



Final Hydrological and Ecological Assessment Report

Identification of areas for baseline and continuous monitoring of water quantity in the Negril Environmental Protection Area, and Scenarios for reduced sedimentation and improved regularity of water flow based on degrees of land use change and restoration needs in the areas of intervention

Consultancy for the Hydrological Assessment of a Wetland Ecosystem

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Final Hydrological and Ecological Assessment Report: *Identification of areas for baseline and continuous monitoring of water quantity in the Negril Environmental Protection Area, and Scenarios for reduced sedimentation and improved regularity of water flow based on degrees of land use change and restoration needs in the areas of intervention*

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**FINAL HYDROLOGICAL AND ECOLOGICAL
ASSESSMENT REPORT**

Consultancy for the Hydrological Assessment of a Wetland
Ecosystem

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List of Abbreviations and Acronyms

CAR/RCU	Caribbean Regional Coordinating Unit
CARPHA	Caribbean Public Health Agency
EPA	Environmental Protection Area
GEF	Global Environment Facility
GPS	Global Positioning System
IWEco	Integrating Water, Land and Ecosystems Management in Caribbean Small Island Developing States
JHTA	Jamaica Hotel and Tourist Association
LIDAR	Light Detection and Ranging
MEGJC	Ministry of Economic Growth and Job Creation
MHURECC	Ministry of Housing, Urban Renewal, Environment & Climate Change
MOF&PS	Ministry of Finance, Planning and the Public Service
MSET	Ministry of Science, Energy & Technology
NCC	Negril Chamber of Commerce
NCRPS	Negril Coral Reef Preservation Society
NEPA	National Environment and Planning Agency
NEPT	Negril area Environmental Protection Trust
NGO	non-governmental organization
NLA	National Land Agency
NWA	National Works Agency
TPDCo	Tourism Product Development Company Ltd.
UAV	unmanned aerial vehicle
UDC	Urban Development Corporation
UNDP	UN Development Programme
UNEP	UN Environment
UWI	University of the West Indies
WRA	Water Resources Authority

Executive Summary

The Integrating Water, Land and Ecosystems Management in Caribbean Small Island Developing States (GEF-IWEco) Project is a multi-focal, regional project that builds upon the work of previous initiatives, to address water, land and biodiversity resource management as well as climate change in ten (10) participating countries. It is funded by the Global Environment Facility (GEF) with the UN Environment (UNEP) as the lead Implementing Agency for regional projects. The main objective of the IWEco project is to contribute to the preservation of Caribbean ecosystems that are of global significance and the sustainability of livelihoods through the application of existing proven technologies and approaches that are appropriate for small island developing states through improved fresh and coastal water resources management, sustainable land management and sustainable forest management that also seek to enhance resilience of socio-ecological systems to the impacts of climate change.

Biodiversity Mainstreaming in Coastal Landscapes within the Negril Environmental Protection Area of Jamaica is the Jamaican IWEco national sub-project. The Lead Partner Organization is the National Environment and Planning Agency (NEPA). The key objectives of this sub-project is:

- To restore the important elements of biodiversity of the Negril Great Morass that are of national, regional and global significance
- To reduce further degradation of peat resources, contributing to improved human health, water quality, air quality and ecosystem functions
- To improve livelihoods and strengthen land use practices within local communities; and
- To strengthen management of the Negril Environmental Protection Area

1.1 Ecological Assessment

To understand the ecological setting and status of the flora and fauna supported by the existing conditions of the Negril Great River Morass, a combination of primary and secondary data was collected. Most of the Morass is a wetland on peat. The wetlands are enclosed to the west by a sandy berm, and to the east and south by limestone hills. The health of the wetlands is closely related to the condition of the adjacent habitats, including the dry forests on limestone of the adjacent Fish River and Negril Hills. Between the wetland and the sea, the natural vegetation is dominated by coastal woodlands, lowland forest, and swamp forests. The interior of the wetland is mainly herbaceous wetland. There are also some mangroves along the coast and the rivers, swamp forests and limestone islands.

Mangroves are found in the Morass where conditions are saline, e.g., along the South and North Rivers, and in Ireland Pen (Orange Bay). Since the 1980s, stands of Red, Black and White Mangroves have increased in area and spread along the canals, including the north of the Cutoff canal, probably in response to increasing salinities. Meanwhile, Buttonwood mangroves that were present as forest and scrub in the centre of the Morass have disappeared. This loss potentially reflects the impacts of increased inundation and disturbance by ganja farmers and charcoal burners. In Orange Bay, the wetlands and mangroves on the coastal side of the main road are under threat from clearing and dumping up for the establishment of a fishing village and squatting.

In addition to mangroves, much of the Morass is herbaceous wetland dominated by Sawgrass *Cladium jamaicense* and hummocky swamp. Historically, the area was also dominated by uniform stands of Giant Swamp Ferns *Acrostichum spp.* or by Pond Coco *Sagittaria lancifolia*. The area of herbaceous wetland has decreased since the 1980s. This is the result of expansion of ganja farming in the centre of the Morass, agriculture, and grazing, mainly on the east and expansion of Mimosa pigra and African Tulip trees southeast of the Royal Palm Reserve. Other possible sources of degradation include drainage, fire, drying

out in some areas and inundation in others, salinization, agriculture, and invasive species. In areas affected by fire, sedges including *Eleocharis cellulosa*, *Rhynchospora globularis* and *R. inundata* dominate.

Freshwater and brackish aquatic habitats in and near the Morass include springs, rivers, streams, canals, ditches, blue holes and natural and artificial ponds. The swamp forest is characterized by the presence of the endemic Swamp Royal Palm or Swamp Cabbage *Roystonea princeps*. The greatest abundance of this species occurs in the Royal Palm Reserve. All the forests stands are dominated by the emergent, *R. princeps*, and the endemic Broadleaf (*Terminalia latifolia*) and Trumpet Tree (*Cecropia peltate*). The common trees of the sub-canopy included *Ficus pertusa*, *Ficus maxima*, and Anchovy Pear *Grias cauliflora* (also endemic). The undergrowth includes the Spider Lily *Hymenocallis littoralis*, as well as ferns such as *Anemia* sp., *Thelipteris* sp. and *Pityrogramma* sp. Range restricted plants of the area include several endemics like *Broughtonia negrilensis*, *Hohenbergia negrilensis*, *Grias caulifera* and *Roystonea princeps*, which is classified as Near Threatened by IUCN (Zona 1998). The rare endemic tree, *Phyllanthus acuminateus*, occurs in the coastal woodland. Anthropogenic habitats within the Morass include agricultural lands and pastures.

Bats are the only native mammals that occur in the Negril EPA. Bird conservation and monitoring plans for the Royal Palm Reserve were prepared in 2007 but have not been implemented. At least four species of reptiles that are classified as threatened by IUCN (2020) have been recorded in or near the Morass. These include the Jamaican (Cat Island) Freshwater Turtle (*Trachemys terrapen*) (also known as the Jamaican Slider and locally referred to as pond turtle or hicatee); the American Crocodile (*Crocodylus acutus*); the Yellow Boa (*Chilabothrus subflavus*); and the Hawksbill Turtle (*Eretmochelys imbricata*). Only one endemic fish – the top minnow, *Gambusia wrayi*, was found. The abundance of juvenile fish suggests that the canal and associated channels into the wetland serve as a nursery for many species of fish. Commercially important species included Jack, Mullet, Snappers, Tilapia and Snook. Snook, tarpon and snappers are of interest to sport fishers. Known invasive fish species in the Morass include African Perch (*Tilapia mossambica*) and the Wolf Cichlid (*Parachromis dovii*). The African Perch reduces habitat for other species, while the Wolf Cichlid is a voracious predator. The fish fauna and the contribution of the Morass to the artisanal fishery of Negril was badly affected by the channelization of the Morass, which made the shallow areas and channels in the Morass that previously served as foraging areas and nurseries for fish inaccessible for most of the year (Aiken 1991).

The ecological functions of the Morass include flood control, groundwater recharge, maintenance of water quality, biodiversity conservation, natural beauty, heritage, recreation and education, support for sustainable agriculture, coastal protection, nursery for marine fish, utilization of natural resources, and carbon sequestration.

1.2 Hydrological Assessment

This assessment provided information on the hydrological analysis conducted for the Negril Great Morass, and on the current hydrological conditions of the Morass. It also helped to identify the causes of the dehydration of the Morass, and presents recommendations on how to increase the water moisture within the Morass.

Five (5) primary controls on the water content/balance of the Great Morass wetland were identified, i.e., direct rainfall; the South Negril River; the North Negril River; the East Canal; and groundwater spring discharges. The Great Morass has been subject to extensive drainage interventions, since the beginning of the 19th century, to try and improve the potential for agricultural production in the area, resulting in significant changes to the river flowing across and through the Great Morass. This has also had a significant impact on intercepting groundwater and allowing saline waters to enter the body of the Morass. The

consequence of the construction of these three main canals has been to route storm water flows rapidly past the Morass from the watersheds to the east and southeast of the Morass – note the Orange and Fish Rivers never used to flow through the Morass.

There has been a significant reduction in effective rainfall in the Negril area with time, which, notwithstanding the manmade drainage schemes, have contributed to the drying of the Great Morass over the last 40+ years. It is possible the reductions of low flows with time could be due to increased water abstraction from the river, but as there are also reductions in high flows, this suggests this is a climate change impact. The lower the water levels are in the rivers and the longer the duration of river low flows, the more likely not only saline intrusion into the freshwater wetland will occur but also increased dewatering of and drying out of the wetland and its underlying peat formation. Once peat starts to dry out it becomes very friable and easily eroded, as well as more combustible, and compacts under its own weight resulting in land subsidence, which itself increases water expulsion, resulting in further dewatering and on-going land lowering, and saline water ingress.

1.3 Recommended Hydrological Restoration Strategies

Understanding the severity of the historical drainage impacts on the Morass hydrology, as well as the on-going impact of climate change on rainfall, evaporation, river flows and groundwater flows, which collectively reduce the water content within the wetland, has enabled an informed multi-stakeholder dialogue on what could or should be the hydrological restoration objectives and targets for the re-wetting of the Morass. Based upon these discussions, four (4) hydrological restoration goals were identified:

- Reducing the risk of wild bush fire to the west of the East Canal.
- Increasing the wetness of the area around the Royal Palm Forest, favoured by the West Indian Whistling Duck.
- Raising water levels or blocking the East Canal; and
- Re-routing the eastern springs into the centre of the Morass.

Each of these separate restoration target areas would need to function as a separate hydrological zone, whilst complimenting each other in an overall coordinated hydrological restoration plan for the Morass. Each of the four hydrological restoration targets/areas has been assessed to identify the optimum water levels required to deliver the ideal areas and depths of water retention in the wetland, using the run-off routing analysis. Based on these goals, the following restoration options were suggested:

1. **Four micro-catchments** – the main idea behind this intervention is to attenuate the water leaving the mini watersheds to give it more time to soak into the wetlands by blocking the flow routes. To do this a low-lying earthen bund constructed with side slopes of 1 in 3 to pond a particular amount of water behind; the higher the bund the greater the water depth is expected to be. Simulated bund elevations with a ridge of 1m are shown to retain 25-50cm of water behind them.
2. **Smaller micro-catchments towards the south in the region of the Royal Palm Reserve** – similarly, their purpose would be to reduce the flow of water leaving this area, thus retaining moisture for longer periods during the dry season. Simulated bund elevations are provided for 25-50cm water retention.
3. **East Canal Blockers with overflow weirs** – the aim of this intervention is to minimize the dewatering of the peat by putting a blocker in the canal e.g. a dam. This would facilitate ponding upstream of the blocker and reduce dewatering of the peat. Installing a blocker with a bund that is 25cm above the height of the canal would cause further ponding in the areas surrounding the

canal. The important features are that the weir level can be altered as necessary by designated officers, and that the weir box plates cannot be removed or altered by unauthorized individuals.

4. ***Ditches and spring-fed pipes*** – use of manually or machine excavated ditches with a flat base of approximately 0.5m width and bank slopes of 1 in 3 to ensure stability and prevent collapse. The aim of this intervention is to channel the water from the springs towards the centre of the Morass to minimize drying out within the inner regions of the Morass and near the reserve, thereby decreasing the risk of bush fires and increasing water level near the Negril Royal Palm Reserve.

To increase the water content of the Morass it is necessary to either increase the amount of water entering the Morass and/or reduce the amount of water leaving it. Due to the substantial historical disturbance of the Morass by large scale drainage infrastructure, the inevitable focus has been to reduce the impact of the drainage infrastructure, specifically to focus on reducing the drainage and reduce the existing water flows leaving the Morass.

Unit costs have been developed per 1m length of bund construction, ditch excavation, pipeline length, as well as for the East Canal blockers. The unit costs provided are for properly engineered and supervised structures, including vegetation and soil removal, trucked-in materials and use of geotextiles to prevent settlement. The unit costs can then be applied to each of the 66 No. water management structures that have been identified. The most efficient structure using storage area per bund length is the 25cm high C3 Wild Bush Fire reduction bund, whereas the most efficient using storage volume per bun length is the 50cm high C3 Wild Bush Fire reduction bund. Unsurprisingly the greatest storage area and storage volume are created by the East Canal blocker B1 with 50cm high surrounding bunds.

For subsequent water monitoring, it is necessary that an entity be assigned the responsibility of monitoring, maintenance, repair and resetting the level of weirs since this function does not currently exist. It is proposed that this be the responsibility of the WRA. It is also recommended that the WRA partner with local stakeholders to include participatory monitoring approaches to operating and maintaining the water monitoring network. Further recommendations to support monitoring include:

- Installing an automated weather station towards the northeast end of the Morass
- Repairing, reinstalling, or replacing the stream flow gauging station on the South Negril River near Springfield, and
- Conducting groundwater monitoring is proposed at the seven (7) springs.

The hydrological assessment conducted under this consultancy provides integrated approaches to environmental management and land use, to improve natural resources of the Negril Great Morass by strengthening policies and legal/institutional frameworks while creating awareness and facilitating capacity building for sustainable land management, considering the influence of climate change. The aim is to promote conservation of key flora and fauna within the Negril Great Morass through restoration of wetland ecosystem services and sustainable use of wetland biological resources. This provides a unique opportunity for much needed restoration of historical hydrological processes, enhancement, and re-establishment of native vegetation communities to provide habitats, and elimination of conflicts which degrade ecosystem functions.



2 Introduction

2.1 Project Overview

The Integrating Water, Land and Ecosystems Management in Caribbean Small Island Developing States (GEF-IWEco) Project is a multi-focal, regional project that builds upon the work of previous initiatives, to address water, land and biodiversity resource management as well as climate change in ten participating countries.

IWEco is funded by the Global Environment Facility (GEF) and UN Environment (UNEP) is the lead Implementing Agency for regional projects. The UN Development Programme also implements some activities aimed at supporting community-based livelihood opportunities through the GEF-Small Grants Programme. The Secretariat to the Cartagena Convention, UN Environment's Caribbean Regional Coordinating Unit (CAR/RCU) and the Caribbean Public Health Agency (CARPHA) are the Project's co-Executing Agencies. Partnership is a central tenet of the project which is being implemented through a network of international, regional, and national partners. The ten participating countries are: Antigua & Barbuda; Barbados; Cuba; the Dominican Republic; Grenada; Jamaica; Saint Kitts & Nevis; Saint Lucia; Saint Vincent & the Grenadines, and Trinidad & Tobago. The project started in 2016 and is due to end in 2023.

IWEco'S OBJECTIVE:

To contribute to the preservation of Caribbean ecosystems that are of global significance and the sustainability of livelihoods through the application of existing proven technologies and approaches that are appropriate for small island developing states through improved fresh and coastal water resources management, sustainable land management and sustainable forest management that also seek to enhance resilience of socio-ecological systems to the impacts of climate change.

Biodiversity Mainstreaming in Coastal Landscapes within the Negril Environmental Protection Area of Jamaica is the Jamaican IWEco national sub-project. The Lead Partner Organization is the National Environment and Planning Agency (NEPA).

JAMAICAN IWEco'S NATIONAL SUB-PROJECT OBJECTIVES:

- **The restoration of important elements of biodiversity of the Negril Great Morass that are of national, regional and global significance**
- **The reduction in further degradation of peat resources, contributing to improved human health, water quality, air quality and ecosystem functions**
- **Improvements in the livelihoods and strengthened land use practices within local communities; and**
- **Strengthened management of the Negril Environmental Protection Area**

The National Sub-Project has five (5) components, with eighteen expected outputs and nineteen outcomes:

COMPONENT 1: Integrated approaches to land management, land use, pollution management and management of the hydrodynamics of the Negril Environmental Protection Area (EPA)

- **Sub-component 1.1: Planning Hydrological Restoration of the Negril Environmental Protection Area**
- **Sub-component 1.2: Land use and management plan for the Negril Environmental Protection Area**
- **Sub-component 1.3: Baseline data compilation (including identification of priority problems and selection of indicators)**

COMPONENT 2: Improvement of water, land, ecosystems and biodiversity resources of the Negril Morass, taking into account climate change, sensitive ecosystems and ecosystem services

- **Sub-component 2.1: Pollution control and development of a monitoring protocol and system for assessment of project indicators**
- **Sub-component 2.2: Habitat/ecosystem rehabilitation investments for conservation of internationally significant, endemic and migratory species**

COMPONENT 3: Strengthening of policies and legal and institutional frameworks and capacity building for sustainable land management, integrated management of water resources and the management of ecosystem services, taking into account climate change

- **Sub-component 3.1: Local Institutional and Community Capacity Building**
- **Sub-component 3.2: Built capacity for managing Wetland Protected Areas**

COMPONENT 4: Communication, awareness, policy dialogue, sustainability and lessons learnt

- **Sub-component 4.1: Knowledge building, lessons learnt and research activities**
- **Sub-component 4.2: Best environmental practice investments by farmers and land owners (to address unsustainable land use within the wetland ecosystems), supported by GEF-SGP**

COMPONENT 5: Project Administration & Monitoring and Evaluation, and Audit

This consultancy, Hydrological Assessment of a Wetland Ecosystem, falls under Component 1, specifically sub-component 1.1: Planning Hydrological Restoration of the Negril Environmental Protection Area (EPA) of the national sub-project and is to be supplemented by the following sub-components and their respective activities (in addition to Components 2-5):

- Land use and management plan of the Negril Environmental Protection Area
- Baseline data compilation (including identification of priority problems and selection of indicators) for the project

2.2 Purpose and Scope of the Report

This report represents Deliverables 3, 4 and 5 to be submitted under this consultancy, namely:

- D3 - Report on areas identified for intervention which will include a detailed digital model (GIS or other) and electronic files
- D4 - Report on the Identification of areas for baseline and continuous monitoring of water quantity in the Negril Environmental Protection Area:
- D5 - Report on three scenarios for reduced sedimentation and improved regularity of water flow based upon degrees of land use change and restoration needs in the areas of intervention



3 Ecological Assessment

This section and sub-sections outline the results of a rapid assessment of the ecological conditions and potential impacts (anthropogenic and natural phenomena, including climate change) that affect the natural habitats throughout the Negril Morass. It includes primary and secondary baseline data on natural habitats within the morass *inter alia*: spatial extent, health, condition, composition, threats and drivers of change (farming, invasive species, fires, change in hydrology, pollution etc.) and suggested indicators for monitoring under rewetting scenarios (see Appendix F for indicators).

3.1 Vegetation and Habitats

The vegetation of the Negril Great Morass has been previously described by NRCA (1981) (Figure 1), Coke (1982) (Figure 2) and Caribbean Ecosystems Ltd (2001). A detailed assessment of the Negril Royal Palm Forest was carried out in 1986 (Anderson *et al.* 1986). Several other assessments of the coastal woodlands and associated habitats have been conducted as part of environmental impact assessments. The Forestry Department effected detailed assessments of the mangroves in 2019-2021. An assessment of the impacts of fire in the Morass was carried out by Lewis (2010) and of invasive plants in the Royal Palm Reserve by Duever (2009). A list of species has been compiled from these studies (Appendix A). This list provides detailed geographical coverage for the wetlands, coastal woodlands, and swamp forest, but there have been no botanical assessments of the adjacent limestone forests. However, the assessments are all more than 20 years old, and are therefore much in need of updating.

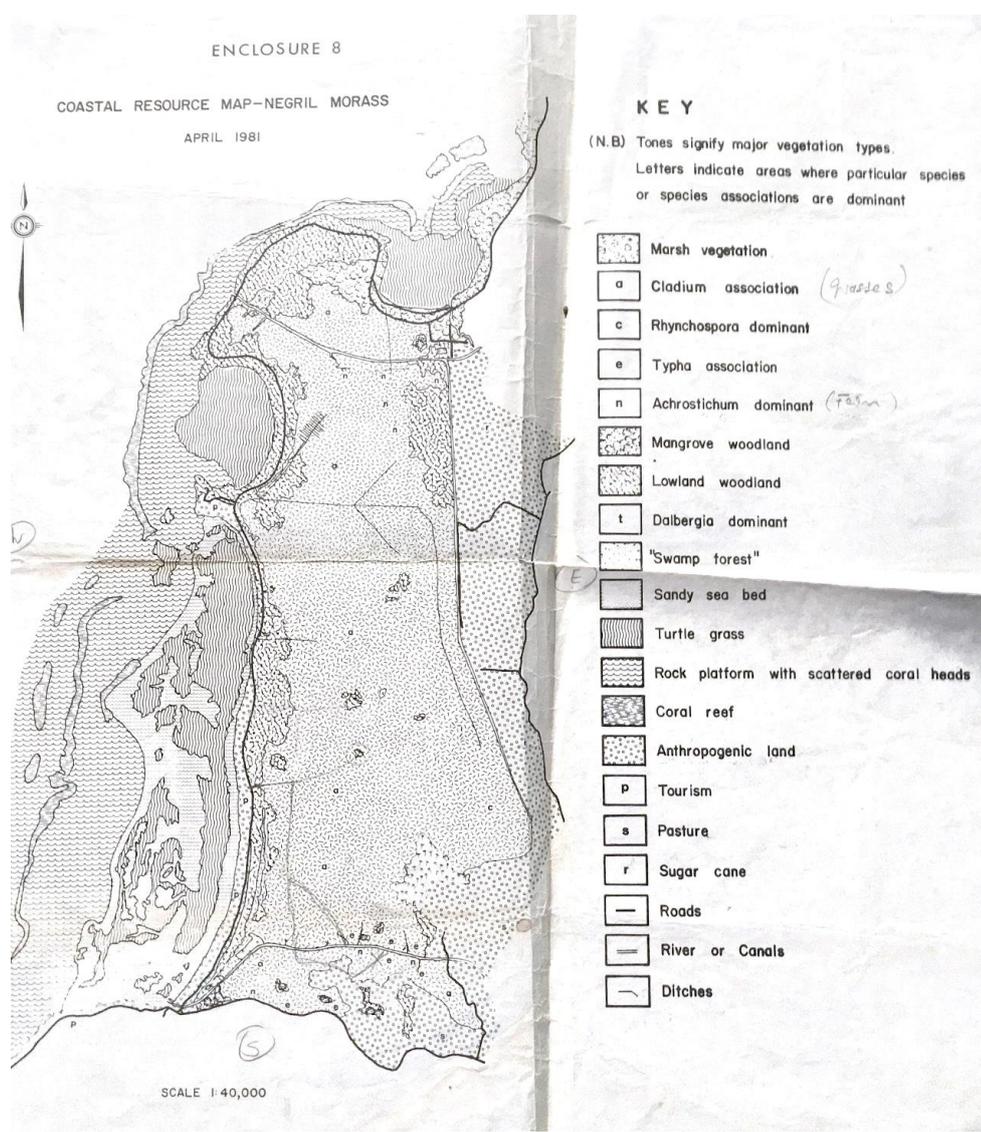


Figure 1 Coastal ecosystems of the Negril Great Morass (NRCD & Traverse Group, 1981)

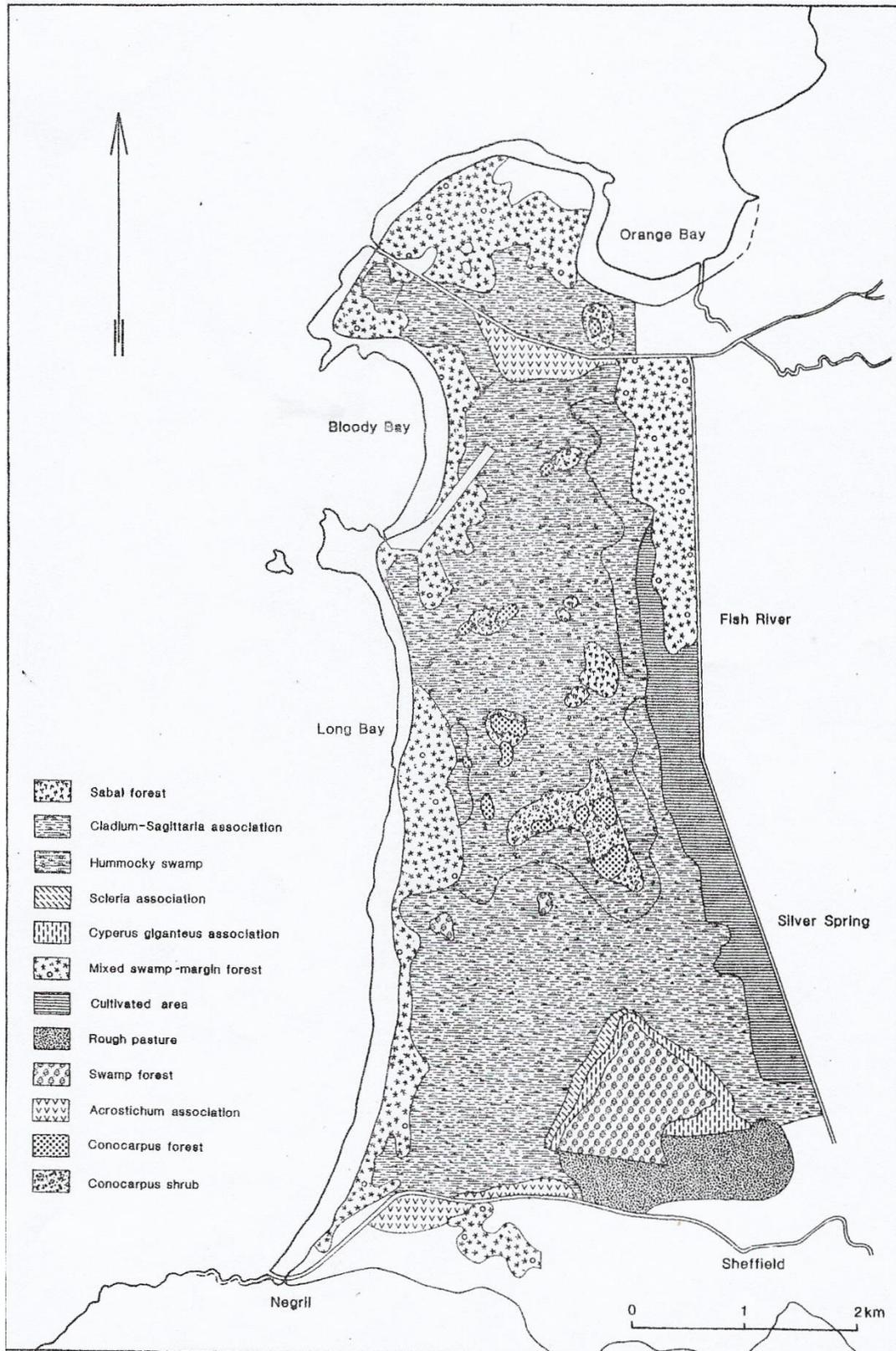


Figure 2 Coastal ecosystems of the Negril Great Morass (NRCD & Traverse Group, 1981)

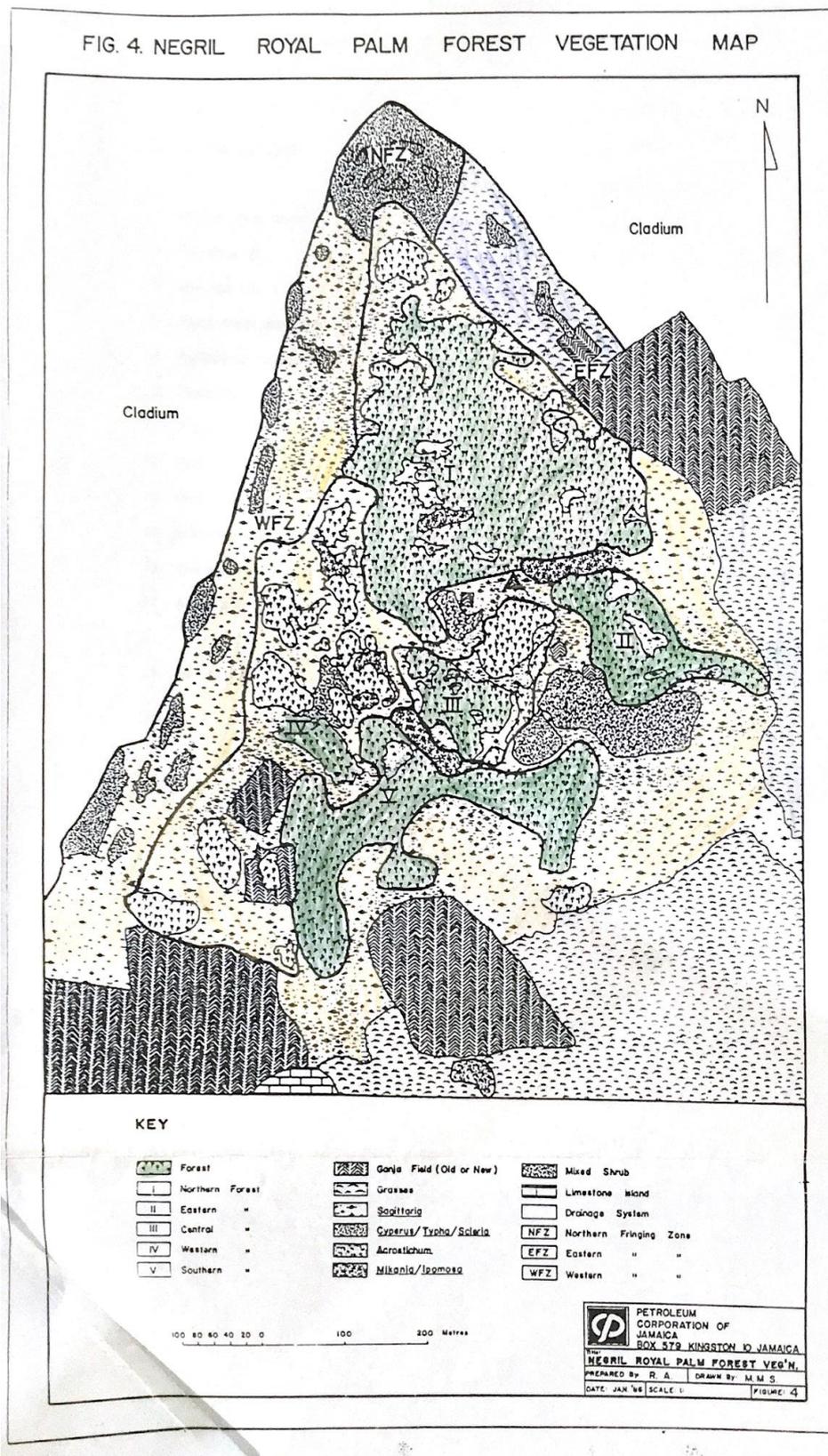


Figure 3 Vegetation of the Royal Palm Reserve before construction of the boardwalk, ponds and structures (Anderson et al. 1986)

Most of the Morass is a wetland on peat. The wetlands are enclosed to the west by a sandy berm, and to the east and south by limestone hills. The health of the wetlands is closely related to the condition of the adjacent habitats, including the dry forests on limestone of the adjacent Fish River and Negril Hills. These hills have

numerous sinkholes and form the catchment area for the swamp (Coke *et al.* 1982). Likewise, the wetland plays an important role in protecting and sustaining the sandy beaches, seagrass beds and coral reefs along the coastline. Between the wetland and the sea, the natural vegetation is dominated by coastal woodlands, lowland forest, and swamp forests. The interior of the wetland is mainly herbaceous wetland, including several formations. There are also some mangroves along the coast and the rivers, swamp forests and limestone islands. The hydrology of the wetland has been greatly altered by various drainage schemes. There are many freshwater springs and upwellings. The North and South Rivers have been canalized and an additional channel cut running North-South to the east of the Morass.



Figure 4 The Negril Great Morass looking northeast towards the Fish River Hills, showing herbaceous wetland and impacts of fire April 2021 (R. Miller)

3.1.1 Mangroves

Mangroves are found in the Morass where conditions are tidally influenced resulting in brackish or saline conditions, e.g., along the South and North Rivers, and in Ireland Pen (Orange Bay). Large Red Mangroves *Rhizophora mangle* are found along the North Negril River (Figure 5, Table 3.1), south of the road at Orange Bay, and at the mouth of the South Negril River. There are also patches of dwarf Red Mangroves near the South Negril River. There are dense stands of White Mangroves *Laguncularia racemosa* in Ireland Pen (Table 3.2). Buttonwood mangroves (*Conocarpus erectus*) occur on the margins of the wetlands, for example on the North Negril River (Table 3.1).

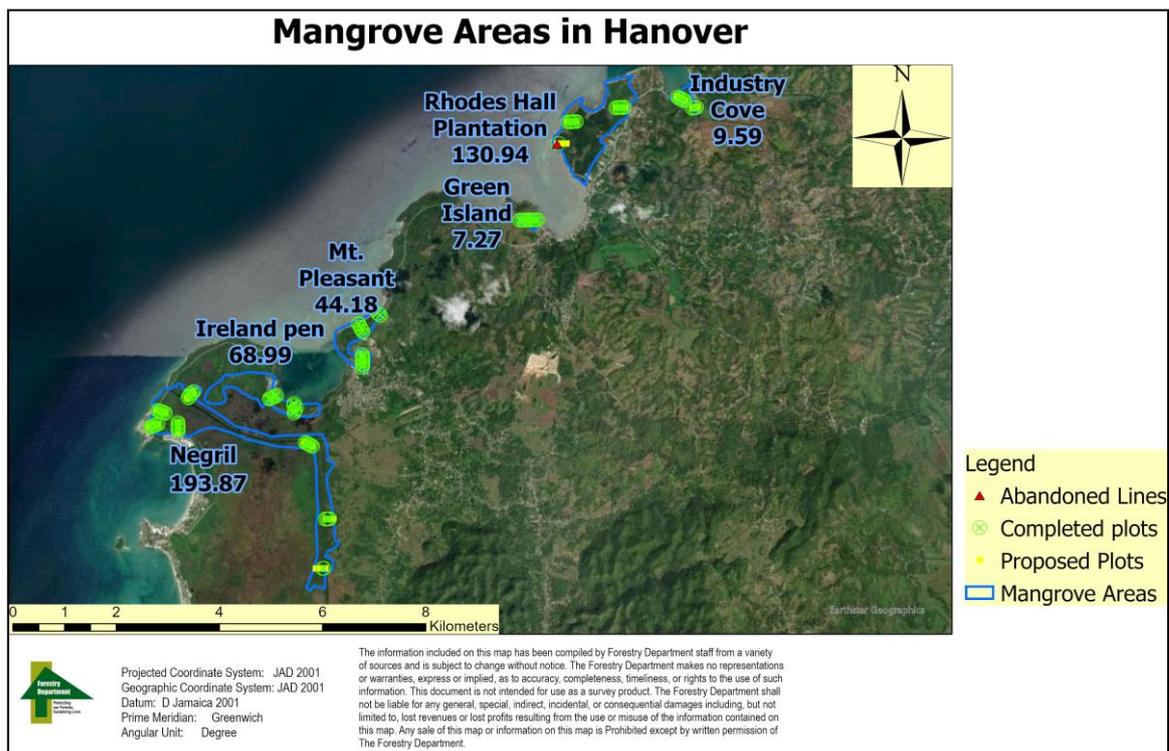


Figure 5 Locations of mangrove survey plots (Source: Forestry Department, 2001)

Table 3.1 Mangrove data from Forestry department from North Negril River and north-south canal

Line number	Species	Type	% Cover (range)	% Root cover (range)	Number of trees	Mean DBH (cm)	Standard Deviation
1	Buttonwood	Fringe	5-70%	10-80%	73	12.07	6.46
2	Buttonwood	Fringe	20-60%	65-75%	74	8.71	3.32
3	White Mangrove, Buttonwood, <i>Guettera</i> , Dogwood, Fig, Bull Thatch, Clusia	Fringe	5-90%	30-70%	34	17.32	11.45
4	Red Mangrove	Estuary	65-90%	30-80%	39	9.38	3.27
5	Red/Black Mangrove/Swamp Fern	Estuary	0-70%	45-80%	48	9.69	4.26
6	Red Mangrove/Logwood/Swamp Fern	Estuary	0-25%	70-80%	8	7.26	4.33
7	Red Mangrove/Acacia/Royal Palm	Fringe	0-30	10-80	15	10.06	4.33

Table 3.2 Mangrove data from Forestry Department from Ireland Pen

Line number	Species	Type	% Cover (range)	% Root cover (range)	Number of trees	Mean DBH	Standard Deviation (SD)
1	White Mangrove	Fringe	45-70%	65-80%	6	9.67	2.89
2	White Mangrove	Fringe	10-35%	35-70%	5	11.84	7.75
3	White Mangrove	-	-	-	8	11.79	3.22
4	White Mangrove	-	-	-	4	8.63	2.94
5	White Mangrove	-	-	-	8	12.61	6.77
6	White Mangrove	-	-	-	4	12.23	5.87
7	White Mangrove	-	-	-	3	8.13	2.35



Figure 6 Mangroves and swamp fern along the South Negril River (Photo. R. Miller)

Since the 1980s, stands of Red, Black and White Mangroves have increased in area and spread along the canals, including the north of the Cutoff canal, probably in response to increasing salinities. Meanwhile, Buttonwood mangroves that were present as forest and scrub in the centre of the Morass have disappeared.

Black Mangroves are the most salt tolerant, while White Mangroves are the least. Buttonwood is usually found in dryer areas, and Red Mangroves in the wettest.

Only the Buttonwood mangroves in the centre of the Morass appear to be declining in area. This probably reflects increased inundation and disturbance by ganja farmers and charcoal burners. In Orange Bay, the "wetlands and mangroves on the coastal side of the main road are under threat from clearing and dumping up for the establishment of a fishing village and squatting" (NEPA 2019).

3.1.1.1 Herbaceous wetlands

Much of the Morass is herbaceous wetland dominated by Sawgrass *Cladium jamaicense*. Coke (1982) identified two main formations: sawgrass and hummocky swamp. NRCA (1981) also recognized that some areas were dominated by uniform stands of Giant Swamp Ferns *Acrostichum* spp. or by Pond Coco *Sagittaria lancifolia*.

The current condition of the herbaceous wetland has not been assessed for more than 40 years. Review of Google Earth images shows many indicators of disturbance. Possible sources of degradation include drainage, fire, drying out in some areas and inundation in others, salinization, agriculture, and invasive species.

The area of herbaceous wetland has decreased since the 1980s. This is the result of expansion of ganja farming in the centre of the Morass, agriculture, and grazing, mainly on the east and expansion of *Mimosa pigra* and African Tulip trees southeast of the Royal Palm Reserve. The available data do not allow for an assessment of changes in the extent of *Acrostichum* spp. Giant Swamp Ferns. These species are sometimes considered to be invasive indicators of salinization of wetlands, but they also grow in freshwater conditions.

Herbaceous wetland is generally found on wet peat soils that are inundated for at least half the year.

Major threats include drought, fire, grazing and invasive species, such as trees and shrubs that are becoming established in areas that are drying out.

3.1.1.2 Sawgrass stands

Species that are sometimes associated with Sawgrass include the vine *Ipomoea sagittata*. In some places, where the cover of Sawgrass is less dense, semi-prostrate herbs such as *Lippia nodiflora*, *Hydrocotyle umbellata* and *Centella asiatica* cover the ground and the showy lily *Crinum americanum* becomes more frequent.

In areas affected by fire, sedges including *Eleocharis cellulosa*, *Rhynchospora globularis* and *R. inundata* dominate. Grasses including *Andropogon glomerulatus* and ferns such as *Blechnum indicum* may also be present.

The sawgrass wetlands are associated with peat soils. Where the water is shallow (about 10 cm) an algal mat is frequently found on the surface of the peat. Coke *et al.* (1982) described the algal mats as follows:

"The algal mat community must be of great importance for the nutrient economy of the Morass as it contains many nitrogen fixing blue-green algae. Furthermore, blue-green and green algae act as precipitators of calcium carbonate. Some species or genera common in the algal mat are *Anabaena* sp. *Aphanothece* spp. *Lyngnya* spp. *Oscillatoria* spp, *Chroococcus turgidus*, *C. limneticus*, *Scyonema* sp. *Pseudanabaena* sp. *Cosmarium* spp. *Gloeotaenium loitesbergianum*, *Spirogyra* and many diatoms."

Broad zonation of the sawgrass swamp stands can be described as follows:

- **"Hummocky (*Cladium*) swamp:** In the northern half of the Morass, which is typically permanently flooded (Williams *et al.* 2012). Sawgrass is found in clumps or hummocks which include small trees (including Button Mangrove *Conocarpus erectus*, Figs *Ficus pertusus* and Bog or Pond Apple *Annona glabra*), climbers (especially Quaco Bush *Mikania micrantha*) and ferns (*Blechnum* sp.). These hummocks are interspersed with small patches of open water, which support water lilies (*Nymphaea* sp. and *Nymphiodes* sp.), small sedges (such as *Eleocharis* sp., *Cyperus ligularis*, *R. inundata* and *R. cyperoides*) and grasses (including *A. glomerulatus*, *Panicum roanokense*, *P. condensum*. Other submerged plants include the carnivorous bladderwort *Utricularia foliosa* and a rare fern *Ceratopteris* sp. Other plants found along riverbanks and more open areas include *Pluchea rosea*, *Ludwigia* spp., Jocoto or Water Calaloo *Acnida cuspidata* and *Vernonia cinerea* (Coke *et al.* 1982). Coke *et al.* (2012) suggested that the hummocks were formed as a result of uneven burning and subsequent subsidence of the peat.
- ***Scleria* association:** On the western margins of the Royal Palm Reserve the sedge Old Woman Razor *Scleria eggersiana* replaces Sawgrass as the dominant species. Other species found in this area are *Polygonum punctatum*, *Phaseolus trichocarpus*, *Ipomoea tiliacea*, *Panicum muticum*, *Commelina elegans*, *Ludwigia peruviana* and *Sacciolepus striata*.

- ***Cyperus giganteus* association:** Areas dominated by the large sedge *Cyperus giganteus*, form a transitional zone between the Royal Palm Reserve and the herbaceous wetlands. Other species commonly found in this zone include *Sagittaria lanceifolia*, *Polygonum acuminatum*, *Cladium jamaicense* and vines such as *Mikania micrantha* and *Ipomoea tiliacea*.
- ***Acrostichum* association:** In some areas (mostly in the southwest of the Morass and along the South River/Canal (CEL 2001) the Giant Swamp fern *Acrostichum aureum* form dense uniform stands. There are also some patches south of the North canal. These areas usually have some standing water.
- ***Typha* association:** The banks of the South River and parts of the north-south canal are dominated by a dense growth of Bulrush *Typha domingensis*. Bulrushes also occur in abandoned fish farms.
- ***Thalia geniculata*:** There are many small freshwater ponds around the Morass, most of which are occluded by *Thalia geniculata*.



Figure 7 Abandoned fish farm near Springfield (*Typha* surrounded by bamboo coconuts, logwood and guango).

3.1.2 Freshwater and brackish aquatic habitats

Freshwater and brackish aquatic habitats in and near the Morass include springs, rivers, streams, canals, ditches, blue holes and natural and artificial ponds. The ecology of habitats has never been assessed and there is no inventory of these sites. An assessment of the freshwater and cave habitats of the Negril EPA was carried out by NEPA in 2007 (NEPA 2007) (Table 3.3). This showed that the greatest diversity of taxonomic groups was found in the Royal Palm Reserve and Orange River, indicating good water quality.

Table 3.3 Results of survey of freshwater sites in the Negril EPA (NEPA 2007). Site 1-Royal Palm Reserve large pond; Site 2-Royal Palm Reserve internal point; Site 3-North Negril near Royal Palm Reserve; Site 4-Duck Pond; Site 5-Fish River; Site 6-Campbellton River; Site 7-Orange River; Site 8-South Negril River at Sheffield; Site 9-New Savannah River.

Scientific [Order:Family]	Name	Common Name	Sample Sites									
			1	2	3	4	5	6	7	8	9	
Hemiptera:Nepidae		Water Scorpion	1	-	-	-	-	-	-	-	-	-
Poecilidae:Cyprinodontiformes		Fish	3	3	1	3	-	-	-	1	-	-
Odonata (Anisoptera*): Aeshnidae/Libellulidae		Dragonfly larva	3	2	-	-	-	3	1	-	3	-
Caenogastropoda:Thiaridae		Swamp ceriths	1	16	1	7	3	4	145	-	215	-
Archaeogastropoda:Neritidae		Nerits	-	-	-	-	-	-	69	-	-	-
Diptera:Chironomidae		Midge larvae	1	-	-	-	-	-	1	65	-	-
Ordonata:Zygoptera*: Coenagrionidae		Damselfly larvae	10	-	-	2	1	-	-	1	2	-
Coleoptera:Dytiscidae		Water beetle	8	-	-	-	-	-	-	-	-	-
Coleoptera:Hydrophilidae		Water scavenger beetle	6	1	-	-	-	-	-	-	-	-
		Unknown species	-	2	1	-	-	-	-	-	-	-
Hemiptera:Gerridae [<i>Serris cormelus</i>]		Water strider	-	-	7	-	-	-	-	-	-	-
Decapoda:		Crayfish	-	-	-	-	-	1	-	-	-	-
Decapoda		Shrimp	-	-	40	-	-	14	160	-	-	-
Class: Malacostraca; Order Amphipoda		Amphipod	-	-	-	-	6	1	2	-	-	-
Class Oligochaeta		Earthworm	-	-	-	-	-	1	-	-	-	-
Diptera:Culicidae		Mosquito larvae	-	-	-	-	-	1	-	-	-	-
Decapoda:Portunidae [<i>Callinectes spp.</i>]		Crab	-	-	-	-	-	-	4	-	-	-
Hemiptera:Notonectidae [<i>Buenoa pallipes</i>]		Back swimmer	54	-	2	-	-	-	-	-	-	-
Araneae:Pisauridae		Fishing spider	-	-	1	-	-	-	-	1	-	-
Tricoptera: Hydropsychidae [<i>Smicridea jamaicensis</i>]		Netspinning Caddisfly	-	-	-	-	-	-	2	-	-	-
Ephemeroptera		Mayfly	-	-	-	-	-	-	-	-	4	-
Total Classification Groups			9	5	7	3	3	7	8	4	4	4

There is no available information on the current ecological condition of these sites except for the North Negril River (NEPA 2019) (Figure 8). This analysis suggested that conditions at NNR1 were good, but NNR2 was worse.

Table 3.4 Macroinvertebrate composition at sites along the N. Negril River

Group	Scientific Classification/Family	Common Name/Species Name	Pollution Sensitivity	NNR 1	NNR 2
Worms	Nematoda	Roundworm	T	√	
	Neritidae	Bussu	SS	√	
Molluscs	Mytilidae	Mussels	S	√	
Insects	Gerridae	Water strider	SS		√
Crustaceans	Paguroidea	Hermit Crab	SS	√	
	Epialtidae	Crab	T	√	
	Palaemoidae	<i>Macrobrachium</i> sp.	S		√
	Ampithoidae	Amphipod	SS	√	
	Aoridae		SS	√	
	Hyalidae		SS	√	
Fish	Eleotridae	Sleeper gobies	S		√

Key: Pollution Sensitivity - T = Tolerant; SS = Somewhat Sensitive; S = Sensitive

NNR 1 was located close to the shore, while NNR2 was further inland.

The Morass has been greatly altered since the 19th century. These changes have been further described in Section 3 below.

Threats to the freshwater habitats include:

- changes to drainage
- excessive abstraction of water from wells, springs and streams that can lower the water table and thus cause drying up of freshwater sources and contribute to changes in salinity
- surface and sub-surface pollution from sewage
- pit latrines
- solid waste
- agricultural runoff
- declining rainfall which has the number of permanent ponds. The sites close to residential/agricultural areas had worse water quality (Figure 8)
- The Morass rivers are also disturbed by boat traffic, boat docking and fishing

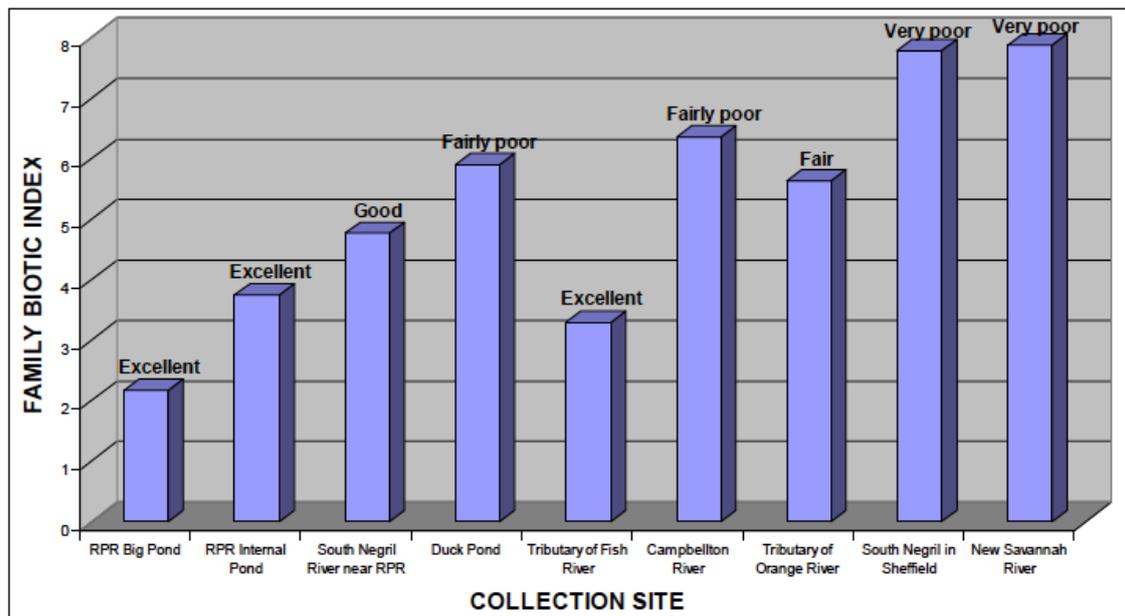


Figure 8 Graph showing water quality at sites in the Morass and other parts of the Negril EPA based on family biotic index (NEPA 2007)

3.1.3 Swamp Forests

The swamp forest is characterized by the presence of the endemic Swamp Royal Palm or Swamp Cabbage *Roystonea princeps*. The greatest abundance of this species occurs in the Royal Palm Reserve, an approximately triangular area of 80 ha in the south of the Morass (Figure 9). This is less than a third of the area that was occupied by swamp forest in 1953, before the canalization of the South Negril River (Anderson *et al.* 1986). Royal Palms also occur as isolated individuals in the Morass and in patches along the western margins of the Morass, some of which may be remnants of swamp forest. In the past, swamp forests included a greater diversity of tree species, but they have been depleted by timber harvest and clearance of the forests for agriculture.

The swamp forest of the Royal Palm Reserve (Figure 3) was described in detail by Anderson *et al.* (1986). They divided the swamp forest into three main zones: forest stands, clearings and fringing zones.



Figure 9 Swamp Forest, herbaceous wetland and scrub (Photo. R. Miller)

There have been no studies of the swamp forest since 1986, and the current condition is unknown. Figure 10 shows that the channelization of the South Negril River resulted in changes in drainage and a reduction of the area of swamp forest. Figure 11 and Figure 12 show that this has been stable since then, despite the construction of the Royal Palm Reserve with its access road and canal.

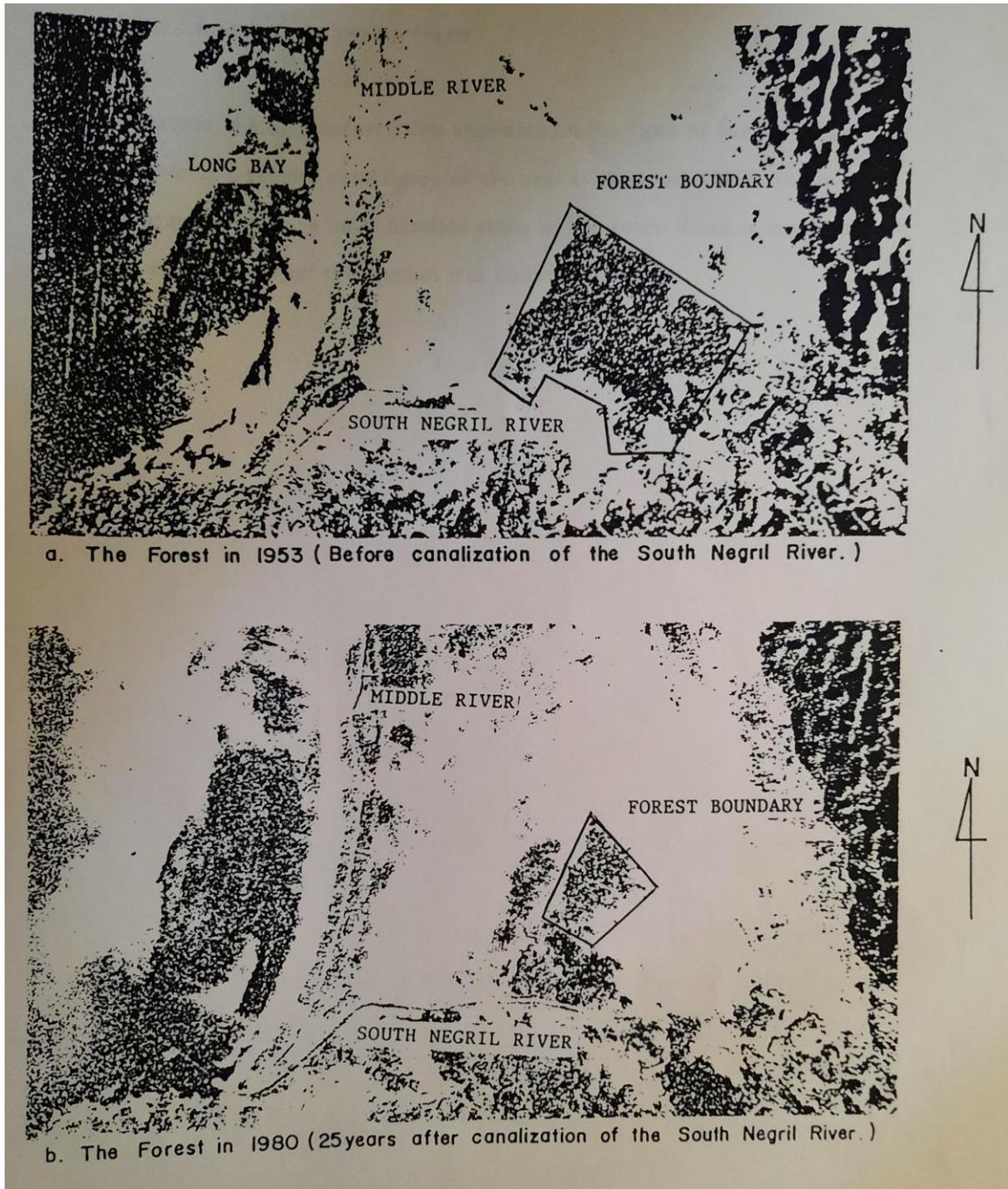


Figure 10 Changes in the extent of the Swamp Forest (1953-1980)

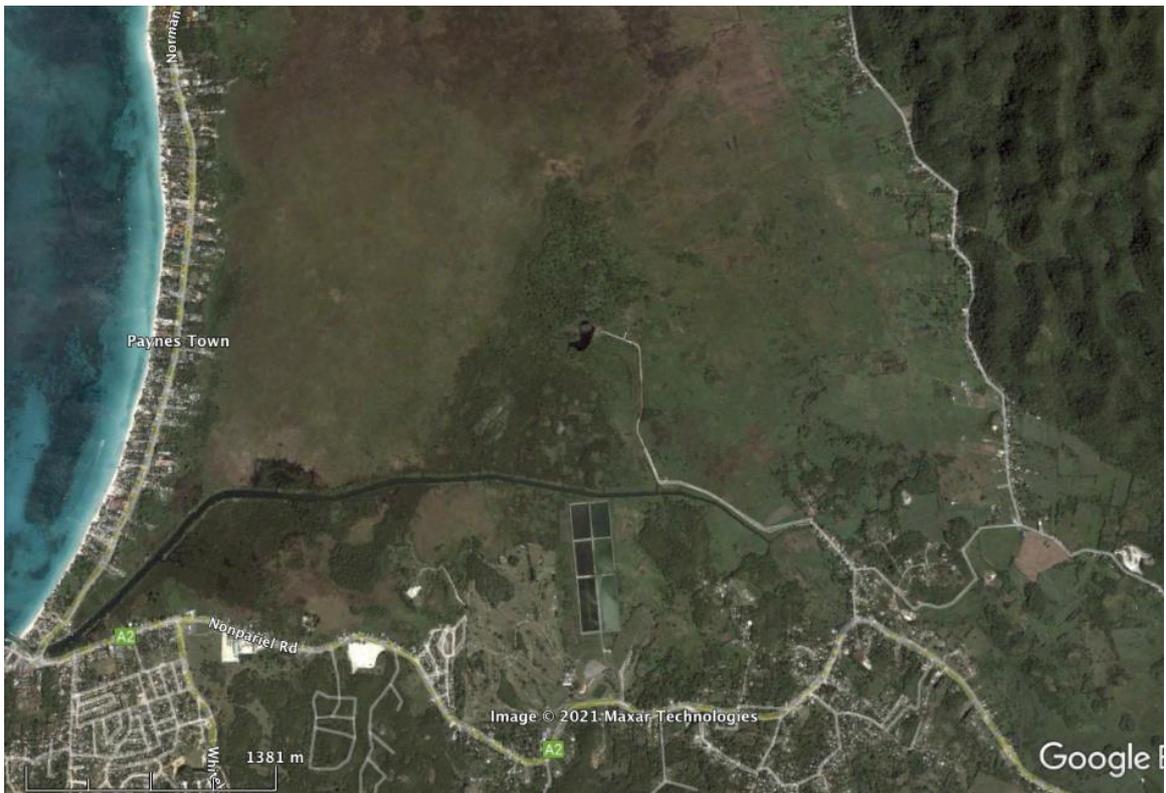


Figure 11 Southern Morass 2003 (Google Earth)

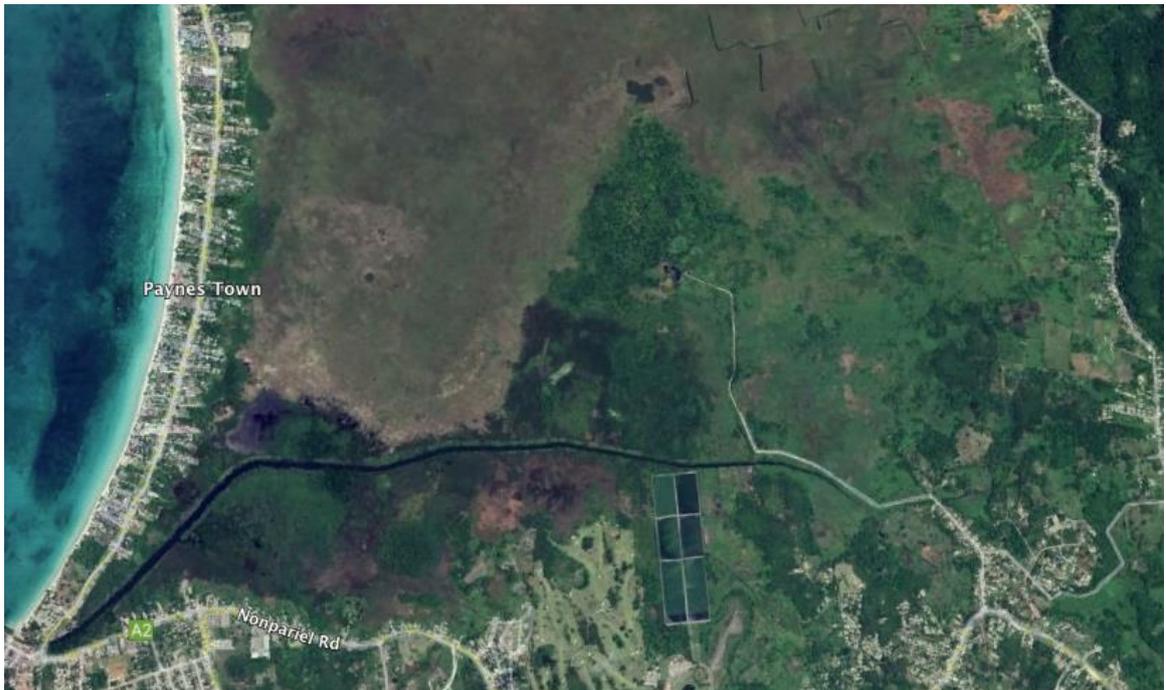


Figure 12 Southern Morass 2021 (Google Earth)

The ecological requirements for the swamp forest have not been described but are thought to include adequate freshwater inflows, water quality and suitable soils.

In addition to the hydrological changes over time, threats include extraction of timber, extraction of Royal Palm seedlings, reaping of hearts of palm, and invasive species including Red Bead Tree, African Tulip tree, and

aquatic ferns (Haynes-Sutton 2021a). Regeneration of seedlings appears to be a problem. Possible causes include grazing by animals, unsuitable hydrological cycles, or lack of shade.

3.1.3.1 Forest Stands

Anderson *et al.* 1986 noted that all the forests stands are dominated by the emergent *R. princeps* and the endemic Broadleaf *Terminalia latifolia* and Trumpet Tree *Cecropia peltata*. The common trees of the sub-canopy included *Ficus pertusa*, *Ficus maxima*, and Anchovy Pear *Grias cauliflora* (also endemic). The undergrowth includes the Spider Lily *Hymenocallis littoralis*, as well as ferns such as *Anemia* sp., *Thelipteris* sp. and *Pityrogramma* sp. Many of the trees support dense growths of creepers such as *Philodendron* sp. and *Syngonium auritum*. The invasive Red Bead Tree *Adenanthera pavonina* has since become established along the boardwalk.

Thirty species of trees were listed from the Royal Palm Reserve including two endemics. Other plants included seven shrubs including the endemic Box Briar or Ink Berry *Randia aculeate* var. *mitis* were listed, twenty herbs, eighteen climbers, five sedges, nine grasses (including the rare *Setaria magna*) and ten ferns (Appendix A).

The forest stands were divided into five groups:

- **Northern Forest:** This is the largest, most diverse and densely covered stand of trees. As well as Royal Palms there are “in order of decreasing frequency, *Ficus pertusa*, *Ficus maxima*, Boardwood *Symphonia globulifera* and Hog Plum *Spondias purpurea*. Interspersed amongst the trees are large Spider Lilies *Hymenocallis littoralis*.” (Anderson et al. 1986).
- **Eastern Forest:** This area has the least diversity of tree cover. The Royal Palms form a dense stand, with (in order of decreasing occurrence) Broadleaf, African Tulip *Spathodea campanulata* (an invasive alien species), Trumpet Tree, and figs. There are also shallow pools of alga-rich water.
- **Central Forest:** The central forest has similar species composition to the other forests. In this area there are also large bromeliads on the tree trunks, and large open areas of *Acrostichum aureum*.
- **Western Forest:** There are no dense stands of trees in the western forest. There are small patches of trees (including Wild Poui *Tabebuia angustata*), African Tulip and West Indian Almond *Terminalia catappa* (another introduced species) with large clearings. There are some ponds with pond weed *Lemna* sp.
- **Southern Forest:** This is a dense stand of trees many of which are heavily overgrown by vines. Pond Apple *Annona glabra* and *Ficus* spp. are abundant.

3.1.3.2 Clearings

Many of the swamp forest trees have been felled to make space for ganja cultivation or for timber extraction. The resulting clearings are of five types which are interspersed with forests throughout the Royal Palm Reserve:

- **Sagittaria dominated:** *Sagittaria lancifolia* is one of the most common plants in forest clearings. It grows from a tuber, and often forms dense uniform stands, or may be associated with ferns and vines.
- **Grasslands (mainly *Panicum* spp.):** These indicate places that have been cultivated. Other species include *P. roanokense*, *P. zizanioides* and *P. condensum*.
- **Acrostichum dominated:** These areas of swamp ferns can form uniform stands and can be associated with vines *Mikania micrantha* and *Ipomoea* sp.
- **Mixed herbs and shrubs dominated:** These areas of herbaceous plants and shrubs including *Ludwigia* spp., *Polygonum punctatum*, *Vernonia cinerea*, *Pluchea rosea*, *Eclipta alba* and *Mitreola petiolata*.
- **Mikania/Ipomoea dominated:** These vines proliferate where the canopy has been removed and can form impenetrable thickets that overwhelm seedlings, preventing regeneration.

3.1.3.3 Fringing Zones

The swamp forest is separated from the adjacent *Cladium* dominated herbaceous wetland by three types of fringing zones.

- Mixed northern association, which includes herbs, ferns and climbers
- *Sagittaria/Cyperus/Sceleria* Western Association
- Eastern *Panicum* Association dominated by *Panicum muticum* with patches of *Cyperus giganteus*.

3.1.4 Other associated forest habitats

Other associated forest habitats include Sabal Forest that was previously found on limestone islands e.g., Sambo Clump in the northeast of the Morass, lowland forest in Bloody Bay and mixed woodland on the eastern margins of the Morass. These forests are being disturbed and cleared for development and agriculture.

3.1.5 Anthropogenic habitats

Anthropogenic habitats include agricultural lands and pastures. The most extensive and destructive form of agriculture is ganja cultivation. Dasheen is often grown in wet peaty soils. Other crops grown on the margins include sugar cane, coconut and vegetables.

3.2 Species

3.2.1 Plants

3.2.1.1 Endemic Species

There are relatively few endemic species in the wetlands of Negril compared to the forests (Table 6). Range restricted plants of the area include several endemics like *Broughtonia negrilensis*, *Hohenbergia negrilensis*, *Grias caulifera* and *Roystonea princeps*, which is classified as Near Threatened by IUCN (Zona 1998). The rare endemic tree, *Phyllanthus accuminatus*, occurs in the coastal woodland (Haynes-Sutton *et al.* 1997).

3.2.1.2 Rare Species

Three other species of plants in the Negril KBA are listed as threatened by the IUCN (Table 6). These are *Zamia erosa*, *Erithalis quadrangularis* and *Zanthoxylum negrilense*. None of these species appear to be found in the Morass. There have been no studies of the distribution and conservation needs of the threatened and endemic plants of the wetlands of Negril (Table 3.5). Eighteen endemic plant species have so far been listed from the wetlands of the Morass and adjacent habitats (Table 3.6).

Table 3.5 Endemic plants of Negril Environmental Protection Area (Haynes-Sutton 2021f)

CLASS	ORDER	FAMILY	SPECIES	COMMON NAME	RED LIST	PRESENCE	HABITAT
CYCADOPSIDA	CYCADALES	ZAMIACEAE	<i>Zamia erosa</i>		VU	Confirmed	Forest
MAGNOLIOPSIDA	RUBIALES	RUBIACEAE	<i>Erithalis quadrangularis</i>		VU	Confirmed	Forest
MAGNOLIOPSIDA	SAPINDALES	RUTACEAE	<i>Zanthoxylum negrilense</i>		EN	Confirmed	Forest

CR – critically endangered, EN Endangered, VU vulnerable, NT Near Threatened.

Table 3.6 Plant endemism in the major habitats of the Negril Great Morass and surrounding areas (Sources: Haynes-Sutton 1992 and CEPF)

FAMILY	ENDEMIC SPECIES	SWAMP FOREST	MANGROVES	HERBACEOUS WETLAND	COASTAL WOODLAND	LOWLAND FOREST ¹
BROMELIACEAE	<i>Hohenbergia negrilensis</i>					
COMBRETACEAE	<i>Terminalia latifolia</i> (Broadleaf)					
LECYTHIDACEAE	<i>Grias cauliflora</i> (Anchovy Pear)					
MALPIGHIACEAE	<i>Malpighia harrisii</i>					
MIMOSACEAE	<i>Pithecelobium alexandri</i>					
ORCHIDACEAE	<i>Brassovola cordata</i>					
	<i>Broughtonia negrilensis</i>					
	<i>Tolumnia pulchellum</i>					
PALMAE	<i>Calyptronoma occidentalis</i>					

¹ There have been no comprehensive botanical assessments of the forests of the Negril EPA.

FAMILY	ENDEMIC SPECIES	SWAMP FOREST	MANGROVES	HERBACEOUS WETLAND	COASTAL WOODLAND	LOWLAND FOREST¹
	<i>Coccothrinax jamaicensis</i>					
	<i>Roystonea princeps</i>					
	<i>Thrinax parviflora</i>					
PASSIFLORACEAE	<i>Passiflora oblongata</i>					
RUBIACEAE	<i>Psychotria balbesiana</i>					
	<i>Randia aculeata</i>					
	<i>Erythalis quadrangularis</i>					
RUTACEAE	<i>Zanthoxylum negrilense</i>					
ZAMIACEAE	<i>Zamia erosa</i>					
TOTAL NUMBER OF ENDEMIC PLANT SPECIES BY HABITAT		8	0	1	10	5
TOTAL NUMBER OF PLANT SPECIES		114	6	59	75	Not assessed

3.2.1.3 Species of economic importance

There is no information about the extent to which native wetland species are currently being harvested, medicinally, food, timber, sticks, horticulture, or craft materials.

3.2.1.4 Invasive species

Apart from an assessment by Duever (2009) of invasive aquatic species in the Royal Palm Reserve, there have been no assessments of the extent or impacts of invasive plant species in the Morass.

3.2.2 Mammals

3.2.2.1 Bats

Bats are the only native mammals that occur in the Negril EPA. They have been found in many caves in the Negril Environmental Protection Area (NEPA 2007), but no assessments have been done of whether any of these bats forage over the Morass.

3.2.2.2 Invasive species

Invasive mammalian species that occur in the Morass include Small Indian Mongoose *Herpestes javanicus*, rats *Rattus spp.*, cats and dogs. These species are predators on native species including West Indian Whistling-Ducks and other birds. Goats, horses and cows also graze in the Morass, penetrating deep into the core when conditions are dry. Their activities disturb the natural regeneration of wetland flora.

3.2.3 Birds

3.2.3.1 Composition of avifauna

Birds are one of the better studied of the groups of the Morass and associated habitats (Sutton 1987; Svensson 1983; Haynes-Sutton and Hay 2010) (Appendix B). The avifauna includes aquatic, coastal and forest species.

3.2.3.2 Endemic, threatened and rare species

Ten of Jamaica's 30 endemic species of birds occur in the area. Rare species include the West Indian Whistling-Duck *Dendrocygna arborea* and the Yellow-breasted Crake *Hapalocrex flaviventer* both of which depend on suitable shallow water habitats in the Morass. The ducks may be keystone species in the Morass because of the role they play in spreading seeds and grazing in the herbaceous wetlands and ponds. They are threatened by loss of nesting and chick rearing habitat and by illegal hunting. The status and conservation needs of West Indian Whistling-Ducks (with a focus on the Royal Palm Reserve) has been treated in detail under a separate consultancy for the IWEco project (Haynes-Sutton 2021d). That report indicated the need for hydrological restoration of the Morass to include maintaining and increasing ponds and inundated areas of suitable depths for foraging and raising chicks. It also noted the need for predator control.

3.2.3.3 Migratory species

The Morass provides important stop-over and over-wintering habitat for many species of migrant waterbirds (including ducks and shorebirds) and land birds (Appendix B) (Haynes-Sutton & Hay 2001; 2003). Increasing the amount of suitable aquatic habitat would increase the numbers and variety of species using the reserve. If this is done in areas where birds can be viewed by the public e.g., at the Royal Palm Reserve this would help to diversify the tourism product.

3.2.3.4 Species of economic importance

White-crowned Pigeons *Patagioenas leucocephala* are another keystone species for the wetlands and surrounding woodlands. They spread the seeds of many tree species. They are a popular gamebird species and are mainly threatened by illegal over-hunting.

3.2.3.5 Invasive species

Invasive bird species in the Morass include European Starling *Sturnus vulgaris* and potentially Shiny Cowbirds *Molothrus bonairensis* and Great-tailed Grackles *Quiscalus mexicanus*. Invasive bird species are not a threat to the Morass.

3.2.4 Bird conservation and monitoring plans for the Royal Palm Reserve

Bird conservation and monitoring plans for the Royal Palm Reserve were prepared in 2007 but have not been implemented (Haynes-Sutton & Hay, 2007a, b). Under this IWEco project, one of the recommended interventions is to restore the known habitats of the West Indian Whistling Duck by improving the hydrology through the implementation of retention bunds.

3.2.5 Reptiles

At least four species of reptiles that are classified as threatened by IUCN (2020) have been recorded in or near the Morass. These include:

- The **Jamaican (Cat Island) Freshwater Turtle** (*Trachemys terrapen*) (also known as the Jamaican Slider and locally referred to as pond turtle or hicatee) is considered Vulnerable (Tortoise and Freshwater Turtle specialist group 1996). There have been no studies of this species since 2005 (Tuberville *et al.* 2005) but it appears to be common in the Morass (D. Hay pers. obs). Although it is protected, it is commonly harvested for food or kept as a pet. Its status, ecology and conservation needs are not known in Negril or any other part of Jamaica. The Red-eared Slider *Trachemys scripta* has been introduced to Jamaica. It can interbreed with the Jamaican Slider, which makes it a threat. So far there are no records of the latter species from the Morass.
- The **American Crocodile** (*Crocodylus acutus*) is also deemed Vulnerable by the IUCN (Ponce-Campos *et al.* 2012). It was either very rare or absent from the Morass in the early 1980s (Haynes-Sutton pers. obs.) but is now present there in small numbers (Daniel Scarlett, pers. comm.) Surveys for crocodiles at Orange Bay in 2019 did not reveal any. One crocodile was observed at Rhodes

Hall. Crocodiles are keystone species that support the overall functions of the ecosystems but are regarded as nuisance species by most of the population (NEPA 2019).

- The **Yellow Boa** (*Chilabothrus subflavus*) is another vulnerable species that occurs mainly in the dry forests but not in the wetlands (Gibson 1996).
- The **Hawksbill Turtle** (*Eretmochelys imbricata*) is a Critically Endangered species that nests along the beaches and in the margins of the coastal woodlands (Mortimer & Donnelly 2008). There have been several studies of marine turtles and a recovery action plan exists (Haynes-Sutton *et al.* 2011).

There is no recent information about the status of any of Jamaica's threatened reptiles, sixteen species of which have been reported in the Negril EPA (Haynes-Sutton *et al.* 1992; NEPA 2019) (Appendix C).

3.2.6 Amphibians

As far as is known, there are no endemic frogs in the Morass. However, invasive amphibians known to occur around the Morass include the Cane Toad *Rhinella maritima* and Johnson's Robber Frog *Eleutherodactylus johnstoni*.

3.2.7 Fish

The only study of the fish fauna of the Morass was carried out by NRCD/Traverse Group (1981). They noted the presence of 28 species of fish in the rivers, 26 of which were marine and 2 were freshwater/brackish (Appendix D). 21 species spend most of their life history in full strength seawater. Exceptions include the endemic top minnow, Grey Snapper and American Eel.

3.2.7.1 Endemic species

Only one endemic fish – the top minnow, *Gambusia wrayi*, was found.

3.2.7.2 Economically important species

Many of the specimens they collected were juveniles, suggesting that the canal and associated channels into the wetland serve as a nursery for many species of fish. Commercially important species included Jack, Mullet, Snappers, Tilapia and Snook. Snook, tarpon and snappers are of interest to sport fishers. Subsistence fishers also fish in the river and the outflow of the sewage ponds for Tilapia and God-a-mi *Sicydium plumieri*.

3.2.7.3 Invasive species

Known invasive fish species in the Morass include African Perch *Tilapia mossambica* and the Wolf Cichlid *Parachromis dovii*. The African Perch reduces habitat for other species, while the Wolf Cichlid is a voracious predator.

3.2.7.4 Threats

The fish fauna and the contribution of the Morass to the artisanal fishery of Negril was badly affected by the channelization of the Morass, which made the shallow areas and channels in the Morass that previously served as foraging areas and nurseries for fish inaccessible for most of the year (Aiken 1991). The shallow mangrove areas in the estuary of the canal were of particular importance as fish nurseries (NRCD & Traverse Group 1981). The impacts of declining water quality including agricultural chemicals and sewage on the fish fauna have not been assessed.

3.2.8 Invertebrates

There have been very few studies of the insect fauna of the Morass apart from some rapid assessments of the more obvious groups including butterflies and dragonflies which have not so far revealed any threatened or rare species (Turland 2021) (Appendix E). Nuisance insects include various species of mosquitoes and horse flies (Tabanids). Fogging for mosquito control with insecticides including Malathion is carried out along the coastal strip. Its impact on other species of insects has not been assessed.

In Negril, the predominant species of land crab that exists is the Blue Land Crab (*Cardisoma guanhani*) while other species, such as the Black Land Crab (*Gecarcinus ruricola*), also occur. They are most often encountered in the breeding season (usually in May or June after heavy rain) when the females migrate across the road between the Morass and the sea, to lay their eggs in the sea. They are popular food and people go out at night with bottle torches to catch them (Haynes-Sutton, pers. obs.). However, residents report that crab populations are declining (e.g., Lenbert Williams, pers. comm.). Occasionally, there is a reverse migration when young *Gecarcinus* crabs return from the sea to the Morass. This mass migration across the beaches is infrequent and can cause concern (Anon. 2012). Migration of crabs is being disrupted by coastal development. Haynes-Sutton (2021f)

The abundance of shrimp in the Morass has apparently declined since the rivers were canalized. Eight species of shrimp were found in the Morass – *Macrobrachium acanthurus*, *M. faustinum*, *M. carcinus*, *Jonga serrei*, *Xiphocaris elongata*, *Micrata poeyi* and two unidentified species (NRCD et al. 1981; Aiken 1992). It is unknown whether the invasive alien species, Australian Red Claw (*Cherax quadricarinatus*), has been introduced to Negril but it was not recorded by NEPA in their most recent 2019 assessment (Haynes-Sutton 2021f).

Shrimp form an essential part of the food chain. Some species also migrate between the sea and the rivers during their lifecycle, and all would have been negatively affected by the channelization of the rivers.

3.3 Ecosystem Functions and Services

The ecological functions of the Morass were summarized in the wetland management plan (Haynes-Sutton 2021f) (Table 3.7). They include flood control, groundwater recharge, maintenance of water quality, biodiversity conservation, natural beauty, heritage, recreation and education, support for sustainable agriculture, coastal protection, nursery for marine fish, utilization of natural resources, and carbon sequestration. All these functions depend to a greater or lesser extent on the hydrology.

Table 3.7 Ecological functions of the Royal Palm Reserve (Haynes-Sutton 2021f)

FUNCTION	DESCRIPTION	ENVIRONMENTAL SIGNIFICANCE	SOCIETAL SIGNIFICANCE
FLOOD CONTROL	The Morass acts like a sponge, absorbing and detaining floodwaters and releasing them slowly.	Although the channelization of the Negril rivers has reduced this function, the wetlands still play a role in reducing the rate and quantity of freshwater outflows (Mandal <i>et al.</i> 2016). Flood cycles maintain germination conditions for plants (Williams <i>et al.</i> 2012). Wet conditions support soil saturation, and hence anaerobic soil condition, with reducing chemical reactions, that support the development of peat.	Some reduction of flooding after storms. Maintenance of the water table reduces the risk of peat fires.
MAINTENANCE OF WATER QUALITY	Morass removes sediments and pollutants from runoff. Plants such as Water Hyacinth (<i>Eichhornia crassipes</i>) take up excess nutrients and pollutants from sewage and agricultural run-off.	The Morass reduces the amount of sediments and pollutants in the outflows (rivers and subsurface springs, if any) that can damage coastal ecosystems and reduce coastal water quality.	Reduction of this function means increased plumes from the rivers, which impacts coastal water quality.
BIODIVERSITY CONSERVATION	Morass provides freshwater and brackish habitat for threatened, endangered or rare species of birds – e.g., West Indian Whistling-Duck (<i>Dendrocyna arborea</i>), invertebrates and plants, migratory birds, very rare ecosystems such as the swamp forests and ecologically important ecosystems such as mangroves. The productivity of the Morass supports food chains in the adjacent marine habitats.	Maintenance of biodiversity supports the ecological services of the wetlands and adjacent coral reefs.	Provision of natural resources including fish, timber, land crabs, thatch. Support for fisheries, ecotourism and landscape conservation.
NATURAL BEAUTY, HERITAGE, RECREATION AND EDUCATION	Actual and potential tourism activities in the Morass include fishing, boating, bird watching and hiking.	Utilization of natural resources for recreational activities helps to develop public support for conservation.	Potentially provides funding for conservation. Increases support for wetland conservation. The Morass has great educational value and spiritual renewal.
SUPPORT FOR SUSTAINABLE	There is the potential for low intensity sustainable agriculture		Supports communities and provides income.

FUNCTION	DESCRIPTION	ENVIRONMENTAL SIGNIFICANCE	SOCIETAL SIGNIFICANCE
AGRICULTURE	in selected areas.		
COASTAL PROTECTION	The Morass is mostly separated from the coast by a road and a sandy berm. Mangroves come down to the sea and protect the coastline from erosion.	Mangrove roots erosion.	Protection for inshore structures.
NURSERY FOR MARINE FISHERIES	Mangroves, rivers and canals support coastal fisheries.	Many commercial varieties of fish and shrimp depend on mangroves and rivers during their life cycle.	Fisheries support the tourism industry.
CLIMATE CONTROL	Evapotranspiration from the Morass maintains the microclimate of Negril.	Regular rainfall supports biodiversity and maintains the water balance of the Morass.	Supports lush environment and water supplies.
UTILIZATION OF NATURAL RESOURCES	Communities harvest crabs, shrimp, freshwater fish, game birds, craft materials, medicinal plants, timber, building materials, charcoal, fuel wood and sticks from the wetlands.	Resource extraction (apart from game bird hunting) is not regulated.	The economic contribution of these products to community well-being has not been described or quantified.
CARBON SEQUESTRATION	"Tropical peat swamps can form one of the most effective carbon (C) sequestration and storing systems because it combines substantial biomass production capacity and dead biomass in nutrient-poor waterlogged soils."	Contributes to Jamaica's nationally determined contribution (NDC) and its obligations under the 2015 Paris Agreement	

Source: Adapted from Williams *et al.* 2012, with additional information from Mandel *et al.* 2016 and other sources.

3.4 Threats to the Ecology

The direct threats to the Morass wetland ecology and functions were summarized in the wetland management plan (Haynes-Sutton 2021f) (Table 3.8).

Table 3.8 Summary of direct threats to the Morass (Haynes-Sutton 2021)

Threat	Summary of major impacts
Development	
Development (housing/urban areas)	Expansion of housing on the margins of the wetland mainly along the southern and western margins directly destroys wetlands (when wetland is cleared or dumped up) and increases run-off, water pollution from sewage, and solid waste pollution.

Threat	Summary of major impacts
Development (commercial/industrial areas)	Expansion of commercial development along the Nonpariel Road, increasing run off and pollution into South Negril wetland (Williams <i>et al.</i> 2012).
Development (tourism/recreation areas)	Expansion of tourism on both sides of the Norman Manley Boulevard is destroying forest ecosystems, interrupting exchange of water and movement of species between the wetland and the sea, contributing to pollution of groundwater (Williams <i>et al.</i> 2012).
Development (mining/quarrying)	Limestone quarrying on the Fish River Hills is damaging the hydrologic balance (Williams <i>et al.</i> 2012) and scarring the landscape (Haynes-Sutton, pers. obs.).
Development (roads/railroads)	The Norman Manley Boulevard cut off the wetland from the sea and blocks migration of species.
Development (utility/service lines)	Utility lines are not a major threat.
Development (flight paths)	Flight paths over the Morass potentially affect birds, but the frequency of flights is very low (Haynes-Sutton, pers. obs.).
Agriculture	
Annual/perennial crops (shifting)	Shifting cultivation in the Fish River Hills and the Morass destroys forest cover and increases run-off and sediments into the Morass in times of heavy rain (Williams <i>et al.</i> 2012).
Annual/perennial crops (small holder)	Wetlands are increasingly being cleared to plant crops including ganja, coco, dasheen, pawpaw and bananas. The area of ganja is increasing, perhaps as a result of the drying of the Morass. Agro-chemicals are being used inappropriately, mainly on the southeast margins of the Morass. This activity increased between 2003 and 2010 (Williams <i>et al.</i> 2012). Ganja farming destroys natural vegetation, disrupts surface water flows, increases the drying of the Morass, and restricts access to inner Morass. Exposure of peat through drainage causes release of carbon dioxide and methane (Jauhianainen <i>et al.</i> 2008).
Annual/perennial crops (agro-industry)	Cane farming is carried out on the east and south of the Morass (Haynes-Sutton, pers. obs.). Some cane fields have been abandoned due to salinization of ground water (CEL 2001).
Livestock grazing/ranching/farming (small holder)	Informal cattle grazing in the Morass disrupts regeneration of vegetation (Haynes-Sutton <i>et al.</i> 2007)
Livestock grazing/ranching/farming (agro-industry)	No data on agro-industry.
Marine/freshwater aquaculture (subsistence/artisanal)	Small fish farms mostly abandoned on the east side of the Morass.
Unsustainable exploitation	
Hunting (intentional)	The Morass is a Game Reserve; therefore, no hunting is supposed to occur, but some hunting takes place in adjacent areas (V. Turland pers. comm.)

Threat	Summary of major impacts
Logging/wood harvesting (intentional; subsistence/small scale)	Harvest of hardwoods from the Morass and limestone islands in the Morass and the Fish River Hills have destroyed forest communities, leaving mainly the non-commercial species (G. Proctor, pers. comm.).
Gathering plants (intentional)	Herbal medicines, garden plants are commonly collected from natural areas but there is no information about the extent of these practices in the Morass.
Fishing/aquatic harvesting (intentional; subsistence/small scale)	A small number of people fish illegally with nets in the rivers. This probably has a minor impact on the fish population (Aiken 1992).
Habitat disturbance	
Disturbance (recreational activities)	Boating, fishing on rivers causes some pollution and disturbance (e.g., Haynes-Sutton 1999).
Fire (increase in frequency/intensity)	Peat fires, usually anthropogenic, have reportedly increased in frequency and severity (Lewis 2010). Drying of the Morass makes the peat more likely to catch fire and fires burn longer once started. The resulting smoke can be a major problem in the resort (Duever 2009). Exposure of peat e.g., in the ditch and furrow approach used in ganja farming causes oxidation, drying and shrinkage of peat. Peat dust is potentially explosive and highly combustible and probably contributes to increasing fire risk during droughts.
Changes in hydrology (Williams <i>et al.</i> 2012)	
Surface-water abstraction (agricultural)	The distribution of surface water has been altered by construction of drainage channels, canalization of the North and South Rivers, and the construction of the East Canal. This has probably resulted in drying of the Morass.
Ground-water abstraction (domestic)	Prior to a central water supply, the hotels and villas had utilized wells. The current impact is thought to be low.
Ground-water abstraction (commercial)	Currently, a water shortage exists in Negril. Water is supplied from wells at Logwood however, the impact of water abstraction on ground water levels is not known but could significantly lower water inflows at some times of year (NEPT 1995). Abstraction of water combined with reduced inflows have probably resulted in increased saline intrusion into the Morass.
Invasive alien species (Duever 2009)	
Invasive alien plants	Changes in hydrology have facilitated the spread of invasive plants in all the habitat types. In the Royal Palm Reserve, the main threats to open aquatic habitats are Water Hyacinth (<i>Eichhornia crassipes</i>) and aquatic ferns (<i>Salvinia</i> spp.). Shallow wet peatlands are affected by the invasive fern (<i>Lygodium microphyllum</i>) and grasses (<i>Panicum maximum</i>), while drier areas – e.g., near Sheffield – are being taken over by trees including <i>Mimosa pigra</i> and African Tulip (<i>Spathodea campanulata</i>). Swamp forests are being invaded by the Red Bead Tree (<i>Adenanthera pavonina</i>) whilst peripheral woodlands are being invaded by Poinciana <i>Delonix regia</i> and bamboo <i>Bambusa vulgaris</i> . Other invasive aquatic species include <i>Schinus terebinthifolius</i> and <i>Sphagneticola trilobata</i> (Duever 2009). Regeneration of swamp forests is being inhibited by over-growth of vines (<i>Ipomoea</i> spp.), but this is largely a response to the opening of the canopy following the removal of the large shade-providing timber trees such as Boarwood (<i>Symphonia globulifera</i>).
Invasive alien animals	Mongoose (<i>Herpestes auro punctatus</i>), cats, dogs, rats, Shiny Cowbird (<i>Molothrus bonairensis</i>) (Haynes-Sutton <i>et al.</i> 2007) and the Cane Toad (<i>Rhinella marina</i>) are common (Haynes-Sutton pers. obs.). The invasive alien fish, <i>Tilapia nilotica</i> , is common in

Threat	Summary of major impacts
	rivers and ponds. Similar habitats in the Black River Morass system are being severely affected by invasive shrimp, catfish and wolf cichlids, but there have been no assessments of these species in the Morass. The Cuban Tree Frog is likely to become a threat in the future.
Problematic native species	<i>Ipomoea tiliacea</i> grows over trees and shrubs in the Royal Palm Reserve and has been considered a threat (Duever 2009).
Pollution (e.g., Haynes-Sutton 1999; Williams <i>et al.</i> 2012)	
Domestic/urban waste-water pollution (sewage)	Before the construction of the central sewage system, most hotels disposed of their sewage through tile fields and soakaways. Consequently, this has polluted the ground water. The Negril Sewage Works has improved the situation but not all hotels are connected and there have been no upgrades in the last 5-6 years. There is a continuing massive increase in the construction and the capacity of the existing plant is vastly exceeded. The outflows from the sewage works are still high. Levels of <i>E. coli</i> in the South Negril River were above acceptable levels for recreation (e.g., Haynes-Sutton 1999). National Water Commission reported plans to expand the plant are in the concept stage.
Domestic/urban waste-water pollution (run-off)	No information on the scale and impacts of run-off.
Agricultural/forestry pollution (nutrients)	The impacts of use of fertilizer on pollution levels have not been assessed.
Agricultural/forestry pollution (sediment)	Run-off in the Sheffield area and into the East Canal, as well as sediments carried to the sea by the South Negril River.
Agricultural/forestry pollution (herbicide/pesticide)	Chemical sprays on ganja are suspected to pollute surface and ground water.
Garbage/solid waste pollution	Dumping of domestic wastes in wetlands disrupts the ecology and contributes to pollution.
Air pollution (smog)	This is a result from peat fires, which are occurring more frequently and over wider areas.
Light pollution	Lights from structures – including hotels, commercial developments, housing and roads – situated on and adjacent to the beach that are not shielded, shine out over the sea attracting sea turtle hatchlings inland.
Geological events (Climate Studies Group 2017)	
Geological events (earthquake/tsunami)	Increased tsunami risk to coastal vegetation and property.
Climate change (e.g., Climate Studies Group 2017)	
Climate/weather (habitat shifting/alteration)	Increased temperatures generally; sea level rise increases risk to properties and changes coastal vegetation. There is also increased salinization of aquifers.
Climate/weather (drought)	Drought increases risk of fire and suitability of habitats; more dry days.
Climate/weather (temperature extremes)	Increased mean daily temperatures; more hot days and hot nights.

Threat	Summary of major impacts
Climate/weather (storm/flooding)	More frequent and intense flood events are expected.

The threats that influence or can be influenced by hydrological modifications are those that are related to changes in drainage, water balance, surface of the wetland and salinity. These include the impacts of climate change on rainfall, temperature, sea level rise (SLR), the stability of the coastal strip that isolates the Morass from the sea, and storm surge.

The impacts of the hydrological modifications, climate change and variability are discussed in greater detail in the next chapter.



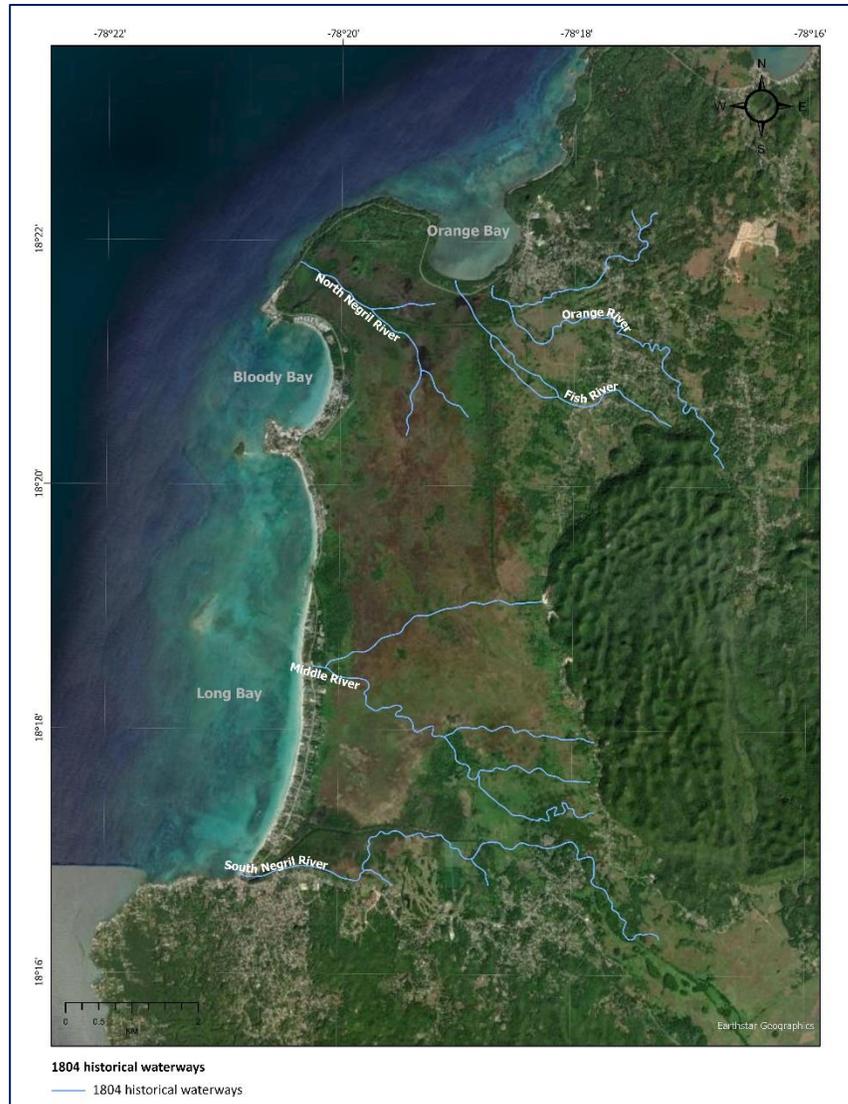
4 Hydrological Assessment

The origins of the Great Morass are attributed to slowly rising sea levels over an eroded karstic limestone bedrock some 8000 years ago (Robinson & Hendry, 2012), resulting in the development of wetland conditions and the formation of peat deposits. The current areal extent of the Great Morass was reached approximately 2,000 years ago (Robinson & Hendry, 2012), and has changed naturally relatively little since. The restoration of historical hydrological and other physical processes is one of four specific objectives of the IWEco funded Negril Morass restoration project.

4.2 Historical Changes to the Morass Hydrology

The Great Morass has been subject to extensive drainage interventions, since the beginning of the 19th century, to try and improve the potential for agricultural production in the area. These have not only significantly changed the river flows across and through the Great Morass but have also had a significant impact on intercepting groundwater and allowing saline waters to enter the body of the Morass.

The earliest records (Robertson, 1804) confirm the natural surface water flow regime prior to any drainage modifications consisted of four main river systems (see Drawing No. 2).

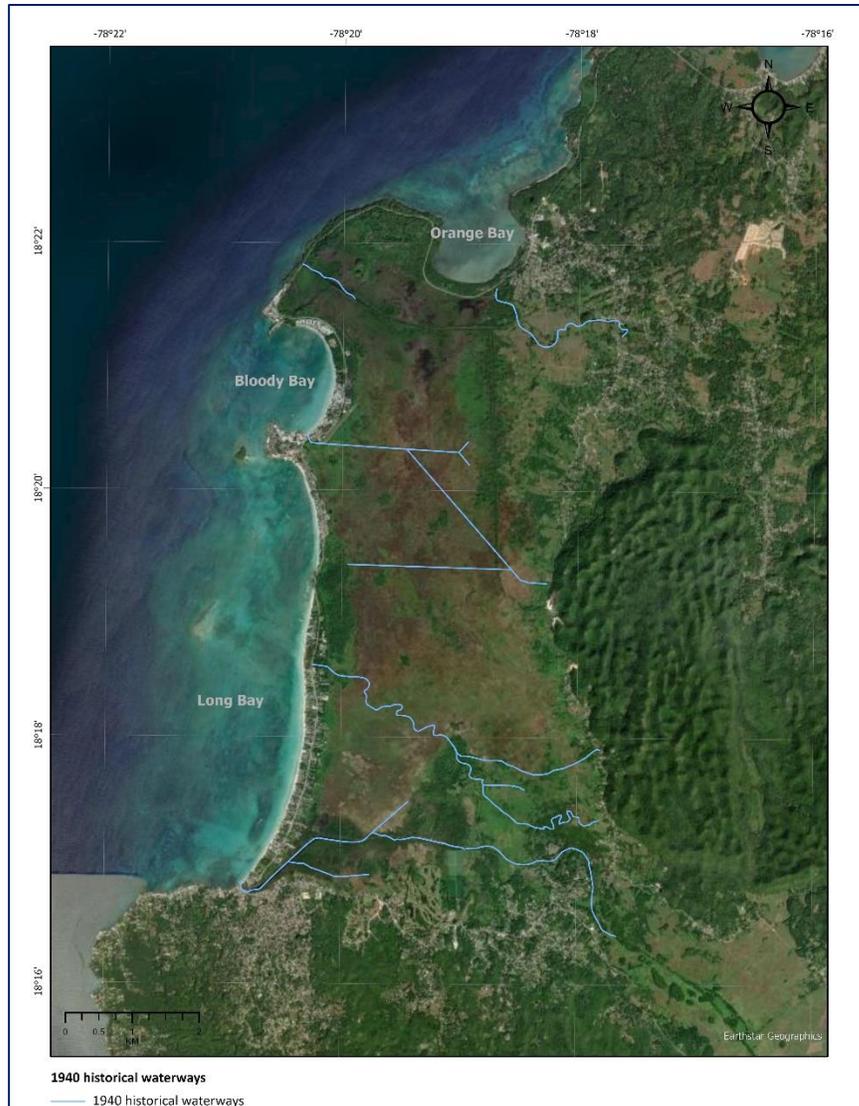


Drawing 2 River routes in Great Morass in 1804

The 1804 land survey shows:

- The Orange River to not enter the Morass at all but to flow north into Orange Bay.
- The Fish River to also flow north into Orange Bay.
- The North Negril River to be entirely sourced from rainfall run-off leaving the Morass.
- The Middle River to be sourced from 4 No. springs issuing from the limestone hills east of the Morass, flow across the southern third of the Morass and to discharge into Long Bay; and
- The South Negril River to meander across the southern extent of the Morass.

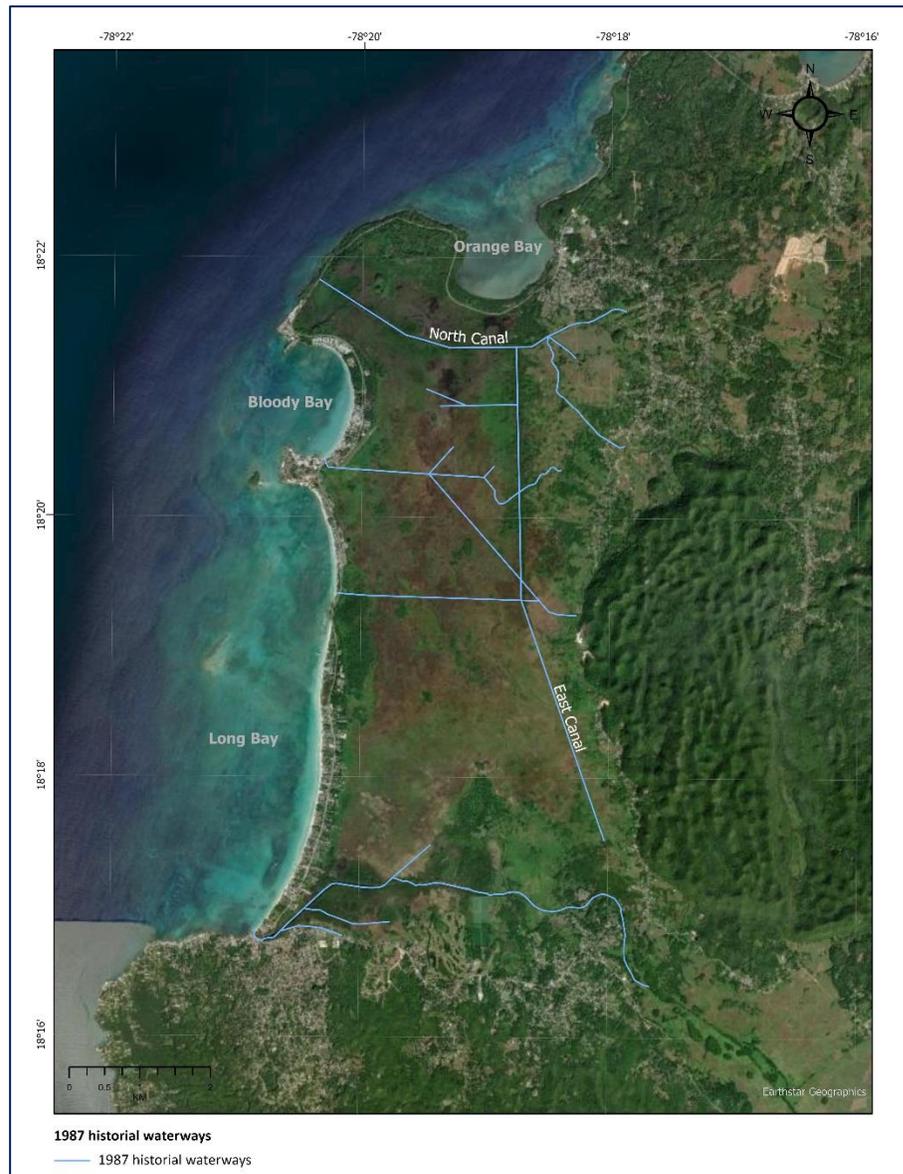
As late as 1940 (Robinson & Hendry, 2012) the 1940-1941 aerial photographic survey (see Drawing No.3) showed:



Drawing 3 River and drainage routes in the Great Morass in 1940

- Orange River still flowing into Orange Bay.
- New west-to-east linear drainage in the northern half of the Morass (sometimes described as the Fish River), collecting a northern spring discharge from the eastern limestone hills and discharging this into the sea at the southern end of Bloody Bay.
- A much-reduced North Negril River – presumably due to the reduction in its catchment due to the above drainage system.
- The Middle River, but less its northern-most branch, which has been captured by the new linear drainage feature; and
- A much-straightened South Negril River.

In the 1950's a major drainage programme was initiated, which drastically changed the drainage routes of the Morass, to those largely observed today (see Drawing No. 4).



Drawing 4 Drainage and river routes in the Grand Morass in 1987

In summary these are:

- The North Canal being excavated - capturing the Orange and Fish Rivers and routing them into the sea where the North Negril River used to discharge.
- The East Canal being excavated and draining into the North Canal – capturing the 4 to 5 spring flows from the eastern limestone hills and drying up the Middle River altogether. Rechanneling water from these springs back into the wetland will be essential to rewetting.
- The remains of the west-to-east linear drainage scheme; and

- The much-straightened South Negril River – this is understood to have been dredged and deepened at this time.

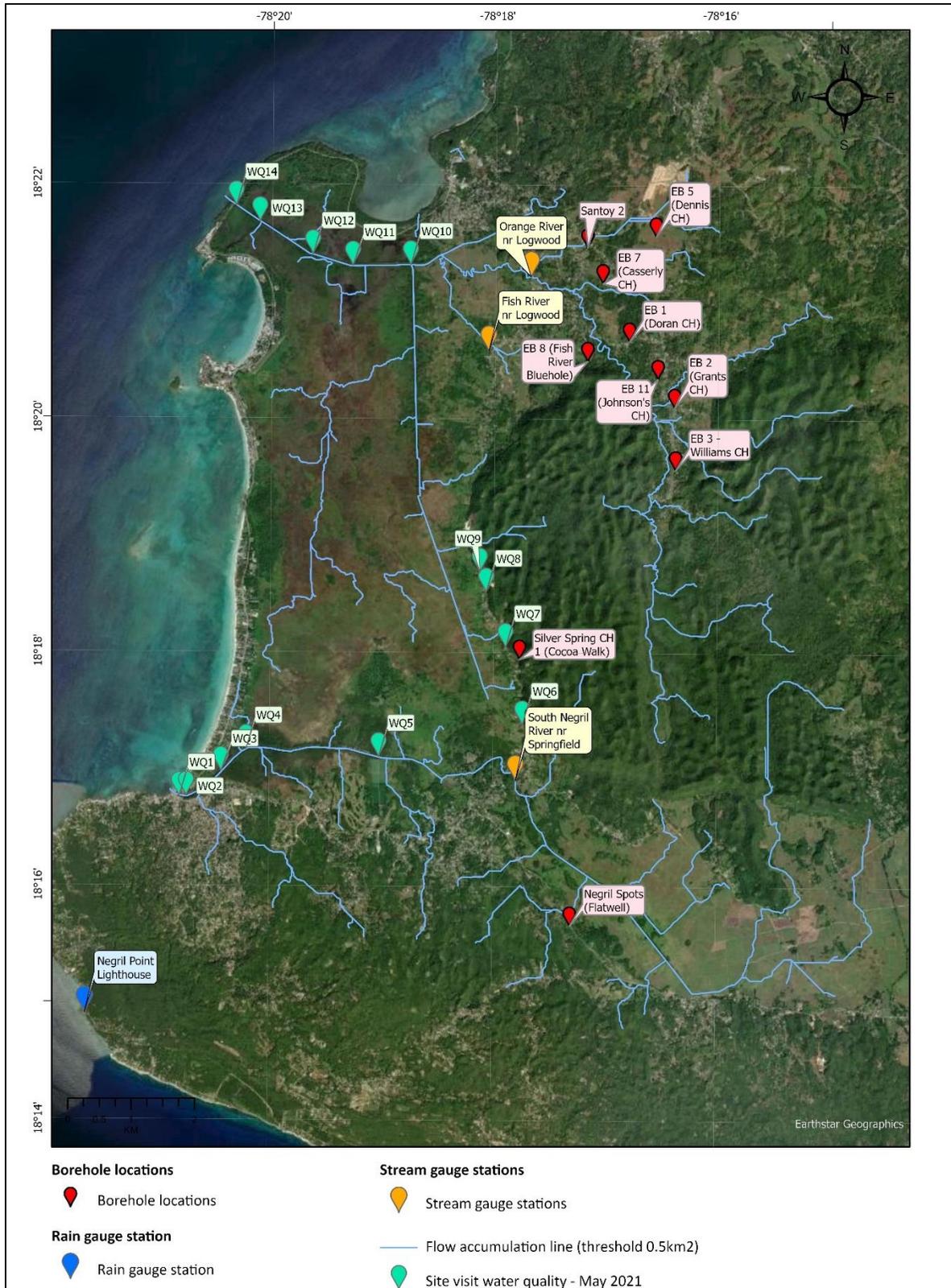
The consequence of the construction of these three main canals has been to route storm water flows rapidly past the Morass from the watersheds to the east and southeast of the Morass – note the Orange and Fish Rivers never used to flow through the Morass.

- Allow saline sea water into the Morass via the canals on high tides and during storm surges.
- Intercept the sediment free groundwater spring flows that used to flow across the Morass in the Middle River; and
- Lower groundwater levels in the Morass wetland and its underlying peat mass, resulting in peat compaction, loss of peat permeability and further reduced groundwater inflow.

4.3 Climatic and Hydrological Variability and Climate Change

In parallel with these manmade hydromorphic modifications, an assessment of available meteorological and hydrological data has been undertaken to understand rainfall and evaporation within the Great Morass, river flows, and how these have changed with time.

The hydrological monitoring network for the Great Morass is somewhat limited (see Drawing No. 5) due to the largely inaccessible nature of the wetland.



Drawing 5 Existing Meteorological and hydrological monitoring network

Meteorological data is available from the Negril Point Lighthouse, and there are active Water Resources Authority (WRA) river gauging stations on the Orange and Fish Rivers. A river gauge used to be maintained on the South Negril River near Springfield but that has not been operated since the 1970's. WRA also monitors groundwater levels in springs and boreholes east of the Morass, but none within it.

4.3.1 Climate Analysis and Aridity

More than 30 years of rainfall data exists. A summary of average monthly rainfall data is shown below (Figure 13). This clearly shows the bi-modal nature of rainfall in Jamaica, with lower rainfall in December to March and June to July.

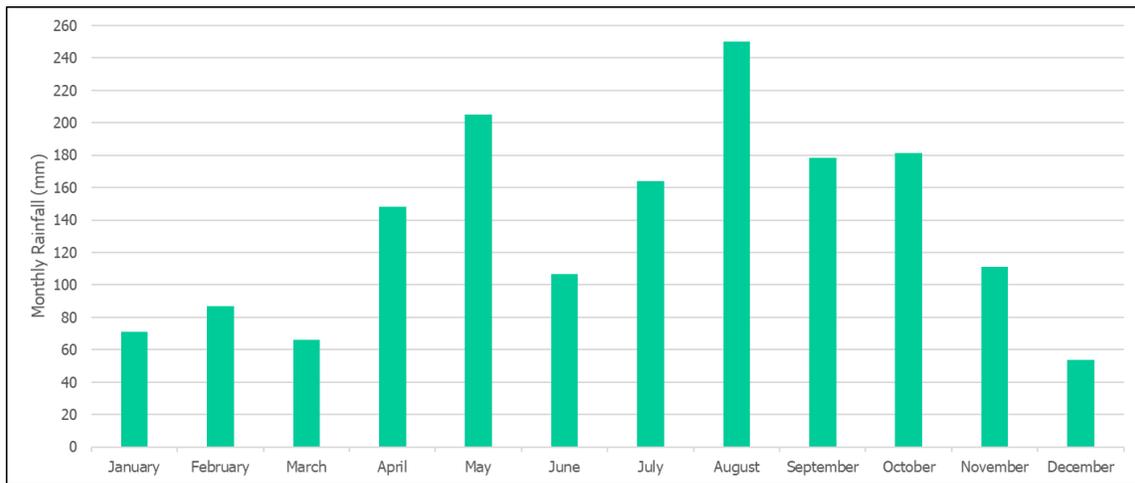


Figure 13 Average monthly rainfall at Negril Lighthouse, 1989-2020

Average monthly evaporation data shows a more uniform seasonal distribution, see Figure 14 below.

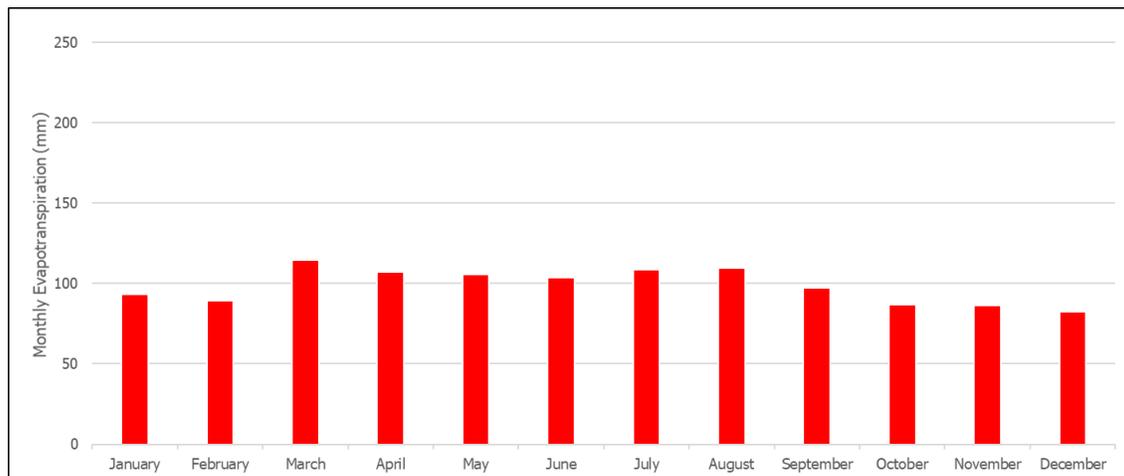


Figure 14 Average monthly evaporation data at Negril Lighthouse, 1989-2020

If we subtract average monthly evaporation from average monthly rainfall then we can estimate the average monthly effective rainfall, *i.e.*, that the rainfall in excess of the evaporation and that available for run-off into rivers and infiltration into the underlying strata.

The seasonal Effective Rainfall distribution shows there is negative effective rainfall for 4 months in a row from December to March, where a cumulative deficit of >100mm develops. This takes all the effective rainfall of April and more than half of May's for the cumulative effective rainfall to become positive. Thereafter 5 months in a row (July to November) all increase the cumulative effective rainfall surplus.

Whilst a crude analysis, the below graph (Figure 15) shows the wetland will naturally get increasingly dry seasonally from December to March, before being re-wetted by effective rainfall April to November.

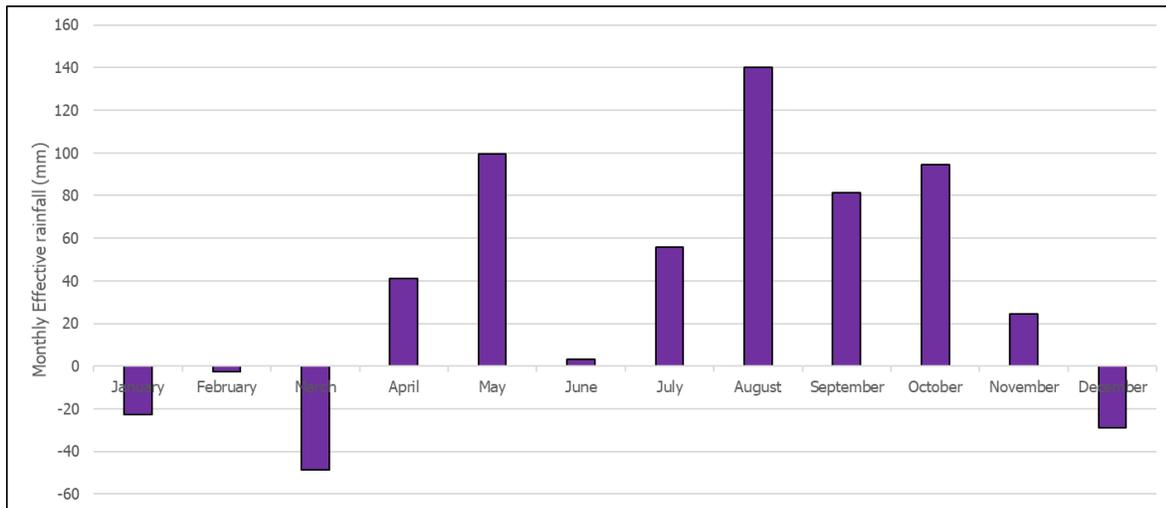


Figure 15 Average monthly effective rainfall at Negril Lighthouse, 1989-2020

Rather than just assessing average rainfall, we can also consider whether rainfall changes with time. The below graph (Figure 16) shows how the cumulative 6-month rainfall total (normalised) varies with time. This is known as the Standard Precipitation Index (SPI). Values of +2 are very wet periods, values of -2 are very dry (drought) periods.

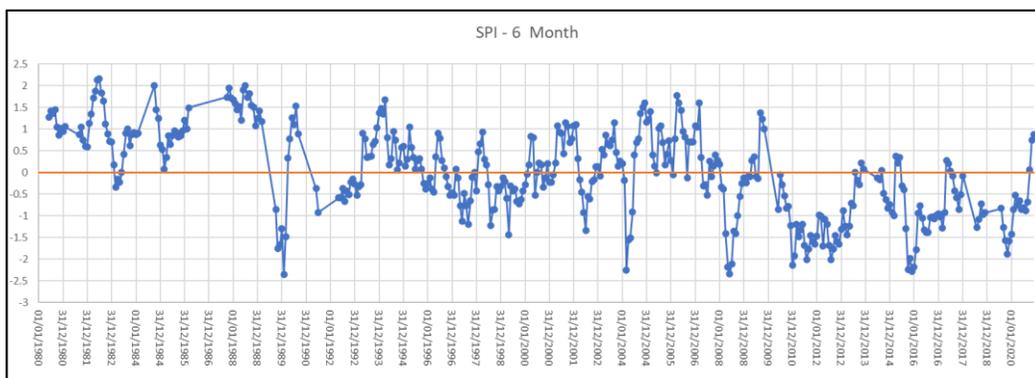


Figure 16 6-month Standard Precipitation Index (SPI-6) for Negril Lighthouse

There is a very clear downward trend in the rainfall with time, which can only be attributable to climate change. This graph is showing an increasing reduction in rainfall over a 40-year period, which will result in both reduced direct rainfall onto the Morass but also lower river flows and lower groundwater spring discharges.

Whereas precipitation is projected to reduce due to climate change, evaporation is expected to increase. The climate change net result of reduction in rainfall and increase in evaporation on effective rainfall is therefore aggravated and more considerable.

The graph below (Figure 17) shows the trend in effective rainfall (normalised) with time. As before +2 means very wet periods and -2 means very dry periods.

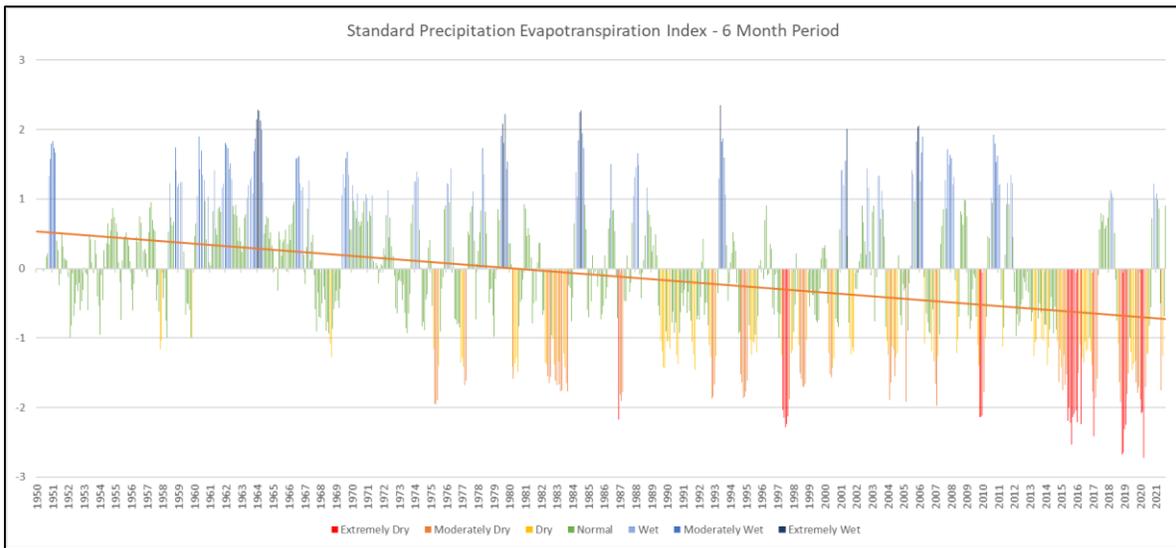


Figure 17 6-month Standard Precipitation Evapotranspiration Index (SPEI-6) for West Jamaica

It is clear there is a very significant reduction in effective rainfall in the Negril area with time, which, notwithstanding the manmade drainage schemes, will also contribute to the drying of the Great Morass over the last 40+ years.

4.3.2 Hydrological Analysis and Low Flow De-watering

Whilst the WRA stream flow gauges on the Orange and Fish Rivers do not measure the entire flows leaving the upstream eastern catchments flowing into the North River, they do provide an understanding of the size and variations in stream flows.

The graph below (Figure 18) shows the WRA reported flows in the much larger of the two catchments belonging to the Orange River, dating back to 1971, over 5 decades.

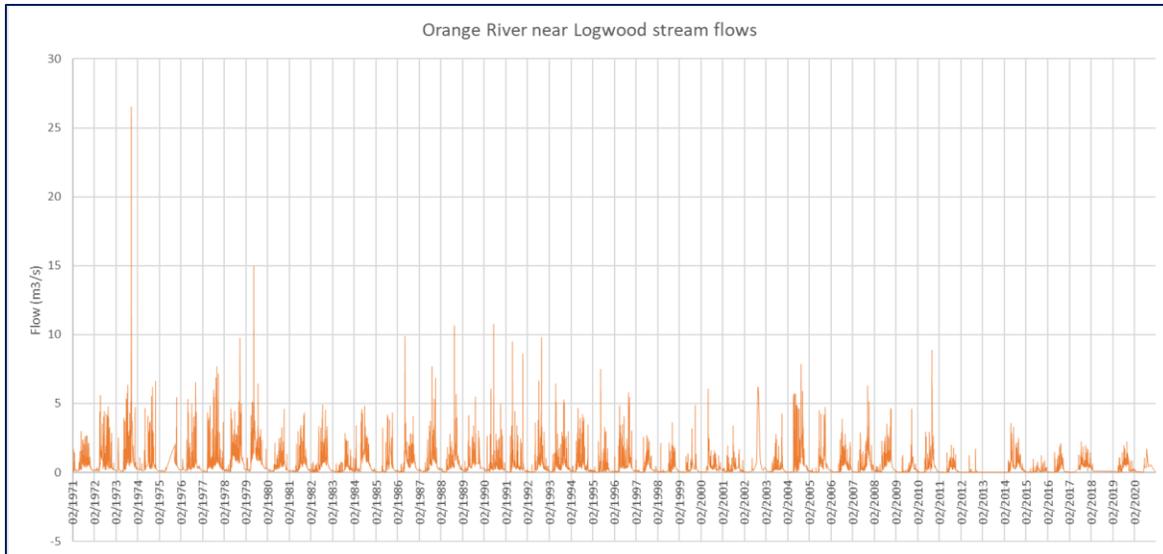


Figure 18 Orange River Flow Hydrograph

The graph shows storm flows up to 27 metres cubed per second (m³/s), reducing to almost no flow at all in each dry season. The river responds quickly to storm events, which is expected given the water course is largely fed by karstic groundwater.

We can also look at trends in river flows with time, to see if there is any evidence of flow reduction with time.

The graph below (Figure 19) shows a flow duration curve for the Orange River, separated decade by decade. The x-axis shows the percentage of the time the flow on the y-axis has been exceeded – so for example (taking the blue line) 0.5 (or 50%) of the time, the flow is greater than 0.1m³/s (*i.e.*, 100 l/s) – note the y-axis is on a logarithmic scale.

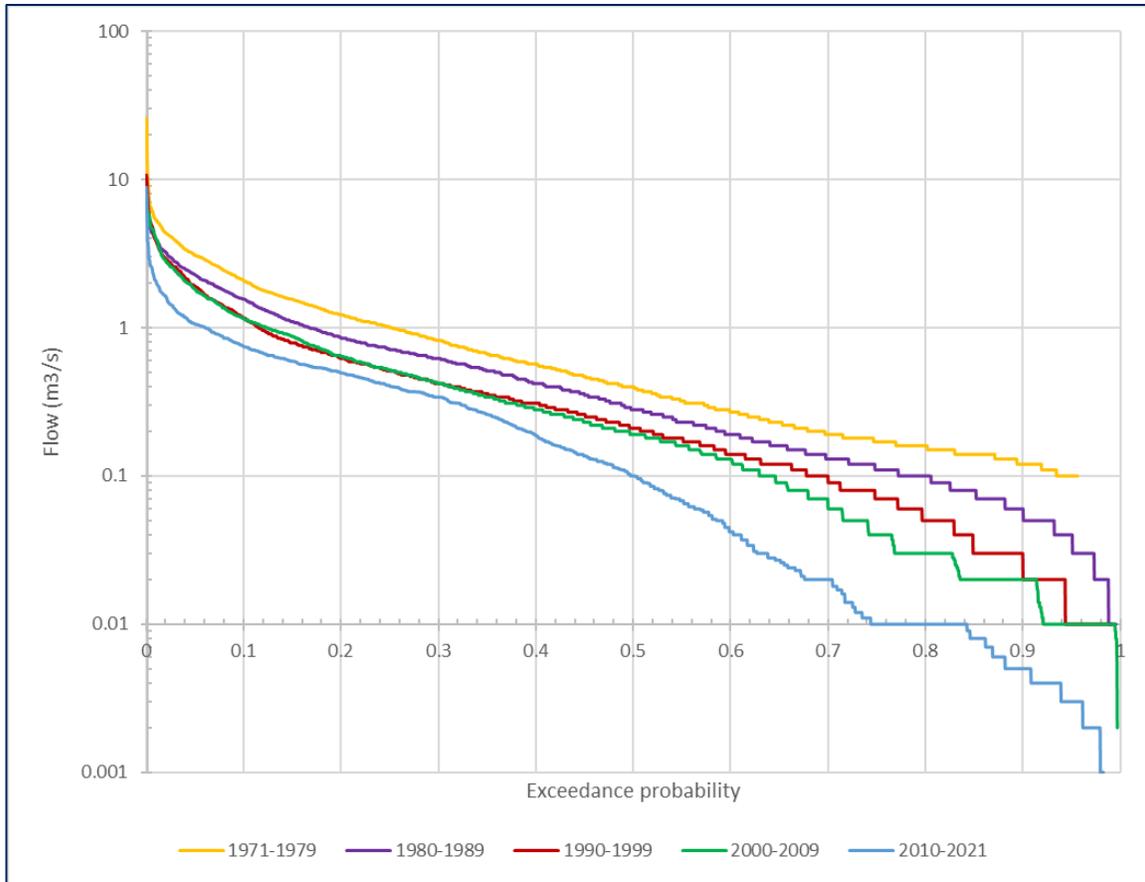


Figure 19 Orange River Flow Duration Curve

Figure 19 above shows that that flows of more than $0.5\text{m}^3/\text{s}$ only occurs 20% of the time in the last decade (the blue line), with 75% of the time flows are only greater than $0.01\text{m}^3/\text{s}$ (10 l/s). These duration curves therefore tell us that the vast majority of the time, the flows in the river are low, with occasional fast flowing turbid storm events – hence water levels in the river are low most of the time, and consequently drainage of the wetland and saline intrusion will occur, most of the time.

Elevated salinities were measured (ESL, 2021) in June 2021 (Table 3.1) as far inland as the mouth of the East Canal joining the North River, *i.e.*, almost 4km inland (see Drawing No.5).

Table 4.1 Baseline Data collected for sites along the North and South Rivers (June 2021)

Site	Site Number	WQ ID	Date	Site description	Estimated Depth (m)	Temp (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (mS/cm)
South Negril River	Site 1	WQ1	22/05/2021	Mouth of river, below bridge	-	25.7	6.73	1.15	6.24
South Negril River	Site 2	WQ3	22/05/2021		1.93	25.5	6.53	1.05	3.15
South Negril River	Site 3	WQ2	22/05/2021	1 st meander, oil on water	1.22	25.5	6.50	1.14	3.43
South Negril River	Site 4	WQ4	22/05/2021		2.34	25.4	6.22	0.48	2.14
South Negril River	Site 5	WQ5	22/05/2021	Sewage treatment outfall, water has a green appearance, oil on water surface	1.10	24.9	6.04	0.50	2.00
North Negril River	Site 6	WQ14	22/05/2021	Mouth of river, below bridge	4.00	26.6	7.01	2.97	7.74
North Negril River	Site 7	WQ13	22/05/2021	At the tributary	3.50	26.7	7.07	2.81	7.91
North Negril River	Site 8	WQ11	22/05/2021	1 st meander, water has a light brown appearance	2.75	25.5	7.07	2.92	4.90
North Negril River	Site 9	WQ12	22/05/2021	Water has a light brown appearance	2.25	25.6	7.08	2.92	3.18
North Negril River	Site 10	WQ10	22/05/2021		2.00	25.0	7.39	4.30	1.03
Springs	Spring 1	WQ6	22/05/2021		-	24.0	6.67	6.27	0.447
Springs	Spring 2	WQ8	22/05/2021		-	26.1	6.89	4.68	0.79
Springs	Spring 3	WQ7	22/05/2021		-	24.6	6.81	6.54	
Springs	Spring 4	WQ9	22/05/2021		-	24.3	7.01	5.57	0.359

The decadal flow duration curves also show a clear reducing stream flow with time, from the 1970's (yellow line with greatest flows) to the 2010's (blue line), for both the high flows and the low flows. It is possible the reductions of low flows with time could be due to increased water abstraction from the river, but as there are also reduction in high flows this suggests this is a climate change impact.

The lower the water levels are in the rivers and the longer the duration of river low flows, the more likely not only saline intrusion into the freshwater wetland will occur but also increased dewatering of and drying out of the wetland and its underlying peat formation.

Once peat starts to dry out it becomes very friable and easily eroded, as well as more combustible, and compacts under its own weight resulting in land subsidence, which itself increases water expulsion, resulting in further dewatering and on-going land lowering, and saline water ingress.

4.4 Components of Wetland Hydrology

From the above morphological and hydrological analysis, we can identify there are 5 primary controls on the water content/balance of the Great Morass wetland. These are as follows:

- **Direct rainfall** onto the Great Morass.
- The **South Negril River** – a straightened and deepened river – which borders the Morass to the south but does not obviously contribute flow into the Morass, yet, does allow saline water to migrate inland adjacent to the Morass.
- The **North Negril River** – an entirely manmade canal – largely bordering the Morass at its northern extent - which lowers groundwater within the Morass at times of low flow, allows saline intrusion into the Morass at times of low flow, whilst pulsing turbid storm water into the Morass *via* the East Canal during periods of high flow.
- The **East Canal** – draining into the North Negril River - which lowers groundwater within the Morass at times of low flow, allows saline intrusion into the Morass at times of low flow, whilst receiving turbid storm water from the North Negril River during periods of high flow; and
- **Groundwater spring discharges** along the eastern edge of the Morass – currently intercepted by the East Canal but which used to flow into the Morass – as well as deeper groundwater up-flow from the karstic limestones beneath the peatland mass.

If the water content of the Morass is to be improved, some or all these major controls on Morass hydrology will need to be altered.

4.5 Hydrological Restoration/Optimization Targets

Understanding the severity of the historical drainage impacts on the Morass hydrology, as well as the on-going impact of climate change on rainfall, evaporation, river flows and groundwater flows, which collectively reduce the water content within the wetland, has enabled an informed multi-stakeholder dialogue on what could or should be the hydrological restoration objectives and targets for the re-wetting of the Morass.

The restoration objectives identified in the wider IWEco project documents were broad and were not all specific to the hydrological re-wetting of the Morass. Voiced priorities during the multi-stakeholder workshops reflecting the diverse interests of different government institutions, private sector businesses and local non-governmental and community-based organisations ranged from ecological conservation and protection to sustainable exploitation.

As detailed above, the major habitats in the Morass are water-dominated, including open water, marsh, mud flats, mangroves, terrestrial forest and swamp forest. The project scoping documents recognise the canalisation of the main rivers in the 1950's, the construction of the eastern canal, as well as tree-felling and illicit cultivation have all contributed to the degradation of the wetland and a reduction in the aerial extent of the Royal Palm Forest.

The project documentation goes onto recognise the threats to the Morass's biodiversity of human-induced drainage of the wetland, coastal development, unsustainable agricultural practises and the proliferation of informal settlements, with the depletion of flora and fauna associated with dropping water levels and further exacerbated by bush fires, peat subsidence, sedimentation, nutrient enrichment and invasion of alien species.

One of the four project objectives is described as the restoration of the historical hydrology of the Morass to reduce the degradation of the wetland, as well as restoration and improvement of the hydrological flow regime to control the extent and pattern of desiccation, and route moisture to critical areas being impacted by changing moisture.

The project documentation also stated the need for restoration of the natural hydrological regime to its pre-drainage state, with attention given to previous hydrological engineering works, and historical and current conditions.

The above project justification led to the need to confirm with national and local stakeholders as to exactly what were the hydrological restoration objectives, and what project constraints (including budget and time) as well as land access and local stakeholder ownership, would limit achieving these objectives.

The following Decision Tree (Figure 20 below) was developed to guide the stakeholders through the various decisions required to arrive at hydrological restoration goals. These included:

- the extent to which a historical restoration should be achieved, and if so which date – *e.g.*, removal of the East Canal, removal of the Orange River, re-capturing the eastern groundwater springs.
- the extent to which specific species should guide hydrological improvements *e.g.*, the West Indian Whistling Duck – and what hydrological conditions its preferred habitat requires.
- the extent to which wild bush fire risks should be reduced.
- whilst being mindful of mosquito breeding risks; and
- the need to avoid impacts on legitimate landowners' activities.

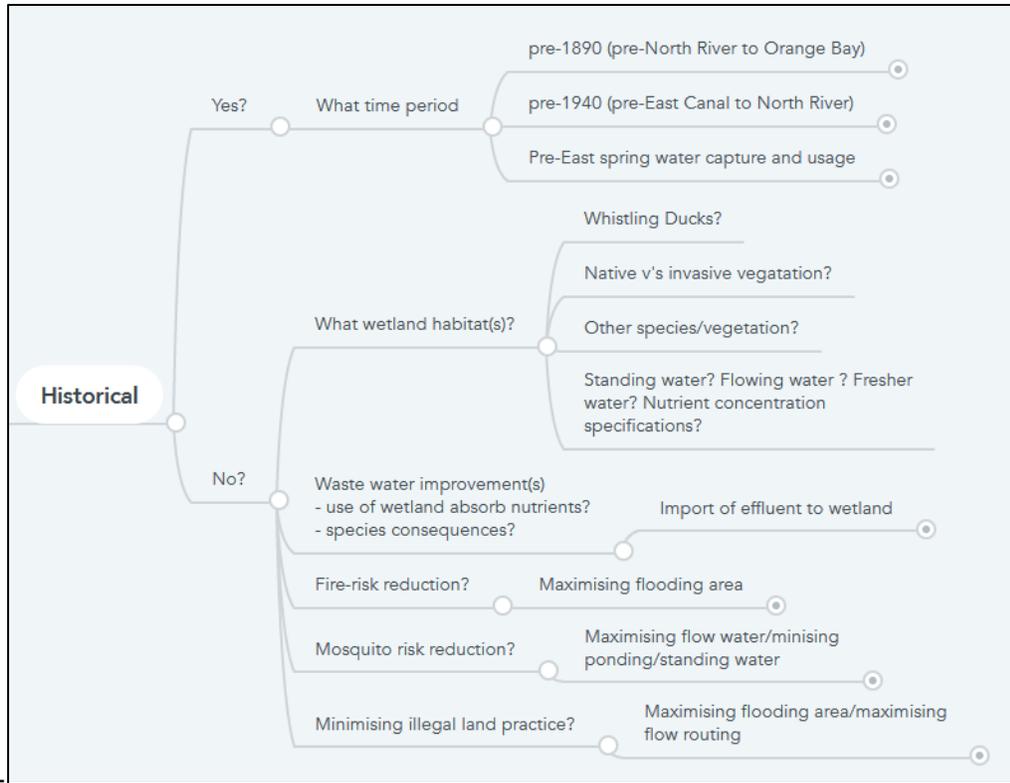


Figure 20 Hydrological Restoration Options Decision Tree Analysis

From a series of workshops with both local Negril stakeholders and NEPA, it became clear the issue of wild bushfire was a priority local concern, whereas the habitat of the West Indian Whistling Duck was a priority for NEPA. NEPA also confirmed that neither of the main rivers should be interfered with – the project could neither afford nor could accept the liability associated with routing more river water into the flat wetland, whereas altering the East Canal was potentially possible.

Based upon these discussions, four hydrological restoration goals were identified:

- Reducing the risk of wild bush fire to the west of the East Canal.
- Increasing the wetness of the area around the Royal Palm Forest, favoured by the West Indian Whistling Duck.
- Raising water levels or blocking the East Canal; and
- Re-routing the eastern springs into the centre of the Morass.

Each of these separate restoration target areas would need to function as a separate hydrological zone, whilst complimenting each other in an overall coordinated hydrological restoration plan for the Morass.

4.6 Hydrological Model Selection Process

The critical importance of first establishing the hydrological restoration goals is further explained in Figure 21 below. Each possible objective requires modelling of different components of the hydrological cycle, which then requires the use of particular modelling approaches: hydraulic modelling for the rivers; groundwater modelling for the hydrogeological regime; and/or terrain run-off modelling for the rainfall run-off within the Morass.

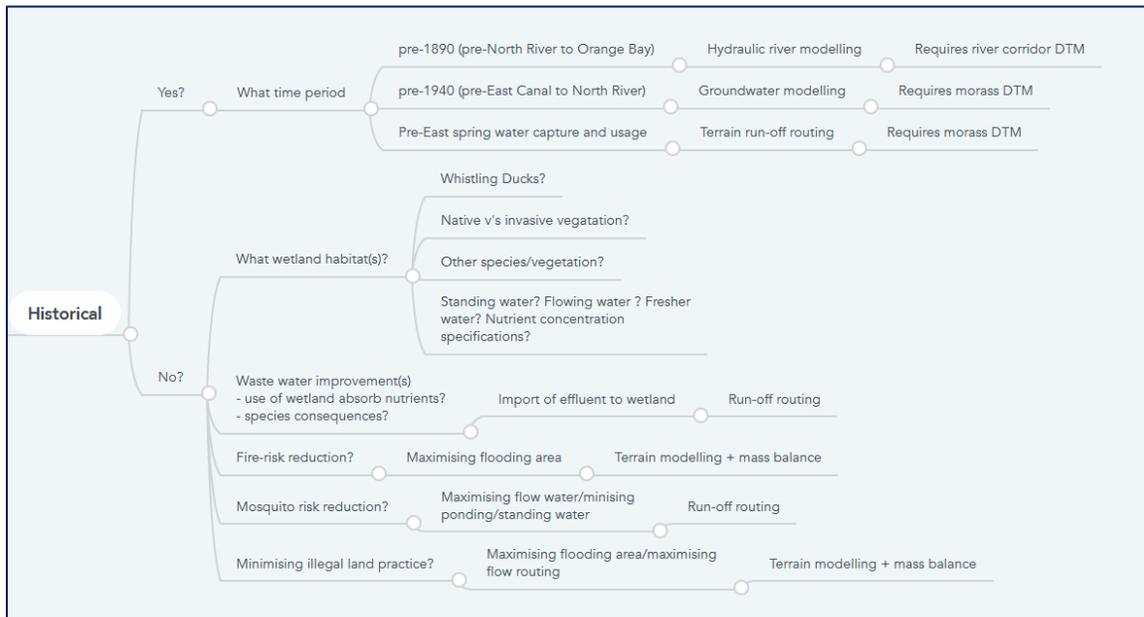


Figure 21 Relationship between hydrological restoration objectives and hydrological model selection

The hydrological restoration targets identified, all led to the use of geomorphological terrain modelling. Such modelling requires the use of very accurate topographic surveys to enable the rainfall run-off flow routes to be determined. In a flat low-lying area like the Negril Morass, which has a ground elevation of <4 metres Above mean Sea Level (mAmSL), then this necessitates detailed topographic surveying across almost 30km² of largely inaccessible wetland. Such a detailed topographic survey did not exist.

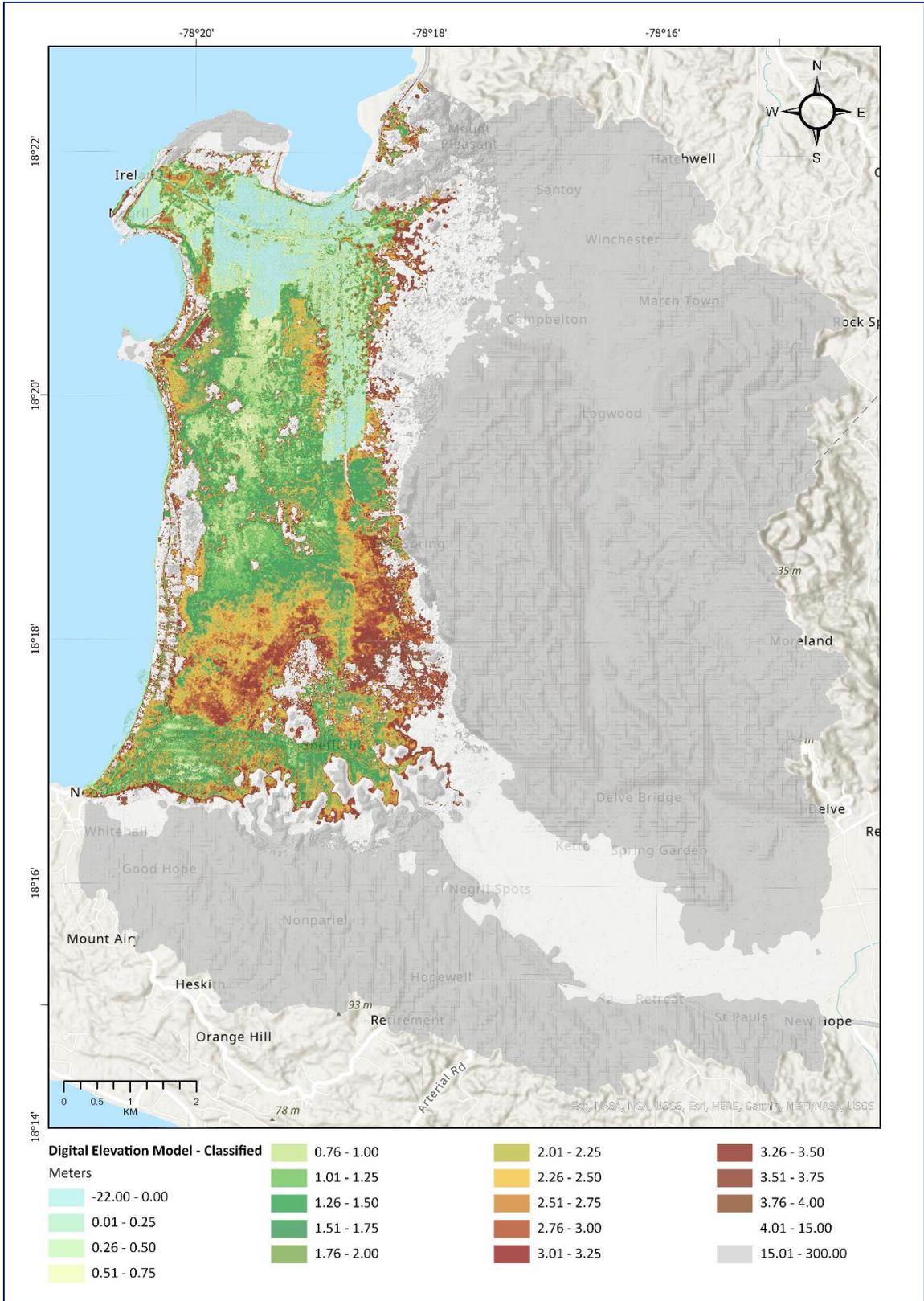
4.7 Topographic Survey and Digital Elevation Model Development

Consequently, the IWEco project had to commission a national surveying contractor to undertake airborne drone surveys of the wetland, using a combination of ortho-photographic and LiDAR techniques, controlled by actual ground surveyed topographic level locations. This work eventually resulted in the generation of a Digital Elevation Model (DEM) which was used for geomorphological terrain analysis and hydrological restoration planning and design.

The DEM is shown below. The colour banding shows the different DEM elevations in 0.25m intervals, ranging from <0.00m AmSL to > 4mAmSL. Elevations > 15mAmSL are also illustrated on the figure below, where satellite imagery has been added to the DEM beyond the drone survey boundary to capture the hills and watersheds inland and upstream of the Morass.

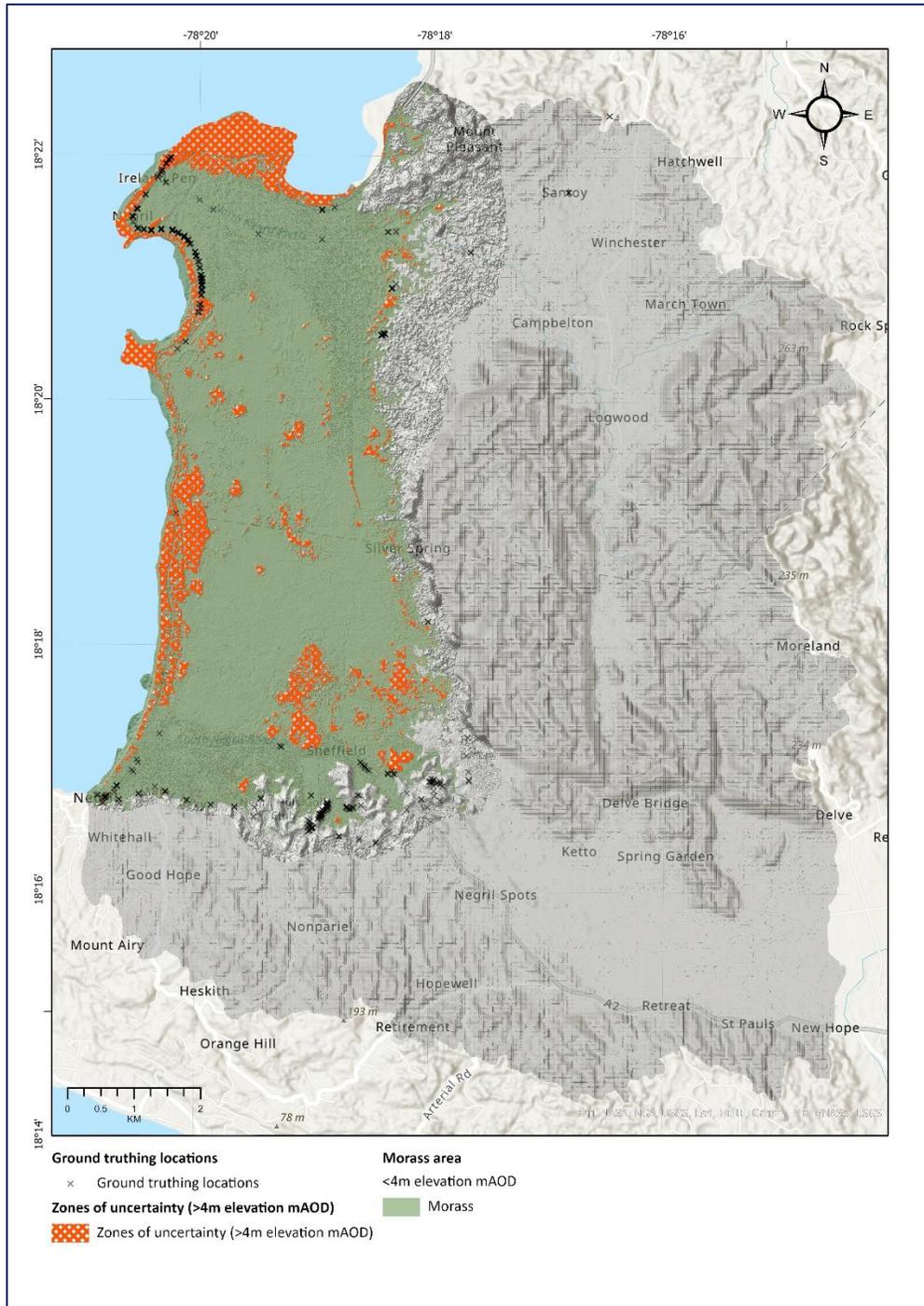
The area of ground elevation <0m AmSL is particularly noteworthy, being restricted to along the North Negril River and northern half of the East Canal. It seems likely this is a function of the excavation of the river and canal, which will have dewatered the peat beneath the wetland, resulting in compression of the peat and associated subsidence and land surface lowering.

Whilst impressive in the detail and granularity that can be seen in the DEM, an audit of the DEM, comparing the elevations to the high-resolution aerial photography used in the surveying process, identified that dense vegetation canopy was captured in the DEM and consequently any elevations in the DEM above 4mAmSL were in fact vegetation.



Drawing 6 Digital Elevation Model of the Negril Great Morass

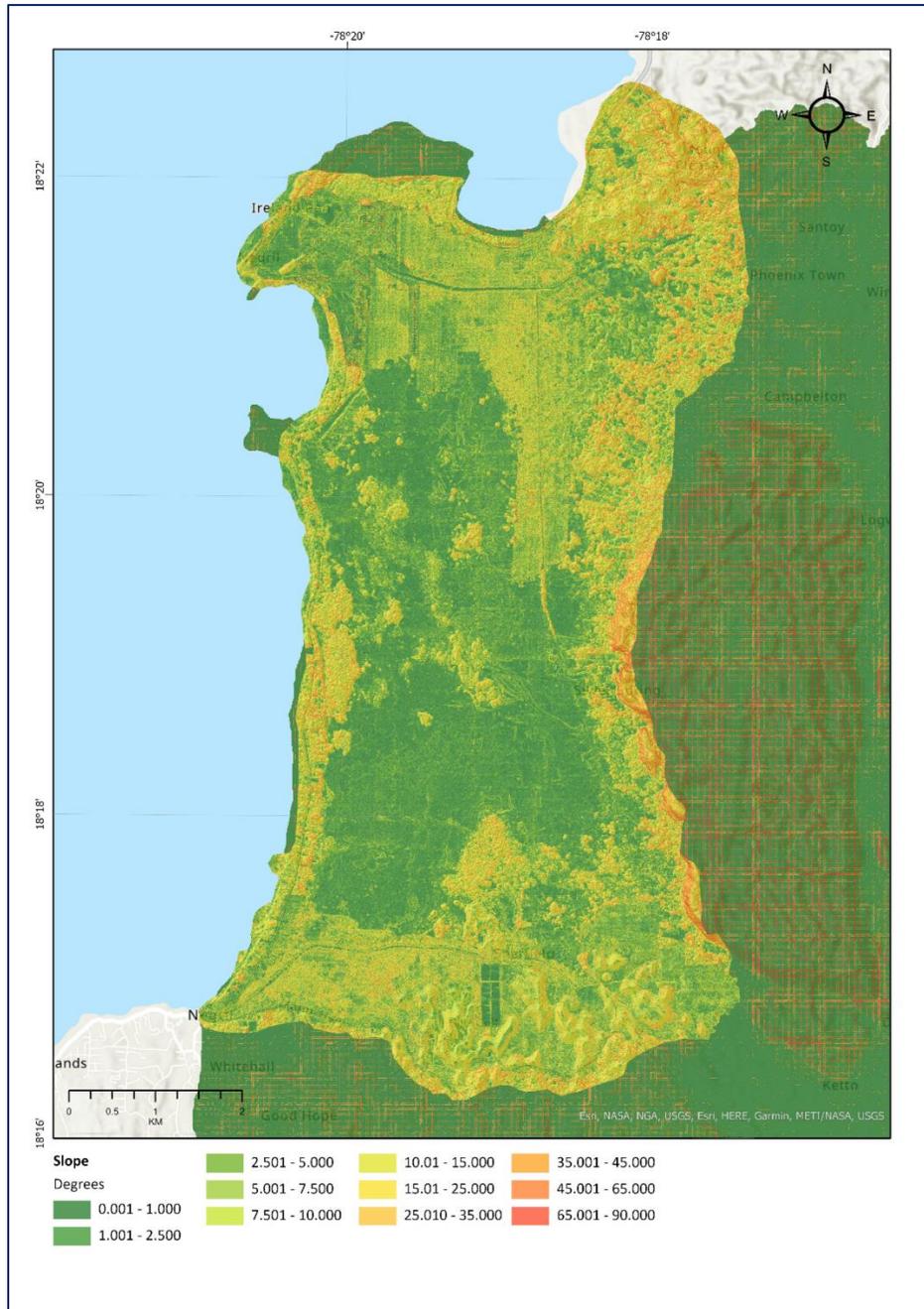
Using this elevation as a criterion to distinguish wetland ground surface from tree vegetation canopy allowed the following 'zonation' of the DEM into areas that were considered 'trusted' or 'reliable' and those that were considered 'zones of uncertainty' within which rainfall-run-off modelling could not be considered to be accurate.



Drawing 7 Morass DEM split into zones of certainty and uncertainty

In defining these areas of certainty and uncertainty, this enabled the modelling results to be evaluated for reliability and to constrain and define hydrological restoration measures which did not impact or inundate land in these areas.

A second screening tool was used to assess the reliability of the DEM. This used the slope or gradient of the DEM in any location to distinguish between the very flat Morass and the very steep change in DEM which could only be explained by the DEM including vertical trees. The slope map is shown below. Green colours are flat slopes, red near vertical slopes, and yellows slope angles in between.



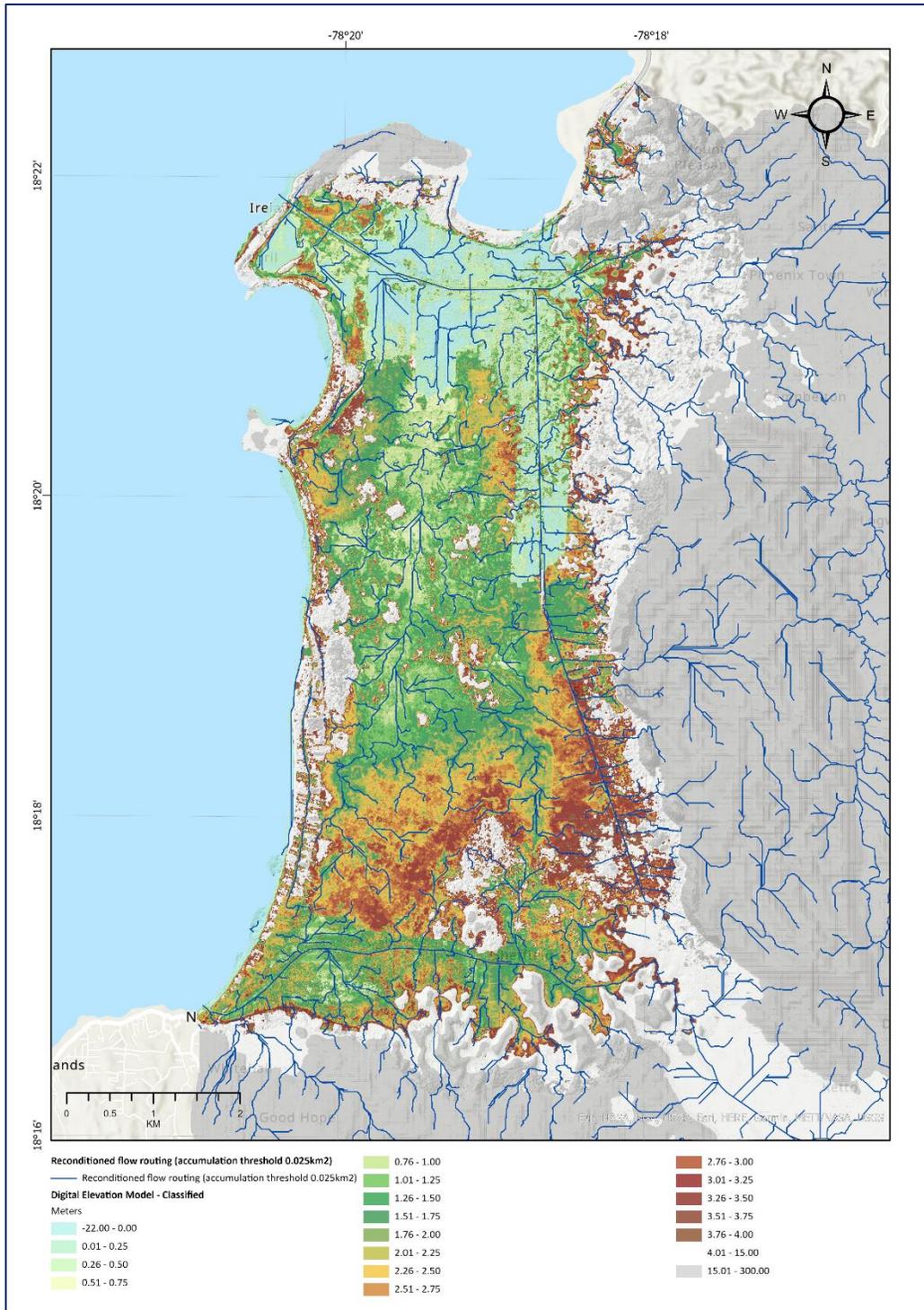
Drawing 8 DEM Slope Map

Areas of higher slope angle (yellow and red) coincide with the more elevated DEM heights above 4mAmSL, confirming the interpretation that these are vegetation artefacts in the DEM and not representative of the Morass wetland surface.

4.8 DEM Geomorphological Terrain Hydrological Modelling Rainfall Runoff Results

The DEM has been imported into ArcGIS and a hydrological flow routing analysis undertaken on it. This allows the alignments and locations of storm water run-off flows to be identified within the digital elevation model.

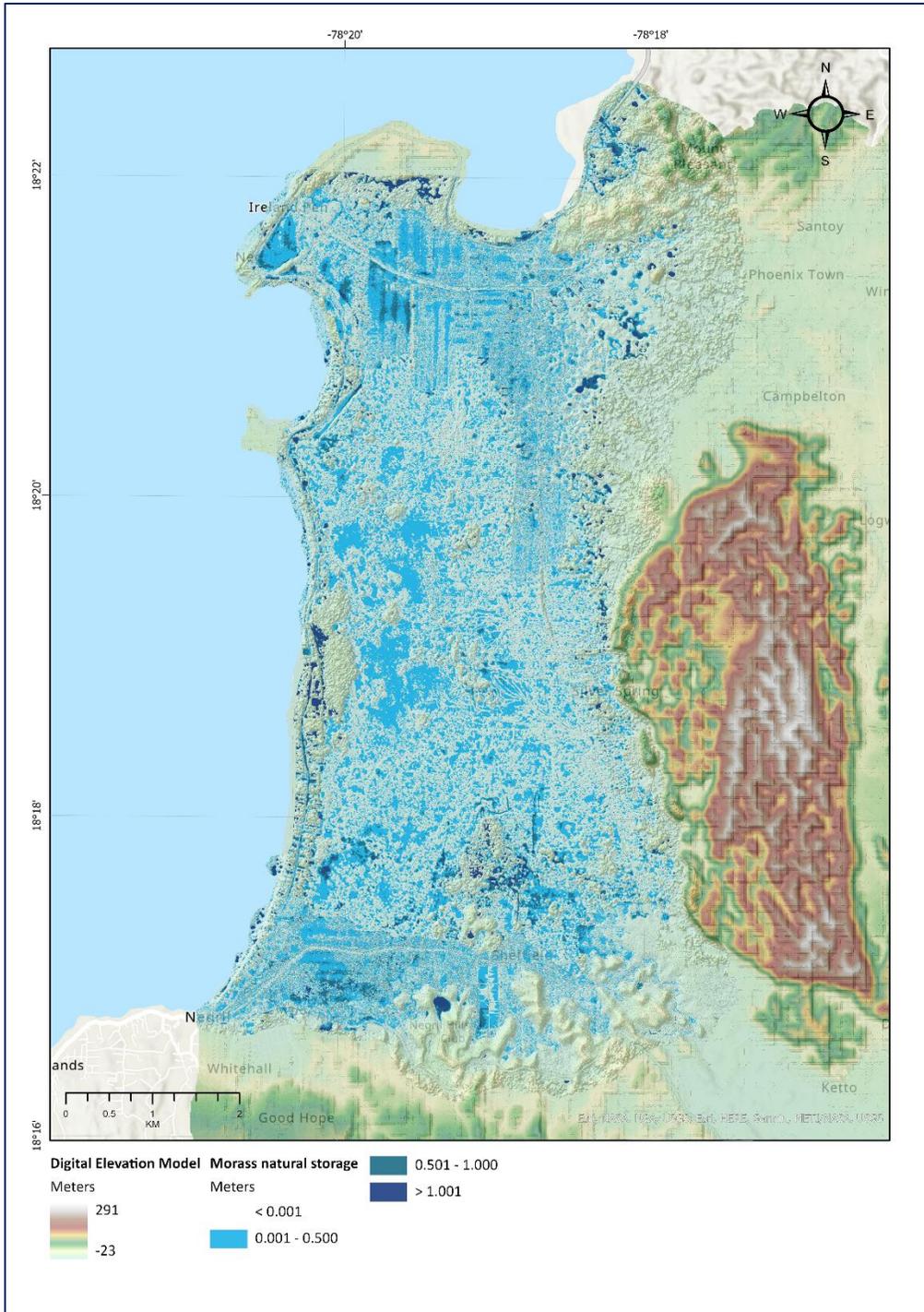
Initial model runs did not result in flow routing consistent with the main rivers and canals, and some further editing of the DEM was undertaken to ensure the rivers and canals dominated the drainage patterns – the problem was primarily the inclusion of the coastal bridges across the rivers in the DEM, which acted as dams in the initial run-off modelling. Once these had been removed from the DEM, the runoff routing analysis reflected the main river and canal routes – this is shown below.



Drawing 9 Hydrological flow routes across the Negril Great Morass

The DEM not only allows the definition and understanding of the rainfall run-off routes across the Morass and into the main water courses and canals, but it also identifies every depression in the DEM, which would be filled during rainfall events.

The existing natural storage within the Morass can therefore be calculated. Drawing No. 10 below shows the location and depth of water of each and every body of naturally ponding water in the Morass following heavy and/or prolonged rainfall.



Drawing 10 Natural rainfall storage areas and depth within the Negril Morass

The maximum natural storage area generated by the hydrological modelling is calculated at 13,500,000m² with a stored volume is 4,030,612m³.

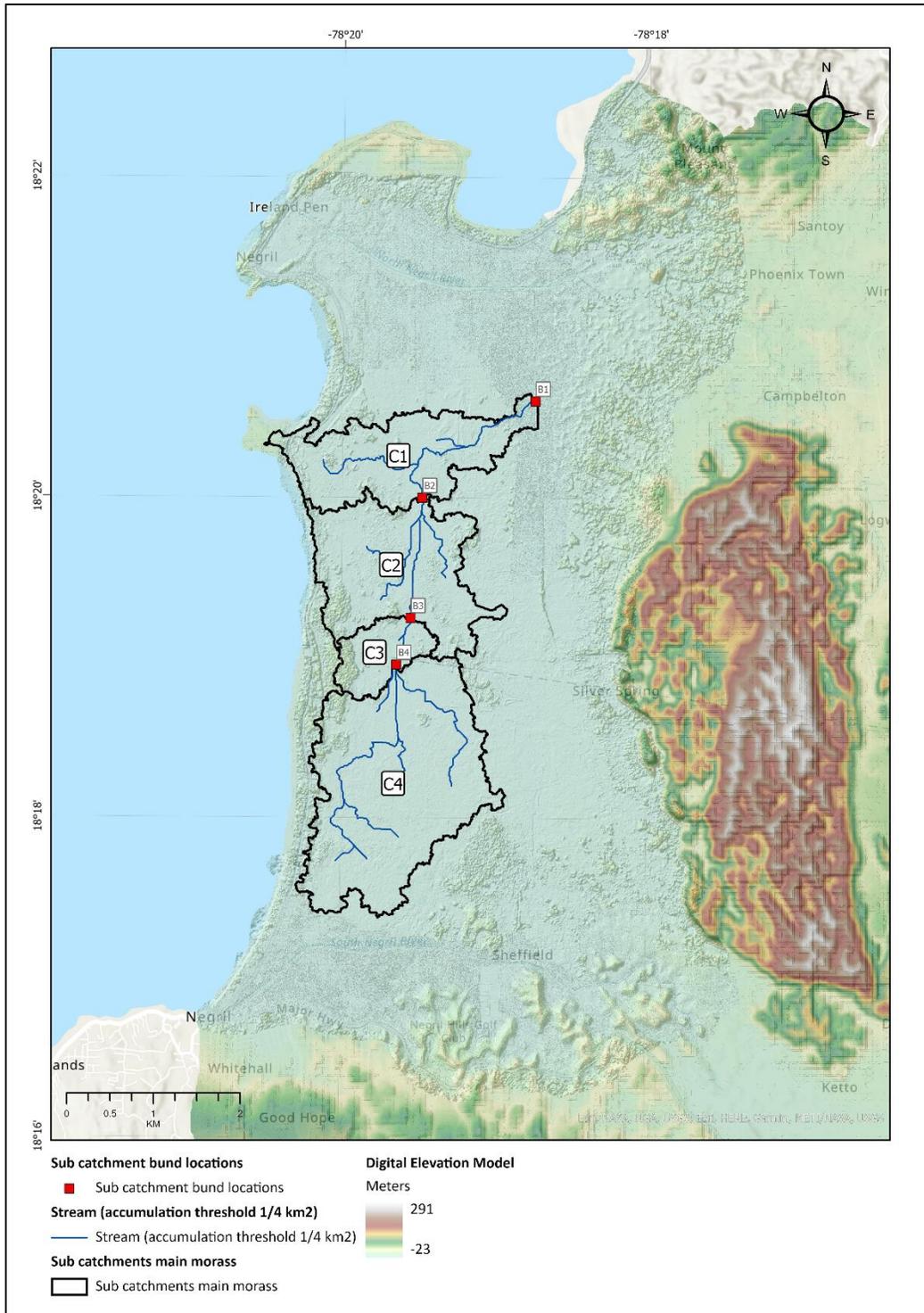
4.9 Water Level Management Plan

Each of the four hydrological restoration targets/areas has been assessed to identify the optimum water levels required to deliver the ideal areas and depths of water retention in the wetland, using the run-off routing analysis above. This is explained further below.

4.9.1 Wild Bush Fire Risk Reduction Measures

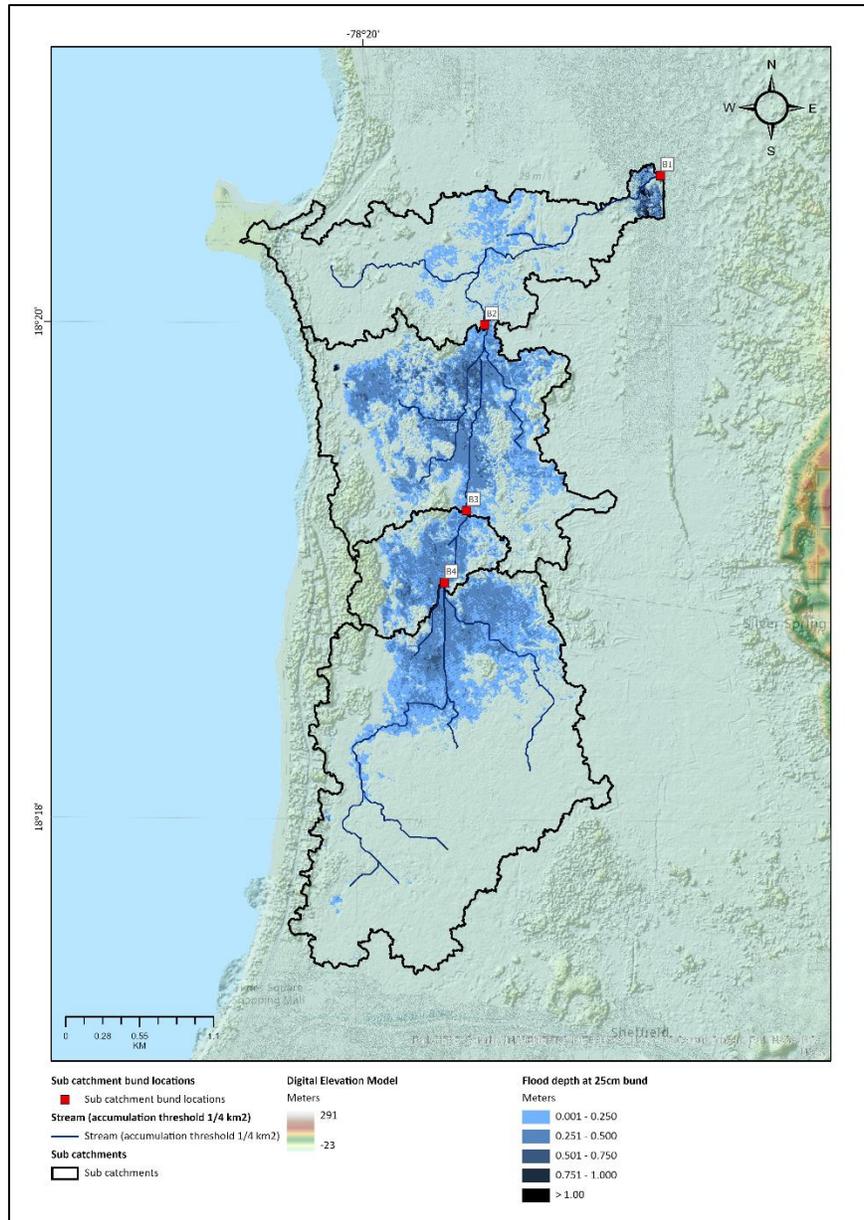
The main area of the recent bushfires is identified as the area west of the East Canal and north of the Royal Palm Reserve. To reduce the bush fire risk, reducing the rainfall run-off using retention structures (or bunds) will result in shallow ponding of rainfall that used to flow into the canals and rivers.

Inundation modelling has been undertaken to assess what would happen if the area was bunded with low-lying earth embankments, which could retain a depth of 0.25m or 0.50m of water behind them. The results for 4 bund locations (mini-earth embankments) are shown below. The bund locations and the catchments which contribute rainfall to these bund locations are shown on Drawing No. 11.



Drawing 11 Wild bush fire area assessed bund locations

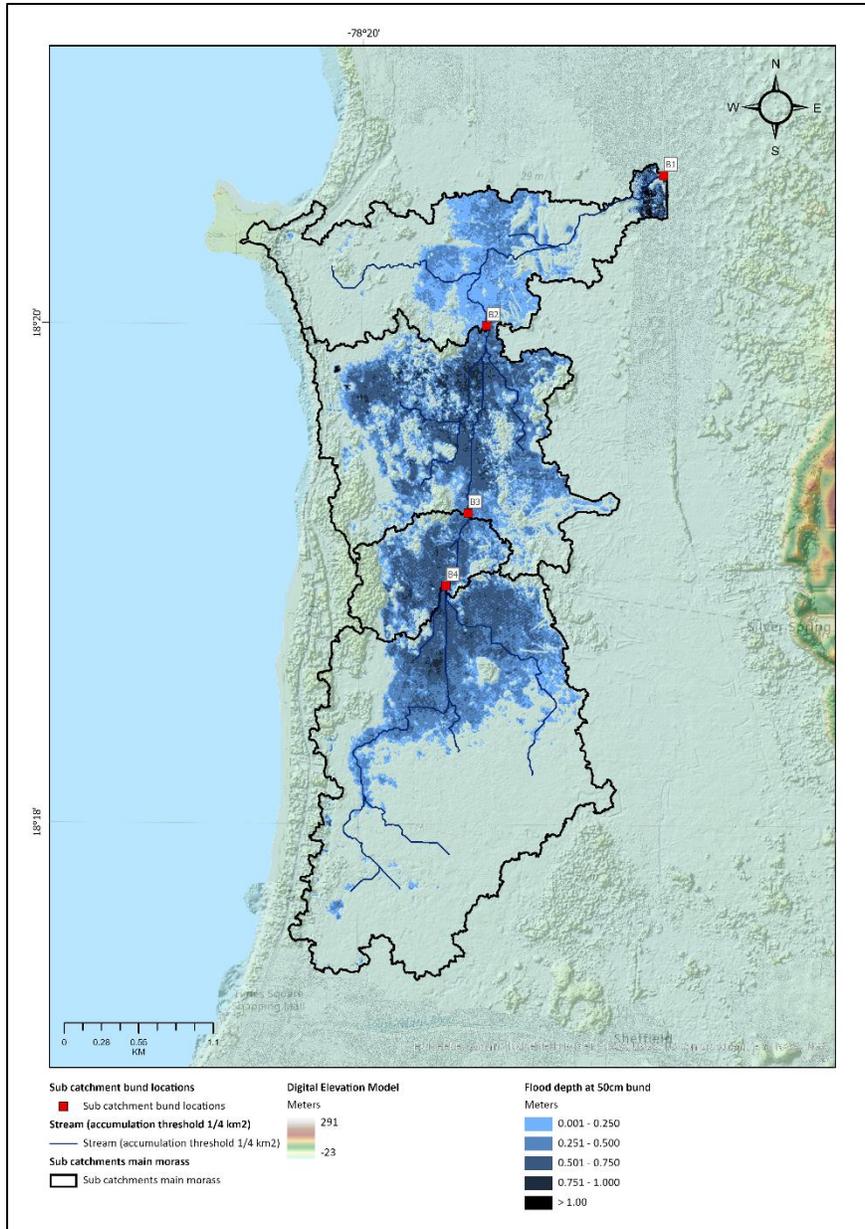
The areas and depths of rainfall ponding inundation are shown for all 4 bund locations for 0.25m high bunds, below.



Drawing 12 Rainfall ponding at four 25cm high embankments

The locations and bund heights have been specifically chosen to prevent rainfall ponding from entering the previously discussed zones of uncertainty. In this way we can demonstrate the ponding will not back-up and impact properties or utilised land along the Negril coastal highway.

The areas and depths of rainfall ponding for the 4 bund locations for 0.50m bund heights are shown in the following drawing. The areas, depths and required bund lengths for each bund location individually are available in Appendix G.



Drawing 13 Rainfall ponding at four 50cm high embankments

Details of achieved flood areas, flood volumes and required bund lengths are shown below. The required depth of rainfall per catchment to fill the volume behind each bund is also presented – enabling an understanding of whether a single rainfall event is required or whether a month of rain is required.

Table 4.2 Wild Bush fire risk reduction measures- water retention details

Catchment	Bund height (cm)	Storage volume per catchment (m3)	Flooded area (m2)	Catchment area (m2)	Catchment area (km2)	Required rain depth to fill catchment storage (m)* (c/e)	Required rain depth to fill catchment storage (mm)**	a). LiDAR derived raw minimum length (m)	b). Manually derived bund length (m)	Flooded area / LiDAR derived raw minimum length (m2/m)	Flooded volume / LiDAR derived raw minimum length (m3/m)
Wildfire C1	25	74,615	604,043	9,896,680	9.90	0.01	8	82	891	7,366	910
	50	414,314	2,152,756	9,896,680	9.90	0.04	42	674	1,810	3,194	615
Wildfire C2	25	430,436	1,995,127	7,703,369	7.70	0.06	56	370	850	5,392	1,163
	50	1,045,330	2,861,582	7,703,369	7.70	0.14	136	776	1,708	3,688	1,347
Wildfire C3	25	255,221	1,164,248	5,116,612	5.12	0.05	50	109	360	10,681	2,341
	50	602,252	1,578,511	5,116,612	5.12	0.12	118	238	639	6,632	2,530
Wildfire C4	25	201,488	887,687	4,426,719	4.43	0.05	46	210	452	4,227	959
	50	464,369	1,193,090	4,426,719	4.43	0.10	105	316	697	3,776	1,470

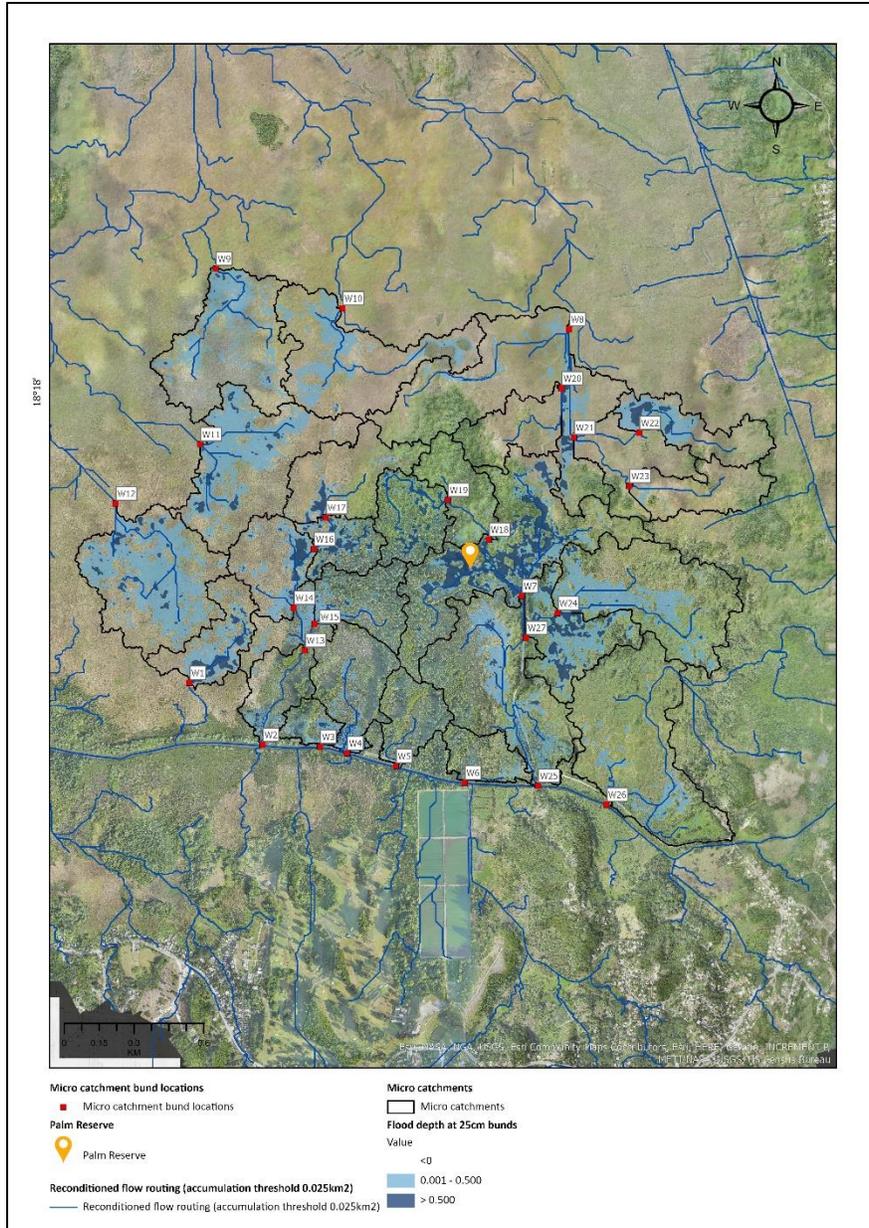
4.9.2 West Indian Whistling Duck Wetland Improvements

The area most favoured by the West Indian Whistling Duck, as identified by NEPA and other project component consultants, is around the Royal Palm Reserve. Whilst the preferred habitat of the Duck depends on season, the general decline in moisture in the Morass is considered to be having an impact on the habitat of the Duck, which includes shallow depths of ponded water for foraging.

Rainfall run-off water retention structures cannot provide habitat change themselves – this will require recommendations and implementation by other technical ecological advisors – but low-lying 25cm to 50cm bunds/embankments can be used to pond rainfall run-off to depths favoured by the Duck for foraging, and which will also increase the moisture content more generally.

If these areas become inundated under greater depths of water, then these bunds will not retain this water, however once any deeper depths of water have receded, the bunds will retain water for longer periods in these locations to a depth consistent with the bund/embankment height.

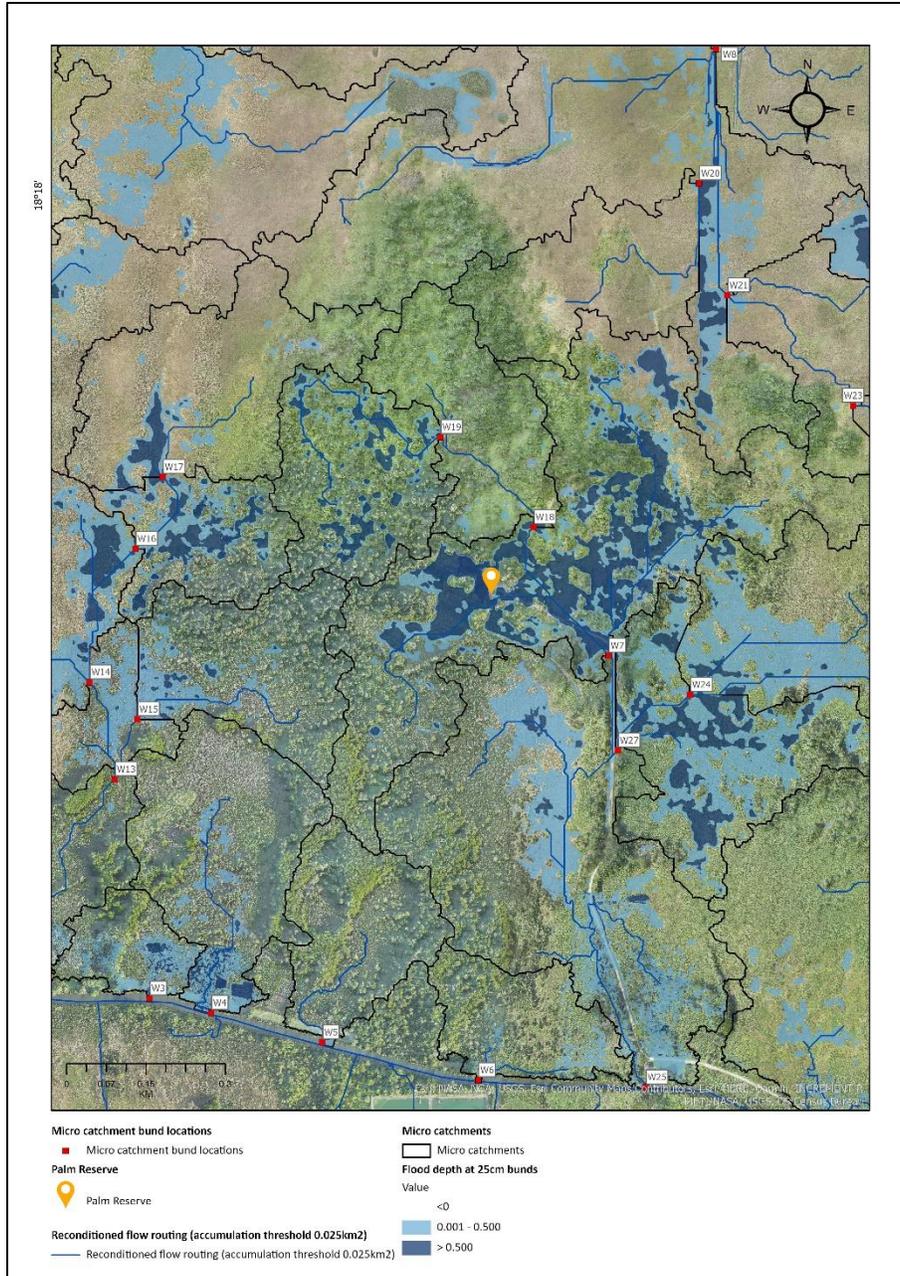
The rainfall ponded areas and depths for the 25cm bunds/embankments are shown below for the 27 micro-catchments located radially around the Royal Palm Reserve.



Drawing 14 Micro-catchment ponded areas for 25cm high embankments

Not all the retention embankments need to be constructed. Individual locations can be prioritised based upon other factors, *e.g.*, including proximity to Duck habitat or sightings, or discarded *e.g.*, possible risk of ponded water inundation into the Royal Palm Reserve properties (*e.g.*, W7). Conversely the embankment at location W27 may reduce flood risk to the Royal Palm Reserve access road.

A close up of the area around the Royal Palm Reserve is shown below.



Drawing 15 Close-up of 25cm embankment rainfall pond extents around the Royal Palm Reserve

Maps of rainfall run-off water retention extent for the 50cm height bunds/embankments are available in Appendix H.

Details of achieved flood areas, flood volumes and required bund lengths are shown below. The required depth of rainfall per catchment to fill the volume behind each bund is also presented – enabling an understanding of whether a single rainfall event is required or whether a month of rain is required. The flood area per unit bund length (m^2/m) ratio and flood volume per unit bund length (m^3/m) provide useful comparisons between options and could be used for ranking priorities in terms of benefit per unit cost.

Table 4.3 Whistling Duck wetland improvement measures- water retention details

Catchment	Bund height (cm)	Storage volume per catchment (m3)	Flooded area (m2)	Catchment area (m2)	Catchment area (km2)	Required rain depth to fill catchment storage (m)* (c/e)	Required rain depth to fill catchment storage (mm)**	a). LiDAR derived raw minimum length (m)	b). Manually derived bund length (m)	Flooded area / LiDAR derived raw minimum length (m2/m)	Flooded volume / LiDAR derived raw minimum length (m3/m)
Whistling duck W1	25	33,769	46,595	103,514	0.10	0.33	326	21	-	2,219	1,608
	50	17,945	79,402	103,514	0.10	0.17	173	669	-	119	27
Whistling duck W2	25	6,108	10,247	84,038	0.08	0.07	73	44	-	233	139
	50	2,960	14,936	84,038	0.08	0.04	35	107	-	140	28
Whistling duck W3	25	6,694	11,152	37,200	0.04	0.18	180	64	-	174	105
	50	3,049	17,668	37,200	0.04	0.08	82	129	-	137	24
Whistling duck W4	25	11,128	17,437	134,690	0.13	0.08	83	111	-	157	100
	50	5,955	24,104	134,690	0.13	0.04	44	191	-	126	31
Whistling duck W5	25	701	741	84,562	0.08	0.01	8	5	-	148	140
	50	73	4,247	84,562	0.08	0.00	1	24	-	177	3
Whistling duck W6	25	3,733	5,940	65,107	0.07	0.06	57	16	-	371	233
	50	513	20,342	65,107	0.07	0.01	8	145	-	140	4
Whistling duck W7	25	115,299	118,556	345,495	0.35	0.33	334	114	-	1,040	1,011
	50	82,310	146,372	345,495	0.35	0.24	238	186	-	787	443
Whistling duck W8	25	28,792	44,752	361,064	0.36	0.08	80	307	-	146	94
	50	11,599	93,737	361,064	0.36	0.03	32	485	-	193	24
Whistling duck W9	25	40,609	67,297	250,565	0.25	0.16	162	81	-	831	501
	50	10,719	174,091	250,565	0.25	0.04	43	658	-	258	16
Whistling duck W10	25	35,411	64,163	255,690	0.26	0.14	138	138	-	465	257
	50	9,344	145,512	255,690	0.26	0.04	37	378	-	385	25
Whistling duck W11	25	63,997	114,157	269,137	0.27	0.24	238	84	-	1,359	762
	50	27,397	180,073	269,137	0.27	0.10	102	609	-	296	45
Whistling duck W12	25	82,697	148,512	275,609	0.28	0.30	300	155	-	958	534
	50	33,252	241,383	275,609	0.28	0.12	121	889	-	272	37
Whistling duck W13	25	8,197	14,986	62,363	0.06	0.13	131	263	-	57	31
	50	2,484	31,123	62,363	0.06	0.04	40	590	-	53	4
Whistling duck W14	25	24,955	37,192	113,748	0.11	0.22	219	106	-	351	235
	50	11,618	72,450	113,748	0.11	0.10	102	480	-	151	24
Whistling duck W15	25	9,545	15,534	105,700	0.11	0.09	90	183	-	85	52
	50	4,482	25,524	105,700	0.11	0.04	42	248	-	103	18
Whistling duck W16	25	21,794	29,126	70,429	0.07	0.31	309	147	-	198	148
	50	13,456	37,316	70,429	0.07	0.19	191	333	-	112	40
Whistling duck W17	25	10,815	14,400	148,874	0.15	0.07	73	98	-	147	110
	50	5,615	29,226	148,874	0.15	0.04	38	153	-	191	37
Whistling duck W18	25	1,345	2,179	96,835	0.10	0.01	14	60	-	36	22
	50	489	4,997	96,835	0.10	0.01	5	73	-	68	7
Whistling duck W19	25	19,887	21,832	103,171	0.10	0.19	193	24	-	910	829
	50	13,788	26,909	103,171	0.10	0.13	134	33	-	815	418
Whistling duck W20	25	1,011	1,675	99,139	0.10	0.01	10	209	-	8	5
	50	261	4,768	99,139	0.10	0.00	3	227	-	21	1
Whistling duck W21	25	787	1,348	116,467	0.12	0.01	7	276	-	5	3
	50	183	3,945	116,467	0.12	0.00	2	483	-	8	0
Whistling duck W22	25	25,048	39,618	105,942	0.11	0.24	236	166	-	239	151
	50	13,326	54,013	105,942	0.11	0.13	126	468	-	115	28
Whistling duck W23	25	2,234	3,400	103,357	0.10	0.02	22	28	-	121	80
	50	379	13,154	103,357	0.10	0.00	4	105	-	125	4
Whistling duck W24	25	43,127	78,715	277,434	0.28	0.16	155	325	-	242	133
	50	18,832	114,958	277,434	0.28	0.07	68	418	-	275	45
Whistling duck W25	25	37,962	69,854	296,848	0.30	0.13	128	227	-	308	167
	50	15,531	107,145	296,848	0.30	0.05	52	467	-	229	33
Whistling duck W26	25	21,988	37,137	346,861	0.35	0.06	63	16	-	2,321	1,374
	50	6,780	86,605	346,861	0.35	0.02	20	32	-	2,706	212
Whistling duck W27	25	46,842	68,990	139,114	0.14	0.34	337	456	-	151	103
	50	27,079	89,335	139,114	0.14	0.19	195	619	-	144	44

It is proposed all 27 bund locations be included in the Water Management Plan, with the IWEco project targeting priority locations for implementation.

4.9.3 East Canal Water Level Control Measures

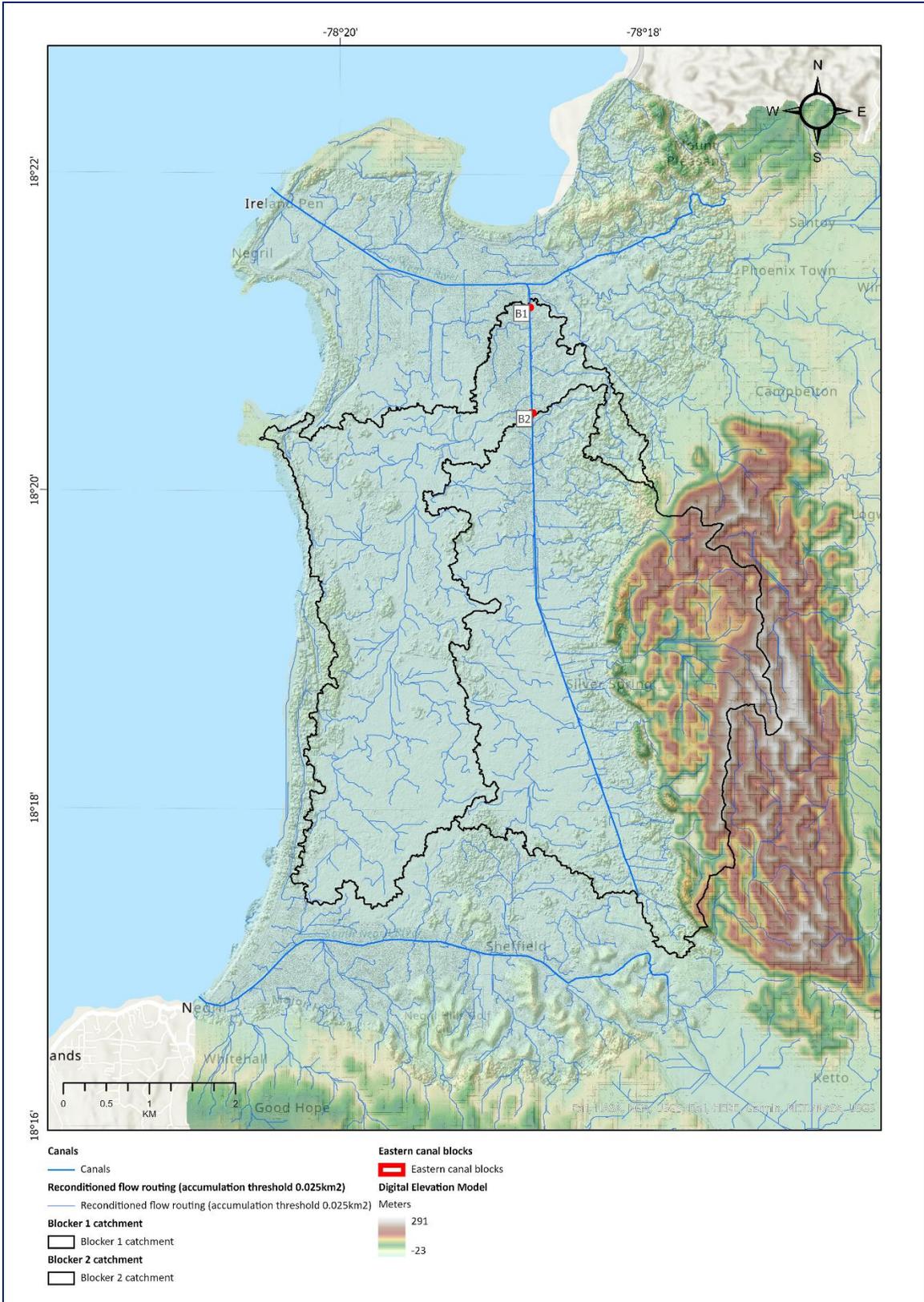
The East Canal has been identified by all stakeholders, including the original IWEco project designers as being a major cause of wetland degradation. Accordingly, reducing or removing this impact is seen as key to wetland restoration and/or improvement.

The hydrological run-off modelling was used to explore two intervention types on the East Canal. The first was to understand the impact of introducing some sort of 'blocker' to the canal which would cause water

levels in the canal behind a blocker to be raised. This would help to understand the effect this would have on water levels within the wetland.

A second intervention type was then investigated which combined the in-canal channel blocker with bunds/embankments either side of the canal, enabling canal water levels to be raised 25cm and 50cm above the canals' bank full level.

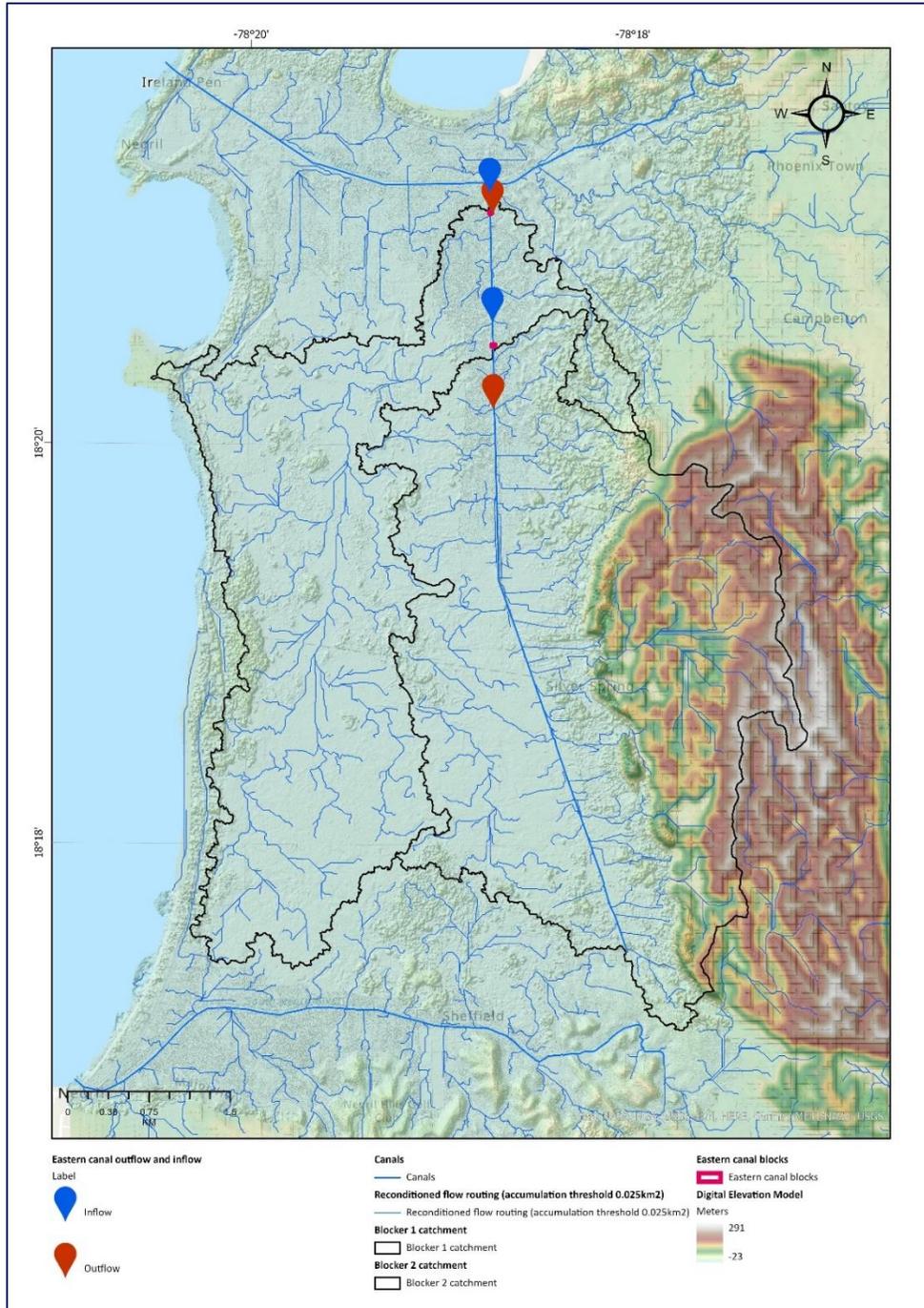
The locations of the two (2) blockers evaluated in the modelling are shown on Drawing No. 16 below, along with their contributing watersheds. The locations were selected as far north as possible to maximise the length of canal that would benefit from water level rising, and local to areas of slightly more elevated Morass, enabling any necessary bund lengths to be minimised.



Drawing 16 Locations of assessed 'blockers' on the East Canal

The hydrological modelling was undertaken with the blockers set at the elevation of the surrounding wetland. Whilst the water levels rose to the height of the blocker at each location, the water levels rose no higher than when the North Negril River rises to this elevation, and no additional water storage was created.

Indeed, what the resulting run-off route flowpaths shows (see Drawing No. 17 below) is that the water leaves the canal close to the blocker and returns to it immediately to the north and downstream of the blocker, hence there is no wider water inundation into the Morass.



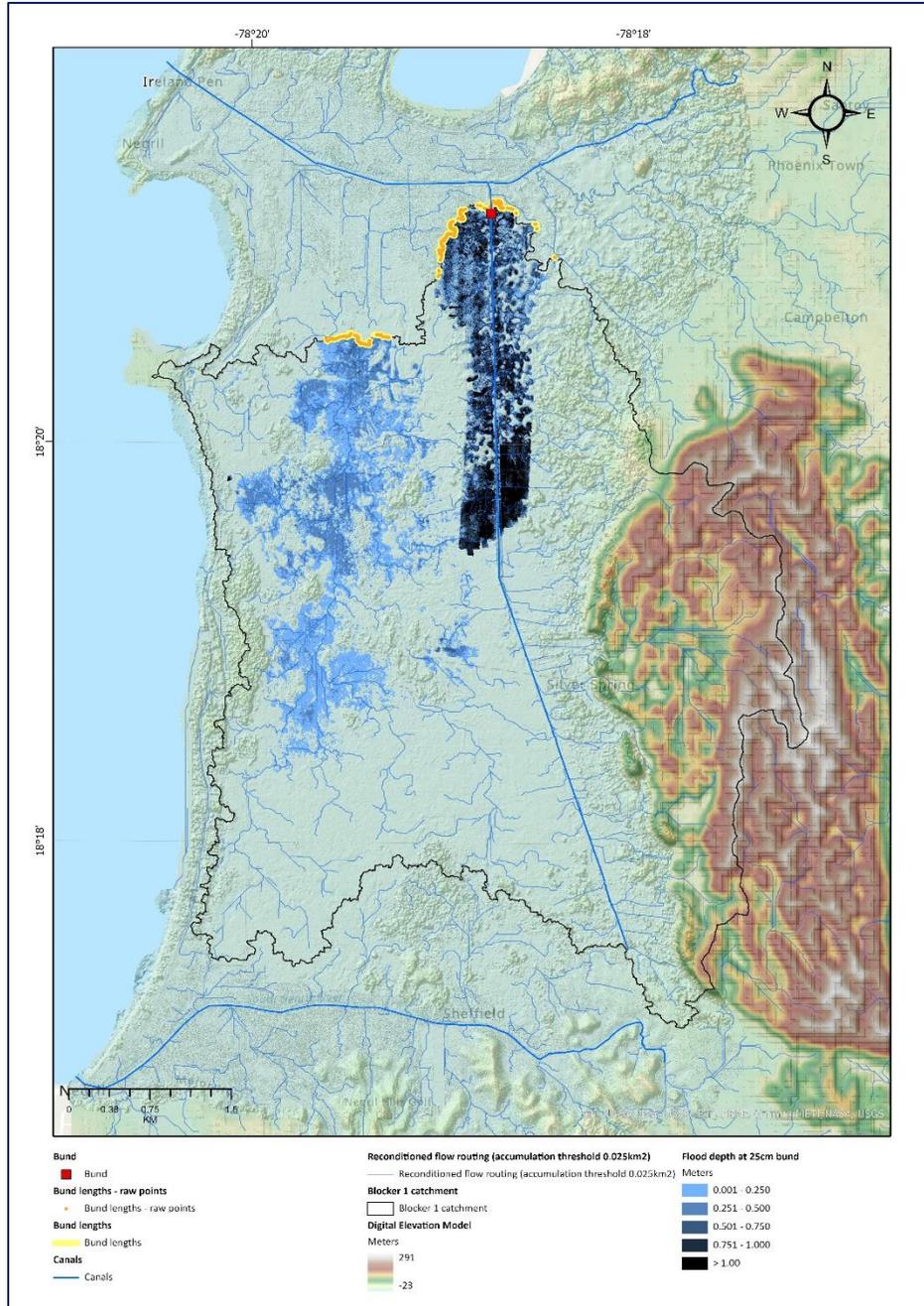
Drawing 17 Outflows and Inflows from the East Canal around the 'blockers'

What the run-off routing modelling work does not demonstrate are two very important benefits of installing a flow blocker (*e.g.*, an earth dam with overflow weir) on the East Canal, which are:

- *Water levels in the canal will not fall and rise with the tidal North Negril River, but be retained at the weir overflow level – these elevated water levels will reduce peat and wetland habitat dewatering in the river low flow and low tide periods, as well as re-wet up the peat and wetland to near ground level; and*
- *Prevent saline water which migrates up the North Negril River into the East Canal from passing the blocker and thus prevent saline water from entering further into the freshwater wetland.*

These are two very valuable and important restoration objectives in their own right. The very low-lying areas around the North Negril River and the East Canal which are below mean sea level (i.e., <0mAmSL) are at least partially caused by the dewatering of the peat beneath the wetland by the river and canal, which causes the peat to compress, compact and result in ground subsidence, thereby making these areas more susceptible to desiccation and inundation by saline water.

However, to ensure the East Canal blockers actually contribute to wetting up a wider area of the Morass, this will require the overflow weirs on the blockers to be above surrounding wetland level, and this will require bund/embankments each side of the East Canal to prevent water leaving the canal from simply flowing overland to the north.



Drawing 18 Water retention areas and depths behind northern 25cm high weir on East Canal

The hydrological modelling has been used to assess the aerial extent and depth of water retention at the 2 blocker locations, for bunds with overflow weirs at 25cm and 50cm elevations above the surrounding wetland.

An example of the resulting inundation area and required bund length is shown on Drawing No. 18 above. The other modelled options are shown in Appendix I.

It is clear that to maximise the wetted area and depth that bund embankments are required not only adjacent to the East Canal but also further into the wetland to the west. Note, that the restoration measure design principle of not entering the 'zones of uncertainty' to the along the western coastal road are still being adhered to, to ensure there is no water inundation on the urban area.

The details of achieved water inundation areas, volumes, and required bund/embankment lengths, as well as area and volume delivered per unit bund length are detailed in Table 4.4 below. A 25cm elevated weir at the northern most location is the most effective in terms of water area, the 50cm bund the most effective at the northern most location in terms of water volume. Examples of 'blocker' type structures are given in the next section.

Table 4.4 East Canal Truncation Measures – water retention details

Catchment	Bund height (cm)	Storage volume per catchment (m3)	Flooded area (m2)	Catchment area (m2)	Catchment area (km2)	Required rain depth to fill catchment storage (m)* (c/e)	Required rain depth to fill catchment storage (mm)**	a). LiDAR derived raw minimum length (m)	b). Manually derived bund length (m)	Flooded area / LiDAR derived raw minimum length (m2/m)	Flooded volume / LiDAR derived raw minimum length (m3/m)
East canal block B1	25	1,713,590	4,290,465	27,173,356	27.17	0.06	63	921	2,766	4,658	1,861
	50	3,019,395	6,097,840	27,173,356	27.17	0.11	111	1427	3,657	4,273	2,116
East canal block B2	25	919,886	1,408,632	15,626,899	15.63	0.06	59	509	1,214	2,767	1,807
	50	1,339,540	1,975,778	15,626,899	15.63	0.09	86	1125	2,257	1,756	1,191

4.9.4 Eastern Spring Flow Capture Measures

The final group of hydrological restoration/improvement options is the re-capturing of the groundwater springs on the eastern side of the Morass and routing them further into the centre of the Morass to better reflect the original water transfer function of the now lost Middle River.

Historically these springs provided the main water source to the Middle River (see Drawing Nos. 2 and 3), which was subsequently intercepted by the excavation of the East Canal in the 1950's (see Drawing No. 4).

The groundwater springs not only provided additional water to the water balance of the central part of the Morass, but this water will have been largely sediment free, due to its groundwater origin, as well as had a more regular flow and temperature, neutral acidity and elevated alkalinity compared to peatland run-off all of which will have influenced the habitat and species of the wetland in this area.

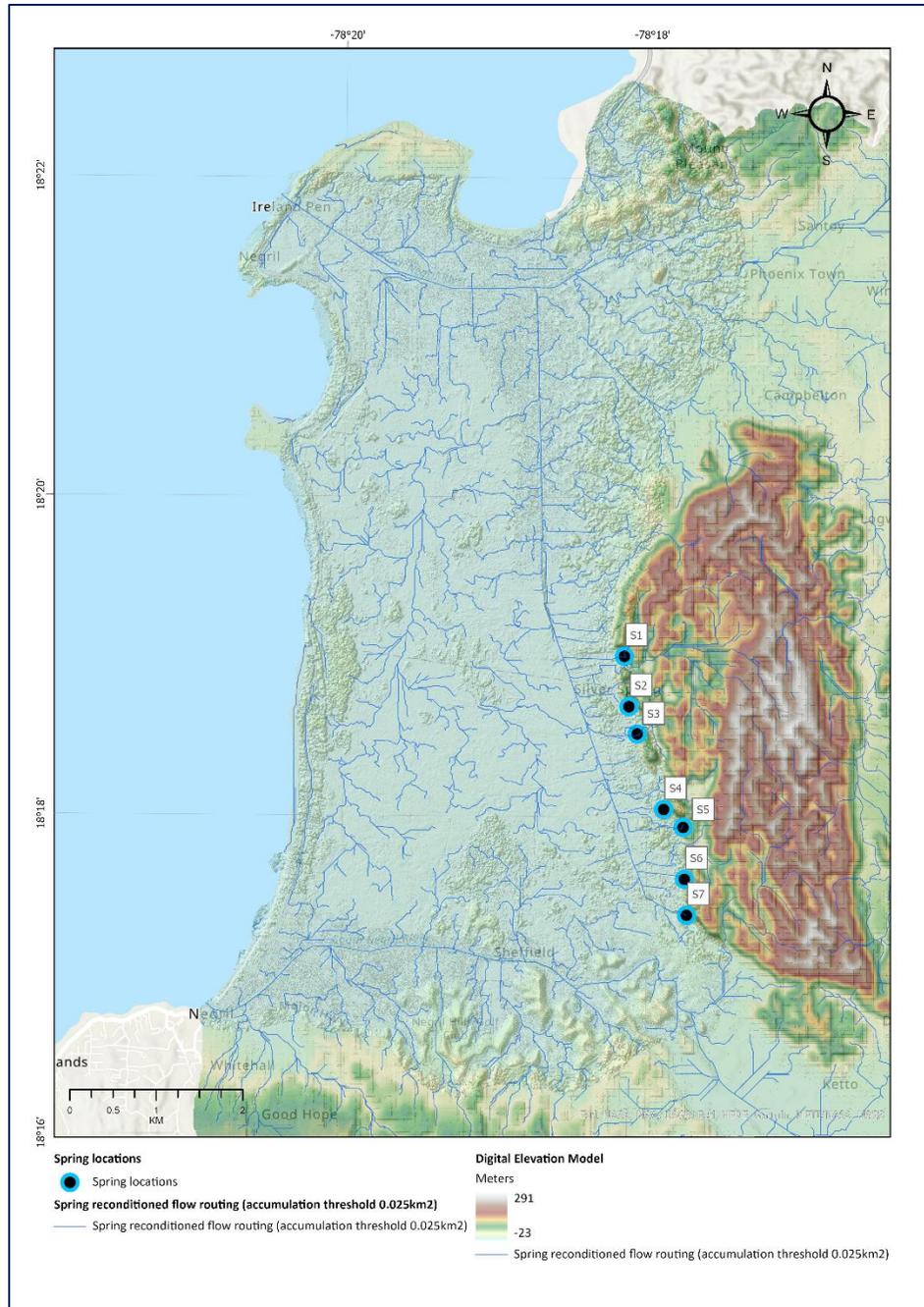
The hydrological modelling shows (see Drawing No.19) that the outflows from all 7 springs are currently captured by the East Canal and therefore no longer contribute to the water content of the central area of the Morass – the area that is now especially vulnerable to wild bush fires.

The spring locations are mostly situated along the eastern boundary road, to the west of which encroachment has occurred into the Morass for a distance of up to 300-400m, with land mostly being used for agriculture. This agricultural land use generally extend up to approximately 100m east of the East Canal.

It is recognised the communities in this area are likely to depend on the spring flows to support their agricultural activities, as well as for domestic purposes like bathing and drinking. Whilst it would be beneficial to the Morass to capture these spring flows as close to their emergence east of the road, doing so would impact these communities.

Accordingly, it is proposed to capture the spring flows once the flows have left the agricultural and residential areas. However, if the encroachment is illegal then capturing the spring flows in 'spring boxes' where they emerge may be preferred by the national and local stakeholders.

The DEM has been used to identify viable transfer routes from the springs, across the East Canal and into the Morass west of the East Canal. These transfer routes (see Drawing No. 20) can consist of a combination of excavated shallow ditches or pipelines. In some locations ground elevations may need to be raised a little to ensure ditch flow to the west – however an assessment of ground levels along each transfer route shows that no excavation or placement is required of more than 1m and in most of the alignment the ditch construction requires <0.5m changes to the current ground surface.



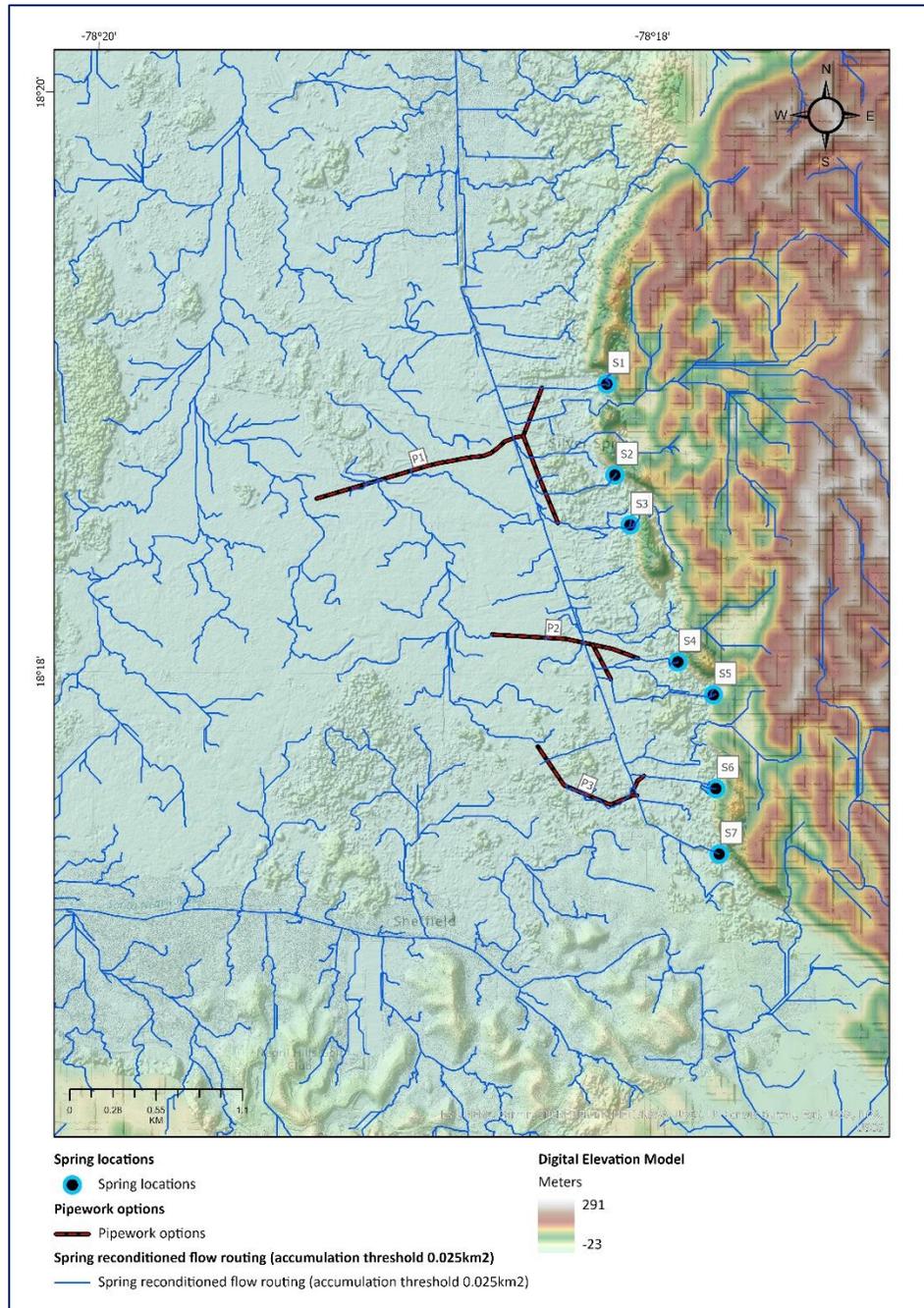
Drawing 19 Eastern spring locations with flow routes into Eastern Canal

Three spring water transfer routes are proposed, which collectively capture 6 of 7 spring emergences. The elevation of spring S2 is too low which will prevent it from being able to be routed across the East Canal, whereas the other springs have sufficient elevation to support flows under gravity. It is not proposed for any of the spring transfers to be pumped. The routes vary in length from 750 to 1,500m.

Each of the water transfer routes will require a crossing of the East Canal. The design of such a crossing has not been specified in this report but could consist of a pipeline suspended across the canal, or a

backfilled plug of material placed across the canal at these locations upon which a ditch can be excavated, or a pipeline buried.

The southern two spring transfers are shown discharging into a part of the central area of the Morass that is not otherwise benefiting from the other proposed intervention strategies – and such the spring flow capture is complimentary to, and augments the other restoration measures.



Drawing 20 Spring transfer routes – ditches and pipework

The northern most spring transfer is shown to discharge into the central area of the Morass which does benefit from the wild bush fire risk reduction measures. This decision has been made because the water would otherwise flow immediately back to the East Canal.

It is self-evident from Drawing No. 20 that a surface water diversion coincident with the western most 300m of the northern extension could be made to route the surface water catchment upstream of this location across to the more western area. In doing so, it would transfer the southern two spring transfers into the more western area vulnerable to wild bush fire.

A close-up aerial photograph of the spring locations, transfer routes and the agriculturally productive land is shown on Drawing No. 21 below, showing the lack of encroachment on the productive land itself by the proposed measures.



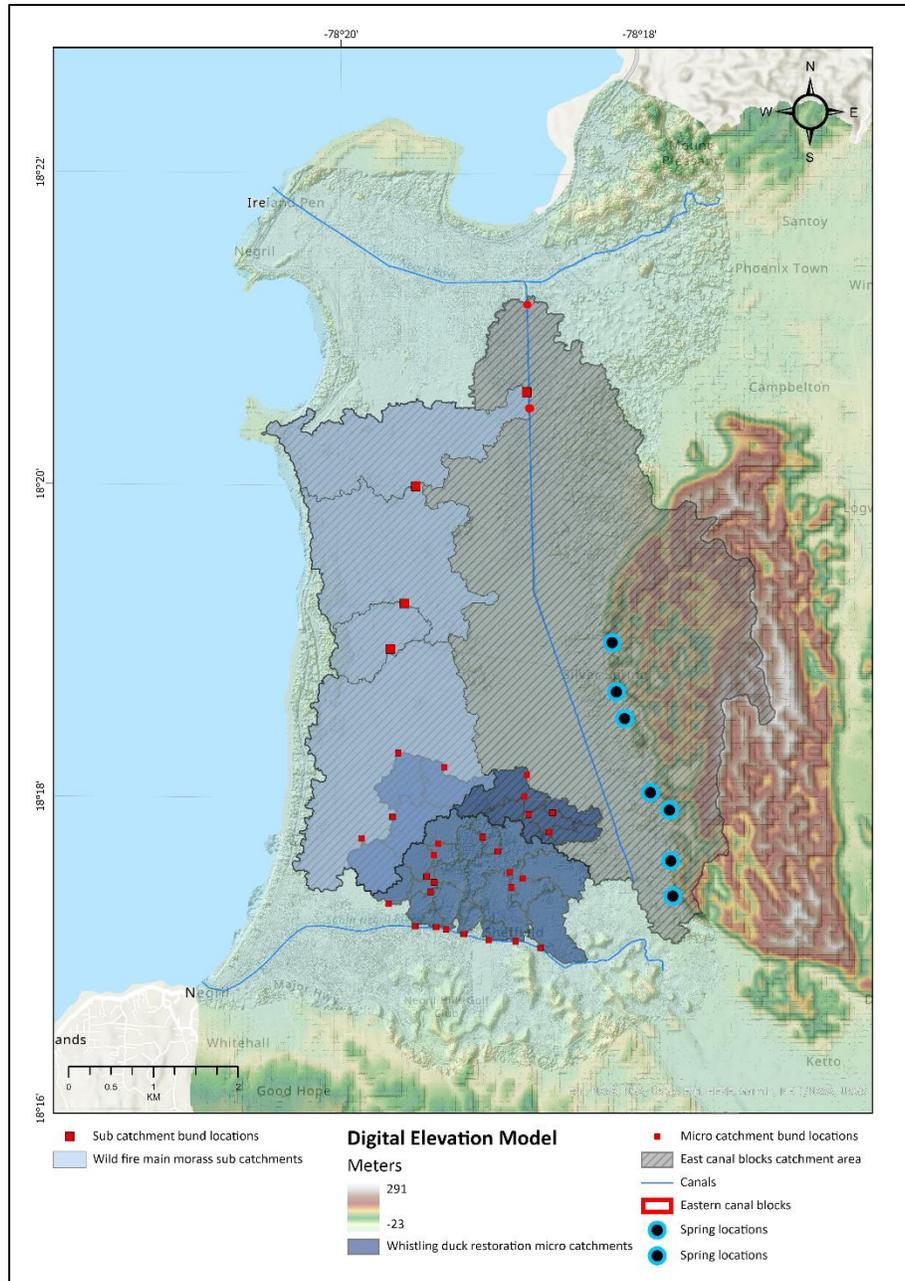
5 Recommended Hydrological Restoration Strategies

The IWeco project includes a component on hydrological restoration of the Negril Great Morass, using hydrological modelling to develop a water level management plan for the wetland and defining hydrological zoning plans to support priority restoration objectives.

Stakeholder consultation, assessment of historical hydromorphic changes to the drainage of the Morass, meteorological and hydrological analysis, coupled with detailed geomorphological terrain rainfall run-off modelling, has enabled the identification of 4 hydrological restoration strategies to support the delivery of the wetland degradation reduction and improvement goals.

5.1 Areas of Intervention

The four hydrological restoration intervention strategies: 4 No. bunds/embankments in the western Morass to reduce wild bush fire risk; 27 No. micro-catchment retention structures to improve Whistling Duck habitat; the blocking of the East Canal; and the transfer of spring flows into the centre of the Morass; cover in total approximately 80% of the area of the Morass (see Drawing No. 22), whilst focusing in on key restoration objectives.



Drawing 22 Coverage of the hydrological restoration strategies

The four hydrological restoration strategies cover different parts of the Morass and whilst the catchments of the interventions do overlap, the areas receiving benefit in terms of increased water inundation largely do not. The approaches are therefore complimentary, avoid duplication, and collectively they provide not only targeted interventions to achieve the specific hydrological restoration goals but also provide a wide area of benefit.

5.1.1 Potential Risks and Corresponding Mitigation Measures

To increase the water content of the Morass it is necessary to either increase the amount of water entering the Morass and/or reduce the amount of water leaving it. Due to the substantial historical disturbance of the Morass by large scale drainage infrastructure, the inevitable focus has been to reduce the impact of the drainage infrastructure, specifically to focus on reducing the drainage and reduce the existing water flows leaving the Morass.

Increasing the water entering the Morass is potentially a much greater challenge and introducing additional water to the Morass potentially has significant risks and liabilities associated with this approach, including unintended flooding of property and livelihoods, introducing poorer water quality, increasing erosion, encouraging invasive species, and so on. It is for these reasons that flood flows from the main rivers were dismissed by NEPA, as was the suggestion of routing partially treated sewage effluent into the Morass.

Three of the four strategies therefore focus on reducing the quantity and speed of water leaving the Morass and are designed to retain rainfall that already falls within the Morass itself.

The deliberate retention and ponding of rainfall run-off in exceptionally flat and low-lying terrain does require a robust understanding of ground elevations. The hydrological analysis has used a very high-resolution bespoke drone-mounted topographic survey to provide the best possible mapping of the wetland terrain. As discussed earlier however, despite the best attempts of the aerial surveyor, the digital elevation model did capture dense vegetation within it. Some of this was then removed using algorithms but remaining artefacts in the DEM remain. These areas were delineated, and the hydrological restoration schemes designed such that their outcomes – i.e., water inundation areas – were not allowed to overlap into these 'zones of uncertainty' in the DEM.

The above approach, combined with the deliberately low height of the proposed retention structures has ensured there is no risk of water retention areas expanding into locations where property exists along the western coastal road as well as other surrounding residential and commercial areas.

It remains important however that the elevation of the retention structures is installed correctly and accurately, requiring trained land surveyors to level the top of the structures. It will be impractical to do this for the entire length of the bunds and embankments, so within the bunds and embankments, overflow weir plates should be used, with their overflow elevation installed to the correct elevation.

There remains a residual risk that the DEM is not accurate to the necessary level of accuracy. To allow for this residual risk, the overflow weirs should use wooden block boards, which can be removed one-by-one if there is a risk of retained waters leaving the uninhabited areas.

For the largest structures – the blockers in the East Canal – the use of wooden block boards is considered essential, as the areas of retained water, once the blockers are integrated into wing-walls, becomes considerable, hence any inaccuracies in the DEM could be more significant. Due to the concerns over concrete infrastructure subsidence into the wetland and underlying peat (this is reported to occur at the wastewater treatment plant) care is being taken to limit the use of heavy material and structures.

Any hydrological management structures require of course a degree of maintenance. The approach taken here is to use the simplest proven technologies, which require little if negligible maintenance and only warrant occasional inspection. All the systems are passive, drain under gravity and require no power supplies.

Such structures can however be compromised by unwanted interference, changing the weir boards for example, or causing damage. It is recommended the East Canal blockers use lockable wooden weir boards which can only be adjusted by those stakeholders who have access to the weir keys.

The only additional inflow to the Morass is from the springs to the east. These springs used to flow into the Morass and as such this intervention is seen more as a reinstatement than a new transfer of water. That said, the spring flow captured is only that unused by the farmers in that area, and the flows from the southern two transfers to eventually return to the East Canal. The northern spring transfer will inundate wetland areas to the west but again this will then flow back to the East Canal via the bush fire retention areas.

5.2 Recommended Intervention Approaches

The following intervention structures are described briefly below, with examples of their inclusion in wetland and peatland restoration projects.

5.2.1 Bunds and embankments

Bunds or embankments are elongate mounds or ridges of material that are constructed to retain water behind them. Typically constructed with side slopes of 1 in 3, and a ridge with of 1m, these bunds are typically sized to retain a depth of 25-50cm behind them. Examples are shown below.

It is unwise to allow water to overflow a bund as it might erode the bund away, so controlled overspill locations need to be designed, which include a weir plate (wood or metal) and erosion protection materials each side e.g., stone, plastic, geotextile et al.

These structures need not be properly engineered as the pressure of water against them is minimal, and they can be constructed manually or with mechanical equipment, enabling them to be constructed in a wide variety of terrains, habitats, and ground conditions.



Figure 22 100mm high grid bunding constructed using an excavator in peatland

If made of local materials, the structures are rapidly colonized by local flora and fauna and soon become unnoticeable. Indeed, it is good practice to remove the vegetation before bund construction, and then place the vegetation back on top of the bund.

5.2.2 Blockers and overflow weirs

The East Canal blockers are likely to be the most significant structures to be implemented. The East Canal geometry is up to 15m wide, approximately 2m deep, with bank sides at 1 in 3, and a floor width of perhaps 2-3m.

Most of the blocking structure is likely to be an earthen embankment, preferably consisting of low permeability clay, but more porous materials can be used. On the top of the embankment, a water level control weir needs to be installed. Again, we recommend a low technology solution, using lightweight materials, which can either be constructed locally from wood, fabricated from metals sheeting, or use bespoke imported weir boxes.

The important features are that the weir level can be altered as necessary by designated officers, and that the weir box plates cannot be removed or altered by unauthorized individuals.

Examples of these weir structures are provided below. Note that none allow for the water passing over the weir to then flow over the retaining structure – nearly all route the water into a pipe which is located within the embankment structure.



Figure 23 Weir using plastic piling sheets and lockable wooden planks to control water level



Figure 24 Wooden weir – weir is raised by adding more wooden planks



Figure 25 Prefabricated steel weir in earth embankment with changeable wooden weir boards

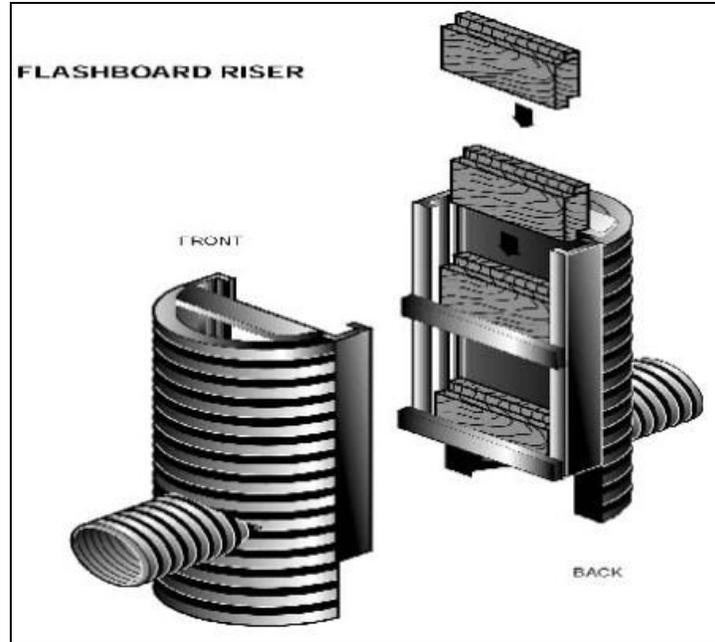


Figure 26 Prefabricated polypropylene twin wall pipe using wooden weir boards within a lockable chamber



Figure 27 Prefabricated corrugated steel headwall integrated into earthen embankment with wooden adjustable weir boards

5.2.3 Ditches and pipework

The use of manually or machine excavated ditches. These should have a flat base of approximately 0.5m width and bank slopes of 1 in 3 to ensure stability and prevent collapse.

Pipework should ideally not be metal. Where plastic pipe is used ideally this should be buried under a thin layer of cover material to reduce both physical damage and the effect of UV sunlight which makes plastic pipe brittle.

Where the ditches need to cross the East Canal, plastic pipework is recommended. The canal crossing can be constructed in many ways, including pipework suspended on wooden trussells; pipework held by slings below cables; or on an earthen bund plugging the canal itself.

5.2.4 Spring box capture and spring flow transfers

The spring waters can be intercepted at their respective headwaters either by installing a spring box (Figure 28) to capture the groundwater and route it into a culvert pipe outflow to transfer the water from the spring locations directly across the canal and to the wetland, or by intercepting the ditch flows fed by the springs at a location further downstream.

The advantage of capturing the spring flows where they emerge from the ground is that the elevation of the springs then provides enough pressure to drive the waters through the pipelines across the East Canal and into the wetlands. Additionally, the spring water is largely free of debris and other material that could block the pipelines. However, the disadvantage is that the local farmers will no longer have access to this water, unless a second supply pipeline or ditch is maintained as well.

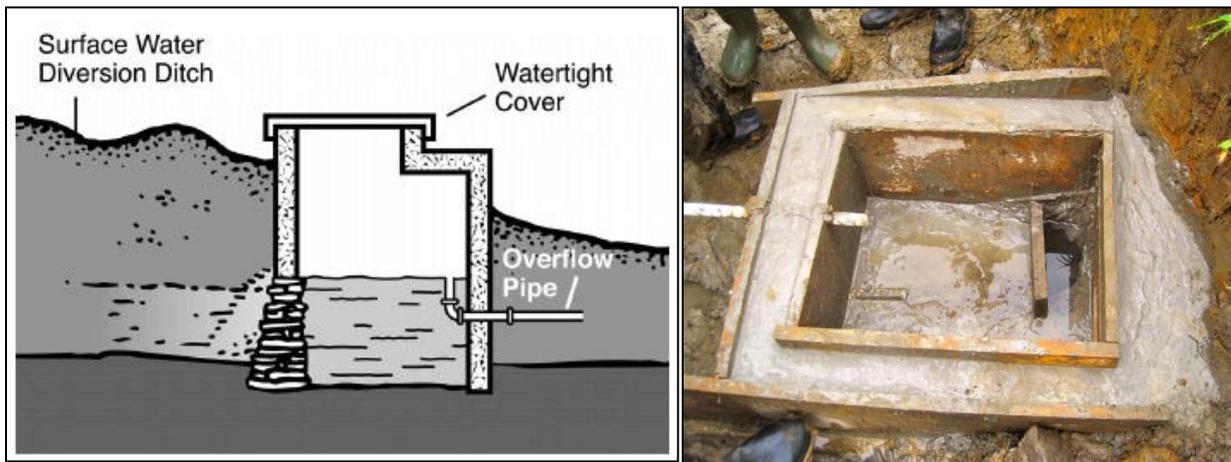


Figure 28 Simple spring box design and construction image

The alternative method of retaining partial access to spring water for the farmers on the east side of the canal, requires the spring water to be intercepted further downstream in the ditch network. The flow could be intercepted by a culvert pipe with a screen to reduce potential blockages (see Figure 29) and a headwall (see Figure 30 and Figure 31) and continue west towards the wetland through a rigid pipe supported by stanchions made of wood anchored into the more resistant strata in the canal bed (see Figure 32). The pipe across the canal would need to have sufficient support with enough stanchions and straps to ensure the stability of it.

To ensure the flow of water, there will need to be enough pressure head difference between the location where the water is captured and its discharge. This pressure head will reduce the flow closer to the East canal the pipeline intake is located.



Figure 29 Culvert pipe to capture spring flow further downstream with protection screen



Figure 30 Low technology culvert headwall consisting of sandbags



Figure 31 Prefabricated concrete culvert headwall



Figure 32 Low technology system to allow spring flow on slung pipe to cross over the canal

5.2.5 Associated Costs for Recommended Strategies

Unit costs have been developed per 1m length of bund construction, ditch excavation, pipeline length, as well as for the East Canal blockers. The unit costs provided are for properly engineered and supervised structures, including vegetation and soil removal, trucked-in materials and use of geotextiles to prevent settlement. It is however possible to construct cheaper bunds.

Table 5.1 Restoration Measures Unit Cost

				Jam \$	Jam \$	US\$	0.0064		
		Bund 950 mm above GL and 450 mm below GL					US\$		
Item	Description	Quantity/m	Unit	Rate	Cost		Unit/m		
1	Excavation	4.50	m3	2,250.00	10,125.00		64.80		
2	Construct Bund with Compacted Marl	8.25	m3	10,000.00	82,500.00		528.00		
3	Geotextile in Base	12.00	m2	1,000.00	12,000.00		76.80		
Sub-Total Specific Bund Costs					104,625.00		669.60		
Contingency @25%					26,156.25		167.40		
Total Specific Bund Costs					130,781.25		837.00		
4	Miscellaneous Works (Access etc.)	1.00	Item	1,000,000.00	1,000,000.00		6,400.00		
5	Contractors Temporary Works	1.00	Item	500,000.00	500,000.00		3,200.00		
Sub-Total General Costs					1,500,000.00		9,600.00		
Total					1,500,000.00		9,600.00		
A	Weir/Flow Control Structure including Weir	1.00	Unit	250,000.00	250,000.00		1,600.00		
		Trench Excavation per 20 m length					US\$		
Item	Description	Quantity	Unit	Rate	Cost		Unit/m		
1	Excavation	60.00	m3	2,250.00	135,000.00		43.20		
2	Miscellaneous Works (Access etc.)	1.00	Item	50,000.00	50,000.00		16.00		
Sub-Total					185,000.00		59.20		
Contractors Temporary Works					1.00	Item	20,000.00	20,000.00	6.40
Sub-Total					205,000.00		65.60		
Contingency @ 25%					51,250.00		16.40		
Total					256,250.00		82.00		
		Syphon/Culvert Under East Canal					US\$		
Item	Description	Quantity	Unit	Rate	Cost		Unit/m		
1	Supply and Install 900 mm HDPE Pipe	18	m	650	11,700.00		4.16		
2	Entry and Exit Structures	2	Item	300000	600,000.00		213.33		
Sub-Total					611,700.00		217.49		
Contingency @20%					122,340.00		43.50		
Total					734,040.00		260.99		
		Control Sluice Gate on Eastern Canal 15 m Wide					US\$		
Item	Description	Quantity	Unit	Rate	Cost		per structure		
1	Excavation	20.00	m3	2,250.00	45,000.00		288.00		
2	Earth Dam Structure Fill Material	28.00	m3	10,000.00	280,000.00		1,792.00		
3	Sluice Gate	1.00	Item	400,000.00	400,000.00		2,560.00		
4	Miscellaneous Works (Access etc.)	1.00	Item	300,000.00	300,000.00		1,920.00		
Sub-Total					1,025,000.00		6,560.00		
Contractors Temporary Works					1.00	Item	300,000.00	300,000.00	1,920.00
Sub-Total					1,325,000.00		8,480.00		
Contingency @ 25%					331,250.00		2,120.00		
Total					1,656,250.00		10,600.00		

These unit costs can then be applied to each of the 66 No. water management structures that have been identified in the report above. Each structure has an estimated bund length and height (see Appendix J), which can then be costed using the unit costs above.

It is possible to estimate the benefit of each of the 66 No. structures in terms of the area flooded and volume of water retained behind each of the bund structures – the efficiency of the structure. This ranking is also included in Appendix J.

The most efficient structure using storage area per bund length is the 25cm high C3 Wild Bush Fire reduction bund, whereas the most efficient using storage volume per bun length is the 50cm high C3 Wild Bush Fire reduction bund.

Unsurprisingly the greatest storage area and storage volume are created by the East Canal blocker B1 with 50cm high surrounding bunds.

The ranking is particularly helpful when considering how to prioritise wetland restoration activities and get the greatest outcome from an intervention.

Equally the rankings are helpful where selecting specific interventions from others is difficult, for example selecting which of the Whistling Duck bunds to construct or in what order. By area per bund length the most efficient Duck bund is the 50cm W26, whereas the most efficient by stored volume per bund length is the 25cm W1.

A cost benefit analysis using the unit costs and ranked benefits is also provided (see Appendix J). The cheapest restoration measure is the 5m long Whistling Duck Bund W5, the most expensive the 50cm high bund and southern blocker (B2) for the East Canal. The most effective structure in terms of cost per square metre of water retention area is the 25cm Wildfire Bund C3 (US\$75K), and the most effective structure in terms of cost per cubic metre of water volume retention is the 50cm equivalent (US\$160K). The East Canal northern blocker with retention bund is the 3rd (25cm) and 4th (50cm) most cost-effective measure by volume and 5th and 6th by area.

The cost of each East Canal blocker without banded wingwall lengths has been priced provisionally at US\$ 10,000. Whilst not resulting in water inundation outside of the canal footprint the blockers will raise groundwater to near surface levels, reduce or prevent salination and prevent further land subsidence – all of which are critically important to protecting and restoring the Morass.

The cost of the spring transfers depends on the lengths of pipeline and ditch deployed, as well as whether secondary farmer supply pipes/ditches are provided. Shallow pipelines are probably cheaper than larger ditch structures, and are the preferred technique. Depending on the length of spring transfer route, these are estimated to cost between US\$ 10-20K each.

5.3 Water Monitoring

The meteorological and hydrological analysis has been reliant upon one weather station at Negril Lighthouse and two (2) River gauging station northeast of the Morass on the Orange River and Fish River.

There is no operational river gauging station on the South Negril River, no measurement of combined flow on the North Negril River, no measurement of spring flows, no measurement of groundwater levels, and no measurement of tides.

There is continuous or routine monitoring of water quality anywhere within or around the Negril Great Morass and no monitoring of water levels within the Morass.

To actively manage the Morass water content and demonstrate the effectiveness of the proposed hydrological restoration structures, a much more robust water monitoring network is required.

It is assumed the water monitoring will be made the responsibility of WRA. It is necessary that an entity be assigned the responsibility of monitoring, maintenance, repair and resetting the level of weirs as we acknowledge that this function does not currently exist. It is also recommended that the WRA partner with local stakeholders to include participatory monitoring approaches to operating and maintaining the water monitoring network. This is particularly valuable for regular monitoring of water quality, especially around storm events, since water quality monitoring is difficult to automate and is very event specific. The following recommendations are therefore being made.

5.3.1 Meteorology and Climatology

Install an automated weather station towards the northeast end of the Morass, ideally near the river gauging stations near Logwood.

5.3.2 Hydrology

Repair, reinstall or replace the stream flow gauging station on the South Negril River near Springfield. This should have a datalogger water level reader. This is, however, dependent on whether the existing station is fixed weir or whether flow gauging. Bubble line systems are becoming increasingly popular in tropical storm vulnerable catchments as they have sacrificial installations within the river channel with the dataloggers themselves at much greater distance and elevation than conventional stilling wells with dataloggers allow.

It is also recommended that level loggers be fitted near the main coastal bridges on the North and South Negril Rivers, to measure the hourly tide changes. Manual stage boards need to also be fitted to these installations.

Manual stage boards should also be fitted at the upstream blocker locations on the East Canal and on the upstream side of the weir plates on the Wild bush fire overflow weirs. If financial resources permit, these 6 sites could also be instrumented with level dataloggers.

Water quality surveys are recommended at four locations along the North Negril River and each side of the blockers on the East Canal monthly, 3 months prior to blocker installation and for the first 12 months afterwards. Thereafter quarterly water quality is proposed.

Water quality in-field monitoring should include temperature, turbidity, salinity, dissolved oxygen and pH. The field probes should also be used to test standing water behind a select number of the bund structures.

Laboratory analysis is not considered necessary.

5.3.3 Groundwater

Finally, groundwater monitoring is proposed at the seven (7) springs. A weir box needs to be installed at the entry point to each of the transfer ditches or pipes. The weir box should be fitted with a v-notch weir and a datalogger installed to measure the flow over the weir. The water level elevation can then be converted to a flow using standard conversion tables.

There are no reported boreholes within the Morass which can be monitored. If any unused boreholes are identified, a selection of 2 to 3 of these should be used for monitoring water level and the salinity profile down the borehole. These should be measured quarterly. Spring water quality monitoring should be undertaken as the surface water monitoring stated above.



6 Conclusion

The hydrological assessment conducted under this consultancy provides integrated approaches to environmental management and land use, to improve natural resources of the Negril Great Morass by strengthening policies and legal/institutional frameworks while creating awareness and facilitating capacity building for sustainable land management, considering the influence of climate change. The aim is to promote conservation of key flora and fauna within the Negril Great Morass through restoration of wetland ecosystem services and sustainable use of wetland biological resources. This provides a unique opportunity for much needed restoration of historical hydrological processes, enhancement, and re-establishment of native vegetation communities to provide habitats, and elimination of conflicts which degrade ecosystem functions.

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Appendix

Appendix A List of Plants of the Morass (Mangroves, herbaceous wetland, swamp forest, coastal woodland and associated forests)

ALISMATACEAE
<i>Echinodorus berteroi</i>
<i>Sagittaria lancifolia</i>
ANACARDIACEAE †
<i>Comocladia pinnatifolia</i>
<i>Metopium brownii</i>
<i>Spondias purpurea</i>
ANNONACEAE
<i>Annona glabra</i>
AMARANTHACEAE
<i>Chamissoa altissima</i>
<i>Acnida cuspidata</i>
AMARYLLIDACEAE
<i>Hymenocallis littoralis</i>
APOCYNACEAE
<i>Rhabdadenia biflora</i>
<i>Rauvolfia nitida</i>
<i>Tabernaemontana laurifolia</i>
<i>Urechites lutea</i>
ARACEAE
<i>Colocasia esculenta</i>
<i>Philodendron sp.</i>
<i>Philodendron lacerum</i>
<i>Syngonium auritum</i>
ASCLEPIDACEAE
<i>Asclepias curassavica</i>
<i>Sarcostemma clausum</i>
AVICENNIACEAE
<i>Avicennia nitida</i>
BIGNONACEAE
<i>Enalagma latifolia</i>
<i>Spathodea campanulata</i>
<i>Tabebuia angustata</i>
BOMBACEAE
<i>Ceiba pentandra</i>
BORAGINACEAE
<i>Bouyeria sp.</i>
BROMELIACEAE
<i>Guzmania monostrachia</i>
<i>Hohenbergia negrilensis</i>

<i>Tillandsia baòölbisiana</i>
<i>Tillandsia flexuosa</i>
<i>Tillandsia elongata</i>
<i>Tillandsia recurvata</i>
<i>Tillandsia utriculata</i>
CANNABACEAE
<i>Cannabis sativa</i>
CAESALPINACEAE
<i>Cassia caymanensis</i>
<i>Haematoxylum campechianum</i>
CACTACEAE
<i>Selenicereus grandiflorus</i>
CELASTRACEAE
<i>Cuervea kapplerana</i>
COMBRETACEAE
<i>Bucida buceras</i>
<i>Conocarpus erectus</i>
<i>Terminalia catappa</i>
<i>Terminalia latifolia</i>
COMMELINACEAE
<i>Commelina elegans</i>
COMPOSITAE
<i>Bidens cynapiifolia</i>
<i>Conyza canadensis</i>
<i>Eclipta alba</i>
<i>Erechtites hieraciifolia</i>
<i>Erigeron cuneifolius</i>
<i>Micania micrantha</i>
<i>Pluchea rosea</i>
<i>Vernonia cinerea</i>
<i>Wedelia trilobata</i>
CONVULVULACEAE
<i>Ipomoea acuminata</i>
<i>Ipomoea batatas</i>
<i>Ipomoea rubella</i>
<i>Ipomoea sagittata</i>
<i>Ipomoea setifera</i>
<i>Ipomoea tilicea</i>
CUCURBITACEAE
<i>Cucurbita sp.</i>
<i>Melothria guadeloupensis</i>
CYPERACEAE
<i>Cladium jamaicense</i>
<i>Cyperus brevifoliusò</i>
<i>Cyperus giganteus</i>
<i>Cyperus haspan</i>

<i>Cyperus ligularis</i>
<i>Cyperus peruvianus</i>
<i>Eleocharis sp.</i>
<i>Fuirena umbellata</i>
<i>Rhynchospora cyperoides</i>
<i>Rhynchospora setacea</i>
<i>Rhynchospora gigantea</i>
<i>Scirpus olnei</i>
<i>Scirpus validus</i>
<i>Setaria sp.</i>
ERYTHROXYLACEAE
<i>Erythroxyllum sp.</i>
EUPHORBIACEAE
<i>Euphophorbia glomerifera</i>
<i>Phyllanthus sp.</i>
<i>Phyllanthus acuminatus</i>
FLACOURTACEAE
<i>Casearia aculeata</i>
<i>Casearia guianensis</i>
GRAMINAE
<i>Andropogon bicornis</i>
<i>Andropogon glomerulatus</i>
<i>Erianthus giganteus</i>
<i>Hymenachne amplexicaulis</i>
<i>Panicum condensum</i>
<i>Panicum elephantipes</i>
<i>Panicum muticum</i>
<i>Panicum roanokensis</i>
<i>Panicum stenodes</i>
<i>Panicum zizanooides</i>
<i>Paspalum densus</i>
<i>Sacciolepis striata</i>
<i>Setaria magna</i>
<i>Sceleria eggersiana</i>
GUTTIFERAE
<i>Symphonia globulifera</i>
<i>Calophyllum calaba</i>
<i>Clusia flava</i>
<i>Clusia rosea</i>
HALORAGACEAE
<i>Proserpina palustris</i>
LAURACEAE
<i>Nectandra coriacea</i>
<i>Nectandra antillana</i>
<i>Oxandra lanceolata</i>
LECYTHIDACEAE
<i>Grias cauliflora</i>

LEMNACEAE
<i>Lemna perpusilla</i>
LOGANIACEAE
<i>Mitreola petiolata</i>
MALPIGHIACEAE
<i>Malpighia harrisii</i>
MARANTACEAE
<i>Thalia geniculata</i>
MALVACEAE
<i>Caperonia castaneifolia</i>
<i>Hibiscus elatus</i>
<i>Malachra sp.</i>
<i>Pavonia spicata</i>
<i>Sida urens</i>
MELIACEAE
<i>Cedrela odorata</i>
<i>Trichila glabra</i>
MIMOSACEAE
<i>Adenantha pavonia</i>
<i>Pithecelobium alexandri</i>
<i>Mimosa pigra</i>
MORACEAE
<i>Brosimum alicastrum</i>
<i>Cecropia peltata</i>
<i>Ficus aurea</i>
<i>Ficus maxima</i>
<i>Ficus membranacea</i>
<i>Ficus perforata</i>
<i>Ficus pertusa</i>
<i>Ficus trigonata</i>
MUSACEAE
<i>Musa sp.</i>
MYRSINACEAE
<i>Wallenia sp.</i>
MYRTACEAE
<i>Calyptanthes palens</i>
<i>Pimenta dioica</i>
<i>Eugenia axillaris</i>
NYMPHACEAE
<i>Nymphaea sp.</i>
<i>Nymphaea ampla</i>
NYTAGINACEAE
<i>Pisonia aculeata</i>

ONAGRACEAE
<i>Ludwigia alata</i>
<i>Ludwigia octovalis</i>
<i>Ludwigia peploides</i>
<i>Ludwigia peruviana</i>
<i>Ludwigia repens</i>
ORCHIDACEAE
<i>Brassavola cordata</i>
<i>Broughtonia negrilensis</i>
<i>Tolumnia tetrapetalum</i>
<i>Tolumnia triquetrum</i>
<i>Vanilla claviculata</i>
PALMAE
<i>Calyptronoma occidentalis</i>
<i>Coccothrinax jamaicensis</i>
<i>Roystonea princeps</i>
<i>Thrinax parviflora</i>
PAPILIONACEAE
<i>Andira inermis</i>
<i>Dalbergia ecastaphyllum</i>
<i>Centrosema pubescens</i>
<i>Lonchocarpus sp.</i>
<i>Phaseolus trichocarpus</i>
<i>Piscidia piscipula</i>
<i>Pterocarpus officinalis</i>
<i>Rhynchosia minima</i>
PASSIFLORACEAE
<i>Passiflora foetida</i>
<i>Passiflora oblongata</i>
PHYTOLACCACEAE
<i>Trichostigma octandrum</i>
PIPERACEAE
<i>Piper amalago</i>
<i>Pipers discolor</i>
<i>Pothomorphe umbellata</i>
POLYGONACEAE
<i>Coccoloba uvifera</i>
<i>Polygonum acuminatum</i>
<i>Polygonum punctatum</i>
RHIZOPHORACEAE
<i>Rhizophora mangle</i>
ROSACEAE
<i>Chysobalanus icaco</i>
<i>Prunus myrtifolia</i>
RUBIACEAE
<i>Borreria laevis</i>

<i>Borreria verticillata</i>
<i>Chiococca alba</i>
<i>Guettarda argentea</i>
<i>Psychotria balbesiana</i>
<i>Psychotria marginata</i>
<i>Randia aculeata</i>
RUTACEAE
<i>Fagara martinicensis</i>
SAPINDACEAE
<i>Cupania glabra</i>
SAPOTACEAE
<i>Bumelia salicifolia</i>
<i>Manilkara sideroxylon</i>
SIMAROUBACEAE
<i>Simaruba glauca</i>
SMILACEAE
<i>Smilax balbisiana</i>
SOLANCEAE
<i>Physalis sp.</i>
STERCULIACEAE
<i>Guazuma ulmifolia</i>
TYPHACEAE
<i>Typha domingensis</i>
UMBELLIFERAE
<i>Centella asiatica</i>
<i>Hydrocotyle umbellatum</i>
URTICACEAE
<i>Boehmeria cylindrica</i>
VERBENACEAE
<i>Lantana camara</i>
<i>Lantana involucrata</i>
<i>Petitia domingensis</i>
<i>Verbena scabra</i>
VITACEAE
<i>Cissus sicoides</i>
FERNS-PTERIDOPHYTA
<i>Achrostichum aureum</i>
<i>Achrostichum danaefolium</i>
<i>Anemia sp.</i>
<i>Blechnum sp.</i>
<i>Blechnum serrulatum</i>
<i>Ceratopteris richardii</i>
<i>Lygodium sp.</i>

<i>Maxonia apiifolia</i>
<i>Nephrolepis exaltata</i>
<i>Osmunda cinnamomea</i>
<i>Pityrogramma sp.</i>
<i>Polypodium latum</i>
<i>Psilotum sp.</i>
<i>Thelypteris gonglodes</i>
<i>Thelypteris interrupta</i>
<i>Thelypteris serrata</i>

Appendix B List of Birds of the NGM

FAMILY, SPECIES, COMMON NAME	COASTAL WOODLAND/BEACH	MORASS
Podicepsidae		
<i>Podyilymbus podiceps</i> PIED-BILLED GREBE		x
Pelecanidae		
<i>Pelecanus occidentalis</i> BROWN PELICAN	X	
Fregatidae		
<i>Fregata magnificens</i> MAGNIFICENT FRIGATEBIRD	X	
Ardeidae		
<i>Ixobrychus exilis</i> LEAST BITTERN		x
<i>Ardea herodias</i> GREAT BLUE HERON		x
<i>Casmerodius albus</i> GREAT EGRET		x
<i>Egretta thula</i> SNOWY EGRET		x
<i>Egretta caerulea</i> LITTLE BLUE HERON	x	
<i>Egretta rufescens</i> REDDISH EGRET		x
<i>Bubulcus ibis</i> CATTLE EGRET	x	x
<i>Butorides striatus</i> GREEN-BACKED HERON	x	
<i>Nycticorax</i> BLACK-CROWNED NIGHT-HERON	X	X
<i>Nycticorax violaceus</i> , YELLOW-CROWNED NIGHT-HERON	X	
Anatidae		
<i>Dedrocygna arborea</i> WEST INDIAN WHISTLING-DUCK		X
<i>Anas discors</i> BLUE-WINGED TEAL		x
Cathartidae		
<i>Cathartes aura</i> TURKEY VULTURE	x	x
Acciptridae		
<i>Pandion haliatus</i> OSPREY	x	x
<i>Circus cyaneus</i> NORTHERN HARRIER		x
<i>Buteo jamaicensis</i> RED-TAILED HAWK	x	x
Falconidae		

FAMILY, SPECIES, COMMON NAME		COASTAL WOODLAND/BEACH	MORASS
Falco sparverius	AMERICAN KESTREL	x	
Rallidae			
Rallus longirostris	CLAPPER RAIL		x
Porzana carolina	SORA		x
Hapalocrex flaviventer	YELLOW-BREASTED CRAKE		x
Porphyryla martinicensis	PURPLE GALLINULE		x
Gallinula chloropus	COMMON MOORHEN		x
Fulica americana	AMERICAN COOT		x
Aramidae			
Aramus guarauna	LIMPKIN		x
Charadriidae			
Charadrius semipalmatus	SEMIPALMATED PLOVER		x
Recurvirostridae			
Himantopus mexicanus	BLACK-NECKED STILT		x
Scolopcaidae			
Tringa melanoleuca	GREATER YELLOWLEGS		x
Actitis macularia	SPOTTED SANDPIPER	x	x
Calidris alba	SANDERLING	x	x
Columbidae			
Columba leucocephala	WHITE-CROWNED PIGEON	x	x
Zenaida asiatica	WHITE-WINGED DOVE	x	x
Zenaida aurita	ZENAIDA DOVE	x	x
Zenaida macroura	MOURNING DOVE	x	x
Columbina passerina	COMMON GROUND DOVE	x	x
Leptotila jamaicensis	CARIBBEAN DOVE	x	x
Psittacidae			
Aratinga nana	JAMAICAN PARAKEET	x	x
Forpus passerinus	GREEN-RUMPED PARROTLET	x	x
Cuculidae			
Crotophaga ani	SMOOTH-BILLED ANI	x	x
Nyctibiidae			
Nyctibius griseus	JAMAICAN POTOO	x	
Apodidae			
Streptoprocne zonaris	WHITE-COLLARED SWIFT	x	x
Tachornis phoenicobia	ANTILLEAN PALM SWIFT	x	
Trochilidae			

FAMILY, SPECIES, COMMON NAME	COASTAL WOODLAND/BEACH	MORASS
Anthracothorax mango JAMAICAN MANGO	x	x
Trochilus polytmus RED-BILLED STREAMERTAIL	x	
Melissuga minima VERVAIN	x	x
Picidae		
Melanerpes radiolatus JAMAICAN WOODPECKER	x	x
Tyrannidae		
Myiarchus barbirostris SAD FLYCATCHER	x	
Myiarchus validus RUFIOUS-TAILED FLYCATCHER		
Myiarchus stolidus STOLID FLYCATCHER		
Tyrannus dominicensis GRAY KINGBIRD	x	X
Tyrannus caudifasciatus LOGGERHEAD KINGBIRD	x	X
Hirundinidae		
Progne dominicensis CARIBBEAN MARTIN	x	x
Hirundo fulva CAVE SWALLOW	x	
Hirundo rustica BARN SWALLOW	x	
Muscicapidae		
Turdus aurantius WHITE-CHINNED THRUSH	x	X
Dumetella carolinensis GRAY CATBIRD	x	x
Mimus polyglottos NORTHERN MOCKINGBIRD	x	
Sturnidae		
Sturnus vulgaris EUROPEAN STARLING	x	
Vireonidae		
Vireo modestus JAMAICAN VIREO	x	
Vireo altiloquus BLACK-WHISKERED VIREO	x	
Emberizidae		
Parula americana NORTHERN PARULA	x	x
Dendroica petechia YELLOW WARBLER	x	
Dendroica magnolia WARBLER	x	
Dendroica tigrina CAPE MAY WARBLER	x	
Dendroica caerulescens BLACK-THROATED BLUE WARBLER		
Dendroica coronata YELLOW-RUMPED WARBLER	x	
Dendroica dominica YELLOW-THROATED WARBLER	x	
Dendroica discolor PRAIRIE WARBLER	x	
Dendroica palmarum PALM WARBLER	x	
Mniotilta varia BLACK-AND-WHITE WARBLER	x	
Setophaga ruticilla AMERICAN REDSTART	x	
Pronotaria citrea PROTHONOTARY WARBLER	x	
Helmitheros vermivorus WORM-EATING WARBLER	x	
Seiurus auricapillus OVENBIRD	x	x

FAMILY, SPECIES, COMMON NAME	COASTAL WOODLAND/BEACH	MORASS
Seiurus noveboracensis NORTHERN WATERTHRUSH	x	
Geothlypis trichas COMMON YELLOWTHROAT	x	
Coereba flaveoli BANANAQUIT	x	x
Euphonia jamaica JAMAICAN EUPHONIA	x	x
Spindalis zena STRIPE-HEADED TANAGER	x	
Tiaris olivacea YELLOW-FACED GRASSQUIT	x	
Tiaris bicolor BLACK-FACED GRASSQUIT	x	
Loxipasser anoxanthus YELLOW-SHOULDERED GRASSQUIT	x	
Loxigilla violacea GREATER ANTILLEAN BULLFINCH	x	
Euneornis campestris ORANGEQUIT	x	
Icterus leucopteryx JAMAICAN ORIOLE	x	X
NUMBER OF SPECIES	87	
Endemic species	10	

Appendix C List of Reptiles of Negril (Haynes-Sutton 1992)

Species Name	D-S-N*
<i>Eleutherodactylus cundali</i>	3-2-1
<i>Eleutherodactylus luteolus</i>	3-2-1
<i>Eleutherodactylus pantoni</i>	3-2-1
<i>Chelonia mydas</i>	x-1-x
<i>Eretmochelys imricata</i>	x-x-1
<i>Aristelleger praesignis</i>	2-2-1
<i>Sphaerodactylus argus</i>	1-1-1
<i>Sphaerodactylus goniorhynchus</i>	3-2-1
<i>Anolis garmani</i>	3-1-1
<i>Anolis grahami</i>	3-1-1
<i>Anolis lineatopus</i>	3-1-1
<i>Anolis opalinus</i>	3-1-1
<i>Anolis sagrei</i>	1-2-1
<i>Anolis valencienni</i>	3-1-1
<i>Celestus cruscus</i>	2-1-1
<i>Crocodylus acutus</i>	x-x-1

*

D (Endemism) → 3 = endemic species, 2 = endemic race, 1 = native species

S (status in Jamaica) → 3= Rare, 2=uncommon, 1=common

N (status in Negril) → 3=Rare, 2=uncommon, 1=common

Appendix D List of fish recorded from the NGM by NRCD-Traverse Group (1981) (in order of abundance) (Aiken 1991)

Scientific Name	Common Name
<i>Cetengraulis edulentus</i>	Atlantic anchoveta
<i>Eucinostomus argenteus</i>	Spotfin Mojarra
<i>Caranx latus</i>	Blue Runner (Jack)
<i>Mugil curema</i>	White Mullet
<i>Centropomus undecimalis</i>	Snook
<i>Sphyreana barracuda</i>	Barracuda
<i>Gerres cinereus</i>	Yellowfin Mojarra
<i>Tilapia mossambica</i>	African Perch
<i>Anguilla rostrata</i>	American Eel
<i>Gambusia wrayi</i>	Top Minnow
<i>Diapterus rhombeus</i>	Schoolmaster Snapper
<i>Achitus lineatus</i>	Silver Mojarra
<i>Strongylura timucu</i>	Lined Sole
<i>Polydactylus virginicus</i>	Gar
<i>Elops saurus</i>	Threadfin
<i>Megalops atlanticus</i>	Ladyfish
<i>Lutjanus griseus</i>	Atlantic Tarpon
<i>Opisthonema oglinum</i>	Atlantic Thread
<i>Harengula sp.</i>	Sardine
<i>Microsiphodon chrysurus</i>	Yellowfin damsel fish

Appendix E Odonates observed at the Royal Palm Reserve (Turland 2021)

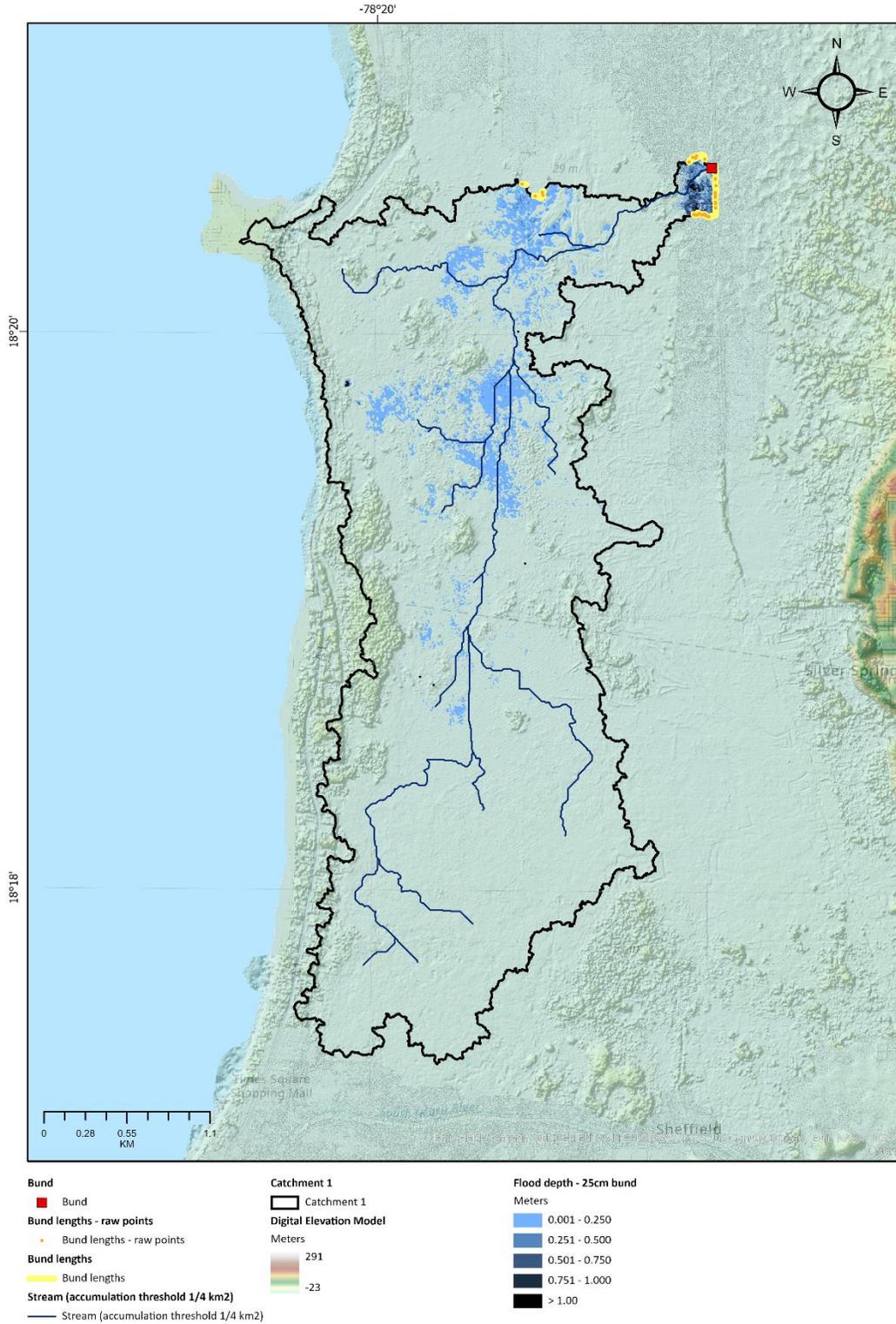
Species Name	Common Name
Coenagrionidae (Pond Damselflies)	
<i>Ischnura capreolus</i>	Tiny Forktail
<i>Ischnura hastata</i>	Citrine Forktail
<i>Ischnura ramburii</i>	Rambur's Forktail
Libellulidae (Skimmers or Perchers)	
<i>Brachymesia furcata</i>	Red-tailed Pennant
<i>Brachymesia herbida</i>	Tawny Pennant
<i>Crocothemis servilia</i>	Scarlet Skimmer
<i>Erythemis plebeja</i>	Pin-tailed Pondhawk
<i>Erythemis vesiculosa</i>	Great Pondhawk
<i>Miathyria marcella</i>	Hyacinth Glider
<i>Micrathyria aequalis</i>	Spot-tailed Dasher
<i>Orthemis macrostigma</i>	Antillean Purple
<i>Orthemis sp.</i> (undescribed)	Antillean Red

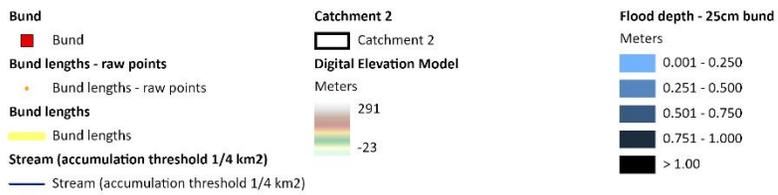
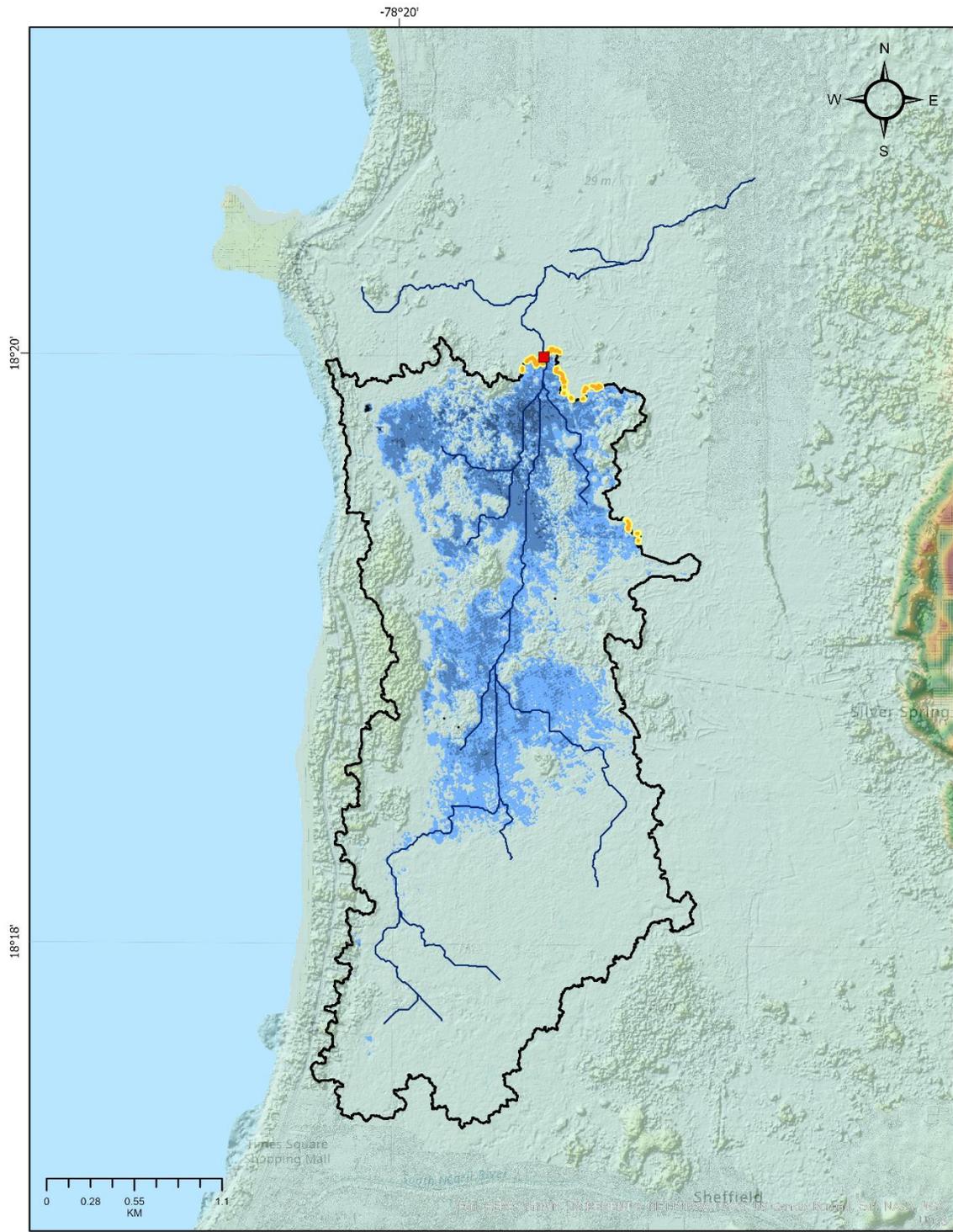
Appendix F Summary of recommendations for monitoring from the Negril EPA Wetland Management Plan (Haynes-Sutton 2021f)

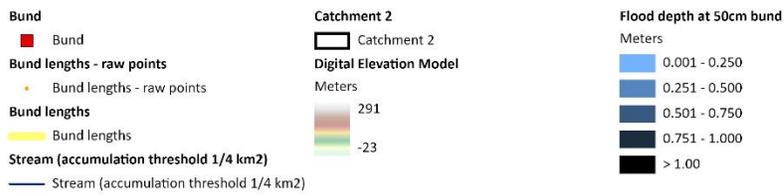
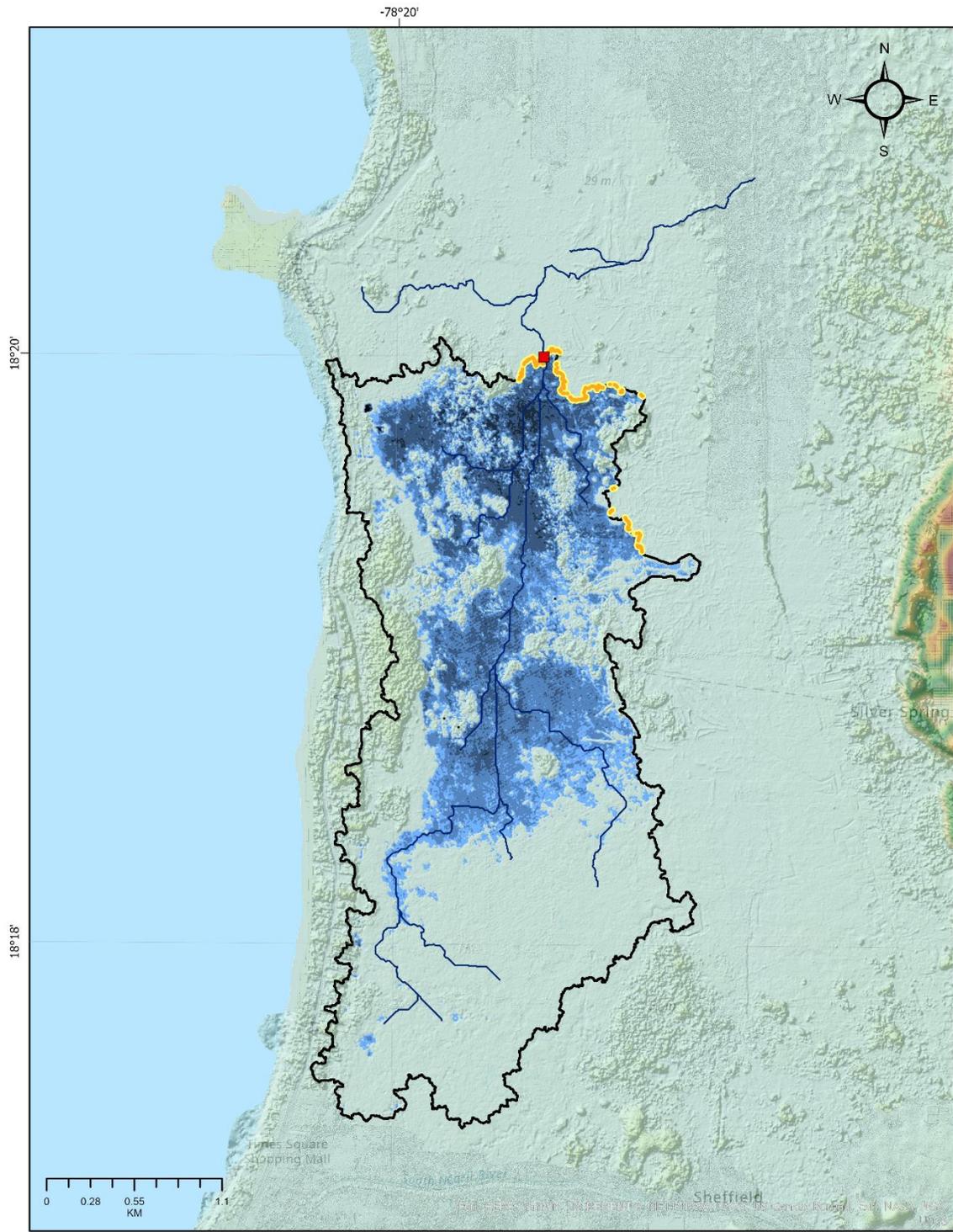
TARGET	INDICATOR	METHODS	LOCATIONS	FREQUENCY	THRESHOLDS
Habitat/land use changes	Extent of mangroves, swamp forest, herbaceous wetlands, ganja, encroachment on wetlands, fire, invasive species	Analysis of Google Earth images, supplemented by drone photography	All wetlands	Every three years	More than 5% change, positive or negative
Fires and natural disasters	Date, extent	Reports on incidents, photographs	All wetlands	When they occur	N/A
Water quality	To be determined by water quality assessment	Water quality sampling and analysis	Rivers, streams, and ponds	Starts once programme designed and funded	To be determined based on proposed assessment and plan
WIWD	Counts of numbers being fed at RPR (including numbers of marked birds)	Reports	RPR	Daily	Annual change in numbers, population estimate from mark and recapture
	Passive Acoustic Monitoring (if feasible)	Swift units (Passive Acoustic monitoring devices available from Cornell Laboratory of Ornithology)	South Negril River, North Negril River, Johns Point, Davis Cove	Annual	Annual changes in numbers
	GSM tracking of WIWD	GSM trackers	Negril EPA	Continuous	Habitat use
Migratory birds	Tracking of species of concern	MOTUS tower(s) and tags	RPR	Continuous	Occurrence of migratory species
Crocodiles	Nocturnal surveys on rivers and ponds			Annual	Changes in numbers
	Number of reports of incidents involving crocodiles	Reports from community members	As necessary	N/A	Annual increase
	Number of crocodiles tagged and recovered and locations	Reports from enforcement teams	As necessary		
	Number of patrols during hunting season	Reports from enforcement teams	Johns Point, NGM margins,	Annual	N/A

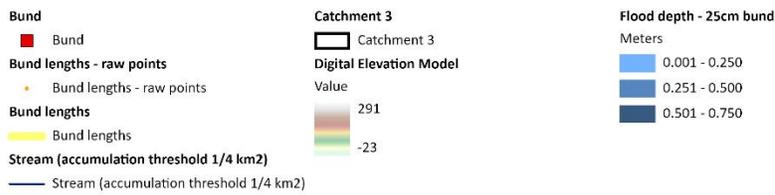
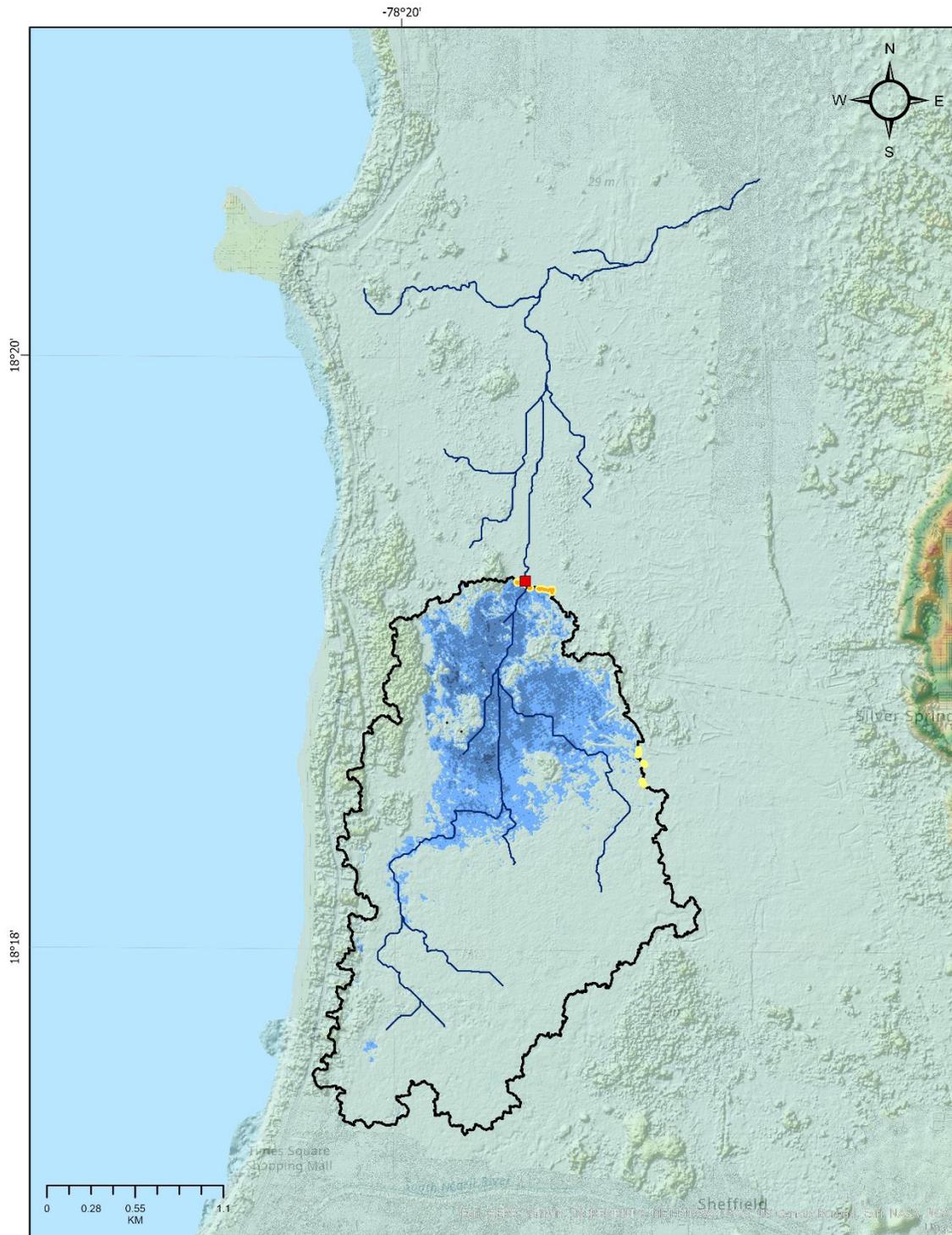
	Number of infractions of environmental laws reported	Reports from enforcement teams	EPA	Year round	N/A
Mangroves status	Permanent plots in mangroves	Select 10 sites for 10 x 10 m quadrats. Permanently mark sites. Assess diameter base height (DBH), species, number of stems, number of seedlings, and signs of damage/threats.	RPR, John's Point, Green Island, Davis Cove	Monitor every 3 years.	N/A
Swamp forest status	Permanent plots in swamp forest	See mangroves above,	RPR	Annual	N/A
Beaches	Changes in beach profiles and width at standard locations	Sandwatch (see Sandwatch website)	Johns Point, Negril Beach, Green Island	Quarterly	10%
Management effectiveness	METT score	Stakeholder workshop.	Negril EPA	Every 3 years	Increase from 2013 baseline of 36 to 46 points

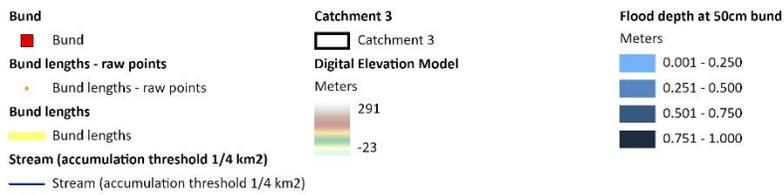
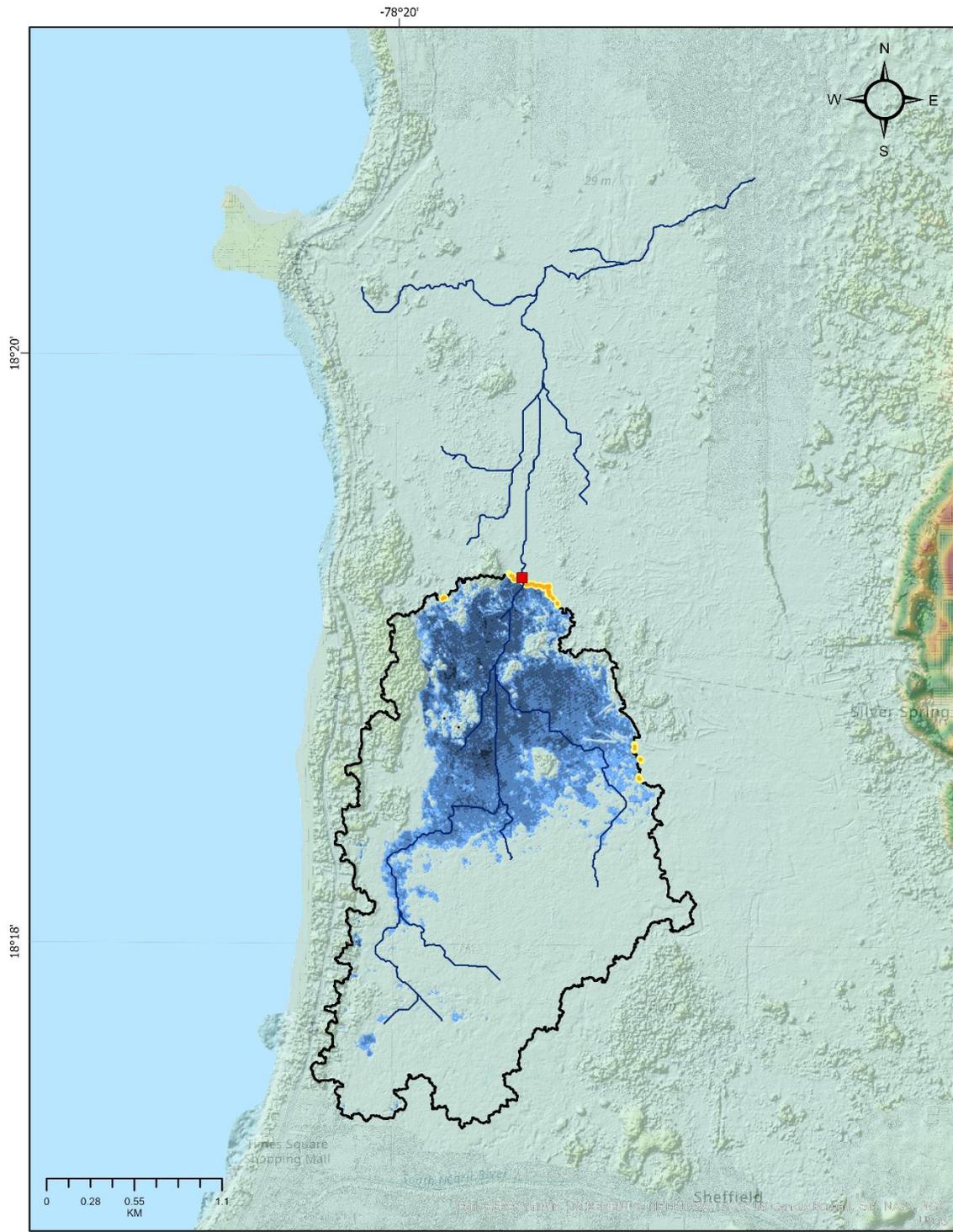
Appendix G Wild Bush Fire Rainfall Ponding Areas, Depths and Lengths of Required Bunds/Embankments

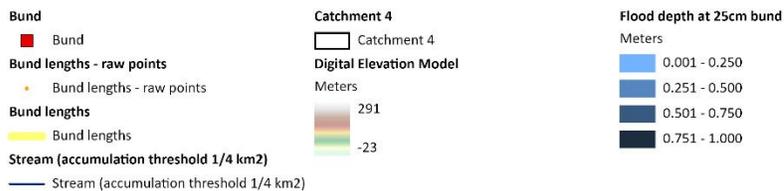
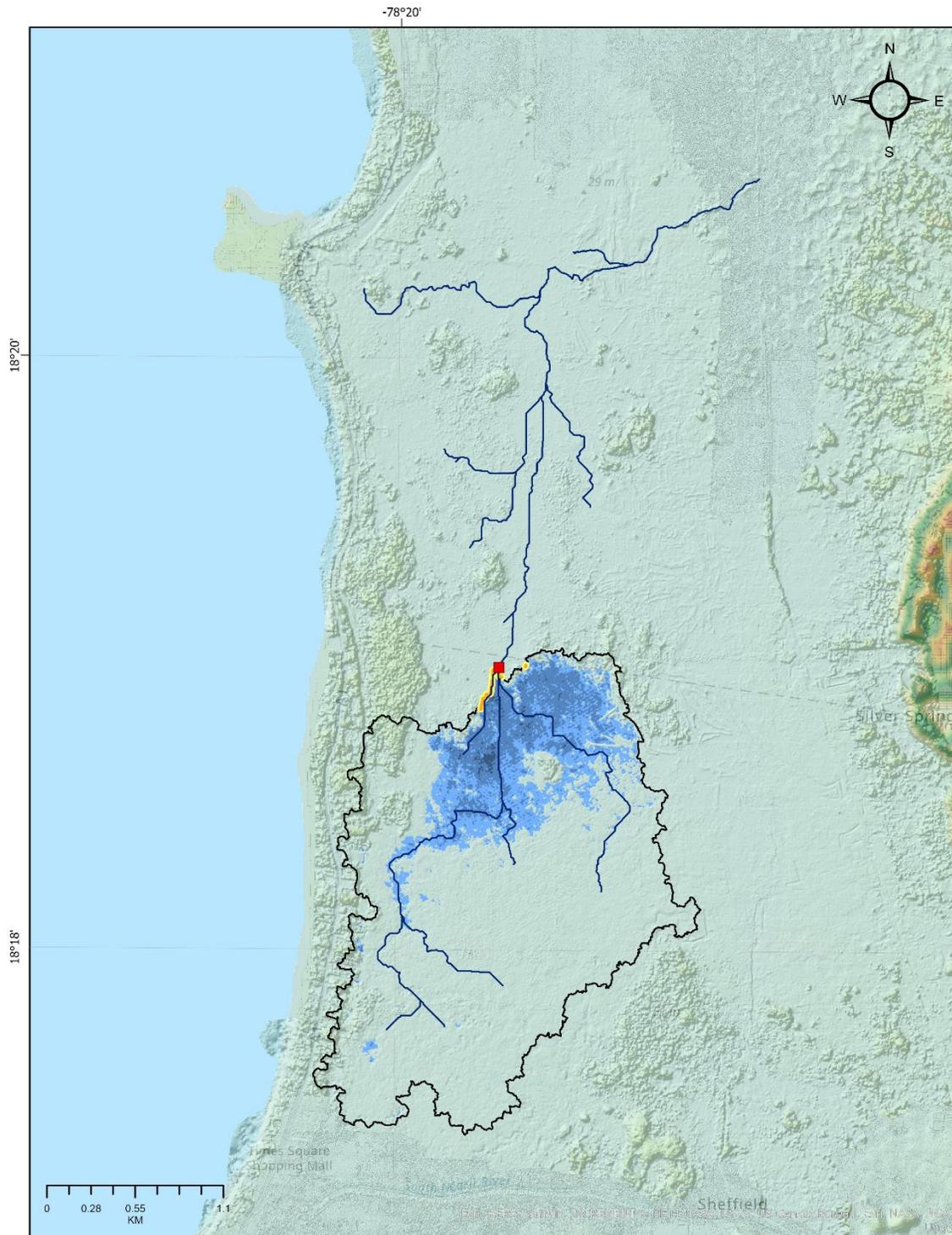


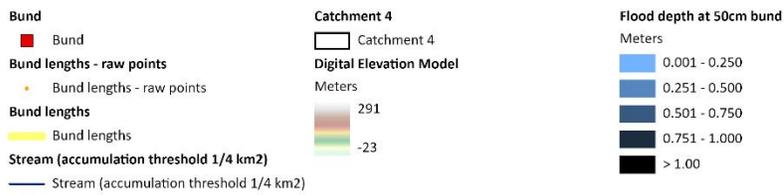
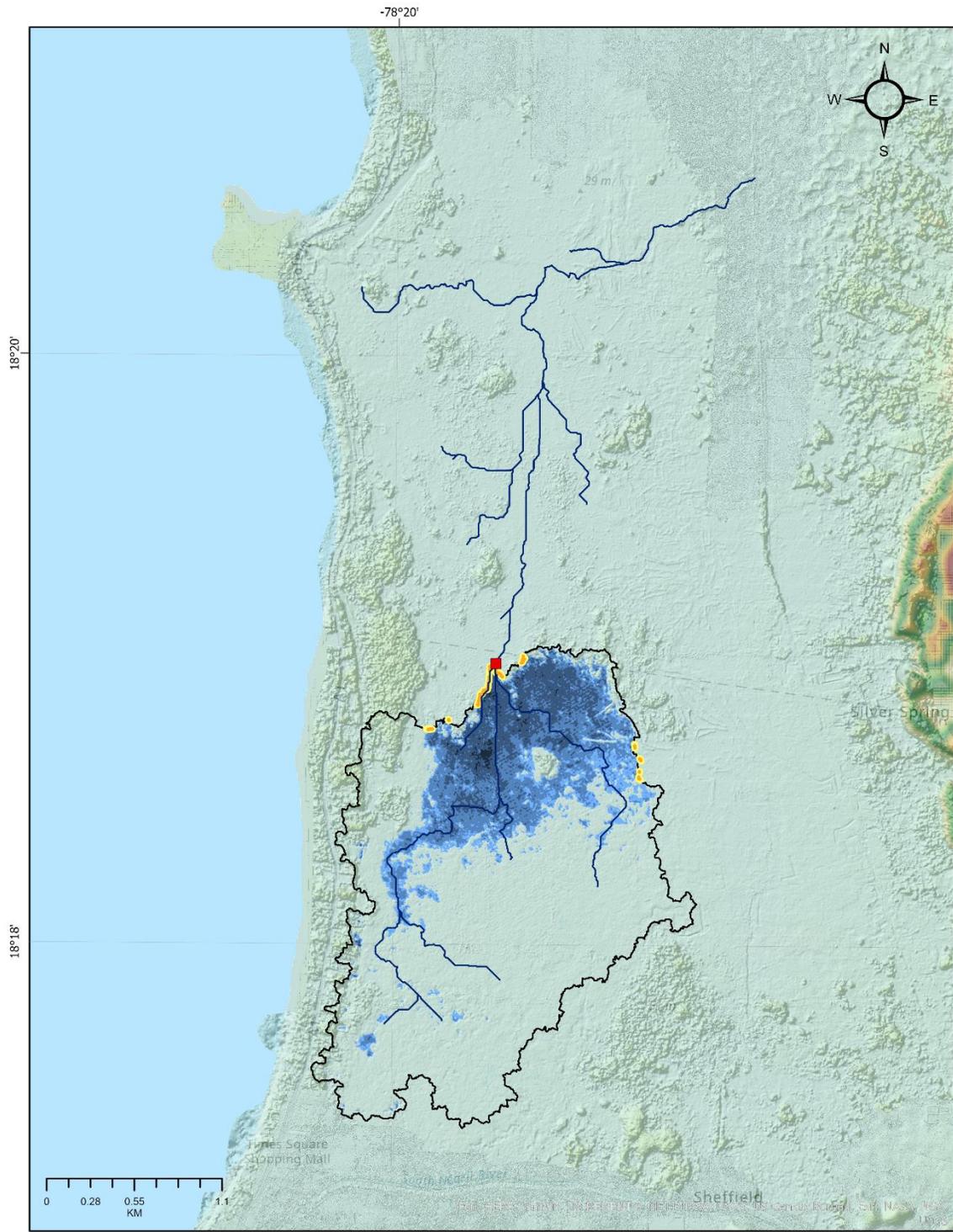




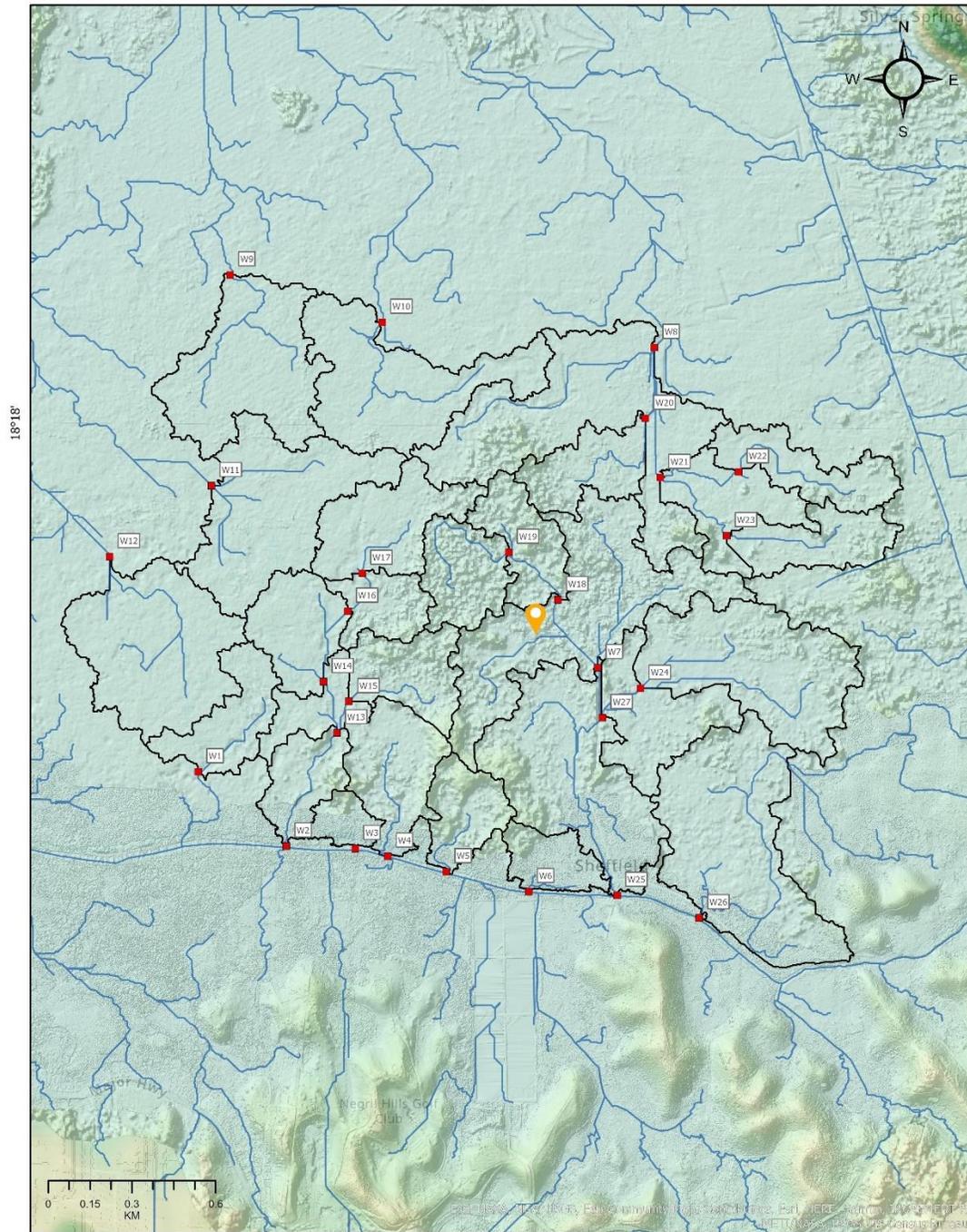




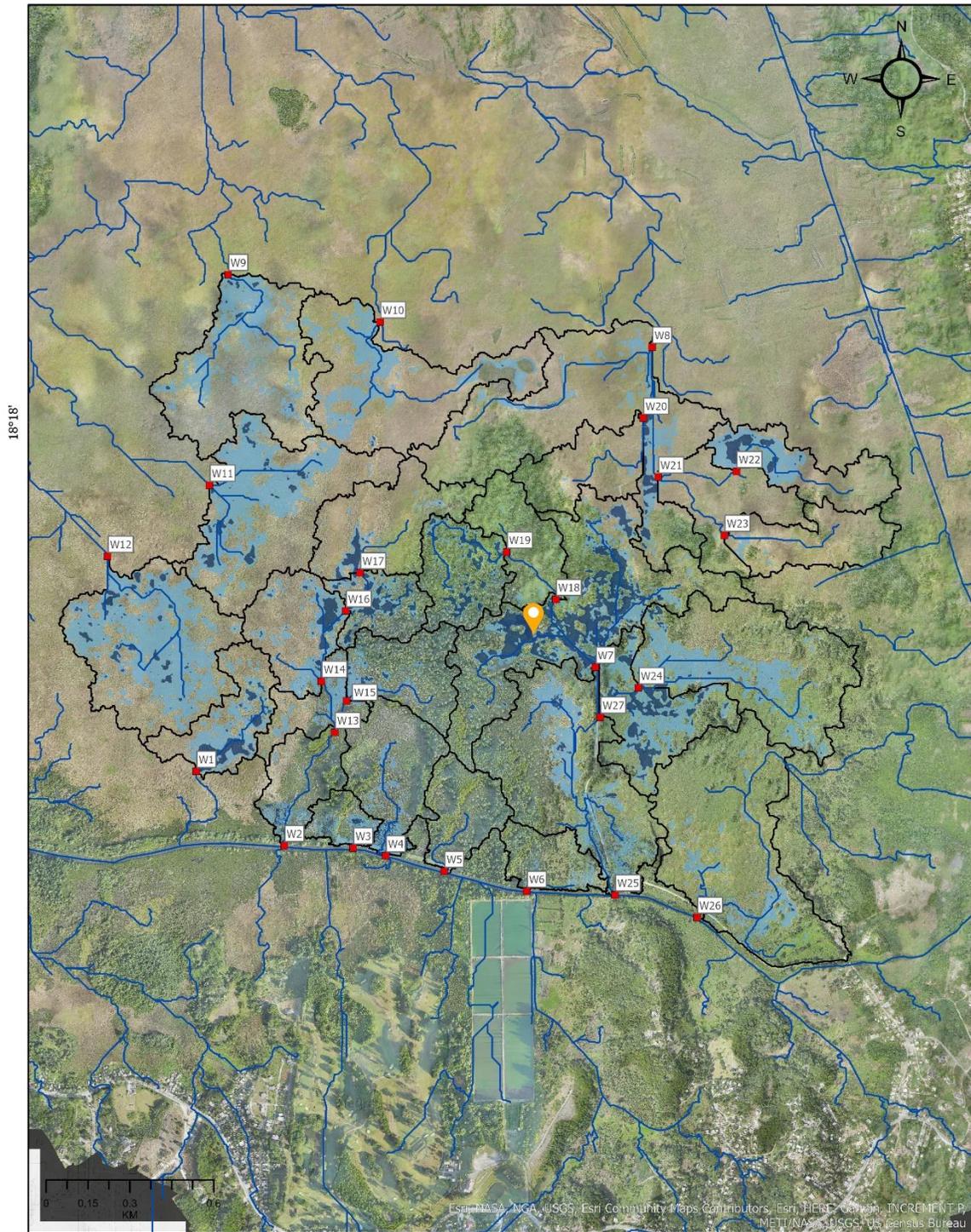




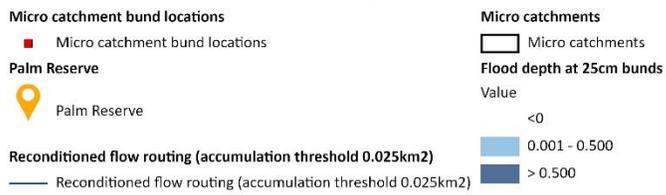
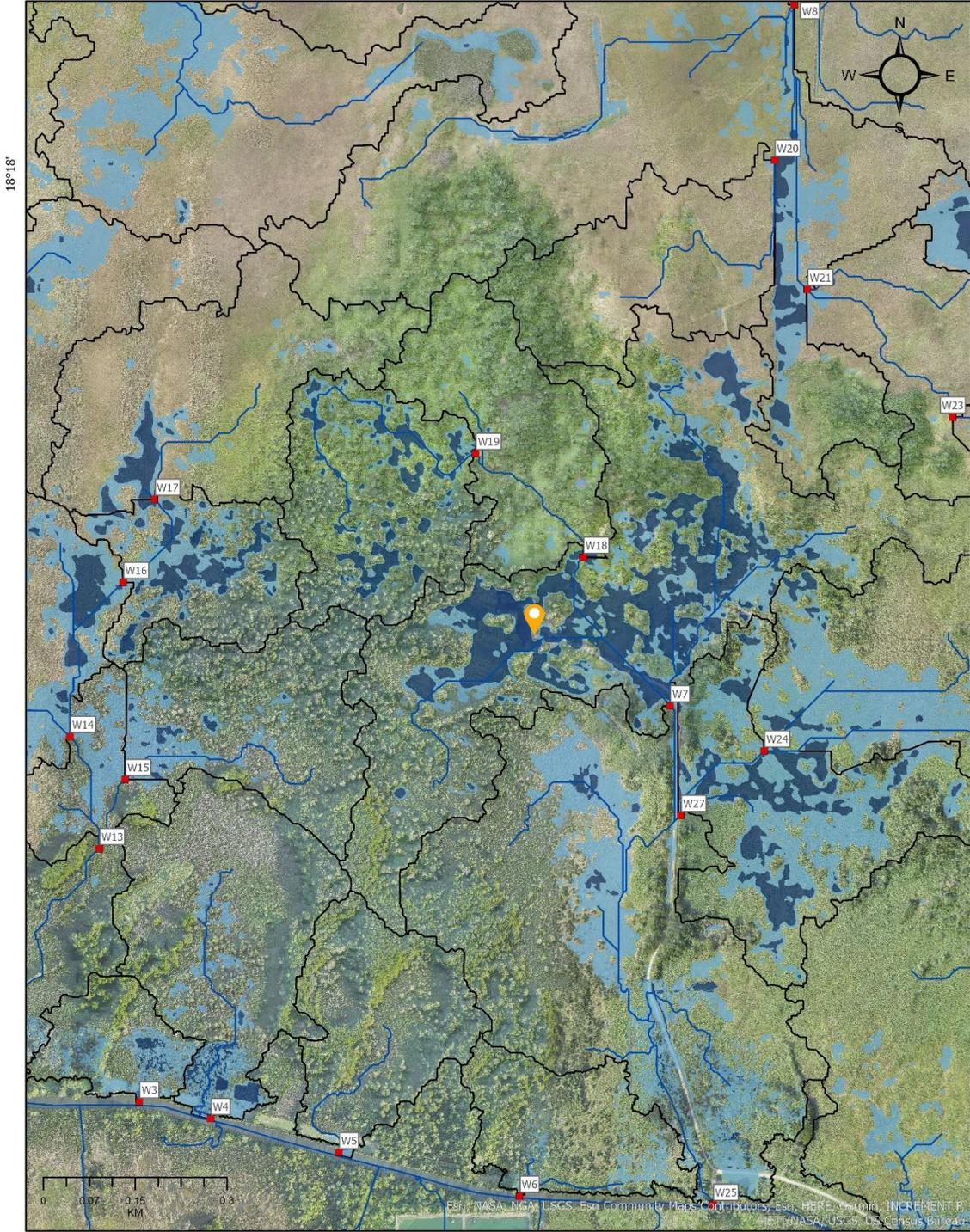
Appendix H West Indian Whistling Duck 25cm and 50cm height bund/embankment rainfall ponding areas and depths

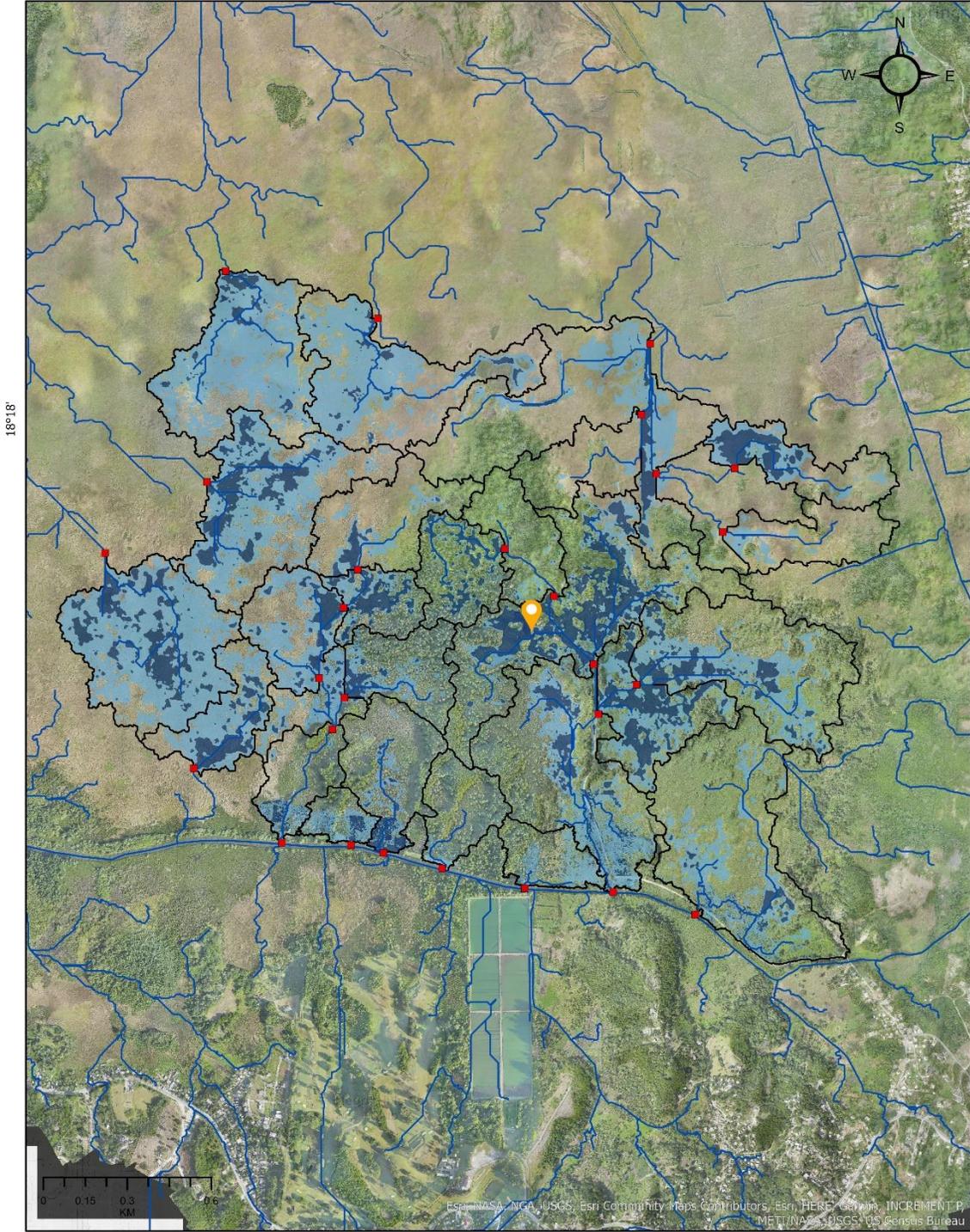


- | | |
|---|--|
| <p>Micro catchment bund locations</p> <ul style="list-style-type: none"> ■ Micro catchment bund locations <p>Palm Reserve</p> <ul style="list-style-type: none"> 📍 Palm Reserve <p>Reconditioned flow routing (accumulation threshold 0.025km²)</p> <ul style="list-style-type: none"> — Reconditioned flow routing (accumulation threshold 0.025km²) | <p>Micro catchments</p> <ul style="list-style-type: none"> ▭ Micro catchments <p>Digital Elevation Model</p> <p>Meters</p> <ul style="list-style-type: none"> 291 -23 |
|---|--|



- | | |
|--|----------------------------------|
| Micro catchment bund locations | Micro catchments |
| ■ Micro catchment bund locations | □ Micro catchments |
| Palm Reserve | Flood depth at 25cm bunds |
| 📍 Palm Reserve | Value |
| Reconditioned flow routing (accumulation threshold 0.025km²) | <0 |
| — Reconditioned flow routing (accumulation threshold 0.025km ²) | 0.001 - 0.500 |
| | > 0.500 |

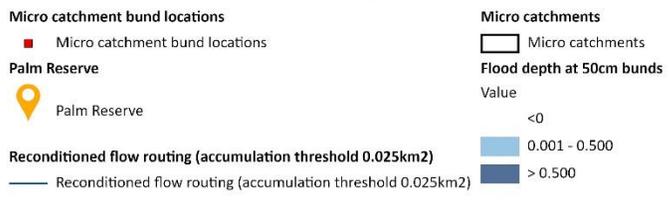
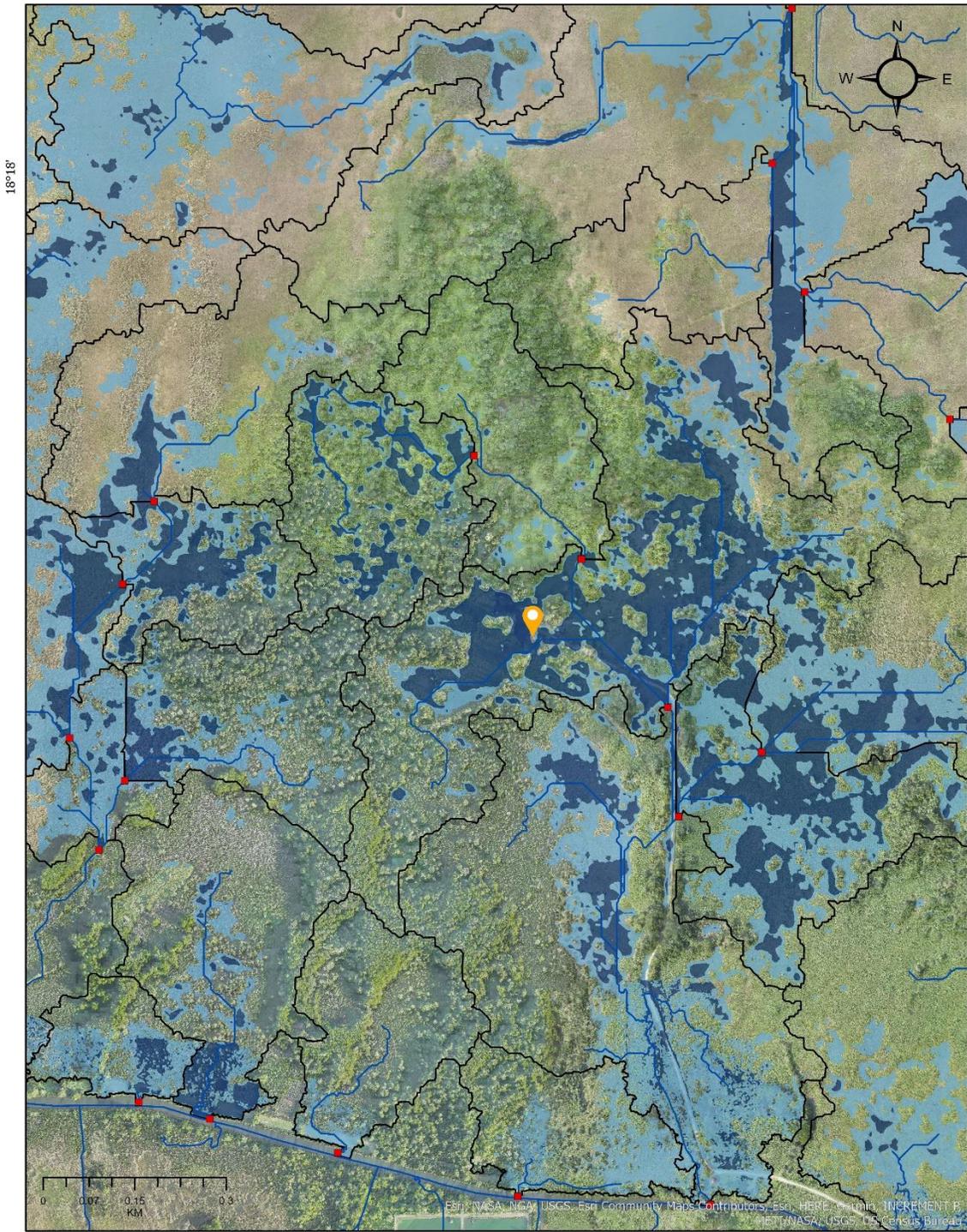




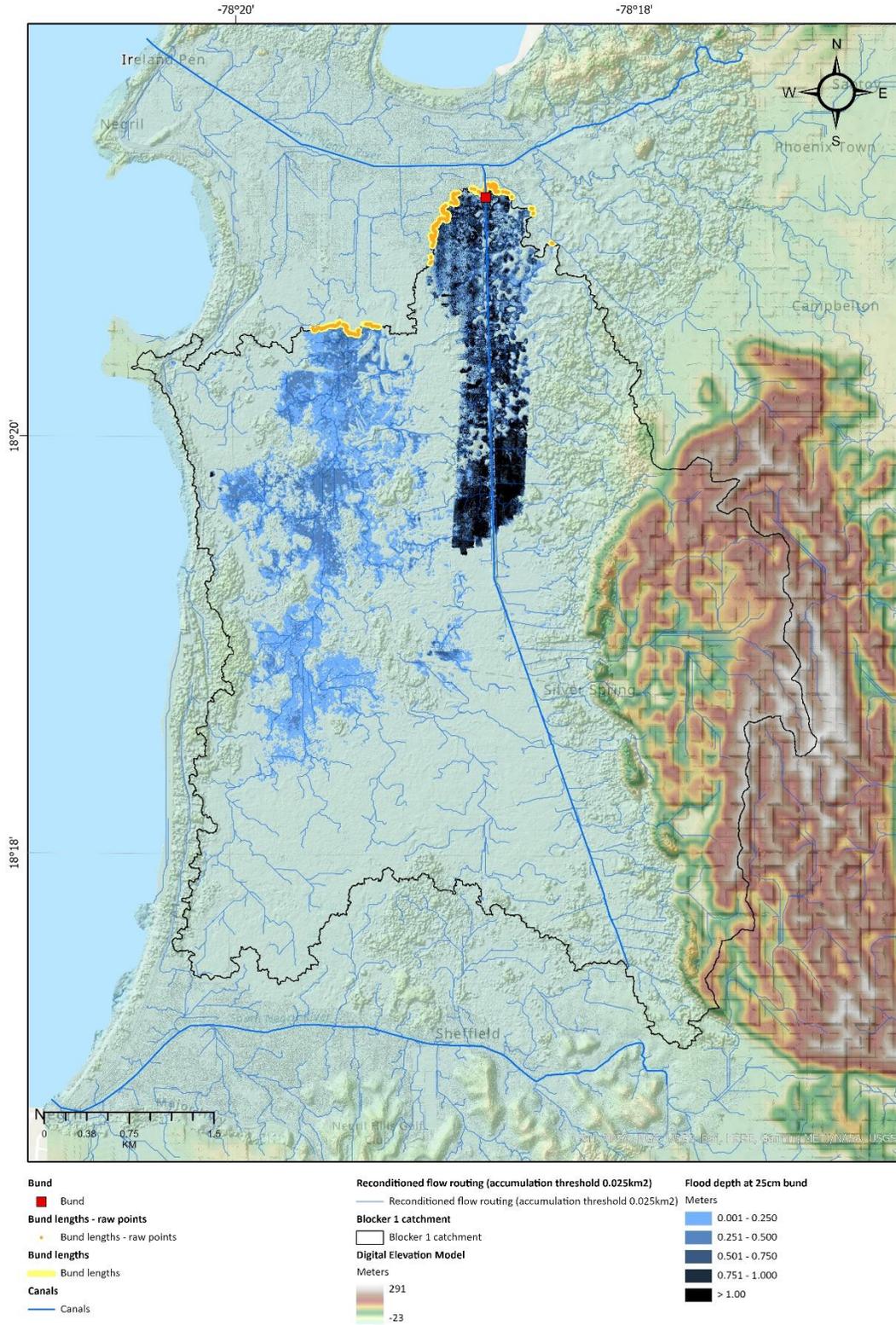
- Micro catchment bund locations**
 - Micro catchment bund locations
- Palm Reserve**
 - 📍 Palm Reserve
- Reconditioned flow routing (accumulation threshold 0.025km²)**
 - Reconditioned flow routing (accumulation threshold 0.025km²)
- Micro catchments**
 - Micro catchments
- Flood depth at 50cm bunds**

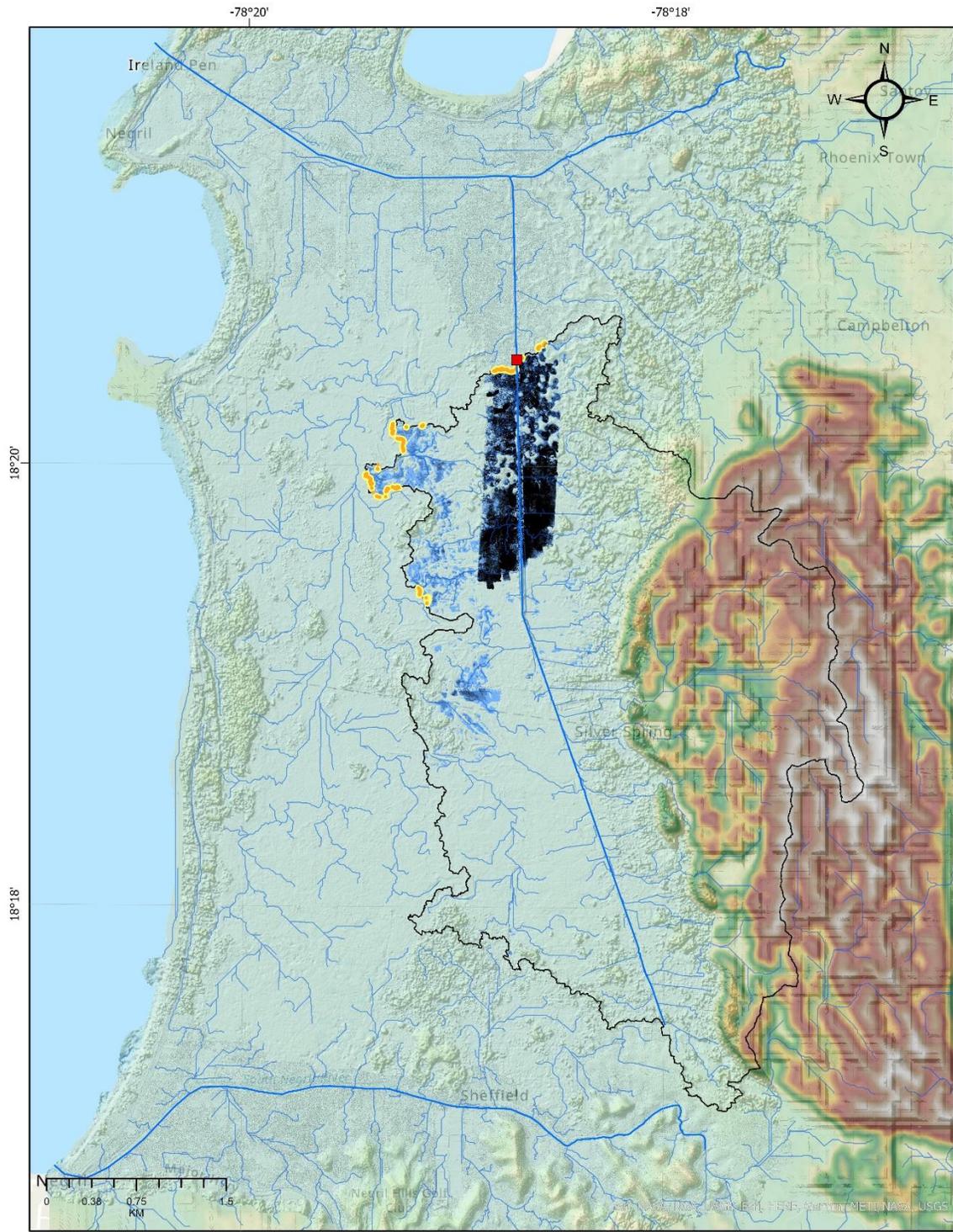
Value

 - <0
 - 0.001 - 0.500
 - > 0.500

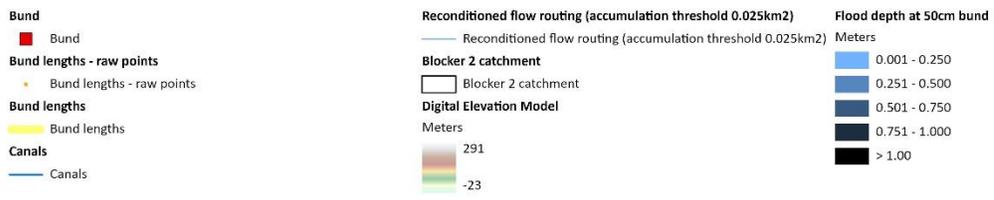
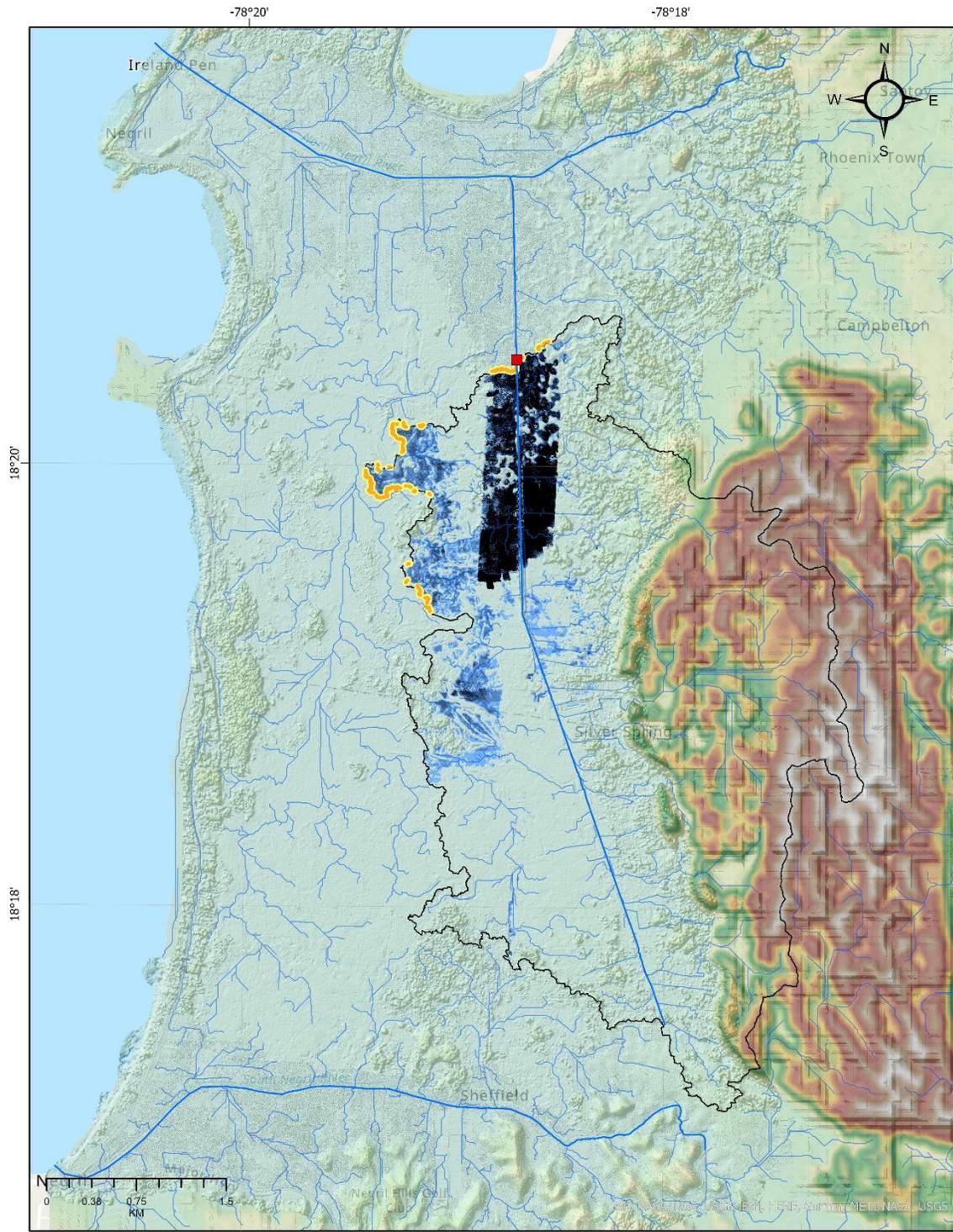


Appendix I East Canal blocking scenarios using overflow weirs and 25cm and 50cm height bund/embankments





- Bund**
- Bund
- Bund lengths - raw points**
- Bund lengths - raw points
- Bund lengths**
- Bund lengths
- Canals**
- Canals
- Reconditioned flow routing (accumulation threshold 0.025km²)**
- Reconditioned flow routing (accumulation threshold 0.025km²)
- Blocker 2 catchment**
- Blocker 2 catchment
- Digital Elevation Model**
- Meters
- 291
- -23
- Flood depth at 25cm bund**
- Meters
- 0.001 - 0.250
- 0.251 - 0.500
- 0.501 - 0.750
- 0.751 - 1.000
- > 1.00



Appendix J Water management structure dimensions, storage areas and volumes, rankings and costs

	Catchment	Bund height (cm)	Storage volume per catchment (m3)	Flooded area (m2)	Catchment area (m2)	Catchment area (km2)	Required rain depth to fill catchment storage (m) (c/e)	Required rain depth to fill catchment storage (mm)	a). LIDAR derived raw minimum length (m)	b). Manually derived bund length (m)	Flooded area / LIDAR derived raw minimum length (m2/m)	Flooded volume / LIDAR derived raw minimum length (m3/m)	
1	Wildfire C1	25	74,615	604,043	9,896,680	9.90	0.01	8	82	891	7,366	910	
2	Wildfire C1	50	414,314	2,152,756	9,896,680	9.90	0.04	42	674	1,810	3,194	615	
3	Wildfire C2	25	430,436	1,995,127	7,703,369	7.70	0.06	56	370	850	5,392	1,163	
4	Wildfire C2	50	1,045,330	2,861,582	7,703,369	7.70	0.14	136	776	1,708	3,688	1,347	
5	Wildfire C3	25	235,221	1,164,248	5,116,612	5.12	0.05	50	109	360	10,681	2,341	
6	Wildfire C3	50	602,252	1,578,511	5,116,612	5.12	0.12	118	238	639	6,632	2,530	
7	Wildfire C4	25	201,488	887,687	4,426,719	4.43	0.05	46	210	452	4,227	959	
8	Wildfire C4	50	464,369	1,193,090	4,426,719	4.43	0.10	105	316	697	3,776	1,470	
9													
10	Whistling duck W1	25	33,769	46,595	103,514	0.10	0.33	326	21	-	2,219	1,608	
11	Whistling duck W1	50	17,945	79,402	103,514	0.10	0.17	173	669	-	119	27	
12	Whistling duck W2	25	6,108	10,247	84,038	0.08	0.07	73	44	-	233	139	
13	Whistling duck W2	50	2,960	14,956	84,038	0.08	0.04	35	107	-	140	28	
14	Whistling duck W3	25	6,094	11,152	37,200	0.04	0.18	180	64	-	174	105	
15	Whistling duck W3	50	3,049	17,668	37,200	0.04	0.08	82	129	-	137	24	
16	Whistling duck W4	25	11,128	17,437	134,690	0.13	0.08	83	111	-	157	100	
17	Whistling duck W4	50	5,955	24,104	134,690	0.13	0.04	44	191	-	126	31	
18	Whistling duck W5	25	701	741	84,562	0.08	0.01	8	5	-	148	140	
19	Whistling duck W5	50	73	4,247	84,562	0.08	0.00	1	24	-	177	3	
20	Whistling duck W6	25	3,733	5,940	65,107	0.07	0.06	57	16	-	371	233	
21	Whistling duck W6	50	513	20,342	65,107	0.07	0.01	8	145	-	140	4	
22	Whistling duck W7	25	115,799	119,556	345,495	0.35	0.33	334	114	-	1,040	1,011	
23	Whistling duck W7	50	82,310	146,372	345,495	0.35	0.24	238	186	-	787	443	
24	Whistling duck W8	25	28,792	44,752	361,064	0.36	0.08	80	307	-	146	94	
25	Whistling duck W8	50	11,599	93,737	361,064	0.36	0.03	32	485	-	193	24	
26	Whistling duck W9	25	40,609	67,297	250,565	0.25	0.16	162	81	-	831	501	
27	Whistling duck W9	50	10,719	174,091	250,565	0.25	0.04	43	658	-	265	16	
28	Whistling duck W10	25	35,411	64,163	255,690	0.26	0.14	138	138	-	465	257	
29	Whistling duck W10	50	9,344	145,512	255,690	0.26	0.04	37	378	-	385	25	
30	Whistling duck W11	25	63,997	114,157	269,137	0.27	0.24	238	94	-	1,359	762	
31	Whistling duck W11	50	27,397	180,073	269,137	0.27	0.10	102	609	-	296	45	
32	Whistling duck W12	25	82,697	148,512	275,609	0.28	0.30	300	155	-	958	534	
33	Whistling duck W12	50	33,252	241,383	275,609	0.28	0.12	121	889	-	272	37	
34	Whistling duck W13	25	8,197	14,986	62,363	0.06	0.13	131	263	-	57	31	
35	Whistling duck W13	50	2,484	31,123	62,363	0.06	0.04	40	590	-	53	4	
36	Whistling duck W14	25	24,955	37,192	113,748	0.11	0.22	219	106	-	351	235	
37	Whistling duck W14	50	11,618	72,450	113,748	0.11	0.10	102	480	-	151	24	
38	Whistling duck W15	25	9,545	15,534	105,700	0.11	0.09	90	183	-	85	52	
39	Whistling duck W15	50	4,482	25,524	105,700	0.11	0.04	42	248	-	103	18	
40	Whistling duck W16	25	21,794	29,126	70,429	0.07	0.31	309	147	-	198	148	
41	Whistling duck W16	50	13,456	37,316	70,429	0.07	0.19	191	333	-	112	40	
42	Whistling duck W17	25	10,815	14,400	148,874	0.15	0.07	73	98	-	147	110	
43	Whistling duck W17	50	5,615	29,226	148,874	0.15	0.04	38	153	-	191	37	
44	Whistling duck W18	25	1,345	2,179	96,835	0.10	0.01	14	60	-	36	22	
45	Whistling duck W18	50	489	4,997	96,835	0.10	0.01	5	73	-	68	7	
46	Whistling duck W19	25	19,887	21,832	103,171	0.10	0.19	193	24	-	910	829	
47	Whistling duck W19	50	13,788	26,909	103,171	0.10	0.13	134	33	-	815	418	
48	Whistling duck W20	25	1,011	1,675	99,139	0.10	0.01	10	209	-	8	5	
49	Whistling duck W20	50	261	4,768	99,139	0.10	0.00	3	227	-	21	1	
50	Whistling duck W21	25	787	1,348	116,467	0.12	0.01	7	276	-	5	3	
51	Whistling duck W21	50	183	3,945	116,467	0.12	0.00	2	483	-	8	0	
52	Whistling duck W22	25	25,048	39,618	105,942	0.11	0.24	236	166	-	239	151	
53	Whistling duck W22	50	13,326	54,013	105,942	0.11	0.13	126	468	-	115	28	
54	Whistling duck W23	25	2,234	3,400	103,357	0.10	0.02	22	28	-	121	80	
55	Whistling duck W23	50	379	13,154	103,357	0.10	0.00	4	105	-	125	4	
56	Whistling duck W24	25	43,127	78,715	277,434	0.28	0.16	155	325	-	242	133	
57	Whistling duck W24	50	19,832	114,958	277,434	0.28	0.07	68	418	-	275	45	
58	Whistling duck W25	25	37,962	69,854	296,848	0.30	0.13	128	227	-	308	167	
59	Whistling duck W25	50	15,531	107,145	296,848	0.30	0.05	52	467	-	229	33	
60	Whistling duck W26	25	21,988	37,137	346,861	0.35	0.06	63	16	-	2,321	1,374	
61	Whistling duck W26	50	6,780	86,605	346,861	0.35	0.02	20	32	-	2,706	212	
62	Whistling duck W27	25	46,842	68,990	139,114	0.14	0.34	337	456	-	151	103	
63	Whistling duck W27	50	27,079	89,335	139,114	0.14	0.19	195	619	-	144	44	
64													
65	East canal block B1	25	1,713,590	4,290,465	27,173,356	27.17	0.06	63	921	-	2,706	4,658	1,861
66	East canal block B1	50	3,019,395	6,097,840	27,173,356	27.17	0.11	111	1427	-	3,657	4,273	2,116
67	East canal block B2	25	919,886	1,408,632	15,626,899	15.63	0.06	59	509	-	1,214	2,767	1,807
68	East canal block B2	50	1,339,540	1,975,778	15,626,899	15.63	0.09	86	1125	-	2,257	1,756	1,191

RANKING 1 = BEST

Storage Area Ranking	Storage Volume Ranking	Rainfall Filling Ranking	Bund Length Ranking	Storage area per Bund Length Ranking	Storage Volume per Bund Length Ranking
12	15	7	15	2	14
4	9	19	61	10	17
5	8	26	46	4	11
3	4	49	62	9	9
10	10	24	21	1	2
7	6	43	38	3	1
11	11	23	35	7	13
9	7	41	43	8	7
34	22	64	4	14	6
26	33	53	60	54	50
54	48	33	10	34	30
51	54	15	20	49	49
53	47	54	12	40	33
47	53	35	24	50	54
48	40	36	22	41	35
45	49	22	33	51	46
60	60	9	1	44	29
66	66	1	5	39	63
55	52	27	2	25	24
61	61	8	26	48	62
19	12	65	23	17	12
17	14	61	32	22	20
35	24	34	42	46	36
23	39	14	54	37	53
31	19	52	14	20	19
15	42	21	59	31	57
32	21	50	25	23	22
18	44	16	47	24	51
21	16	60	16	16	16
14	25	39	57	28	40
16	13	62	29	18	18
13	23	44	63	30	43
50	45	47	40	60	47
40	55	18	56	61	60
38	28	58	19	26	23
28	38	40	52	43	52
49	43	38	31	58	38
44	51	20	39	57	56
42	30	63	27	36	28
37	36	55	45	56	42
52	41	32	17	45	32
41	50	17	28	38	44
57	57	11	11	62	55
62	62	5	13	59	58
46	31	56	6	19	15
43	35	48	9	21	21
58	58	10	34	65	59
64	64	3	36	63	65
59	59	6	41	66	64
65	65	2	53	64	66
36	27	59	30	33	27
33	37	45	51	55	48
56	56	13	7	53	37
63	63	4	18	52	61
27	18	51	44	32	31
20	32	31	48	29	39
29	20	46	37	27	26
22	34	25	50	35	45
39	29	30	3	13	8
25	46	12	8	12	25
30	17	66	49	42	34
24	26	57	58	47	41
2	2	29	64	5	4
1	1	42	66	6	3
8	5	28	55	11	5
6	3	37	65	15	10

670 US\$

Total Cost (US\$)	Cost per flooded area (US\$/m2)	Cost per flooded volume (US\$/m3)
54,940	0.09	0.74
451,580	0.21	1.09
247,900	0.12	0.58
519,920	0.18	0.50
73,030	0.06	0.29
159,460	0.10	0.26
140,700	0.16	0.70
211,720	0.18	0.46
14,070	0.30	0.42
448,230	5.65	24.98
29,480	2.88	4.83
71,690	4.80	24.22
42,880	3.85	6.41
86,430	4.89	28.35
74,370	4.27	6.68
127,970	5.31	21.49
3,350	4.52	4.78
16,080	3.79	218.99
10,720	1.80	2.87
97,150	4.78	189.24
76,380	0	



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