inundated or saturated to the soil surface. Such hydrological conditions drive the formation of wetlands.

3.0 Role of Wetlands in the Landscape

Until recently wetlands were considered to be nonproductive wastelands and sources of poisonous gasses and disease. They were areas to be avoided or drained, and over the past century large areas of wetland in the United States have been drained, especially in the Midwest. In Ohio and Iowa, for instance, between ninety and ninety five percent of presettlement wetlands have been drained[3].

In recent years there has been a growing realization that far from being wastelands of no social or economic value, freshwater, saline, and coastal estuarine wetlands are vital and productive components of the landscape that provide services to human society that are invaluable. It turns out that wetlands are among the most, not the least, productive ecosystems on earth, rivalling the productivity of coral reefs and far exceeding the productivity of even the most productive agricultural systems. We now understand that wetlands serve as important water storage areas, absorbing precipitation and flood waters like a sponge and releasing them gradually to effluent streams. Wetlands also serve as filters, removing minerals, nutrients, and pollutants from waters passing through them--indeed, wetlands have been called the "kidneys of the landscape."

Occupying low areas in the landscape, wetlands are the recipients of runoff and drainage from surrounding uplands and upstream areas. Because of their unique hydrology and biological structure, wetland ecosystems are often very effective filters of the water passing through them. Wetlands have been shown to be effective in removing nitrate and phosphorus from agricultural runoff and drainage, in purifying sewage from human settlements and animal confinement operations, and in treating acid mine drainage and industrial effluents.

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[3]Each spring, people living in cities such as Des Moines, Iowa and Columbus, Ohio, which lie downstream from major agricultural areas, receive NITRATE WARNINGS, alerting them that nitrate levels in their drinking water has risen to the point where the water is dangerous to drink, especially for infants, and could cause methhaemoglobinaemia. If wetlands had been retained at strategic locations in the otherwise drained agricultural landscape, they would have largely removed the nitrates (and other pollutants) from the agricultural drainage before it entered distributary streams and aquifers.

Constructed wetlands are now being used for treating municipal sewage, acid mine drainage, industrial effluent, and effluent from animal confinement operations in many parts of the U.S. and Europe. They show particular promise for treating non-point sources of pollution such as runoff from agricultural fields. Wetlands usually provide these essential services at a fraction of the cost of traditional sewage and water treatment technologies.

Beyond these very critical services, wetlands also serve as vital wildlife habitat and nurseries. Because they are among the most productive ecosystems on earth, wetlands provide a base for complex food chains that culminate in animals important to man. They also provide shelter for juvenile fish and shrimp which later migrate as adults into deeper waters of lakes or to the sea and for waterfowl during nesting and feeding periods. Without these nurseries fish, shrimp and waterfowl production and harvests will decline. Of course, wetlands also provide essential habitat for numerous other wildlife species, most of which will disappear from the landscape if wetlands are not conserved.

Finally, wetlands are valued amenities in the human environment, providing watering and bathing sites for cattle and buffalo, protein from subsistence fishing, fiber for thatch and basket weaving, and, where properly maintained, places of beauty and peace in an otherwise monotonous and much altered landscape.

4.0 Wetland Conditions in Zones 1 and 5

4.1 Climate and Hydrology

The climate of the project area is dominated by two monsoonal seasons. Maha, the rainy season, extends from October through January or February, and Yala, the dry season, runs from May through August. Total annual precipitation averages approximately 1,800 mm, 75 percent of which falls during Maha. June and July can be totally dry in the project area (Dimantha, 1992; TAMS,1980).

The project area lies in the drainages of the Mahaweli Ganga and the Maduru Oya (Fig. 1). The Mahaweli Ganga is the largest river system in Sri Lanka, draining 10,327 square kilometers (16 percent of the country). It is one of the few rivers in Sri Lanka that receive precipitation runoff during both monsoons. The Maduru Oya is a smaller stream draining only 1,541 square kilometers (Baldwin, 1991). A major tributary of the Maduru Oya, the Kuda Oya, is a braided stream that drains much of Zone 5. It joins the Maduru Oya at the north end of Block 503 which is bounded on the east and west and lies totally within the flood plain of these two rivers (Fig.2).

Lowland flooding along the Mahaweli Ganga, Maduru Oya, and Kuda Oya within and adjacent to Zones 1 and 5 has been and continues to be a frequent event during Maha. Interviews with farmers indicate that where such flooding occurs, water depths on the flood plain during flood events range from a few centimeters to more than a meter. The water remains on the land for a few to several days, gradually returning to the channel through surface and subsurface flows. Even after standing waters recede, poorly drained soils may remain saturated to or near the surface through Maha, being recharged by local precipitation and reflooding. Indeed, during Maha, precipitation alone may cause poorly drained soils to remain saturated for extensive periods of time.

Interbasin transfer of water for irrigation has reduced downstream flows in the Mahaweli Ganga and increased flows in the Maduru Oya basin. Because of these diversions, the frequency and duration of flooding along

the Mahaweli Ganga have declined, reducing flood water inputs to flood plain forests and villus. In the Maduru Oya basin, however, runoff and drainage from irrigated fields cause localized flooding and waterlogging of soils even during Yala. This is particularly evident in areas where natural or man-made obstructions retard drainage.

4.2 Soils

Zones 1 and 5 of System B occupy a mature, mantled peneplain derived from the degeneration of the underlying Pre-Cambrian rocks. Numerous prominent rocky remnants ranging up to more than 500 meters in height dot the undulating plain. Soils are mostly less than one meter in thickness. Those occupying upland areas are shallow to moderately deep reddish brown sandy clay loams that are well drained. Lower undulating terrain supports shallow to deep, grey-brown soils underlain by an impermeable quartz layer. Lowland areas are dominated by poorly drained alluvial soils (TAMS, 1980). Such soils are particularly abundant in Zone 5.

Dimantha (1992) found three soil series in Block 503, the Bulatiebbe, Timbiri Aru, and Odigar Villu series. The most common soils in the Block belong to the Timbiri Aru series (78 percent of the area). These are deep, alluvial soils that are poorly drained. Top soils are dark greyish brown, dark brown, to black clay loam or clay, while subsoils are grey to greyish brown with many mottles, indicating that these soils are saturated for periods during the year. Under irrigation, periods of saturation are likely to increase in duration. These are seasonally hydric soils. The TAMS report (1980) indicates that these soils remain waterlogged throughout the Maha.

Levees along the west (left) bank of the Maduru Oyo are made up of deep, moderately well drained alluvial soils of the Bulatiebbe series. These soils occupy approximately 12 percent of Block 503. Top soils are brown to dark brown loamy sands or sandy loams. Subsoils are yellowish brown to brown with only faint mottling, indicating that these soils are rarely saturated.

The braided stream channels that drain Block 503 from south to north (Fig. 3) are underlain by soils of the Odigar Villu series which are deep and poorly drained. A black surface layer rests atop a clay-loam or clay mineral soil that is grey to dark greyish green. Mottling and gleying is well developed throughout the profile indicating that these soils are saturated most of the time. These hydric soils occupy approximately 10 percent of Block 503.

4.3 Vegetation

Hydrophytic vegetation includes plant species that are specially adapted to living in areas where the substrate is saturated for extended periods of time. These species have adaptations that enable their roots to metabolize under anaerobic conditions. Species that grow only under these conditions are called "obligate hydrophytes," those that are usually found in these conditions but are occasionally encountered in better drained situations are called "facultative hydrophytes," and those that are usually found in upland situations but are often found at the margins of wetlands or in shallow water are called simply "facultative" species. Wetlands will have more than fifty percent of their vegetation dominated by obligate hydrophytes, facultative hydrophytes and facultative species. If more than fifty percent of the vegetation comprises obligate upland or facultative upland species, the site is not a wetland.

Hydrophytic vegetation is common throughout Zones 1 and 5. It is most evident in villus, in shallow areas in and on the margins of tanks, in

shallow stream beds, on the banks of larger streams, and in impounded areas along roads and dikes, all areas recognized as marshy or swampy and all areas that would be officially classified as wetlands according to the vegetation criteria. But, hydrophytic vegetation is also found scattered in what would normally be considered uplands, especially on the poorly drained soils so common in Zones 1 and 5. In these "upland areas" any small depression that holds water for an extended period of time is often occupied by plant species usually found in or around water bodies. Species of Scirpus and Cyperus are commonly found in these situations.

It must be noted here that the mere presence of hydrophytic vegetation does not automatically mean that the site must be classified as a wetland. If the area supports hydrophytic vegetation only because of some unnatural disturbance, such as an impoundment caused by a road or dike, the area may be classified as disturbed and treated as a special case (see Federal Interagency Committee for Wetland Delineation, 1989). On the other hand, wetlands caused by impoundment or other human activity might still be worth saving in the landscape. Judgements of this type go beyond the wetland delineation process and involve social, economic, legal and political as well as scientific judgements.

Hydrophytic plant species found in Zones 1 and 5 are listed in APPENDIX C. Those classified as floating leaved or submersed macrophytes are all obligate hydrophytes as are most of the emergent macrophytes. Many of the grasses would be classified as facultative or facultative hydrophytes, because they occupy the margins of wetlands.

4.4 Overview of Wetland Status in Zones 1 and 5

It can be said that those areas of Zones 1 and 5 of System B that are underlain by poorly drained soils are a "wetland waiting to happen." All conditions are there for the natural succession of wetland vegetation on any site where natural or man-made conditions lead to the saturation of the soil for an extended period of time - several weeks each year. Where standing water is present for most of the year, mature wetlands will evolve through natural succession without any help from man (See for instance Fig. 4 and APPENDIX G, #2, p. 37).

Prior to extensive human habitation and cultivation of these low-lying, poorly drained soils, this area undoubtedly functioned as a giant sponge, capturing water in the soils or in pools and releasing it gradually during the dry months. This storage and release would have moderated flood conditions and increased stream flows during the dry months. Scattered wetlands (villus, marshes, wet meadows, etc.) occupying low areas in the landscape, would have filtered and purified waters draining through them. Riverine and riparian forests that may be inundated only during and immediately after flood events also serve as important sinks for silt and nutrients, purifying the river waters as they pass and increasing the fertility of the riparian soils.

Human intervention has altered this landscape dramatically in areas such as Zones 1 and 5. Agricultural activities have altered the hydrology of the area. Wetlands, thought to be "wastelands," are drained whenever possible, so the land can be "made productive" or effluent waters can more rapidly be removed from the land. Much or even most of these alterations are both reasonable and acceptable from a social and economic point of view. With proper planning and management, these alterations can also be "acceptable" from an ecological or ecosystems point of view. The important thing to remember is that natural forces and cycles in local ecosystems interact in complex ways to maintain the stability of the overall landscape and allow for ecological resiliency in that landscape. In doing these things, natural ecosystems also provide services that are

vital to human existence and quality of life, such services as water storage, water purification, fuel, fibre, and food for both humans and their domesticated animals. The structure of the ecosystem can be altered considerably to accommodate man, as long as the processes of the landscape are not destroyed. Wetlands are vital sites for many of these important processes.

Interestingly, there has probably been an overall increase in water bodies, including wetlands as a result of development activities in Zones 1 and 5. Certainly all of the wetland creation has been inadvertent and is viewed largely as a negative factor that decreases the amount of productive land. Plans exist to drain many of these wet areas. A classification of wetlands in Zones 1 and 5 is presented in APPENDIX C (according to Cowardine et al., 1979). The status of these wetlands is discussed below.

The replacement of upland areas with paddy cultivation also increases area considered to be wetland. Paddies are wetlands when inundated and they do perform some of the vital services of wetlands during those periods. Paddy cultivation also has some serious impacts, similar to those of upland cropping, that offset their positive contributions while flooded. The most important of these impact is the contribution made by paddy cultivation to the pollution of effluent waters with nitrates, phosphates and other nutrients caused by over fertilization of the rice crop. Pesticide and herbicide residues also accrue to effluent streams. Little information on these water quality factors is available for Sri Lanka and no information is available for the project area. Maintenance or creation of wetlands at critical locations in the landscape might ameliorate these negative impacts of cultivation.

4.5 Villus

Villus are freshwater marshes and lakes that occupy low areas in the Mahaweli Ganga flood plain between the channel levees and the adjacent uplands. While no villus actually occupy Zones 1 or 5, Handipan, Bendiya and Gengala Villus which are situated in the Mahaweli flood plain south of Mannampitiya (Fig. 2) do receive drainage runoff from Zone 1 and are therefore considered here.

The basin morphologies of these three villus differ. Gengala Villu appears to have a shallow basin with a central pool area of standing water. Because of the shallow basin morphology, evaporation from this villu during Yala exposes broad expanses of mud flats and marginal grassland around its periphery. The pool area supports a rich wetland flora, including emergent, floating leaved, and submersed hydrophytic macrophytes and algae. This vegetation further supports a large number of waterfowl species, and the presence of fishing birds suggests that fish populations are also surviving.

Handipan and Bendiya Villus have steep shores adjacent to Zone 1 and shallower shores on their northern edges. Both of these connected villus support extensive pockets of wetland vegetation in shallow, protected areas around their shore lines. These areas include robust emergent, floating leaved, and submersed hydrophytic macrophytes and algae. The deeper open water areas of the villu are too deep and susceptible to wind and wave action to support wetland vegetation. These villus are popular sites for gathering reeds used for mat making. They also support large populations of waterfowl and a commercial fishery.

Villus are unique ecosystems that provide vital habitat for wildlife and important economic benefits for local human populations (TAMS, 1980). Occupying low points in the landscape, villus are sinks for silt,

nutrients, and various pollutants that are carried into them in drainage and flood waters. Reduced flows in the Mahaweli caused by upstream diversions for irrigation have reduced both the frequency and magnitude of flooding. Because of this altered hydrology, an increased percentage of the water entering these villus is made up of runoff and drainage from uplands. Wetland areas within the villus will contribute to the purification of these drainage waters, but there is concern that agrochemicals will be taken up by villu plants that are grazed extensively, especially during Yala. Care must be taken to insure that these wetlands do not become contaminated to the point that they are a danger to animal life and human populations.

4.6 Tanks

In Zones 1 and 5, 43 tanks occupy a total of 1,739.36 hectares. These include one very large tank, the Pimburettewa Wewa, a major reservoir on the Kuda Oya and a few moderate size tanks such as the Ellewewa Tank in Zone 1 and the Aralaganwila Wewa in Zone 5. But most tanks are much smaller village tanks that occupy small drainages

The larger tanks and the deep areas of the smaller tanks do not support wetland vegetation. Wetland vegetation thrives in areas between 0 and 150 cm in depth. Such areas frequently occur on the upslope margins of most of the moderate to small size tanks, and some of these tanks could rightfully be classified as marshes. These wetland areas vary in quality from sparsely vegetated fringes and shallows to having mature, complex and diverse floras and faunas. The heavily vegetated tank wetlands are most certainly contributing significantly to water purification. They also provide valuable habitat and feeding areas for waterfowl and other wildlife. And finally they seem to be a valuable asset to the local human communities, judging by the amount of usage they were receiving when we visited them. They serve as water sources, bathing and clothes washing sites, places of relaxation, water holes for cattle and buffalo, and fishing and reed gathering sites. All of these activities were repeatedly observed on tanks throughout Zones 1 and 5 during this assessment.

4.7 Impoundments

Impoundments as here defined are areas that are inundated or saturated because some downstream natural or man-made obstruction impedes the flow of water. Natural impoundments include such things as fallen trees and sand bars. Man-made impoundments include anticuts, dams. roads, dikes, and bunds. In Zones 1 and 5 any of these obstructions is likely to result in the creation of wetland conditions of some type.

Artificial and natural impoundments on the Kuda Oya and Narana Ela have created ponds that support hydrophytic vegetation at least along their banks. Unapproved anticuts, especially along the Narana Ela, are backing drainage water into paddy lands in Block 502 (Fig, 4). Natural blockages caused by vegetative growth, a combination of dense emergent macrophytes such as Typha and prolific populations of the floating water fern (Salvinia) clog drainages and back water up into cultivated areas. Roads and broken culverts have stimulated the development of poorly drained marshy areas along roads and drainage ditches. All of these conditions foster the development of wetlands. Seepage under tank dams also creates wetlands.

Some of these wetlands are of low quality, hold stagnant waters, or are not situated optimally in the landscape and should, therefore, be drained. Others, however, should be assessed for the benefits that they might be providing in the form of water purification and wildlife habitat before any decision to drain is made. There are definitely trade offs involved

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with these impounded wetlands. U.S. guidelines for delineation recognize this and classify these wetlands as problem sites for delineation. Each problem site must be considered separately on its own merits.

Still other impounded wetlands are of very high quality, supporting a rich hydrophytic vegetation and animal life and being so situated in the landscape that they provide water storage and purification, water and bathing areas for live stock and humans, and other services and amenities. These wetlands should be preserved.

4.8 Drainage Water Quality

Little information is available on the quality of drainage waters coming off agricultural areas in Sri Lanka, including the project area. There is serious concern about the probable high concentrations of pesticides and herbicides in these waters and nitrate and phosphate levels in drainage and runoff are also probably high.

Pesticides are known to accumulate in animal tissues and are concentrated through the food chain. There is concern about possibly high concentrations of pesticides in fish being harvested from villus and tanks into which drainage water flows. There is also concern about pesticide build up in grasses associated with villus and tanks and how much of this might be getting into grazing animals that are eaten by humans. There are similar concerns about the use and abuse of other agrochemicals. Ikram Mohyuddin, specialist in integrated pest management, says that farmers in Zones 1 and 5 use up to 10 times the pesticide and herbicide they need and that most of this probably is getting into the effluent waters.

There should be concern for nitrate levels in these effluent waters too, because nitrate levels in excess of 11 mg/liter in drinking water (FAO standards) are considered dangerous. They undergo conversions in the body that result in a blood condition in infants called methaemoglobinaemia. Nitrate is negatively charged and therefore is easily leached into ground water where it flows into wells. In sparsely populated areas of the dry zone well nitrate levels average between 1 and 25 mg/liter with most of the high levels occurring in the more populated areas surrounding Trincomalee and Batticaloa (Dissanayake and Weerasooriya, 1987; Kuruppuarachchi et al, 1990). There are no data available on well nitrate levels in Zones 1 and 5. There is reason to be concerned, however, because of the intensive use of nitrogen fertilizers on crops in the area. The only data we have on the fate of this nitrogen in System B comes from a lysimeter study (Kemdaragama, 1988) that showed that leaching from rice paddies removes 15.5 kg/ha nitrogen each year and 75 percent of this is in the form of nitrate. This will accrue to surface and ground waters.

Phosphate pollution of effluent streams is also of concern. Phosphorus is lost largely by surface runoff directly into drainage ditches. Phosphorus is the major limiting factor in aquatic systems. Excessive phosphorus in lakes (tanks, villus, reservoirs, etc.) causes eutrophication which at its extreme can lead to deoxygenation of the water column and the death of fish and other aquatic life.

Finally, there is serious concern about the impact of human waste on water quality and human health (Dissanayake and Weerasooriya, 1987). Pathogenic bacteria from human waste in soakage pits and septic tanks have been shown to contaminate drinking water wells in Sri Lanka and elsewhere. Again there are no data on this type of contamination in Zones 1 and 5.

Strategically placed, functional wetlands show promise in removing many of these pollutants from waters passing through them. Human and animal waste can often be successfully treated in constructed wetlands that are

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relatively compact and inexpensive. The advantage of treating these wastes in wetlands is that the treatment occurs above ground, reducing the danger of seepage into drinking water supplies. Wetlands are also known to be very effective in denitrifying nitrates, converting them into harmless nitrogen gas and oxygen which are then given off to the atmosphere. Phosphorus is often trapped in wetlands as a result of sedimentation, although the degree to which wetlands serve as a net sink for phosphorus depends upon local conditions. Little is know about the effect that wetlands have on pesticides and herbicides. We do know that heat speeds the breakdown of these chemicals, so this may be facilitated to some degree in the shallow waters passing slowly through wetlands. Such wetlands could enhance the quality of effluent waters leaving Zones 1 and 5 to be used further downstream and improve health conditions in the project area by protecting the quality of drinking water supplies.

4.9 Habitat and Wildlife

There has undoubtedly been an overall increase in waterfowl habitat as a result of development activities in Zones 1 and 5. The creation of reservoirs, tanks, impoundments, and paddy fields has created feeding areas for herbivorous and carnivorous birds. Every part of the irrigated area abounds with ibis, herons, egrets, anhinga, storks, fishing hawks and eagles, and other species.

The project has probably increased crocodile habitat, although data on previous habitat extent is unavailable for this area. Farmers reported several areas along drainage ditches where they refrain from trespassing because crocodiles live there.

This and other projects in the region have had a serious impact on elephant habitat. For instance, elephants still frequent deep areas along the Kuda Oya adjacent to Block 503. They also bathe in the wetland pools in the center of Block 503. With development, these areas will be subsumed into the agricultural landscape, and further forays of elephants to these sites will place them in direct confrontation with farmers, a situation that is common elsewhere in the region. It should be noted that elephants do move fairly freely through the floodplain of the Mahaweli Ganga, visiting the various villus. Here also, there are frequent encounters with Zone 1 farmers on the margin of the flood plain.

4.10 Human Use

Note has been made of human usage of various wetland areas in Zones 1 and 5, but the obvious importance of these ecosystems in a largely altered landscape deserves special comment. Wetland ecosystems support several subsistence and commercial ventures. In tanks and villus they serve as nurseries for small fish and freshwater shrimp. Being highly productive, they produce large amounts of biomass that dies and serves as a substrate and energy source for populations of bacteria. These bacteria are grazed by microinvertebrates which are in turn eaten by macroinvertebrates. This food chain ultimately supports the animals that are an important subsistence and commercial protein source for human populations. Wetland vegetation also provides cover and protection for young and adult fish and waterfowl.

Several species of emergent macrophytes are collected and used in making bed mats and rattan ware. These include the cattails, Typha angustifolia and Typha javanica; the reed Cyperus corymbosus (often cultivated for this purpose); and the triangular stemmed bull rush Scirpus grossus. The common reed Phragmites communis, commonly used for rattan and caning was not found in Zones 1 and 5, but it would grow there if planted. One commercial collector gathering stalks of Scirpus grossus along the shore

of Handipan Villu said that bundles of 40 dried stalks sell in Batticoloa for one rupee. Twenty five bundles are needed to make one mat which would sell in Batticoloa for 50 rupees and in Colombo for 100 rupees. He said, however, that mats made from flat or round leaved species are more expensive, selling in Batticoloa for 100 rupees. It is not uncommon to see women carrying bundles of reeds on their heads, either for commercial use of for making mats and utensils for their households.

Several species of hydrophytic plants serve as food crops for subsistence or marketing. Perhaps the most common of these is Ipomeae aquatica , locally known as kang kung. This plant grows in fresh flowing water in wetlands. It is easy to harvest and continues to produce while being harvested. It is used as a potherb here and is a major commercial crop in East Asia. There should be commercial potential for kang kung if appropriate varieties, such as the white stemmed variety popular in China, and commercial markets could be developed. Limnocharis flava, a common dominant in the more developed wetland areas, is eaten throughout Southeast Asia as a substitute for spinach or endive, but it does not seem to be used here. Several other species are harvested for use as vegetables including the leaves of several species of Ranunculus and the pods of Neptunia. The underground corymbs of Trapa (often called water chestnut) are also harvested. There might be opportunities for cultivating the more familiar water chestnut, Eleocharus, on a commercial basis. Finally, cattails (Typna) is a plant of many uses (See APPENDIX C) but is poorly exploited in Sri Lanka.

Also, mention has already been made of the value of these wetlands for washing clothes, bathing, watering animals, and as aesthetic patches of nature in the cultivated landscape, all incommensurable values, but values just the same.

4.11 Wetland Conditions in and Adjacent to Block 503.

Block 503 is drained by a braided channel that branches off from the Narana Ela just before the latter joins the Maduru Oya (Figs. 2,3). Damming of the Narana Ela at its junction with the Maduru Oya as part of Block 503 infrastructure development will direct Narana Ela flows northward across Block 503 through this braided channel. Along its course this channel descends approximately 20 feet from an elevation of 138.7 feet to 119.6 feet where it joins the Kuda Oya. The Narana Ela diverges from the Kuda Oya at an elevation of 157.9 feet. Along its path the 503 channel has occasional deeper spots, e.g between lines M and N, astride line P, and, most notably between lines R and T on the 4 chains to 1 inch engineering survey sheets (Fig. 3). These depressions hold standing water even in Yala and are apparently kept open by elephants. The major depression between lines R and T is part of a large wetland area encompassing two interconnecting braids of the channel and covering approximately 40 hectares. The deepest area lies between lines S and T, contains water to a depth of approximately 0.75 meters in July, and covers approximately 5 hectares.

The lowest areas throughout the entire central drainage system exhibit hydric soils and support hydrophytic vegetation. These two facts, combined with the evident presence of wetland hydrologic conditions, means that all of these channels qualify as jurisdictional wetlands. The total coverage of such wetlands in Block 503 probably approaches 120 hectares, but most of this is in narrow bands at the bottoms of the drainages. Alteration of hydric conditions along these narrow channels is of minor concern, but the broader and deeper areas, especially that between lines S and T, should be conserved.

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Most of the drainage from Block 503 irrigation (Fig. 6), approximately 550 hectares of cultivation, will accrue to this central drainage and almost all of this will pass through the wetland area between lines R and T. For this assessment this drainage area is referred to as Drainage B.

Braids of the Kuda Oya (Fig.7) as it passes the west side of Block 503 support wetlands in various stages of development and quality. These braids receive Kuda Oya flows primarily during flood events, but contain water above the surface even in July. They also receive surface runoff from adjacent uplands and drainage from small tributaries of the Kuda Oya and drainage ditches. These wetlands contribute to the purification of Kuda Oya water and should be conserved during development of Block 503 and improvement of the Kuda Oya channel. A few shoreline wetlands occur along the bank of the Maduru Oya, but these are neither extensive nor well developed.

4.12 Riparian Forests Adjacent to Block 503

Riparian forests along the Kuda Oya are in poor condition. Rarely is the tree cover more than one tree wide on either bank and in many places trees have been entirely removed for short or extended distances, especially on the west (left bank). This has been caused by a variety of social pressures including burning during periods of chena cultivation, burning and grazing of extant Iluk (Imperata cylindrica) grassland, encroachment of paddy cultivation, and harvesting fuel wood and timber. With the exception of chena, these pressures continue and will increase unless measures are taken to reduce them.

Of the trees remaining, many are in poor condition with numerous dead branches and snags. This is especially true of the larger, mature trees that are the primary seed source. Further, many of the larger trees are located physically in the main channel of the Kuda Oya or on the tips of small peninsulas jutting out into the channel. These trees are slated for removal as part of channel clearance activities planned for Block 503 development. Planned channelization could also eliminate trees on the convex banks of meanders if efforts are made to straighten the channel.

The current in the main channel of the Kuda Oya is very swift as it passes block 503, even with the presence of large trees growing in the channel and numerous logs that have fallen partly or fully across the channel. In places where tree cover has been removed, the current is eroding the banks, especially concave banks on channel bends. Banks in July are between 1 and 2.5 meters above water level, and deep channels are cut through to water level wherever smaller drainages enter, especially when this occurs on the high, concave banks at bends. These banks and ditch sides are very unstable and erodible. Reforestation of these sites is especially critical.

Similar conditions exist in the riparian forests along the braids of the Kuda Oya. Here, however, erosion is less of a problem, because the current in these braids is very slow. Some reforestation along these braids will, nevertheless, be required.

Because of security problems, a thorough examination of the riparian forests on the west (left) bank of the Maduru Oya was not possible. Visits to the Maduru Oya at various sites along the east side of Block 503 revealed a riparian forest in even worse condition than that along the Kuda Oya. For extended distances the left bank is devoid of trees and is dominated by scrub about 1.5 meters high or by Iluk grassland. Bank erosion is common.

Riparian forests along the Narana Ela as it traverses the southern boundary of Block 503 has been largely removed on both banks and replaced by paddy. Extensive reforestation will be required along this portion of the Narana Ela. Consideration should also be given to tree planting along the drainage through the center of Block 503 into which the Narana Ela will be diverted. This drainage is essentially devoid of trees at this time.

5.0 Development of Block 503

5.1 Planned Infrastructure Development and Improvement

Block 503 is bounded on the west by the Kuda Oya and on the east by the Narana Ela and Maduru Oya. The Narana Ela is a branch of the Kuda Oya, diverging from the latter between grid lines I and J on the 4 chains to 1 inch engineering survey sheet. At present the Narana Ela joins the Maduru Oya between grid lines M and N, but this junction will be sealed off during Block 503 development, forcing Narana Ela flows through a braided stream complex that flows north through Block 503, draining into the Kuda Oya at line U (MARD/MDS, 1991). Blockages along the Kuda Oya and Narana Ela, both natural and man made, retard drainage from Block 502. These blockages will be removed, during 503 development. This will further enhance flows through the drainage channels in Block 503. Some widening, channelization, and diking of the Kuda Oya is also planned to facilitate Maha runoff, and a series of dikes will be installed along the west bank of the Kuda Oya just upstream from its confluence with the Maduru Oya to eliminate overflow into Zone 2 croplands. Some diking of minor streams entering Block 503 from the Maduru Oya will be necessary to maintain the integrity of the 503 drainage systems (Fig. 5).

Irrigation supply canals planned for Block 503 (Fig. 6) will deliver 1.93 cumecs, enough water to command approximately 1,000 hectares of irrigated land. Current supply and drainage canal design will divide Block 503 into three drainages. Approximately 200 hectares will drain into the Kuda Oya via a current braid of the Kuda Oya that will be closed off were it diverges from that stream (Drainage A in Fig. 6). Approximately 550 ha will drain into the central channel receiving Narana Ela flows (Drainage B). Drainage from fields in the northern end of Block 503 will accrue to a small drainage to the Kuda Oya and is designated as Drainage C (approx. 250 ha).

5.2 Potential Impact on Wetlands

Installation of infrastructure in Block 503 could adversely impact the wetland areas along the central drainage. The establishment of a drainage gradient that is too steep could result in the drainage of all wetland areas, unless they are retained by dikes. Increased flows through the central drainage as a result of irrigation runoff and drainage and increased flows via the Narana Ela, however, could increase water supplies to these wetlands. Because the major wetland area between lines R and T lies below command, conservation of this area should be possible. Conservation of other wetlands along this drainage will be more difficult but should be designed into the drainage plan.

Improvement of the Kuda Oya basin as it passes Block 503 could have catastrophic impact on riverine wetlands in the main channel of the Kuda Oya and riparian wetlands occupying its braids and flood plain. Channelization and widening could eliminate conditions in the main channel that support wetlands and will probably totally eliminate wetlands occupying braids, indeed the braids themselves might be eliminated. Diking the sides of the Kuda Oya could eliminate riparian wetlands by filling or by cutting them off from their sources of water from the river.

Diking might also result in the creation of new wetlands along their upland sides as a result of impoundment of runoff and drainage.

5.3 Potential Impact on Riparian Forests

Improvement of the Kuda Oya basin could severely impact riparian forests on both banks. If minimal setback required by Sri Lankan regulations (20 m) is adopted, large areas of trees will be lost. Dike construction on both banks may result in the loss of trees. Further, even trees immediately adjacent to the channel are slated to be removed as part of the channelization process. If improvement of the Kuda Oya adjacent to Block 503 resembles improvement of the Kuda Oya in Block 502, the riparian forests could be totally eliminated.

In determining the width of the Kuda Oya, which, in turn, determines the width of the setback required by Sri Lankan regulations, the river width should include all braids of the system. This would increase the required setback to at least 40 meters.

Development of Block 503 will increase human use of this area. This will probably increase the use of the riparian forest areas for fuel wood. West bank settlers already partake freely of these forests for fuel wood. Further, farmers will tend to crop as close to the dikes as possible, removing any trees that lie outside the dikes. Thus, the siting of dikes will have a significant impact on both riparian forests and riparian wetlands.

5.4 Potential Impact of a No Development Strategy

The cancelation of infrastructure development in Block 503 will not halt the development of agricultural activities. Second generation farmers are already cultivating paddy with water they are diverting from the Narana Ela and Kuda Oya. This practice will undoubtedly continue and expand even without infrastructure development. Anicuts and other impoundments constructed in the Kuda Oya and Narana Ela to provide a water source for irrigation will further impede drainage through these two basins and increase water logging of soils in Block 502. Even without additional water, farmers will continue to use Block 503 for grazing, burning the Iluk to generate palatable feed. Cancelation of planned diking of the west bank of the Kuda Oya adjacent to Zone 2 will result in continued severe flooding that makes large tracts of land in that area unfit for agriculture.

Positive impacts of a No Development Strategy include the preservation, at least temporarily, of riparian forests (although wood collection for fuel wood will ultimately eliminate these forests anyway unless alternative sources of fuel wood can be generated) and wetlands along the Kuda Oya and riverine wetlands within the channel of the Kuda Oya. A no development strategy will certainly slow migration into Block 503, thus preserving elephant habitat. Elephants make use of deep water areas in the 503 wetlands and the Kuda Oya. Judging from the quantity of their droppings, elephant use is considerable. Development will result in increases in elephant-human contact as has occurred elsewhere in System B. And finally, no development would reduce and delay threats to wetlands along the central drainage of the Block.

5.5 Opportunities for Wetland and Riparian Forest Enhancement

5.5.1 Wetlands for Water Purification on 503 Drainages

Small constructed wetlands could be installed on all three drainages in Block 503. These wetlands would improve the quality of drainage waters

passing through them, removing nitrates and reducing silt loads, BOD_5, pathogenic bacteria, and phosphorus levels; and possibly pesticide and herbicide levels.

The ratio of constructed wetland to drainage basin area should approximate 1/100. Therefore, the wetland for drainage B should have a surface area of 5 to 6 hectares, while those in drainages A and C should be about 2 ha each. Design criteria for these wetlands are provided in APPENDIX E. Multicellular wetlands (2 or more linked basins) would be more effective than single larger wetlands. Those in drainages A and C might have two cells whereas that in drainage B might have three or four. Each wetland should be equipped with control structures that allow for water depth manipulation and the collection of quantitative input and output data for each cell.

Precise engineering designs cannot be provided at this time because final infrastructure designs for Block 503 development have not been completed. Final engineering designs should incorporate these constructed wetlands according to the general design criteria in APPENDIX E. Once precise locations are established for the constructed wetlands, specific site conditions including, topography, soil type, local vegetation, and relationship to the Kuda Oya can be determined and used to develop the specific designs for each wetland and the procedures to be used in vegetating them once they are constructed.

5.5.2 Riverine and Riparian Wetlands in the Kuda Oya

Wetlands occurring within the river channel or on adjacent flood plains are responsible for a major part of the purification that a stream undergoes as if flows along it course. Riverine and riparian wetlands are well developed already in the Kuda Oya adjacent to Block 503 and can easily be conserved or even enhanced. By including all braids of the Kuda Oya within the dikes, destructive channelization, clearing, and dredging can be minimized; the increased breadth of the diked channel will compensate for the lack of such improvements. Some channel contouring could be done in the smaller braids to eliminate undue stagnation during dry periods. Conserving riverine and riparian wetlands will not prohibit the removal of man-made anticuts from the Kuda Oya channel.

5.5.3 Riparian Forests on the Kuda and Maduru Oyas

Reforestation of the riparian forests along the Kuda and Maduru Oyas provides an opportunity to enhance significantly the native biodiversity of the area by restoring the native climax forest. To accomplish this, a reforestation program will have to be designed to exploit the processes of natural succession. The forests along the Kuda Oya are "trying" to move into the adjacent grassland; stunted individuals of various riparian forest species can be found in these adjacent grasslands on both sides of the river. Expansion of the forest into these grassland areas. however, is limited by the Iluk, a fierce competitor, by fire, and by grazing. With some protection from fire and grazing, natural succession might be able to extend these forests into the Iluk, but this would take time. This process could be speeded by transplanting larger trees of appropriate species into these areas. The larger trees would be able to compete better with the Iluk.

In designing a reforestation program and selecting appropriate species for transplanting, the natural constraints of plant succession must be taken into account. The major constraint in reestablishing the climax forest is that most of the tree species characteristic of climax forests cannot survive in full sunlight while they are very young; their seedlings and saplings require shade. Therefore, a reforestation program designed to

restore the natural climax forest, must be carried out in stages. The first stage would be the planting of pioneer species that can survive in open, sunny areas and that can compete with the Iluk. Once these trees have become established and developed a canopy, the shade loving climax species can be introduced under them. Of course all of this requires that the young trees, pioneer and climax, be protected from fire and grazing until they are large enough to be immune. It also assumes that there will be a supply of shade loving climax tree seedlings for transplanting when conditions become appropriate. Such genetic stock could be raised under artificial shade in nurseries, possibly under contract to local farmers.

Climax species to consider include: Vatica obscura a gallery forest species that is also the only dipterocarp that grows in the dry zone (it is also a source of resins.), Terminalia arjuna (Kimbuk) which has medicinal value, Diospyros embryophitica (Timbiri), and Polyalthia longifolia. Other native species that have non timber value to local communities could also be included.

The riparian forest must be wide enough to allow natural regeneration to take place once the climax is restored. A band of trees one or two deep is subject to edge effects, especially the penetration of sunlight to the forest floor. Unless sufficient width is allowed to provide shaded habitat on the forest floor, climax tree regeneration will be inhibited. Therefore, it is recommended that the riparian forests be restored to a width of 40 meters on each side of the river. The islands that lie between the main channel of the Kuda Oya and its braids could also be reforested.

If the Kuda Oya is considered to include all of its braids, it is sufficiently wide to require at least a 40 meter set back according to Sri Lankan law. Regardless of this setback requirement, the ecological constraints noted here argue for such a setback to provide conditions that will foster self maintenance and regeneration of the climax forests.

Attempts to reestablish the climax forest and increase natural biodiversity will fail unless alternative fuel wood supplies are developed for local consumption. Therefore, this program must include a concerted effort to stimulate the development of a fuel wood industry in the area. For such plantations, fast growing species such as Australian pine (Casurina) and Eucalyptus would be appropriate, but these exotic species should not be used in the reforestation of the riparian forests, even as pioneer species.

6.0 Retrofitting Wetlands into Zones 1 and 5

As was mentioned in Section 4.4, large areas of Zones 1 and 5 are "wetlands waiting to happen." Because of this natural ecological potential, opportunities abound for establishing or maintaining wetlands at critical sites in both Zones. Because of the greater preponderance of poorly drained soils in Zone 5, opportunities are especially plentiful there.

The protection of natural wetlands and the setting aside of land for the creation of constructed wetlands in areas being developed (e.g. Block 507) is relatively simple, because land has not yet been allocated to farmers. In areas that have already been developed, however, the retrofitting of wetlands into the developed landscape or the conservation of volunteer wetlands that have arisen as a result of poor drainage, is more problematic and involves political, economic, and social, as well as ecological consideration. For this reason, an exhaustive site by site ecological assessment of potential sites for conserving or retrofitting wetlands into Zones 1 and 5 would not be profitable here. Instead, a set

of guidelines for selecting sites where wetlands might be established or retained to enhance water quality of drainage or which could be drained without much ecological loss is provided. A few examples are given for clarification.

1. Position or retain wetlands at places where small streams, drains, or swails enter larger streams so that waters leaving the smaller flows pass through the wetland before entering the larger stream. For example: wetlands could be established in Blocks 502 and 506 where drainage canals and small streams enter the Kuda Oya, where small streams enter the Narana Ela from Block 502, or before drainages from Blocks 102 and 103 enter the Hungamala River and the Handiman and Beniya Vullus.

2. Locate several small wetlands on small streams, drains, or swails higher in the drainage rather than one large wetland on a larger stream low in the drainage. Several smaller wetlands scattered through the upper basin are less obtrusive, less expensive, and more effective in removing pollutants than are fewer but larger wetlands at the foot of a drainage. An example of such a small wetland is the natural marsh that has developed behind a weir installed under a bridge over the Narana Ela west of Divuldamana in Block 502 (See Fig. 4 and Section 7.3).

3. Strive for one percent of each drainage basin being set aside as wetlands strategically located to intercept and purify outflow water.

4. Strive to retain all existing volunteer wetlands that meet all or some of these three guidelines. Wetlands that meet all three should have high priority for conservation. These wetlands may have formed inadvertently as a result of impoundment behind roads, dikes, etc. or as a result of impeded drainage, but many of them occupy strategic sites and are providing water purification services. Do not drain simple to drain. Unless there are compelling reasons to drain, leave these wetlands alone. **ERR ON THE SIDE OF <u>NO DRAINAGE</u>.**

   There are numerous examples of this situation. One of particular interest is the waterlogged area astride and to the east of drain D4/502 (Fig. 4). In this area, water tables will have to be lowered to allow for agriculture. A conservative approach to drainage should first remove all artificial blockages downstream and see if this alone provides sufficient drainage to allow for agriculture. If it does not, then implement some channel clearing and dredging in the ditches draining the site. It is possible that water tables here can be lowered sufficiently without totally eliminating wetlands from the basin. As a last resort, establish an artificial impoundment on the outflow stream just before it enters the Narana Ela. A small wetland at this site (1 percent of the drainage basin) would provide adequate filtration, and even a smaller wetland at this site would provide some purification of water before it enters the Narana Ela.

5. The following situations are generally good candidates for drainage, although even in these extreme situations, thought should be given to retaining wetland attributes.

a. Where wetlands have no outflow and are poorly drained resulting in the pooling of truly stagnant water[4]. Examples of this are some of the seepage areas at the foot of dams. Such areas are of little importance in water purification because they receive little or no input of agricultural runoff, they are mosquito breeding sites, and they tend to destabilized the dams.

b. Where large areas of land are taken out of agricultural production because of soil water logging, e.g. the D4/502 area noted above. Even here attempt should be made to retain some wetland for water purification.

c. Where there is concrete evidence that water logging is causing salinization.

All drainage basins in areas of Zones 1 and 5 already developed should be assessed for possible retrofitting with appropriate wetlands to process drainage waters leaving the System. Conservation of as many extant wetlands as possible should be implemented as policy immediately, but a major effort to retrofit developed areas in Zones 1 and 5 should not be undertaken until performance data are available for the constructed wetlands recommended for Block 503 and for the natural wetland on the Narana Ela near Divuldamana in Block 502.

7.0 Recommendations

7.1 General Landscape Development

The quality of effluent waters in rural areas can be enhanced by following three general rules of watershed development. These rules should guide project planning and design for Block 503 and improvement, operation, and maintenance of existing infrastructure in Zones 1 and 5.

1. Maintain riparian vegetation along all effluent streams. Riparian vegetation, usually trees, will stabilize stream banks and intercept surface flows carrying nutrients and other pollutants before they reach the stream.

2. Protect or install small wetlands at strategic locations on drainages in the watershed. A series of small wetlands scattered strategically through the landscape will filter and cleanse agricultural runoff and drainage from fields, provide short-term water storage capacity, and serve as watering and bathing sites. Properly designed and vegetated, they may also produce plant and animal crops of benefit to human communities.

3. Install microwetlands at homestead sites for treating human wastes. Small, inexpensive, and easily maintained wetlands have proven to be effective in treating human waste and sewage. Because this wetland treatment occurs at the surface, ground water and well contamination is greatly reduced.

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[4]Caution - Water flows very slowly through wetlands and may appear to the uninitiated to be stagnant. Also, water in deeper areas of some wetlands may cease flowing during the driest months of the year. Villus are a good example of the latter situation.

7.2 Block 503 Development

7.2.1 Natural Wetland Conservation

Drainage gradients in Block 503 should be established so that the deeper areas along the braided stream draining the center of the Block and which hold standing water into the summer are conserved. These natural wetlands support a rich variety of plant and animal life and will contribute to purification of drainage waters flowing from Block 503 croplands. The northernmost of these depressions (lying between lines S and T) might be incorporated as part of a constructed wetland on Drainage B recommended as in 7.2.2.

7.2.2 New Wetland Construction

Constructed wetlands should be installed at three locations in Block 503 strategically placed and designed to capture and filter water in Drainages A, B, and C (see Fig. 6). Construction of these wetlands while developing other infrastructure in Block 503 will minimize costs and insure that wetland filtering systems are in place to receive drainage from irrigated fields. See APPENDIX E for design criteria for these wetlands.

7.2.3 Conservation of Riverine Wetlands in the Kuda Oya

Channelization and dredging of the Kuda Oya basin and dike construction along its banks as it passes Block 503 should not destroy riparian and riverine wetlands. Channelization should be limited to removing anticuts and logs from the main channel, and dikes should be located well outside the wetlands occupying the small braids of the Kuda Oya. (See 5.5.2 above)

7.2.4 Conservation and Restoration of Riparian Vegetation

7.2.4.1 A tree planting program should be initiated to restore native riparian forests in bands at least 40 meters wide along both banks of the Kuda Oya and the left bank of the Maduru Oya amd 20 meters wide along the Narana Ela adjacent to Block 503. Trees should also be planted on islands that lie between the main channel of the Kuda Oya and its small braids. The goal of this program should be to restore climax forests along these rivers, thus increasing native biodiversity. Therefore, only native species should be employed (See 5.5.3 above).

7.2.4.2 Flood control dikes along the Kuda Oya should be located outside the riparian forest regeneration zones on both banks, and no living trees should be removed from the banks or the channel. Standing trees in the channel will have little impact on flow of the Kuda Oya in Yala or Maha and are too valuable to be sacrificed. Conservation of existing riparian forests should not cause serious problems on the right bank where land has not yet been allocated to farmers, but will be a problem several places along the left bank where farmers are cropping right up to what is left of the riparian forest. Consideration in these situations should be given to trading land in Block 503 immediately across the river for left bank land that would allow for the construction of dikes outside the riparian forests.

7.2.4.3 Effort should be made to stimulate the development of fuel wood plantations in the area to relieve fuel wood gathering pressure on riparian forests. Attempts to protect and restore riparian forests will fail unless a reasonable alternative source of fuel wood is developed.

7.3 Drainage Water Quality Monitoring

A program should be initiated to monitor water quality at the control structures on the constructed wetlands in Block 503 and at two locations in Zones 1 and 5. (See APPENDIX G)

7.4 Conserving and Retrofitting wetlands in Zones 1 and 5 (See Section 6.0 above)

7.4.1 Careful consideration should be given to minimizing the draining of impounded wetlands in the developed Blocks of Zones 1 and 5. While most of these areas would not be protected under U.S. regulations because they exist only by virtue of inadvertent impoundments, many are quality wetlands that are purifying the waters passing through them. It should be recognized that these wetlands are good things to have in the landscape and that they should be saved whenever possible.

7.4.2 The retrofitting of developed areas in Zones 1 and 5 with constructed wetlands is not a high priority at this time. While there are several sites in Zones 1 and 5 that would be ideal locations for constructed wetlands, such retrofitting will benefit from lessons learned from development and monitoring of constructed wetlands in Block 503 and from the water quality monitoring recommended in Section in 7.3 above. Guidelines outlined in Section 6.0 should be used to identify strategic sites for future wetland construction, and these sites should be reserved for future retrofitting with constructed wetlands,e.g. no development or improvement should be carried out at these sites that would preclude or restrict future wetland construction.

7.5 Extension Wetlands Education

MARD extension specialists should work with local farmers and their families, especially those adjacent to any wetlands being protected and monitored, to inform them of the value of the wetlands. Extension specialists might also offer wetlands workshops for school teachers. Local wetlands could serve as teaching laboratories for biology classes.

The following two recommendations go beyond the present scope of the MARD project but are offered here because of their potential value to water resource management in Sri Lanka.

7.6 Demonstrating Use of Wetlands for Sewage Treatment

A demonstration project should be undertaken to examine the use of constructed microwetlands for human sewage treatment at the farm or hamlet level. This project could be undertaken by MARD, the Mahaweli Authority, or both. Several microwetland systems should be constructed for this study, so different designs and planting schemes can be tested and compared. These systems should be very inexpensive to install and require little or no maintenance.

7.7 Wetlands Management Education and Training

US AID should provide support for the development of programs for short-term training and long-term education of wetland managers. Wetlands are an important and threatened resource in Sri Lanka. They also represent a resource that can be tapped for point and non point sources water purification, sewage treatment, and urban storm water control. Professional managers are needed to design, operate and maintain such systems.

1. Short-term training courses should be initiated for government officials and community leaders to alert these decision makers and managers to the value and functions of natural and constructed wetlands. These could be offered in Sri Lanka or the United States.

2. Opportunities should be made available to qualified professionals to pursue post-graduate education in the U.S. at institutions offering graduate degrees in wetland ecology and management.

3. Selected university instructors could be sent to the United States for post-doctoral training and experience in wetland ecology and management. These individuals should be expected to implement wetlands education programs in the their universities upon their return.

REFERENCES

Baldwin, Malcolm F. (ed.). 1991. Natural Resources of Sri Lanka, Conditions and Trends. Natural Resources, Energy and Science Authority of Sri Lanka, Ministry of Industries, Science and Technology. Colombo. xi + 280 pp.

Brown, M.T. 1987. Conceptual design for a constructed wetlands system for the renovation of treated effluent. Report from the Center for Wetlands, University of Florida

Cook, C.D.K., B.J. Gut, E.M. Rix, J. Schneller, and M. Seitz. 1974. Water Plants of the World. Dr. W. Junk b.v., Publishers, The Hague. viii + 561 pp., Illus.

Cowardine, L.M., V. Carter, F.G. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service, FWS/OBS-79/31, Washington, DC. v + 103, Illus. GPO 024-010-00524-6.

Davis, C.B. and A.G. van der Valk. 1988. Ecology of a Semitropical Monsoonal Wetland in India. Final Report. School of Natural Resources, Ohio State University, Columbus, OH 43210. 104 pp.

Dimantha, Sunil. 1992. Soil and Land Use. Technical Report. Mahaweli Agriculture and Rural Development Project. 23 pp.

Dissanayake, D.B. and S.V.R. Weerasooriya, 1987. Medical geochemistry of nitrates and human cancer in Sri Lanka. International J. Environmental Studies, 30:145-156.

Federal Interagency Committee for Wetland Delineation. 1989. Federal Manual for Identifying and Delineating Jurisdictional Wetlands. U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S.D.A. Soil Conservation Service, Washington, D.C. Cooperative technical publication. vi + 131 pp.

Fennessy, M.S. and W.J. Mitsch. 1989. Treating coal mine drainage with an artificial wetland. Research Journal Water Pollution Control Federation 61 (11/12):1691-1701.

Hammer, Donald A. (ed.). 1989. Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Inc., 121 South Main St., Chelsea, MI 48118. xxii + 831 pp. ISBN 0-87371-184-X.

Hammer, Donald A. 1989. Constructed wetlands for treatment of agricultural waste and urban storm water. In: Majumdar, S.K. et al. (eds.), Wetlands Ecology and Conservation: Emphasis in Pennsylvania. Pp.333-348. The Pennsylvania Academy of Science

Hotchkiss, Neil. 1972. Common Marsh, Underwater, and Floating-leaved Plants of the United States and Canada. Dover Publications, Inc., New York. v + 124 pp., 750 illus.

Jayasuriya, A.H.M. 1991. Some Soil-Vegetation Relationships in Mahaweli System B. Development Alternatives, Inc./Mahaweli Economic Agency/Mahawaeli Engineering and Construction Agency. Pimburattewa, Sri Lanka. 56 pp. ISBN 0-486-22810-X.

Kendaragama, K.M.A. 1988. Evaluation of nitrogen and potassium leaching in non-calcic brown soils under irrigated rice in Mahaweli System B. MPhil thesis (unpublished). Post Graduate Institute of Agriculture, University of Peradeniya. Peradeniya. 68 pp,

38

Kuruppuarachchi, D.S.P., W.A.R.N. Fernando, and A.R. Lawrance. 1990. In: Gunawardena, E.R.N., (Ed.). Irrigation and Water Resources. Proceedings of a Symposium. Agricultural Engineering Society of Sri Lanka, 24-25, August. Kandy. i + 213 pp.

Kusler, Jon A and Mary E. Kentula, (eds.). 1990. Wetland Creation and Restoration, The Status of the Science. Island Press, Washington, DC. xxv + 591 pp. ISBN 1-55963-044-2.

MARD/MDS. 1991. Development of Block 503, System B. Development Alternatives, Inc. Pimburattawa, Sri Lanka. 6 pp., 3 Illus.

Mitsch, W.J. and K.K. Cronk. 1992. Creation and restoration of wetlands: some design considerations for ecological engineering. In: Lal, R. and B.A. Stewart (eds.), Advances in Soil Science, Vol. 17. Pp. 217-259. Springer-Verlag. New York.

National Academy of Sciences, 1976. Making Aquatic Weeds Useful: Some Perspectives for Developing Countries. Report of an Ad Hoc Panel of the Advisory Committee on Technology Innovation. National Academy of Sciences, Washington, DC. viii + 175 pp.

TAMS. 1980. Environmental Assessment: Accelerated Mahaweli Development Programme. 4 Volumes. Tippetts-Abbett_McCarthy-Stratton. New York, New York.

Tolisano, James. 1992. An Environmental Assessment of the Mahaweli Agriculture and Rural Development Project. Development Alternatives, Inc./USAID.

van Lavieren, L.P. 1991. Guidelines for Conservation Management of Wetlands in Sri Lanka. Wetland Conservation Project, Central Environmental Authority, Colombo, and Euroconsult, The Hague. Technical Report 1. Euroconsult, Arnhem. iv + 57.

Watson, J.T. and J.A. Hobson. 1989. Hydraulic design considerations and control structures for constructed wetlands for wastewater treatment. In: D.A. Hammer (ed.), Constructed Wetlands for Wastewater Treatment, pp. 379-392. Lewis Publishers, Inc., 121 South Main St., Chelsea, MI 48118. xxii + 831 pp. ISBN 0-87371-184-X.

Wile, I., G. Miller, and S. Black. 1985. Design and use of artificial wetlands. In: P.J. Godfrey, E.R. Kaynor, S. Pelczarski, and J. Benforado (eds.), Ecological Considerations in Wetland Treatment of Municipal Wastewaters, pp. 26-37. Van Nostrand Reinhold, New York.

APPENDIX A

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APPENDIX B

WETLAND DELINEATION CRITERIA IN THE UNITED STATES

In recognition of the significant importance of wetland ecosystems as components of our landscape and suppliers of services vital to our economies and health, the U.S. government, many state governments, and other governments around the world have taken steps to protect remaining wetlands and revitalize or restore critical wetlands that have been drained or damaged in the past. In the United States wetlands are protected under Section 404 of the Clean Water Act, the "Swampbuster" provision of the Food Security Act of 1985, Section 10 of the Rivers and Harbors Act of 1899, and the Emergency Wetlands Resources Act of 1986. Of these, Section 404 and "Swampbuster" are most important. Under these acts, activities detrimental to jurisdictional wetlands are forbidden. Four federal agencies are responsible for identification and delineation of jurisdictional wetlands: the Army Corps of Engineers (Corps), Environmental Protection Agency (EPA), Fish and Wildlife Service (FWS), and Soil Conservation Service (SCS). Three closely related definitions of wetlands are used by these agencies in making wetland jurisdictional decisions. These definitions form the basis of the Unified Federal Method for Wetland Delineation (Federal Interagency Committee for Wetland Delineation, 1989) that is used by all agencies and supported by a broad consensus of wetland and social scientists. The following definitions and descriptions of wetland criteria are extracted from that manual and form the basis for this report.

1. The Corps and EPA define wetlands in administering the 404 program as:

   "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

   (EPA, 4C CFR 230.3 and CE, 33CFR 328.3)

2. The SCS defines wetlands on agricultural land under "Swampbuster" as:

   "Areas that have a predominance of hydric soils and that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions, except lands in Alaska identified as having a high potential for agricultural development and a predominance of permafrost soils."

   (National Food Security Act Manual 1988)

3. The FWS has led a cooperative effort to develop an inventory of U.S. wetlands and uses the following definition in their Classification of Wetlands and Deepwater Habitats of the U.S. (Cowardine, et al. 1979)

   "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly un-drained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season each year."

Obviously, these definitions overlap considerably. The first two include only vegetated areas, while the FWS recognizes non-vegetated wetlands. Other than the SCS's Alaska exclusion, this is the only difference among them.

Using these definitions, the four federal agencies have promulgated a set of mandatory technical criteria for wetland identification and delineation. These mandatory criteria are:

> "Wetlands possess three essential characteristics: (1) hydrophytic vegetation, (2) hydric soils, and (3) wetland hydrology, which is the driving force creating all wetlands. The three technical criteria specified are mandatory and must be met for an area to be identified as wetland. Therefore, ares that meet these criteria are wetlands."

Hydrophytic vegetation is defined as "macrophytic plant life growing in water, soil or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content." Plants may be obligate hydrophytes, but a majority of plants growing in wetlands are also capable of growing in various degrees in non-wetland situations. The determination that an area has hydrophytic vegetation depends on the percentage cover or frequency of hydrophytic species in the vegetation. But, if a site has hydric soils and wetland hydrology, the area is considered to have hydrophytic vegetation even if percentage cover and frequency criteria are not met in the field. Such areas are considered to be disturbed and are treated as special cases in wetland delineations.

Hydric Soils are defined as "soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part." Hydric soils may be organic or mineral soils (in Sri Lanka most hydric soils are mineral soils, including those in System B.). When anaerobic conditions develop in mineral soils, a process called gleizatation occurs. Ferric iron is converted to ferrous iron which can be totally removed from the soil, leaving behind a grey or greenish or bluish grey gley layer. Continuously saturated mineral soils are gleyed to the surface and are always hydric. Mineral soils that are alternately saturated and drained (anaerobic/reduced and aerobic/oxidized) usually develop mottles of different colors within the soil profile. If the soil is predominantly grey with colored mottles, it is saturated for long periods of time and is considered hydric. Soils that are predominantly red or yellow with grey mottles are saturated for shorter periods of time and may not be hydric. Brightly colored mineral soils are rarely hydric. If saturated soils are oxygenated or if they contain little or no organic matter, gleization may not occur. Such soils are still considered to be hydric for wetland delineation purposes.

Wetland Hydrology - "The driving force creating wetlands is 'wetland hydrology', that is, permanent or periodic inundation, or soil saturation for a significant period (usually a week or more) during the growing season." "Numerous factors influence the wetness of an area, including precipitation, stratigraphy, topography, soil permeability, and plant cover. The frequency and duration of inundation or soil saturation are important in separating wetlands from nonwetlands" (primarily as they affect the development of anaerobic conditions). It should be noted that "in the absence of visible evidence of significant hydrologic modification, wetland hydrology is presumed to occur in an area having hydrophytic vegetation and hydric soils."

APPENDIX C

HYDROPHYTES FOUND IN PROJECT AREA

GRASSES

Brachiaria mutica (Forsk.) Stapf
Shallow to deep water in marshy low areas
Digitaria ciliaris (Retz.) Koel
Shallow water and lake edges, grass margins, flooded depressions
Echinochloa colonum (L.) Link
Shallow water and grazed margins
Hygrorhiza aristata (Retz.) Nees
Obligate hydrophyte, shallow to deep water
Oryza eichingeri Peter
Marshy areas
Oryza rufipogon Griff
Marshy areas, rice paddies
Panicum repens L.
Marshy meadow and shallow ponds, good pasture, weed in paddy
Paspalidium flavidum (Retz.) A. Camus
Shallow water and adjacent to streams
Paspalidium germinatum (Rorssk.) Stapf
Villu edges, tank fringes, often in water
Paspalum vaginatum Sw.
Common on grazed margins of villus and tanks and in marshy areas
Saccrolepis indica Chase
Common in broad shallow marshy depressions on grey soils
Saccrolepis interrupta Stapf
In water up to 60 cm deep, villus, near wells, rice fields

EMERGENT MARSH MACROPYTES

Cyperus distans L.f.
Tank margins
Cyperus compressus L.
Stream and ditch banks
Cyperus corymbosus Rottbell (also called C. malaccensis Lamark
Villu, tank, and stream margins in shallow to moderately deep water. This species is prized for mat making and is occasionally cultivated for that purpose.
Juncus effusus L.
Marshy areas, poorly drained soils
Limnocharis flava (L.) Buchenau
A dominant in many marshes in Zones 1 and 5. Eaten in SE Asia as a substitute for spinach or endive.
Polygonum spp.
Members of this large group of plants are common on the margins of villus, tanks, marshy areas, and streams. It is easily recognized by the sheaths that encircle the stems above the leaves at each node.
Scirpus grossus (L.f.)
Villus and marshy bottom edges. Prized for mat making
Scirpus articulatus L.
Villus and tanks, bases often submerged
Typha angustifolia L. "Cattail"
Very common in all wetland areas, forms homogeneous stands. Prized for mat making. All parts of the Typha plant are usable by humans. The rhizomes are an excellent source of carbohydrate, the very young leaves can be used as a pot herb, mature leaves are used in mat making, thatch, etc., and the fruiting heads are ground to make flour.
Typha javanica Schnitzl.
Similar to T. angustifoia but with narrower fruiting heads (see not above)

FLOATING LEAVED MARSH MACROPHYTES

Alternanthera sessilis (L.) DC
Open water areas in wetlands
Eichornia crassipes (Mart.) Solms "Water hyacinth"
Very common in all open water wetlands, serious weed in paddy
Marsilea spp.
Common in still water. Looks like a 4-leaved clover.
Monochoria vaginalis (Burm. f.) Kunth
Related to water hyasinth, open water
Monochoria hastata Solms
Open water
Neptunia oleracea Lour.
Fixes nitrogen, only legume in local watlands. Seed pods often harvested for food.
Nelumbo nucifera Gaertn.
Common in ponds up to 1.5 meters deep. This is an important plant in the Hindu and Buddhist religions.
Nymphaea stellata Willd.
Common in ponds up to 1.5 meters deep
Pistia stratiotes L.
Common tanks, marshes, and villus. Often mixed with Salvinia
Salvinia molesta Mitchell
Common weed often clogging channels and invading paddy land.
Trapa natans L.
Often referred to as water chestnut. The corymbs are spinose and are sometimes collected for food.

SUBMERSED MARSH MACROPHYTES

Aponogeton jacobsenii H. Bruggen
Common in flowing marsh waters up to 1.5 meters deep
Aponogeton natans (L.) Engl. & K. Krause
Floating below and at surface in flowing marsh waters
Najas gramineae Del.
In open marsh water
Ceratophyllum demersum L.
Abundant in open water wetlands

APPENDIX D

CLASSIFICATION OF WETLANDS IN ZONES 1 AND 5, SYSTEM B

	System	Subsystem	Class	Subclass	Water Regime
Handapan Villu	lacustrine	littoral	emergent wetland	persistent and nonpersist.	intermittent. exposed
Bandiya Villu	lacustrine	littoral	emergent wetland	persistent and nonpersist.	intermittent. exposed
Gengala Villu	lacustrine	littoral	unconsol. shore	nonpersist., mud, and vegetated	intermittent. exposed
Tank wetlands	palustrine		emergent wetland	persistent and nonpersist.	permanently flooded
	lacustrine	littoral	"	"	"
Impoundments	palustrine		emergent wetland	persistent and nonpersist.	seasonally or semi-perman. flooded
04/502 Saturated Area	palustrine		emergent wetland	persistent	saturated to seasonally flooded
Natural 503 Wetlands	palustrine		emergent wetland	persistent and nonpersist.	semi-perman. flooded
Narana Ela Wetland	palustrine		emergent wetland	persistent and nonpersist.	permanently flooded

APPENDIX E

SITING CONSIDERATIONS AND DESIGN CRITERIA FOR CONSTRUCTED WETLANDS

Constructed wetlands should be situated and designed to function as much like natural wetlands as possible. To accomplish this we must apply all of our understanding of ecological systems, e.g. energy flows, mineral cycles, and ecological succession, to the site selection and design process. The overall objective in siting and design of constructed wetlands is to maximize efficiency and longevity and minimize maintenance.

E.1 Criteria for Site Selection

1. Wetland hydrology is the most important factor in wetland development and success. Wetlands should be situated to take advantage of streams, drains, and ground water for their water supply. Situations that will require pumping of water should be avoided when at all possible. Artificial maintenance of wetland hydrology is extremely expensive and maintenance intensive.

2. Soil conditions at the site are critical. Sites with poorly drained soils that will hold water in the wetland are much preferred. If such soils are not present at the site, they will have to be brought in and used to seal the bottom of the constructed wetland. While this is possible and is often done, it is very expensive.

3. Functional objectives may limit siting options, i.e. if the wetland is being constructed to remove nitrogen and phosphorus from agricultural runoff and drainage, it will have to be situated to intercept those flows. Understanding the functional objectives of the constructed wetland is also an important consideration during wetland design and evaluation.

4. Land availability can be a serious problem in siting constructed wetlands which are land intensive compared to traditional water treatment technologies.

5. Proximity to existing wetlands will determine the availability of natural seed sources which are important in ecological invasion and succession. It may also be important when design and construction require the importation of clay soils for bottom sealing or the transplanting of wetland vegetation.

6. Frequency and duration of flooding and drought conditions will be important in designing wetlands to survive these natural events.

7. Location in the watershed is a critical concern. Is it better to construct several small wetlands scattered in the upper part of the watershed or to construct one or a few larger wetlands lower in the drainage basin. Most experts favor the former. Smaller wetlands scattered through the landscape seem to be more effective in removing pollutants and in reducing flood levels than are fewer large wetlands lower in the basin. The smaller wetlands are also less obtrusive and generally easier and more economic to build and maintain.

   Another concern about large wetlands is that they usually require the damming of larger, first or second order streams. Most wetland ecologist discourage the construction of such in-stream wetlands, because they unduly interfere with the natural hydrology (drainage) of the basin. Only rarely do such blockages occur naturally on any

but the smallest streams. Wetlands on the larger streams and rivers occur along the banks, on sand bars, or most frequently as riparian wetlands on the flood plains, e.g. villus. Again, small wetlands scattered on higher order streams and in swails are much preferred.

E.2 General Design Guidelines (adapted from Mitsch and Cronk, 1992)

1. Design for minimum maintenance. Establish hydrologic conditions that foster natural ecological succession at the site. The natural wetland that develops will be adapted to current conditions and able to adjust and change as these conditions change. Thus, it will be self maintaining.

2. Design to use natural energies and cycles. Design to take advantage of natural stream flow and drainages, natural seed sources, natural ecological succession, natural plant-animal interactions (including food chains), and natural mineral cycling and transformation processes. Avoid designs that require pumping, horticultural maintenance, and stocking of animal populations.

3. Design the wetland to fit the landscape. Fit the wetland to the natural contours as much as possible and plan for floods and droughts which are natural climatic events to which the wetland should be adapted.

4. Design the wetland to accomplish one major objective. The wetland may perform several functions, including water purification, water storage, sewage treatment, wildlife and fish habitat, but precise design criteria will depend on the primary objective.

5. Give the wetland time to develop. The establishment of a diverse wetland flora and fauna through natural succession may take several years to complete and full operational capability may take even longer. Allow the wetland to evolve naturally. Natural succession will enhance diversity and stability in the wetland and thereby reduce maintenance costs. They will become self designing and self maintaining.

6. Design for function rather than form. Natural succession during the development of the wetland may self create a wetland that has different species or a different arrangement of species than had been originally designed. As long as the wetland is performing the functions that it was designed to perform, it does not matter what species are carrying out those functions. Horticultural manipulation of the vegetation to meet some preconceived notion of what the wetland should look like is expensive, unnecessary and may even be counterproductive by inhibiting the wetland's ability to self design and maintain. Judge the success of the wetland on how well it functions, not on its form.

7. Provide a buffer zone of 5 to 10 meters around the wetland. This zone should be planted to native grasses common on wetland fringes in the area. The buffer zone will filter surface runoff before it enters the wetland and will stabilize the banks.

8. Shallow areas of the wetland may require some protection from cattle and water buffalo. Cattle and buffalo can turn shallow wetland areas into sterile water holes, especially if they invade the area during the period when wetland vegetation is in the early stages of succession. Protection from grazing and trampling will be especially important during this early establishment period. Animal use of the deeper areas is less damaging, especially after the

plants are established; indeed grazing can stimulate plant growth in a mature wetland.

9. Do not over engineer. Engineering should be limited to establishing the basic hydrologic conditions required for the development of a functional wetland. The wetland should be fitted to the landscape. Avoid designs that call for straight lines, right angles, and expensive and high maintenance structures and control devices. Over engineering almost always results in wetlands that are more expensive to build and maintain than they need to be.

E.3 General Design Criteria

The primary objective of constructed wetlands proposed for Block 503 is water purification of agricultural runoff and drainage. This will also be the primary objective of any wetlands constructed elsewhere in Zones 1 and 5 at some time in the future. The following general criteria should be followed when designing and installing these wetlands.

1. **SURFACE AREA: Ratio of wetland to drainage area = 1/100**

   Studies on removal efficiencies for nitrogen and phosphorus indicate that removal improves with increasing size of the wetland until the wetland equals about one percent of the drainage area, after which removal is not improved by larger wetland size.

2. **DIMENSIONS: Optimum would be a length to width ratio of 10 to 1.**

   Generally, the wetland should be longer than it is wide to minimize short circuiting. The dimensions of the basin into which the wetland is to be placed should guide the determination of shape and dimensions.

3. **HYDROPERIOD: Design to withstand the 100-year flood. Don't worry about dry periods**

   Wetlands in Zones 1 and 5 experience flooding every Yala and in places these are severe. The primary design concern is with the engineered structures, especially the dike or dam. If the dam holds and the constructed wetland has self designed, it will survive and recover with no help from man. Wetlands will also survive and recover after drought.

4. **DEPTH:: 15 to 100 cm**

   Most of the wetland should be no deeper than 30 cm to maximize water-substrate contact. A mixture of shallow and deeper areas will enhance the development of vegetational diversity throughout the wetland. Bottom contours should be designed to provide the following depth distribution:

Wetland Surface Area	Water Depth
50%	15 cm or less
25%	15 to 30 cm
25%	30 to 100 cm

Inflow and outflow structures should be installed to allow for flow control and monitoring. Nitrogen and phosphorus removal efficiencies are often increased by occasional draining of the wetland. Occasional draining may also be desirable for mosquito

control. Monitoring demands that quantitative volume of flow samples be possible to collect.

5. **LOADING RATES:** **The loading rate (amount of water entering the wetland/area/time) is the major factor determining how well the wetland functions.**

TARGET: 5-6 cm/day

Most of the research on loading rates has been done on wetlands designed for human and animal sewage treatment or for acid mine drainage purification. Little information is available on optimal loading rates for wetlands designed to purify agricultural runoff and no information is available for any of these systems in the tropics. Recommended loading rates for human sewage treatment are approximately 2 cm/ day (Wile et al., 1985; Brown, 1987). Fennesy and Mitsch recommended a loading rate of 5 cm/day for treating acid mine drainage. A loading rate of 5-6 cm/day ought to be adequate for removing nitrogen and phosphorus from agricultural runoff. Lower loading rates would be even better.

6. **RETENTION TIME:** **1 to 5 days**

$$t = L W n d / Q$$

L = length of wetland
W = width of wetland
n = porosity (= 1.0 without vegetation[5])
d = average depth
Q = average flow

Recommended retention times range from 1 day for acid mine drainage to 21 days for human sewage. Agricultural runoff would fall at the low end of these.

7. **WATER FLOW:** **General Bottom slope less than 1.0 %**
Multicell systems preferred
Design to avert short circuiting

While the general bottom slope should be very shallow, scattered holes and rises will increase plant species diversity.

The larger wetland systems such as that planned for Drainage B in Block 503 should be designed to be multicellular and arranged stepwise along the channel.

If a cell is too broad, water flowing through it might travel directly from inlet to outlet leaving most of the water in the cell stagnant (short circuiting). To reduce the chance of short circuiting in such situations, multiple input points should be provided.

8. **SUBSTRATE SOILS:** **Poorly drained clay is preferred**

The bottom of the marsh should be made up of heavy clay soils with low permeability to minimize seepage. If basin excavation and

[5]Watson and Hobson (1989) recommend that total wetland porosity be between 0.86 and 0.98.

contouring removes such soils, they should be saved and reapplied to the surface as a sealer. Ideally, the clay layer should be at least 18 inches deep.

E.4 ESTABLISHING VEGETATION: Plug transplanting is recommended

As already suggested, natural succession should be allowed to take place in the wetland to enable the wetland to self design and adapt. To get the process started, however, some careful seeding or transplanting should be done.

Planting options include:

1. Rely on natural seed banks and recruitment: Substrate soils will have seeds in them. Those of wetland species can be stimulated to germinate by maintaining water levels suitable for germination for a period after the wetland is constructed. Seeds of wetland species will also invade the new wetland site (recruitment) and will germinate if soil moisture conditions are properly maintained during the germination and early establishment period. An interesting feature of the seeds of most wetland plants is that they cannot germinate under water. Germination and early growth of the seedlings occur only under draw down conditions while the soil surface is moist but not inundated.

2. Import seed banks in soil collected from nearby wetlands: This process is similar to that above, except for the added cost of soil importation. Such costs can be considerable, so imported soils are applied to only a small percent of the bottom area of the new wetland, usually spotted in some pattern throughout the basin. The positive aspect of this method is that imported wetland soils will usually have well developed and diverse seed banks.

3. Seeding: Seeds can be broadcast in the new wetland while the wetland is held in draw down-moist soil condition. Seeds can be locally collected or purchased from seed companies. Use of local seed sources is strongly recommended, because they are adapted to local conditions. Studies comparing establishment success of commercial vs. local seeds demonstrate that commercial seeds have a high failure rate, whereas local seeds have a high success rate.

4. Transplant rhizomes, tubers, corymbs, or roots of individual plants or transplant soil plugs containing collections of coexisting species: Either of these options is preferred over option 1 to 3 in situations where adequate local sources of plant material are present. Success rates from such transplants tend to be very good and site conditions do not have to be as rigidly controlled for establishment of such transplants. Of these two options, plug transplanting is recommended here, because it brings an entire complex of plant, animal and microbial species to the new site. Also, by transplanting intact soil plugs, included roots, rhizomes, corymbs, etc. are kept in a natural condition with a minimal amount of traumatization.

Plugs should be approximately 30 cm deep and 30 cm in diameter. Tops of emergent plants in the plugs can be cut 10 to 15 cm above the soil surface.

Plugs should be transplanted the same day they are collected and should be enclosed in plastic bags during transport.

The planting pattern for each cell will depend on the functional objective established for that cell, but a general rule is that plugs should be planted at a density that will enhance effective competition with invaders and in a pattern that will produce a complex mosaic of small homogeneous stands within the wetland. The final vegetation design for each cell should be done in consultation with an experienced wetland ecologist.

APPENDIX F

WETLAND MANAGEMENT GUIDELINES

Properly designed wetlands will require little maintenance. As a matter of fact, in much of Zones 1 and 5 self designing and self maintaining wetlands will volunteer on sites wherever appropriate hydrologic conditions are established, even when not planned. There are, however, some general management guidelines that should be followed.

1. Grazing and Harvesting

Some protection from grazing and harvesting should be provided while the new wetlands are becoming established. Protection from grazing will be especially important in the shallow zones of the marsh. Cattle and water buffalo could wipe out young stands of vegetation before their roots and rhizomes can become firmly established. This process could take about three years. Harvesting should also be discourage during this three-year period. After the vegetation has become established, however, some grazing and harvesting will usually stimulate production. Over grazing and trampling can still lead to the destruction of vegetation and the creation of open water or even mud hole conditions. This should be monitored and kept under control. Educating the farmers is the best way to manage carrying capacity. Another is to provide ample wetland capacity in the landscape to satisfy demand for grazing and harvesting. Optimally, human use of the wetland should be encouraged. These wetlands should be seen by the local people as resources for their use - and protection.

2. Water Quality Monitoring

A regular water quality monitoring program should be established on all constructed wetlands and on other wetlands conserved for water purification purposes. See APPENDIX G for guidelines for such a program. Data from the monitoring program will be valuable in assessing the effectiveness and efficiency of the wetlands. Such information will be valuable in managing the wetlands and in designing new constructed wetlands in the future. Water sampling should be intensive during the years the wetland is becoming established and should be continued after that at a reduced frequency.

3. Infrastructure Maintenance

Dams and control structures will require the same operation and maintenance procedures afforded other infrastructure in the Zones 1 and 5. Dams should be inspected regularly, especially after major flood events. Dams and buffer zones should be planted to native grasses found around villus to minimize maintenance costs and provide grazing for cattle and buffalo during Yala.

4. Periodic Drainage

Once the wetlands have become established (after 3 to 6 years) they should be drained periodically (every 5 to 7 years). This will allow the substrate to oxidize and stimulate the germination of seeds in the substrate seed banks (seeds of most wetland species cannot germinate under water). This will rejuvenate the wetland. In multicell wetlands, cells can be drawn down individually, leaving others full and operational. A draw down of three months during Yala should be enough to revitalize the wetland, but slightly longer draw downs will not hurt. Wetlands are adapted to surviving drought.

5. Wetland Manager

As natural and constructed wetlands become established as water management features of the urban and agricultural landscape in Sri Lanka, there will be a growing need for professional wetland managers to design, construct, operate, and maintain these systems. While single wetlands will be largely self maintaining, an extensive system of wetlands will require special technical and management expertise. Steps should be taken to initiate training opportunities to insure that such expertise is developed in Sri Lanka.

APPENDIX 9

WATER QUALITY MONITORING

Water quality monitoring should be carried out at three sites in Zones 1 and 5. Sampling and analysis could begin immediately at the first two sites and should begin at the third as soon as the constructed wetlands come on line. The three sites are:

1. Major drain convergence in Zone 1

   Three major drainage systems (LB DCL 2, 3, and 4) converge at a bridge approximately half way between Dimbulagala and Pelatiyawewa on MARD Road No. 6 (Fig. 2, point "A"). A water sampling station at this point would enable MARD to monitor drainage water quality for a major section of Zone 1. Further, this site is slated for major drain improvements that will channelize the flow into the riparian forest and villus along the Mahaweli Ganga. This might be an excellent place to locate a constructed wetland to improve the quality of the effluent waters if that proves to be a problem. Such controls are important in protecting the riparian areas and especially the villus along the Mahaweli Ganga.

2. Natural marsh on Narana Ela in Block 502

   A natural marsh has developed in an impoundment caused by a 0.5 meter sill under a bridge where the dirt road (not on the maps) leading west from Divuldamana to the Kuda Oya crosses the Narana Ela (Fig. 4). This is a high quality wetland which extends more than 500 meters south of the bridge. The left bank is under paddy cultivation and the right bank is under paddy on upper slopes and alternative upland crops on the lower slopes. By monitoring water quality in the runoff from this drainage basin, MARD will be able to assess quantities of chemicals coming off the land and the impact of the wetland in removing these chemicals from the water.

   Water quality sampling at this site should include samples at the bridge and samples from each drainage canal entering the marsh from both sides. Information should also be gathered on cropping patterns, and amounts and timing of water, fertilizer, pesticide and herbicide applications on all field in the marsh's watershed. A complete vegetation analysis should also be carried out on this wetland to define its ecological structure.

3. Constructed Wetlands in Block 503.

   Virtually nothing is known at this time about how constructed wetlands will function in the tropics. A monitoring program on the constructed wetlands in Block 503 will provide valuable information that can be used for managing these wetlands and for designing other constructed wetlands to be installed elsewhere in Zones 1 and 5, in Sri Lanka, and in the tropics. This would be a major contribution to sustainable development efforts worldwide.

   The 503 constructed wetlands will undergo an extended period of development as their vegetation matures and their operational capabilities develop. To monitor the effectiveness of these wetlands during this development period, water samples should be collected at all control structures. This will provide information on operational efficiency and effectiveness for each cell and enable managers to assess the relative effectiveness of different vegetative assemblages in removing target pollutants. Annual

vegetation surveys should also be carried out to define the vegetation component of the cells, and annual soil samples should be collected from the wetland botton to assess the content of cations, pesticides, and herbicides in the substrate. Additionally, data should be collected on cropping patterns and periodic (once per month and immediately after major storm events) water samples should be collected from drainage ditches where they enter the central channel that leads to the wetland. This will enable MARD and Sri Lankan officials to relate pollutant loads to general cropping patterns in the subbasins of these drainages. The details of this monitoring plan should be worked out with the consultation of water quality specialists and ecologists.

This monitoring program should be designed to run for at least one full year at sites 1 and 2 and for at least three years at Site 3. Water samples should be collected weekly (monthly on 503 drains, see above) and more often during major storm events. Analyses should quantify the presence of nitrates, phosphates, pesticides, herbicides, and fecal coliform at all sampling sites. Facilities for all recommended analyses are available at the Institute of Fundamental Studies at Kandy.

APPENDIX H

WETLANDS IN THE AGRICULTURAL LANDSCAPE

The natural landscape is a complex mosaic of more or less homogeneous landscape units. This mosaic and each of its units are adapted to local environmental conditions. Each landscape unit type carries out internal functions to process energy, cycle materials, produce and consume. They also exchange energy and materials with surrounding units. Each unit will be more or less stable according to how efficiently it is able to accomplish these functions. At any one time, some of the units may be unstable, but the health of the landscape is dependent upon the stability of the mosaic, e.g. MOSAIC STABILITY.

Wetlands are important components of natural landscapes. Occupying low spots in the landscape, they are the recipients of runoff and drainage from units upslope or upstream. In this position, wetlands perform essential functions of WATER STORAGE, mediating flood impacts downstream, and WATER PURIFICATION, the removal of various pollutants and nutrients from the waters passing through them, thereby providing clean water to downstream ecosystems. Also, by virtue of their high productivity, wetlands serve as the base for grazing and detrital food chains that are especially important for the young of various animals, e.g. they are nurseries.

Wetlands are defined by three factors:

1. Wetland Hydrology: the presence of saturated conditions or standing water for at least one week during the year.
2. The presence of an anaerobic zone in the soil.
3. The dominance of hydrophytic vegetation, plants adapted to anaerobic conditions in the soil.

Therefore, open water systems such as lakes, reservoirs, deep rivers, etc. are NOT wetlands, but a wet meadow IS ! These criteria are used to define jurisdictional wetlands in the U.S.A.

How do wetlands function?

Hydrophytic plants are able to survive anaerobic conditions in the soil because they have internal air channels in their stems and roots that carry oxygen to the roots. Some of this O_2 leaks into the soil forming a thin aerobic layer around the root hairs, thus creating a tremendous surface area in the soil where aerobic and anaerobic conditions exist side by side. This environment allows for both aerobic and anaerobic chemical transformations carried out by bacteria in the soil. For instance, ammonia can be oxidized in the aerobic zone to nitrate and the nitrate can diffuse into the adjacent anaerobic zone where another bacterium converts it into nitrogen and oxygen gasses, thereby cleansing the water of NO_3.

Hydrophytic plants also provide a tremendous surface area in the water column for the establishment of algal and bacterial populations. These organisms extract pollutants from the passing water and transform them into harmless compounds. They also serve as a food source for microinvertebrates, and are thus the base of a grazing food chain that leads up to organism eaten by man. Of course hydrophytic vegetation is also grazed by larger animals such as cattle, elephants, plant eating fish, etc. and thus serves again as a base for a food chain important to man.

Finally, hydrophytes die and decompose. Decomposition is carried out by bacteria that use the plant tissue as a substrate and energy (carbohydrate) source. Most hydrophyte tissues, however, do not contain enough nitrogen to enable the bacteria to obtain all the nitrogen they need, so the bacteria extract nitrogen from the water - alas water purification. The decomposition process is often fairly slow, especially in temperate and cooler climes, and dead plant material may build up on the marsh floor and become buried by subsequent layers of dead

plants. By this process, some pollutants may become buried for long periods of time. Some types of coal or metal ores have been formed this way.

In System B, there are several types of wetlands:

1. Villus are riparian wetlands that are found along the flood plain of the Mahaweli Ganga. These and other riparian wetlands get most of their water inputs from local runoff and occasional flooding of the adjacent river. Villus are important water purification systems for the Mahaweli Ganga and provide essential grazing for cattle during Yala. They are also important to man as fisheries and the source of reeds.

2. Natural Marshes: All low lying areas of Zones 1 and 5 that are underlain by poorly drained soils are potential if not actual wetlands. In Zone 503 natural marshes are frequented by elephants and crocodiles. Riverine wetlands occupy the channel of the Kuda and Maduru Oyas, and riparian wetlands are common in the braids of the Kuda oya and in small villus along its flood plain. And finally, natural volunteer wetlands form where ever impeded drainage creates wetland hydrologic conditions. One such wetland in Block 502 is a very high quality marsh that has developed naturally behind a man-made weir on the Narana Ela near Divuldamana. Other natural marshes will self develop under similar conditions.

3. Tank Marshes: Wetlands occur where water depths are less than 1 meter and the optimum depth is about 30 cm. Therefore, one finds marshes in areas of tanks that have these depths. Tank marshes provide essential nursery and water purification services and should therefore be protected.

4. Impoundments: Structures such as dikes, anticuts, berms, roads, broken culverts and canal walls can create conditions suitable for the development of wetlands. Such conditions abound in System B. Many of these wetlands provide only marginal services to the landscape and could be drained with little adverse impact. Other impounded wetlands, however, may be located at critical points in the drainage where they intercept and purify runoff from surrounding agricultural land in the basin. Or they may be providing other valuable landscape services. Such wetlands should be conserved and protected even though they were inadvertently (or fortuitously) created.

The agricultural landscape is highly altered and unstable. It is a landscape that is sustained by high inputs of subsidies from man in the form of money, energy, chemicals, and water. Purification of runoff waters would require additional inputs from man as would the provision of such amenities as wildlife habitat, watering places for cattle, grazing or fodder during Yala, nurseries for fish and reed farms for bed mats, etc. etc. etc. Strategically situated wetlands can provide all of these services to the landscape and man at a fraction of the cost of more traditional technologies. Wetlands will enhance MOSAIC STABILITY in the agricultural landscape.