BTO Research Report No. 436

Qurm Environmental Information Centre (QEIC) Development Project: Creation of Natural Lagoons and Visitor Facilities

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A BTO-MAT report to the Japan International Cooperation Agency (JICA)

May 2006

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Registered Charity No. 216652

Recommended citation: Grieve, A., Holloway, S.J., Rehfisch, M.M. & Fletcher, D. J. 2006**.** *Qurm Environmental Information Centre (QEIC) Development Project: Creation of Natural Lagoons and Visitor Facilities.* Research Report 436**.** British Trust for Ornithology, Thetford, UK**.**

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Entered Public Domain May 2006 and published by British Trust for Ornithology
The Nunnery, Thetford, Norfolk, IP24 2PU

ISBN 1-904870-74-0

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1. INTRODUCTION

1.1 The Qurm Environmental Information Centre Development Project

Oman has been designated as the centre for mangrove conservation in the Middle East. The Qurm Nature Reserve at Muscat, Oman, established by Royal Decree in 1975, is a popular recreation area that contains good examples of mangrove forest.

The Qurm Environmental Information Centre (QEIC) Development Project has been established as part of the objective to conserve and manage mangrove ecosystems in Oman (National Biodiversity Strategy & Action Plan 2001) under the auspices of the Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR) of the Sultanate of Oman aided by an initiative by the Government of Japan through the Japan International Cooperation Agency (JICA). Mangrove ecosystems provide a rich resource for both humans and the environment (Rehfisch & Holloway 2005, Holloway, Al-Kiyumi *et al*. 2006). An integral part of the Project is the creation of natural lagoons and a "nature trail" linked to the QEIC building proposed to be constructed at the Qurm Nature Reserve to provide facilities for the implementation of public awareness and education programmes for residents, visitors and tourists (JICA 2004).

1.2 Location

Qurm Nature Reserve lies within the municipality of Muscat on the Batinah coast of Oman, approximately 314 kilometres south of the border with the United Arab Emirates at Khatmat Malahah (see figure 1.1). It is surrounded on three sides by Muscat which has a population exceeding 1 million people and on the northern side by the Gulf of Oman (see figure 1.2).

1.3 Description of Site

The total area of Qurm Nature Reserve is 136 hectares of which tidal mangrove occupy an area of 74 hectares and 28 hectares of sabkha and sand dunes lie between 17 hectares of two tidal creeks which enter the reserve from the Gulf of Oman (see figure 1.3). The remaining habitat consists of pools lined with *Juncus*, an artificial brackish water 'scrape' and *Acacia* and *Prosopis* scrub (Kürschner 1986)

1.4 The provision of created natural wetlands and visitor facilities

Initially, as part of the proposed Qurm Environmental Information Centre a constructed artificial wetland was planned to help protect and secure the area from any further development pressures (JICA 2004). However, the constructed artificial wetland would have replaced much of the area of sand dune and sabkha in Qurm. This should be avoided if possible for the following reasons:-

a) The sand dune and sabkha habitats support a wide range of plants, invertebrates and birds and their survival would be threatened if a large part of the sand dunes and sabkha area is destroyed.
b) Sand dune and sabkha habitat is being destroyed elsewhere along the coast and it is important to retain examples of this habitat as part of the natural ecosystems at Qurm.
c) Qurm is a nature reserve and the protection of the extent of existing habitats is one of its most important functions.
d) Construction of a visitor centre and creation of wetlands should be carried out in an environmentally and ecologically sensitive manner to ensure that Qurm Nature Reserve is seen to be a demonstration of best practice for this type of development.

Following the re-assessment of the importance of the sand dune and sabkha areas, alternative areas are put forward for the provision of created wetlands at Qurm Nature Reserve but still within the initial proposed development area (see figure 1.4). Table 1 compares the strengths and weaknesses of the former proposed artificial lagoon against the new proposals described here for created natural lagoons.

1.5 Objectives for the provision of created natural wetlands and visitor facilities

The main objectives in providing created natural wetlands and visitor facilities at Qurm Nature Reserve relate to the provision of the Qurm Environmental Information Centre as detailed in the Objective of the QEIC Development Project (JICA 2004).

a) To provide created natural habitats including mangrove planting as a contribution to mangrove and coastal management and the study of coastal ecosystems.
b) To provide visitor viewing facilities, including created lagoons and observation hides, to a wide range of audiences for the implementation of public awareness and educational programmes.
c) To provide natural habitats for the environmental study of coastal habitats by a wide range of researchers and educators using QEIC.
d) To contribute to data collection and information dissemination for the QEIC as a centre for mangrove conservation in Arabia.
e) To provide staff training in the management, maintenance and monitoring of a nature reserve and mangrove conservation in coastal ecosystems.

1.6 Project components

The provision of created natural lagoons and a "nature trail" as part of the QEIC Development Project can be divided into 7 elements.

a) Creation of a natural lagoon with islands, water control sluices, connecting inlet ditch(es) to a mangrove creek and a mangrove planting area.
b) Creation of a freshwater pool with water control sluices and the provision of a fresh water supply.
c) Provision of a stone nature trail pathway linking the QEIC to created wetlands and observation hides which will also include a floating boardwalk section.
d) Siting of two observation hides.
e) Provision of planted mangrove as screening of one observation hide and as screening of created freshwater natural lagoons.
f) Provision of planted native tree species as screening of one observation hide.
g) Provision of information for displays in observation hides, nature trail leaflets and reserve information leaflets.

Figure 1.5 shows the elements necessary for the creation of natural lagoons and a nature trail on the Qurm Nature Reserve. It is important that the construction of these elements does not damage the important ecological features of the site and that they are compatible with the existing habitats of the site. The lagoons will be created in the lowest part of the site in front of the QEIC in the interface area between existing mangrove and sabkha. This area is already affected by tidal inundation and conversion to natural lagoons will not lead to a major change in the natural conditions of this area. Some existing mangrove will be incorporated into the natural lagoon and any loss of mangrove will be replaced by mangrove planting inside the natural lagoon and as screening in other parts of the development site. A small loss of sabkha will be replaced by sabkha-like habitat created inside the natural lagoon. The main area of sabkha and sand dunes will be unaffected by the creation of the natural lagoons.

The nature trail will consist of a stone path which utilises the interface between the sand dunes and sabkha without damaging the main area of these habitats and links in a circular route to the QEIC. The route will also allow access to the JICA nursery area and it will link to the circular footpath over a floating boardwalk through the mangrove. Full details of these elements are provided in the following sections.

2. WETLAND CREATION

2.1. Natural Lagoon

2.1.1 Objectives of the Creation of Natural Lagoon

a) To create a naturally operating natural tidal lagoon system
b) To provide nesting and feeding areas for breeding waders
c) To provide feeding and resting areas for passage and wintering waterbirds
d) To provide close views and a wildlife experience for a range of people visiting the nature reserve
e) To provide an area to be transplanted with mangrove seedlings to create additional mangrove

2.1.2 Description of Proposed Natural Lagoon

It is proposed that a 1.9 hectare natural lagoon be created in the low area lying between Ordnance Datum levels of 1.00 and 1.25 on the edge of the existing sabkha and existing mangrove in front of the proposed QEIC (see figure 2.1). The exact position of the proposed natural lagoon banking close to the proposed QEIC will be determined by the final design; thus the position of the centre and the positions of the various features shown in these plans and figures may have to be adapted according to the final design of the QEIC. Any plans for the re-positioning of the lagoon banks will have to be carried out prior to the start of the creation of the natural lagoon.

Any loss of mangrove caused by the creation of natural wetlands will be replaced by the planting of mangrove seedlings within the newly created natural lagoon to form new areas of mangrove (see figure 2.2 lagoon design). As well as being at a lower level than the main part of the sabkha area and thus within the tidal inundation zone (below Medium Water High Tides), the water table was shown in October to lie approximately at or just over 1 metre below ground level in this area (Fugro 2005 and see figure 2.3). The main elements of the natural lagoon are as follows:-

a) A 1.9 hectare irregular shaped natural lagoon created with shallow areas.
b) A number of variably sized islands within the lagoon will permanently be above water.
c) An inlet sluice to allow interchange of water between the Eastern Creek and the natural lagoon and with the ability to maintain water within the natural lagoon (see section 2.3 for sluice details).
d) Shallow and deep areas of permanent water to provide a range of conditions to help ensure that the lagoon is attractive to a range of birds and invertebrates (*eg* Rehfisch 1994).
e) Freshwater inlet from proposed freshwater pool to make it possible to manipulate the salinities of the natural lagoon.
f) The planting of mangroves to offset losses during construction and to provide an additional mangrove area as part of the Qurm mangrove objectives.

The lagoon needs to be of an irregular shape and depth to provide the maximum edge effect for a range of invertebrates and birds (Rehfisch 1994, Bamber *et al*. 2001). The majority of the lagoon will have shallow shelving depths to 60 centimetres with deeper areas to a depth of 1 metre (OD 0.0); this should ensure that some parts of the lagoon are within the maximum height of the existing water table. The ability to flood above this to a depth of +0.9 (Medium High High Water) using high tides through the installation of an inlet sluice will allow higher water levels to be held within the natural lagoon and thus to control water levels most of the year. It is also important to occasionally flush tides through the lagoon and back out again and this can also be achieved through the sluice system. See section 2.3 for further details on sluice management and operation.

Islands provide nesting habitat for waders that is relatively safe from terrestrial predators and human disturbance. The islands also need to be irregular in size, height and shape to provide the variety of microhabitats that help attract a diversity of birds and plants. The top of the islands should lie above 1 metre OD, which is above Medium High Water tides, and they should have shelving sides. Shallow slopes to the islands and the natural lagoon banks will reduce the effects of wave borne erosion. However, it may still be necessary to use stones along some of the island edges to reduce such erosion. The erosion levels will have to be monitored regularly and there may be a need for the periodic replenishment of protective stones.

The ability to reduce salinities is also very important to stop hypersaline conditions developing (Bamber *et al* 2001). Therefore the construction of an adjacent fresh water pool linked through a sluice to the natural lagoon is very important (see 2.2). In addition the use of tidal flushing will also help to reduce the risk of hypersaline conditions developing. Flushing involves flooding the lagoon with a series of very high successive tides, and then letting the very salty water flow out. It is likely that evaporation will be at its highest when temperatures are at their highest during the summer and salinities will increase at this time within the natural lagoon. This makes access to freshwater necessary if suitable conditions for invertebrates and birds are to be maintained throughout this hot period.

2.1.3 Method of construction of Proposed Natural Lagoon

The shape and size of the proposed natural lagoon, the islands and position of the sluices is shown in figures 2.2, 2.3 and 2.4. Excavation should be carried out by at least two earth-moving machines, a bulldozer and a Hymac (or similar machine). The exact position of the islands and banking nearest to the QEIC building will depend on the final design of the QEIC building.

The bulldozer should be used very carefully to ensure that it does not damage the surrounding habitat. The movements of the bulldozer when creating the natural lagoon are represented diagrammatically in figure 2.4.

The Hymac will help widen the lagoon and will help construct the connecting creek that will be used to bring in tidal water to the created lagoon. The Hymac should always travel along the existing creek within the mangrove to minimise damage to the environment. It is likely that a period of about 5 days will be required to carry out the work necessary to create the natural lagoon and the connecting creek. The Hymac will also be required to excavate the banking to install the sluices as well as to carry out various other tasks relating to the overall project (see later sections). Careful advance planning is necessary to ensure the optimal use of this expensive equipment.

The work to create the natural lagoon should be carried out when the local breeding birds are not nesting and when tidal cycles are at their lowest between June and September.

2.1.4 Operation of the Proposed Natural Lagoon

The highest tides in the tidal cycle do not vary greatly through the year; therefore it is possible to let tidal water into the natural lagoon throughout the year. Water levels should be kept at a high level through the spring and summer to help protect any nesting birds on the islands from ground predators. Water levels can then be dropped for the autumn and winter to provide feeding areas for passage and wintering species of birds (Rehfisch 1994). At this time of the year it may be possible to let tidal water in and out during each tidal cycle and set the outside extension pipe at a lower level.

2.2 Freshwater Pool

2.2.1 Objectives of the Creation of Freshwater Pool

a) To create a freshwater pool and to provide a supply of fresh water to it.
b) To provide nesting and feeding areas for species of birds and insects that may not use the natural lagoon.
c) To provide additional habitat for freshwater plants such as *Phragmites* and *Juncus* that are presently found at Qurm
d) To provide a source of freshwater to supply and control salinities on the created natural lagoon.
e) To provide an educationally very useful pond-dipping area for school children visiting the QEIC.
f) To provide a source of freshwater to help establish planting of *Acaccia* and screening of natural lagoon

2.2.2 Description of Proposed Freshwater Pool

We propose creating a small freshwater pool of approximately 0.2 hectares close to the QEIC as shown in figure 1.5. The exact size, position and proximity to the QEIC of the pool will depend on the final design of the QEIC building. The freshwater pool will be viewed from the QEIC building. To minimise disturbance to wildlife, access to the pool will be restricted to staff for management purposes, and to researchers and school children on specific dates.

The pool will be of irregular shape with a single sluice pipe connecting it to the created natural lagoon to allow fresh water to be let into the natural lagoon when required. Vegetation associated with freshwater sites in the area will be encouraged to grow. A pond-dipping platform will be constructed at the lagoon edge closest to the QEIC building to allow access for researchers, students and school children to carry out projects associated with freshwater pools, including pond-dipping.

2.2.3 Method of Construction of Proposed Freshwater Pool

The banks of this small pool will follow the 1.00 – 1.25 OD contour. It should be dug by the Hymac and at the same time the sluice can also be put in by the Hymac. A supply of freshwater will have to be provided from the QEIC. It may be possible to recycle some of the water used in the QEIC into the freshwater pond by planting reed *Phragmites australis* and *Juncus rigidus* to act as a filter. Another possibility would be to recycle all water directly from a sceptic tank system serving the whole QEIC building, into the freshwater pool, if such a system is considered for the QEIC building.

2.2.4 Operation of the Freshwater Pool

The freshwater pool should be kept at as high level as possible throughout the year by the provision of a regular supply of freshwater. The freshwater pool holds approximately 1 million litres of water but once filled, it will just require the regular input of relatively small amounts of freshwater through the year.

2.3 Sluices

2.3.1 Objectives of the Provision of Sluices

Sluices are to be constructed for the following purposes:-

a) To facilitate the flooding of the created natural lagoon by the high tides of the tidal cycle.
b) To stop a rise in salinities by flushing high tides into and out of the natural lagoon.
c) To allow the natural lagoon to be drawn down if required.
d) To provide a connection through a sluice to a freshwater pool to allow freshwater to be input into the natural lagoon to stop salinities from rising too high.

2.3.2 Sluice design

It is proposed that rigid plastic pipes be used to provide the sluice on the created natural lagoon, and that a flexible pipe be used for the created freshwater pool.

A set of three pipes will be used for the main inlet sluice connecting the created natural lagoon to the main creek in the mangrove; the tidal waters and high tide waters used for flushing the lagoon will arrive though this sluice (see figures 2.5 and 2.6). Twin walled, 225 mm diameter rigid pipes should be used; these are usually supplied in lengths of 4 metres. Right-angled collars for 225 mm diameter rigid pipes should be used to provide the bend and a small section of rigid pipe can also be connected to the outside of the bend to extend the pipe up to the proposed water level for the natural lagoon (see figure 2.5).

A single flexible pipe will be required for the sluice between the freshwater pool and natural lagoon. The ends of the pipe can be physically lifted above the required water levels for the natural lagoon and freshwater pool to stop water running from one waterbody to the other (see figure 2.7).

The natural lagoon sluice must be sited at or slightly below the OD 0.0 metres level to facilitate flooding on the cycle of high tides. To help ensure a watertight structure, clay should be used as a base for the sluice. The excavation of the sluice area should be deeper to allow the placing of this clay base, and also the clay bank section, to house the sluice pipes.

2.3.3 Operation of the natural lagoon sluice

The right angle section and extension pipe on the outside of each sluice needs to be in an upright position to hold the maximum level of tidal water inside the natural lagoon (see figure 2.6). Water is let on to the natural lagoon by twisting the outside pipe slowly sideways and down so that the pipes are lower that the outside high tide level to allow tidal water to flow into the lagoon.

If it is necessary to let water out of the lagoon then the outside extension pipe can be removed or twisted around so that its exit is lower than the level of water inside the lagoon.

2.3.4 Operation of the freshwater pool sluice

The normal position of the flexible pipe on the freshwater pool will be above the existing water levels inside the freshwater pool. However, the flexible pipe can be lowered by hand when it is necessary to let fresh water into the natural lagoon (see figure 2.7).

3. PROVISION OF VISITOR FACILITIES

3.1 Nature Trail

3.1.1 Objectives of the Provision of a Nature Trail

The provision of a nature trail is aimed at providing an excellent visit experience. The nature trail directs visitors to certain key features of the Qurm Nature Reserve linked to the displays and facilities at the QEIC.

a) To provide an all weather footpath for use by all visitors including wheelchair access from the QEIC to features of interest on the site.
b) To provide easy access to the main places of interest on the site and thus provide visitors with experience of the mangrove and tidal creeks, the mangrove nursery, the natural lagoon, the JICA nursery lagoon and the sabkha linked to the bird observation hides.
c) To provide an easy to use circular route of limited distance to encourage as many people as possible to use the nature trail.
d) To use boards, nature trail signs, and other methods to disseminate information to the users of the nature trail and the observation hides.

3.1.2 Route of the nature trail

It is proposed to use the nature trail to link the QEIC building with the main features of the site (see figure 3.1). The exact position of this nature trail, particularly the link to QEIC, will be determined by the final position of the QEIC building.

The main features linked by the nature trail are the QEIC building, the JICA mangrove nursery, an arm of the mangrove through which a floating boardwalk or boardwalk bridge will be made, a wooden bird observation hide overlooking the lagoon near the JICA nursery, the sabkha area, a stone-built bird observation hide overlooking the created natural lagoon and a return link to the QEIC (see figure 3.1).

3.1.3 Design of the nature trail

The nature trail will be built using similar bricks to those used on the pavements in the area (see figure 3.2). The nature trail path will be smooth enough and wide enough to allow wheelchair access along its whole length.

The nature trail from the QEIC to the JICA mangrove nursery should be at existing ground level. A wooden floating boardwalk (see figure 3.3) or wooden boardwalk bridge through an area of mangrove will be a major feature of the walk between the JICA nursery to the proposed wooden bird observation hide. This boardwalk will give close views of the actual mangrove. The trail will then skirt around the edge of the sand dunes and along the edge of sabkha to the wooden bird observation hide. Along this section the edge of the JICA nursery lagoon can be excavated slightly to provide conditions suitable for mangroves to be planted to screen the area between the nature trail path and the nursery lagoon (see figure 3.1). Here the path can be kept lower than ground level and some spoil used to raise the banks on either side of the path. This should help further hide people using the nature trail and limit disturbance to wildlife (see figure 3.4a).

The nature trail path will then pass between the edge of the sabkha and the edge of the sand dune system to a stone bird observation hide overlooking the created natural lagoon. On this return section of the nature trail to the QEIC, again the path will be sunk below ground level, will have raised spoil banks on each side, and will be further hidden by the planting of native shrubs and trees between the nature trail and the created natural lagoon (see figure 3.4b).

3.2 Observation hides

3.2.1 Objectives of the Provision of Observation Hides

To provide close views of birds and two lagoons without disturbing birds that may be using the created natural lagoon and the JICA nursery lagoon.

Two observation hides are proposed:-

a) An 8 metre by 2 metre wooden bird observation hide on legs and constructed on the edge of the JICA nursery lagoon to view the lagoon.
b) An 8 metre by 2 metre stone and concrete bird observation hide to view the created natural lagoon.

The proposed positions of the two hides are shown in figure 3.1. Their exact position will need to be determined on site when plans are finalised for the exact route of the nature trail.

3.2.2 Design of Wooden Bird Observation Hide

The hide specialist of the UK can provide the design plans for the wooden bird observation hide, including the type of wood required and full specifications. The hide will not require windows and the viewing slots will be open as rain is infrequent and unlikely to affect the inside of the hide. Open slots will improve ventilation in the hot weather of Oman. A cooling system based on natural airflow may have to be incorporated into the design. A bay for wheelchair access will be incorporated into the design (see figure 3.5 for an example of hide design).

3.2.3 Siting of Wooden Bird Observation Hide

The wooden observation hide will be placed on a base of wooden legs sunk into the edge of the JICA nursery lagoon. These legs need to be tanalised and treated with preservative before being set into concrete drums. The specialist bird hide builder in the UK can supply full details if provided with detailed requirements.

3.2.4 Design and Siting of Stone Bird Observation Hide

The stone bird observation hide will be placed on a concrete base and set into the bank of the created natural lagoon. The lagoon banks on each side of the hide will be built up to screen the approach to the hide. The design of this hide will be based on an existing stone-built bird observation hide already in operation in Oman and like the wooden hide it will have open slots for windows to provide natural air flow for ventilation.

The full design for the hide can be provided and the design will include a bay for wheelchair access.

3.2.5 Access to bird observation hides

Access ramps will need to be constructed to allow wheelchair access to both hides. A wooden access ramp will need be built for the wooden hide as it will need to traverse a small section of intertidal mud. The brick nature trail can be extended on to a sand ramp to gain access to the stone observation hide.

3.3 Pond-dipping platform

The provision of the pond-dipping platform on the freshwater pool is for the use of visiting researchers and in particular for pupils from schools. Pond-dipping is an excellent educational activity that is widely used all over the world.

The design of a pond-dipping platform is a simple extension from the boardwalk design and full details can be provided if the proposal to build one is accepted. Rather than wood it is possible to use recycled plastic with the appearance of a dark grained wood to make a pond-dipping platform. Figure 3.6 shows two designs of pond-dipping platforms.

3.4 Provision of Information on the nature trail

Information dissemination on the nature trail can be carried out in a variety of ways including:-

a) Information leaflets available at the QEIC
b) Information posters in the observation hides.
c) Nature trail information posts.
d) Listening posts and audio tapes.
e) Video cameras linked to the QEIC.

Examples of the types of information boards and nature trail signs can be provided.

4. MANGROVE AND SHRUB PLANTING

4.1 Mangrove planting

Two types of mangrove planting are proposed. One planting fulfils the major objective of providing an experimental mangrove plantation within the created natural lagoon. The second mangrove planting will help screen the freshwater pool, the nature trail footpath, the JICA nursery lagoon and the proposed wooden hide.

4.1.1 Experimental mangrove plantation

An experimental mangrove plantation plot is proposed for an area within the created natural lagoon (see figure 2.2). Where mangrove will be planted, it will be necessary to establish the amount of spoil to be removed in relation to the water depths intended for the natural lagoon and the tidal regime that will be established. In conjunction with advice from JICA, the guidelines that have been produced for the creation of tidally irrigated mangroves will need to be consulted and applied to the proposed mangrove plantation within the created natural lagoon (see Technical Guideline for Afforestation in JICA 2004).

4.1.2 Provision of mangrove screening to the nature trail and wooden observation hide

It is proposed to screen by planting mangroves the nature trail path leading to the wooden hide that will overlook the existing Nursery Lagoon. This will require a small amount of excavation (linked to the construction of the nature trail path) by a Hymac machine that will extend the edge of the existing Nursery Lagoon closer to the nature trail (see figure 4.1). This will provide the required depth for the tidal flooding that allows the natural transplanting of mangrove seedlings (Hogarth 1999, Rehfisch &. Holloway 2005). The exact technical requirements will be established by reference to Technical Guideline for Afforestation (JICA 2004) and consultation with JICA officers carrying out mangrove planting in Oman. As mangrove seedling growth is of 20-40 cm per year (Mr Tomoo Shoji pers. comm.) temporary artificial screening may be used until the natural screening is sufficiently tall (see figure 4.2 for example of reed screen).

4.1.3 Provision of mangrove screening to the created freshwater pool

A further area of mangrove planting can be carried out to screen the freshwater pool from the boundary and main road by extending an existing area of mangrove. Some excavation will be required to provide the required depth in relation to tidal levels and the exact planting requirements established by reference to Technical Guideline for Afforestation (JICA 2004). As for 4.1.2, temporary artificial screening may have to be used to allow the screening mangroves to grow sufficiently tall.

4.1.4 Provision of tree screening of path to hide looking over the natural lagoon

To avoid disturbance to the created natural lagoon by people using the nature trail and stone bird watching hide it is proposed that native trees and shrubs be planted in the area between the nature trail and the natural lagoon (see figure 3.4b). The details of how to prepare the area will be dependent on the tree and shrub species to be planted. Highly salt-tolerant species in the Poaceae (Graminae) and Cyperaceae families that grow in Qurm will be used and species such as A*cacia tortilis* and *Prosopis cineraria* will require freshwater irrigation to help establish them in less than ideal conditions. As for 4.1.2, temporary artificial screening may have to be used to allow the screening mangroves to grow sufficiently tall.

5. SUPERVISION OF CONSTRUCTION OF WETLAND AND NATURE TRAIL

5.1 Supervision of wetland creation.

The work detailed above requires supervision by a manager or consultants who have extensive experience of wetland creation. The proposal may need to be modified in light of conditions on the ground resulting from the final design of the QEIC building and also during the wetland construction period. The exact position and size of the QEIC building may mean that the size and position of the created natural wetlands may have to be realigned. Ground conditions may require additional work to ensure sluices are watertight. The information obtained on soil sediments, for example, are not as complete as one would wish when planning the creation of wetlands. Supervision of the movement of spoil is required to ensure that surrounding habitat is not damaged during the construction of the natural wetlands. The height of the islands may have to be modified by further information on water levels and the ability to successfully hold water within the natural lagoon. An experienced wetland manager will be able to monitor the work as it is carried out to ensure that it is carried out efficiently and cost-effectively. The cost of errors could be important.

5.2 Supervision of nature trail construction.

The siting and construction of bird observation hides, boardwalks and the nature trail path also require to be supervised by a manager or consultants who have experience of bird hide and nature trail construction. In particular the exact location of the hides may be influenced by factors that only become apparent once digging starts. The exact route of the nature trail needs to be more accurately mapped on the ground taking account of contours in the existing habitat. The design, size and position of either a floating boardwalk or boardwalk bridge need to take into consideration the distance of mangrove and creek to be crossed. Many of these decisions will be taken after more detailed examination of the exact locations selected for the construction of the structures.

5.3 Further consultation on mangrove planting and the provision of native trees.

Further research and survey is required to establish the work needed to prepare the proposed mangrove and tree plantation areas that are intended to be inside the created natural wetland. The conditions inside the created natural lagoon will be slightly different from existing mangrove plantations in Oman and careful consideration is required to ensure their success in consultation with the expertise now becoming established by JICA and the overall mangrove project.

6. OPERATION AND MANAGEMENT: AFTER CARE MANAGEMENT

The after-care of the new habitats should be detailed in an Operation and Management Manual. Experienced consultants should develop the manual, and the routine implemented by an experienced site manager or the consultants.

6.1 Natural lagoon

After construction of the natural lagoon further management may be required to maintain the islands and control unwanted invasion of vegetation. Bank erosion is a possibility and remedial action such as the provision of stone sides to the bank and islands may have to be considered. The gentle slope of the bank sides should help to reduce the effect of wave action but this needs to be monitored.

6.2 Freshwater Pool

The introduction of native plants species into the pool may be considered, in particular the reed *Phragmites australis.*

6.3 Wooden Observation Hide

Maintenance of the wooden bird observation hide will be required. Usually water based preservatives are used for this purpose.

6.4 Mangrove and tree plantations

After care of mangrove should follow the Technical Guideline for Afforestation (JICA 2004). Watering of trees and shrubs planted to screen the stone bird observation hide may need to be carried out.

6.5 Floating/Bridge Boardwalk

Maintenance of the boardwalk using a water-based preservative will be necessary as will be occasional repairs. If a floating boardwalk is to be constructed, leaking floats will need to be replaced.

7. OPERATION AND MANAGEMENT: MONITORING

The regular monitoring of the success of the scheme should be detailed in an Operation and Management Manual. Experienced consultants should develop the manual, and the routine implemented by an experienced site manager or the consultants.

7.1 Natural Lagoon

Monitoring of the natural lagoon will be required to provide information for ongoing management. Salinities need to be monitored at least fortnightly to determine whether freshwater needs to be used to reduce salinities.

Water levels also need to be monitored regularly to determine how high to set the inlet pipes to allow continued flooding by the high tide cycles.

7.2 Freshwater Pool

Water levels need to be monitored to establish whether additional freshwater is required to maintain water levels. Monitoring of possible algae blooms needs to be carried out and remedial action taken should such blooms occur.

7.3 Long term monitoring

A programme of research and long term monitoring of the lagoons, mangrove plantation, bird assemblages, invertebrate communities, and other fauna needs to be established to take advantage of a very fine resource. The research should then be carried out by a combination of Qurm staff, researchers and students, and for basic work, provide school children with an introduction to scientific research.

8. CONCLUSIONS

Almost worldwide mangroves are in retreat as a result of over-exploitation, pollution and climatic change.

With intelligent and informed management, such as is being developed in the Qurm Nature Reserve by the Government of Oman, it is possible to maintain mangroves as a valuable natural resource, managed for sustainable exploitation. The Qurm Nature Reserve has the major advantage of being in the centre of the large city of Muscat that has excellent local and international communication links. Paying visitors should help offset the running costs of the educational centre and could even contribute towards the programme of mangrove expansion throughout Oman and the Middle East.

Equally important, the location of the Qurm Environmental Information Centre presents Oman with an ideal opportunity to develop a strong focus in applied marine research. This could be achieved through cooperation on national research programmes with Sultan Qaboos University but also through the development of international research initiatives with overseas institutes. The QEIC could act as a lead institute promoting research into those subjects most relevant to the economy and protection of the marine environment of Oman. Research initiatives may certainly include improved fisheries management, the development of sustainable aquaculture programmes, the evaluation of marine biotechnology resources, the management of endangered marine species and the promotion of well managed eco-tourism.

In combination, the QEIC, the nature trail, the natural lagoon, the freshwater pool and the rare birds found at the Qurm Nature Reserve (Holloway, Al-Kiyumi *et al*. 2006) should help ensure that the Qurm Nature Reserve becomes a particularly attractive educational and recreational resource for Oman and its visitors.

Acknowledgements

Special thanks are due to the Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR), the Ministry of Environment of the Sultanate of Oman and the Government of Japan through the Japan International Cooperation Agency (JICA) for having facilitated the project. Thanks are due to Mr Ali Al-Kiyumi, Mr Tomoo Shoji and to Dr Barry Jupp for much useful advice.

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Table 1 Strengths and weaknesses of two options for lagoon creation

Option 1 Creation of 8 hectare artificial lagoon and nature trail

Strengths	Weaknesses
Lagoon creation instead of urbanisation of area	Large area of natural sabkha destroyed
Depth allows greater tidal exchange	Large area of natural sand dunes destroyed
Large body of water attractive to winter ducks	Lagoon not ecologically fitted to existing site
Mangrove plantation created	Lagoon constructed on highest ground
Excess spoil used for levelling of QEIC site	Higher ground requires deeper excavation
Little damage to existing mangrove area	Water table much deeper below ground
Spill-over system requires less maintenance	Large amount of spoil generated
Viewable from QEIC	Retaining wall 3 metres above ground
Regular tidal flushing keeps salinities level	Large water body and waves cause erosion
	No islands for nesting birds
	Footpath close, leading to danger of disturbance
	Concrete construction is not ecological
	No shallows for wide range of birds/invertebrates
	No control of water levels
	Many tidal exchanges bring more silt
	Effect of storm flooding uncertain
	No freshwater source other than from creeks
	Salinity levels may increase to hypersalinity

Option 2 Creation of 1.9 hectare natural lagoon and nature trail

Strengths	Weaknesses
Utilises low ground that is already tidal	Some loss of mangrove
Water table closer to surface	Person required to operate sluices
Less requirement to excavate as deep	Effects of storm flooding uncertain
No major loss of sabkha area	If water table low, levels low in summer
No major effect on sand dune systems	Less spoil available for QEIC site levelling
Mangrove plantation created to offset losses	Wave action can erode islands
Sluices to control water levels	Sluices may not be watertight
Less tidal exchange and less silting	Salinities may rise despite freshwater input
Islands for nesting birds	
Freshwater source to reduce rise in salinities	
Variable depths for range of invertebrates	
No footpath around so less human disturbance	
Screened observation hide to avoid disturbance	
Most spoil used for banking and islands	
Retaining banks not as high	
Viewable from QEIC and closer than Option 1	
Footpath system less disturbing to whole site	
Footpath system utilises low ground	
Additional viewing provided by second hide	
Floating boardwalk feature through mangrove	
Water levels can be dropped if water level high	

Figure 1.1 Qurm Nature Reserve, Muscat, Oman located in black rectangle.

Figure 1.2 Qurm Nature Reserve, Muscat, located in white rectangle.

Figure 1.3 Main habitats of Qurm Nature Reserve

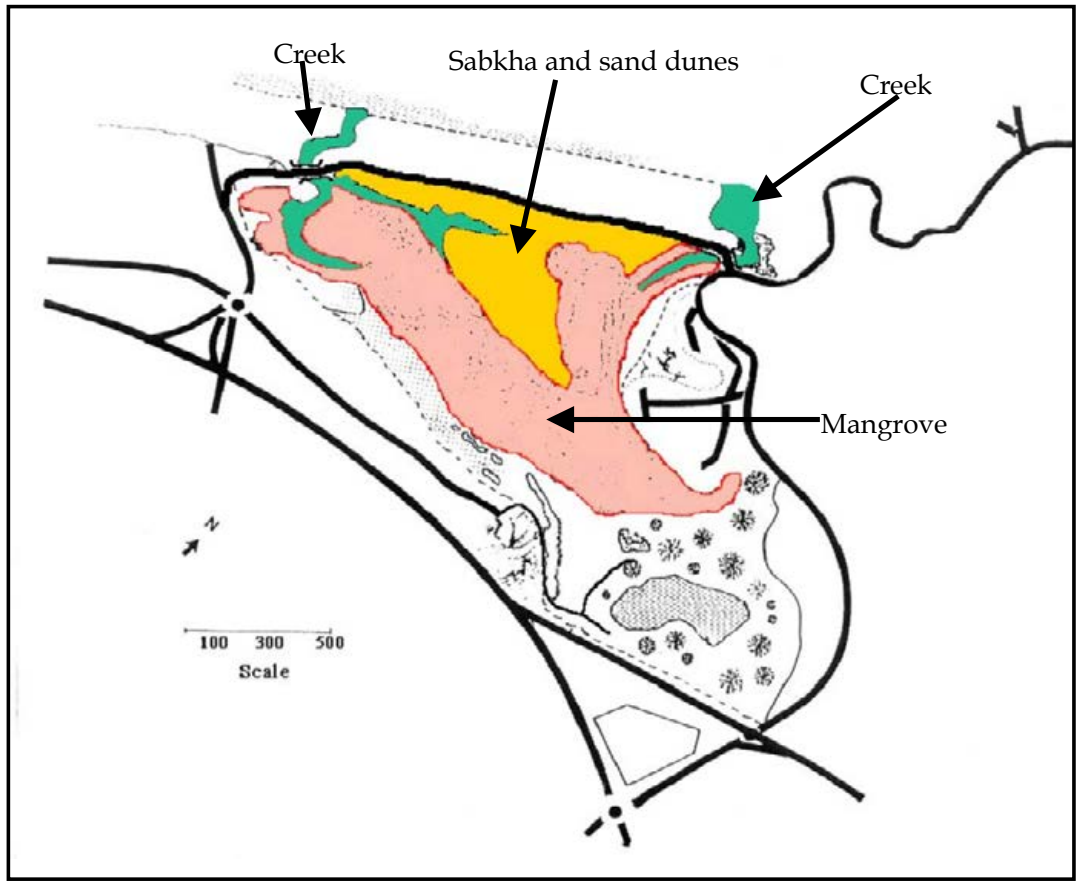


Figure 1.4 Proposed QEIC and area of proposed lagoon creation and nature trail

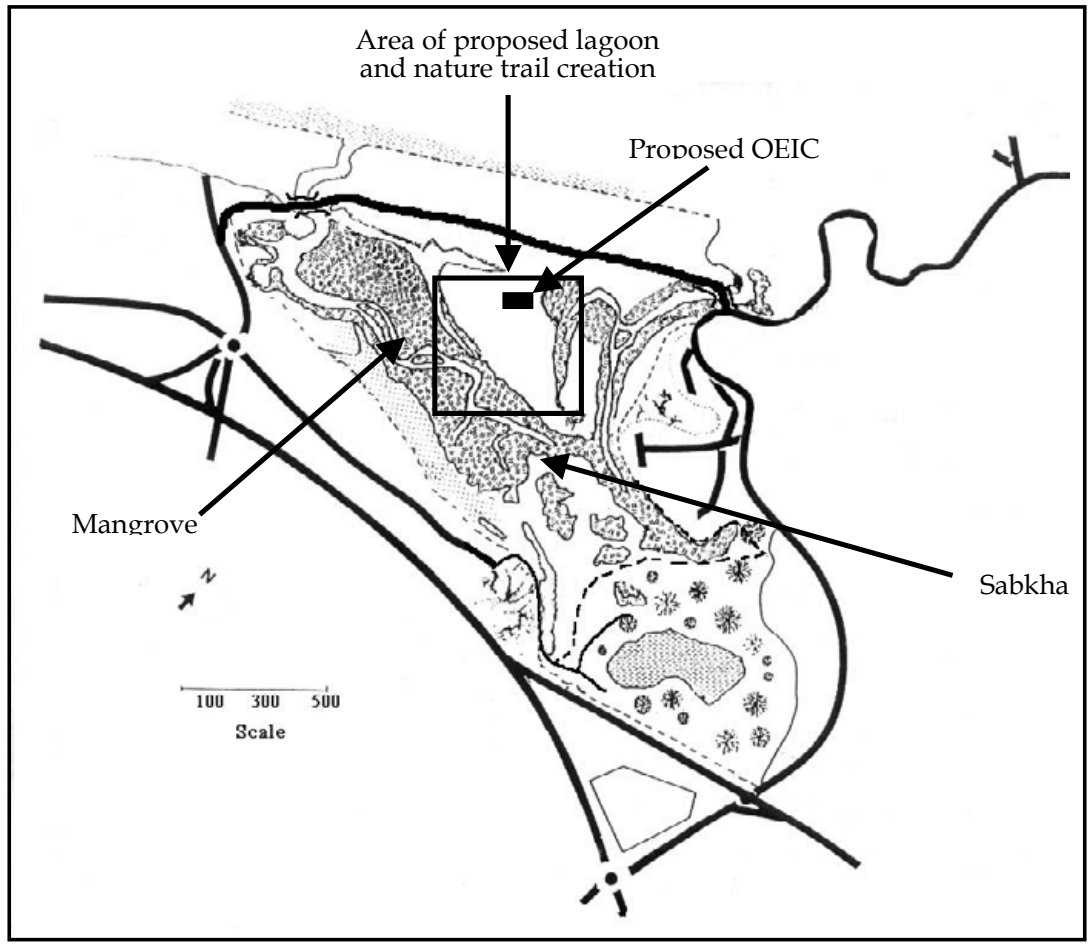


Figure 1.5 Plan of proposed natural lagoons and nature trail

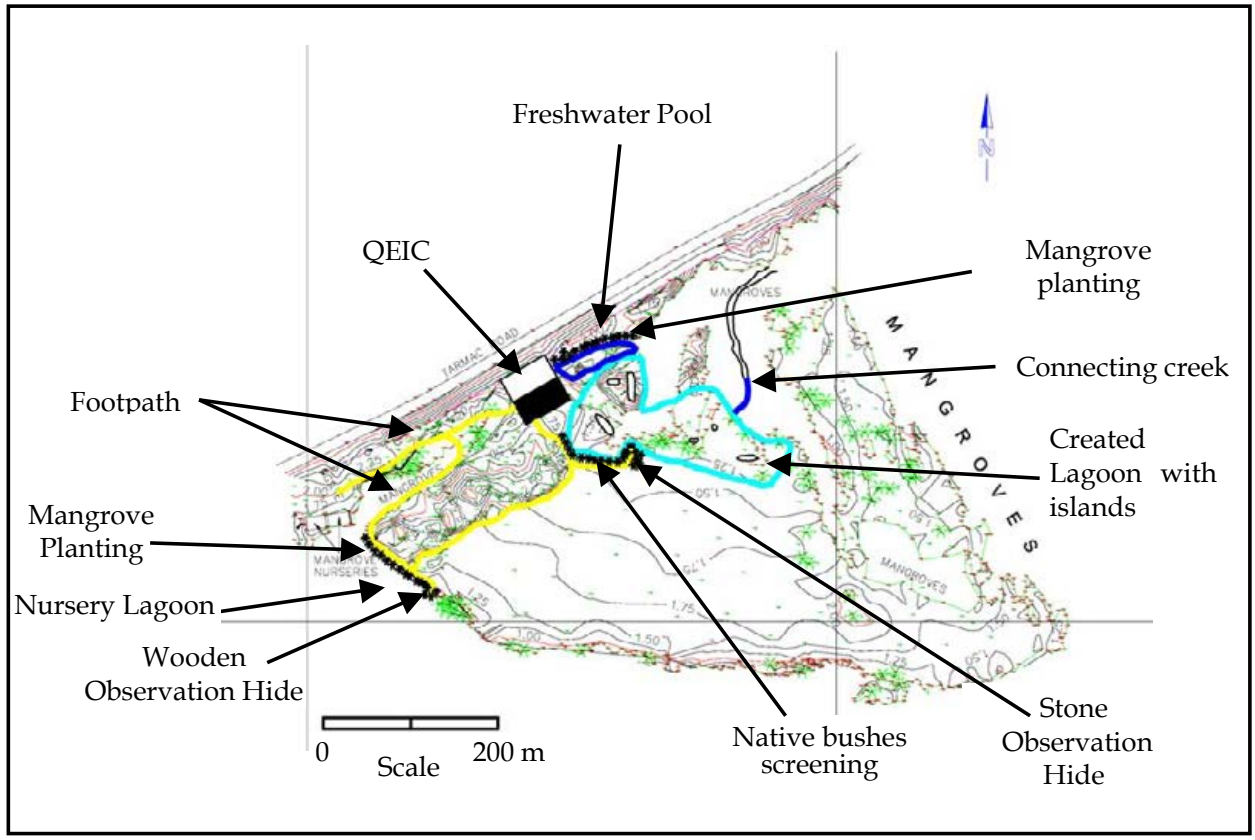


Figure 2.1 Site of construction of natural lagoon

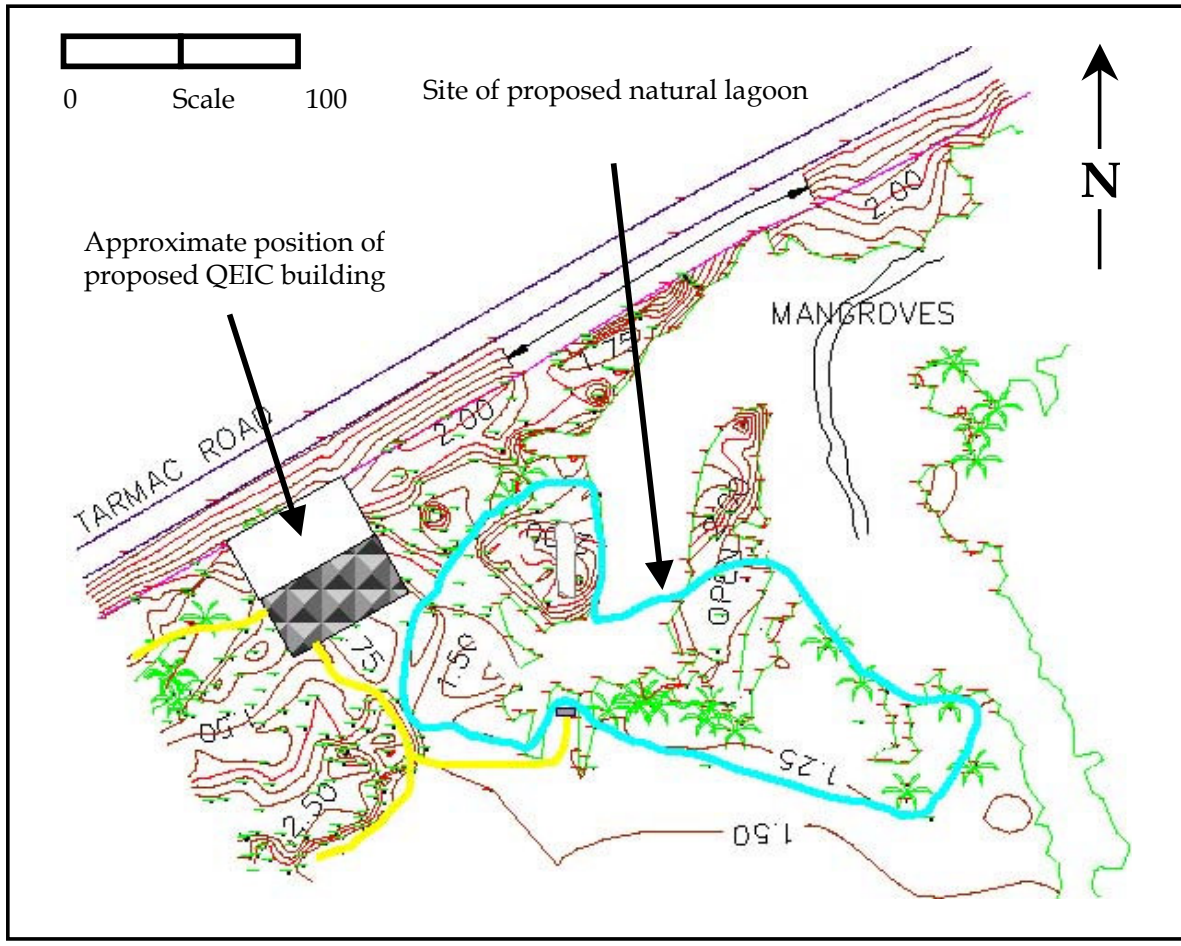


Figure 2.2 Plan of construction of natural lagoon

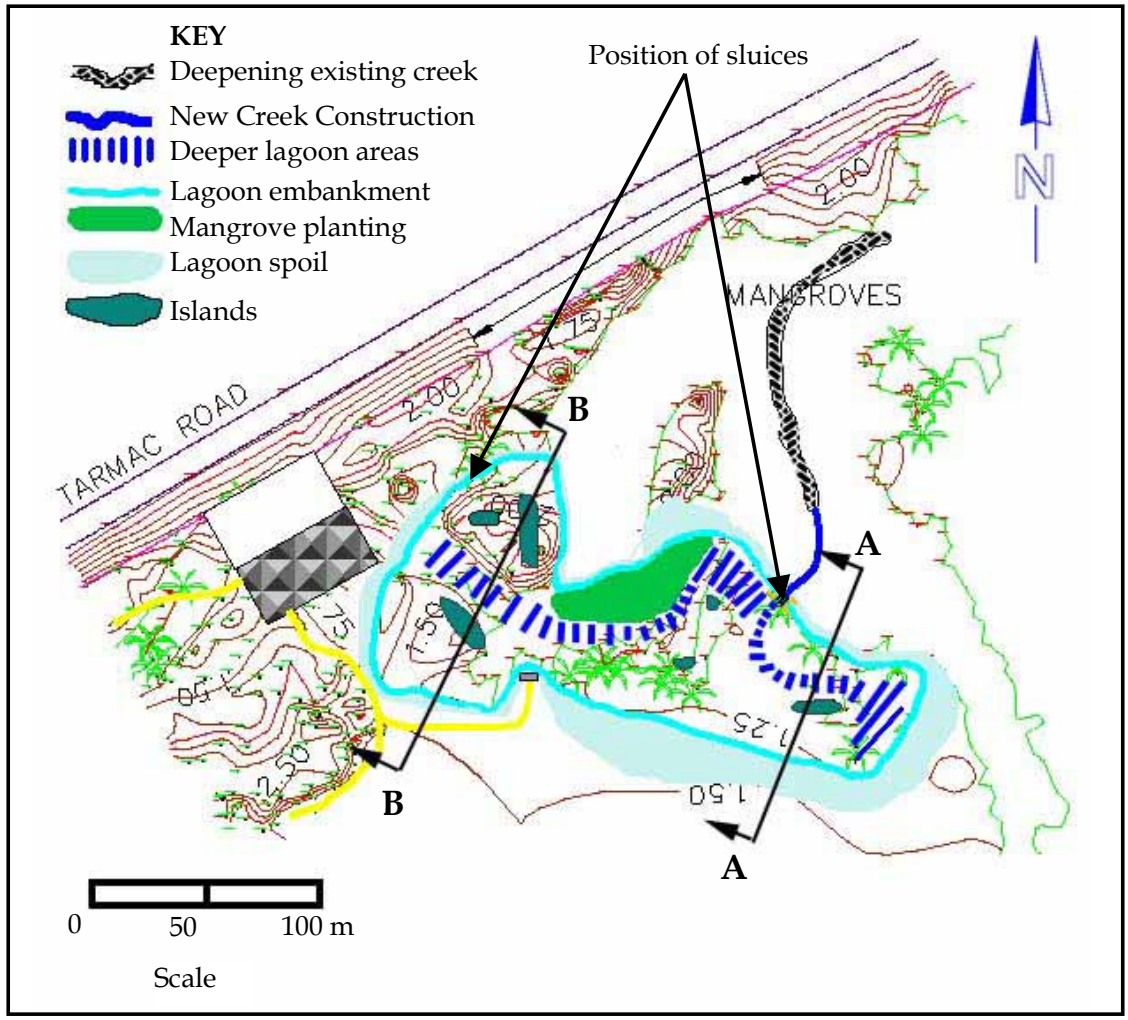


Figure 2.3 Section plans of constructed natural lagoon. See Figure 2.2 for location of sections.

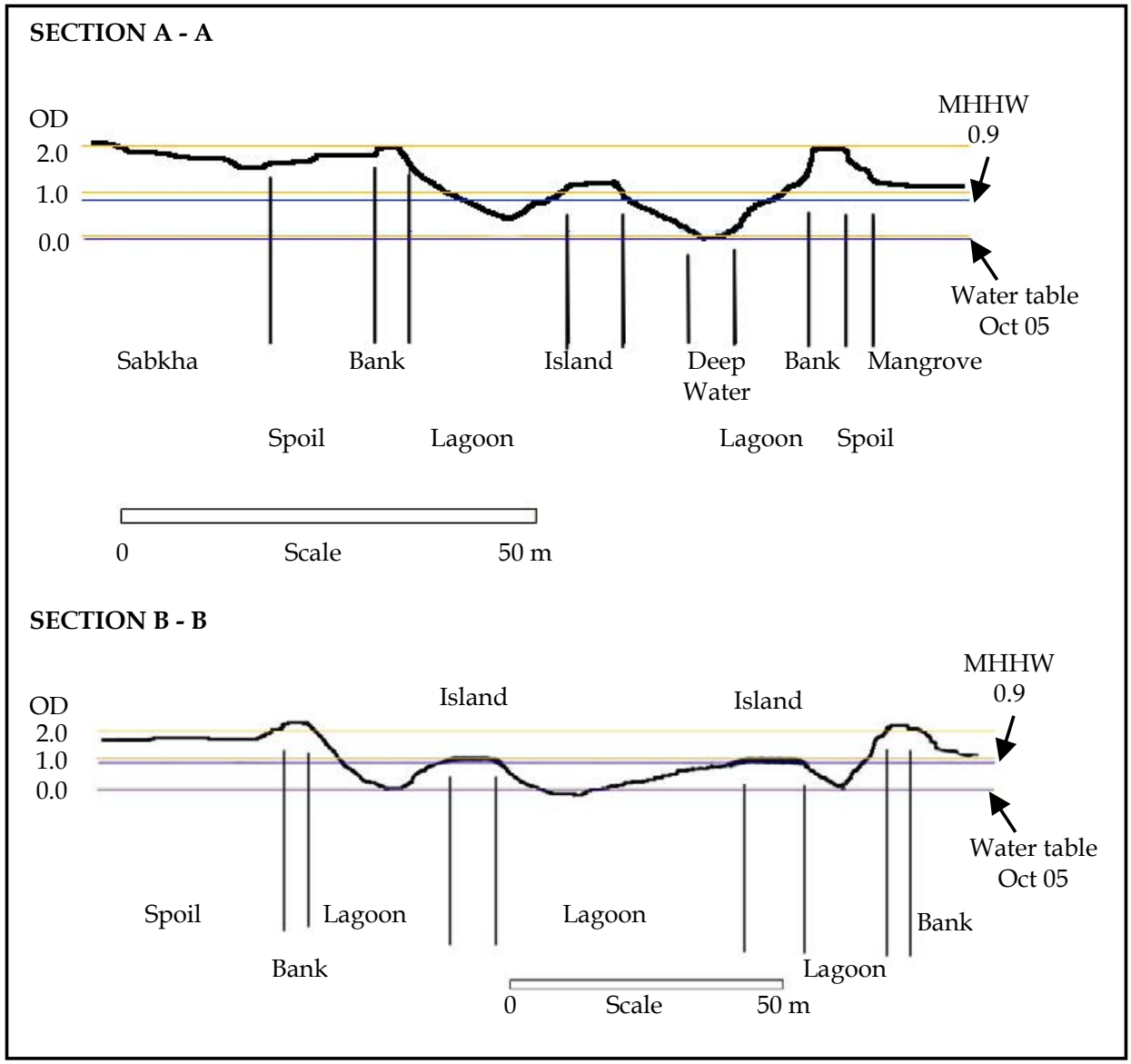


Figure 2.4 Movement of spoil needed for the construction of the natural lagoon, its islands and its deeper areas. Arrows show the direction of spoil movement by bulldozer.

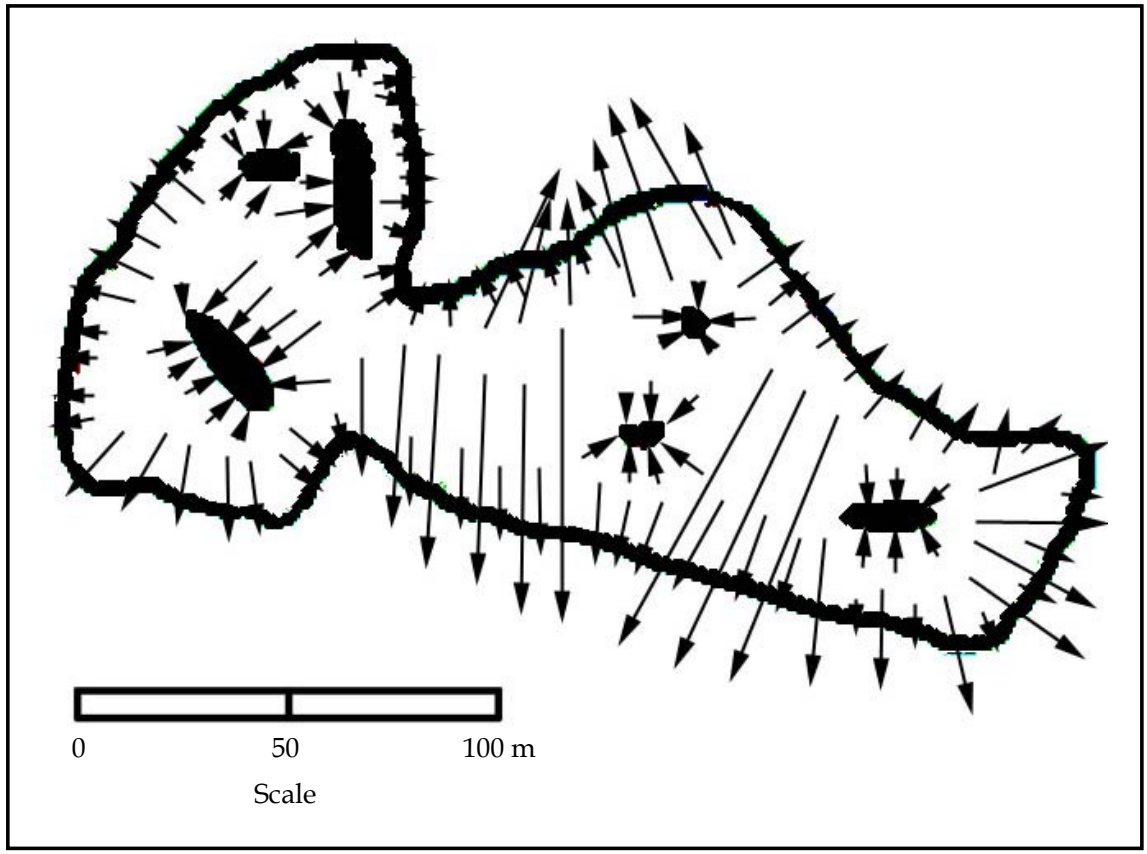


Figure 2.5 Design of the sluice system for the created natural lagoon / freshwater pool. (a) Example of three pipe sluice for inlet to natural lagoon, and (b) section through a basic sluice design to show how it can control water levels.

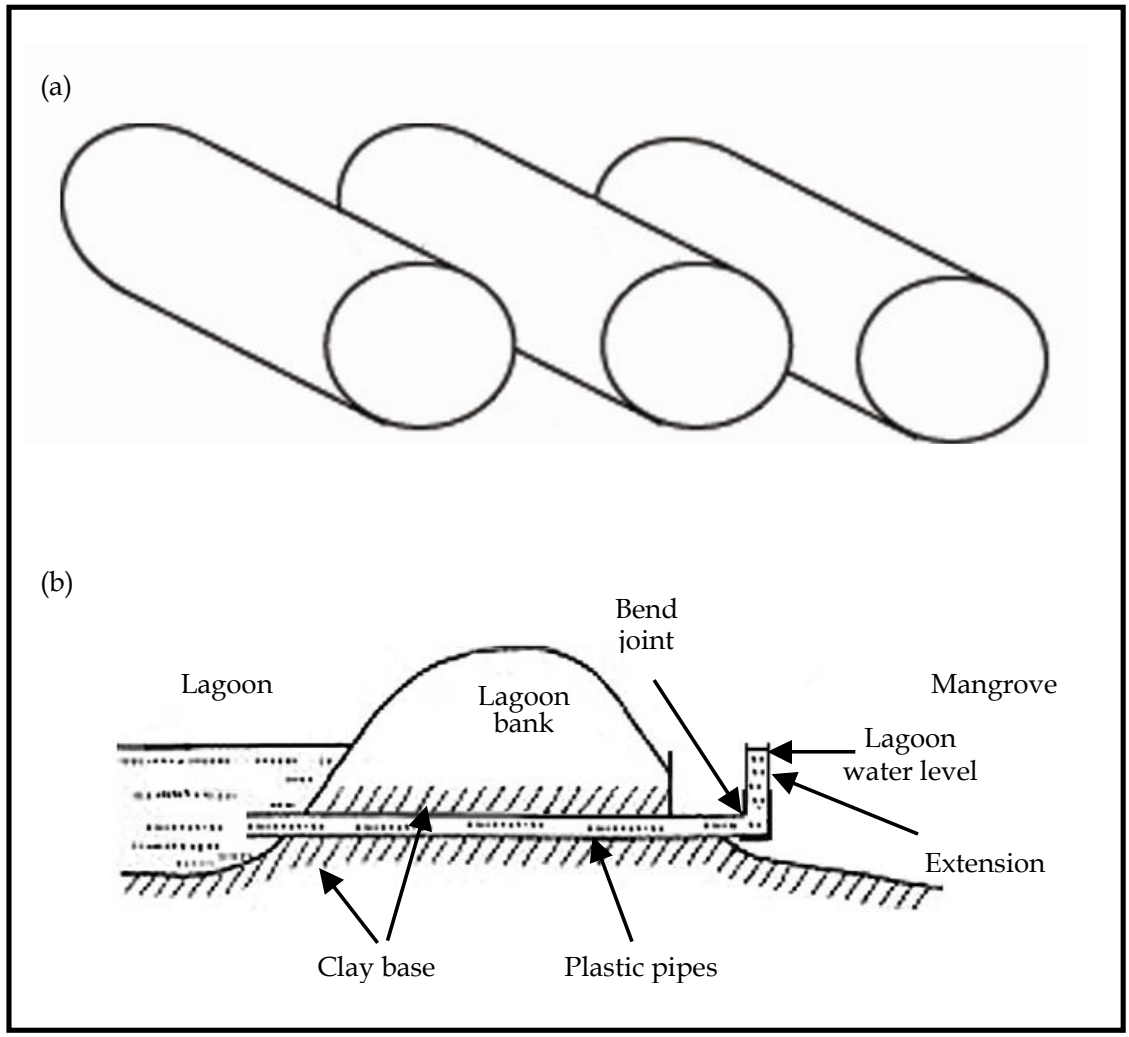


Figure 2.6 Example of sluice system

Figure 2.7 Design and operation of flexible pipe system

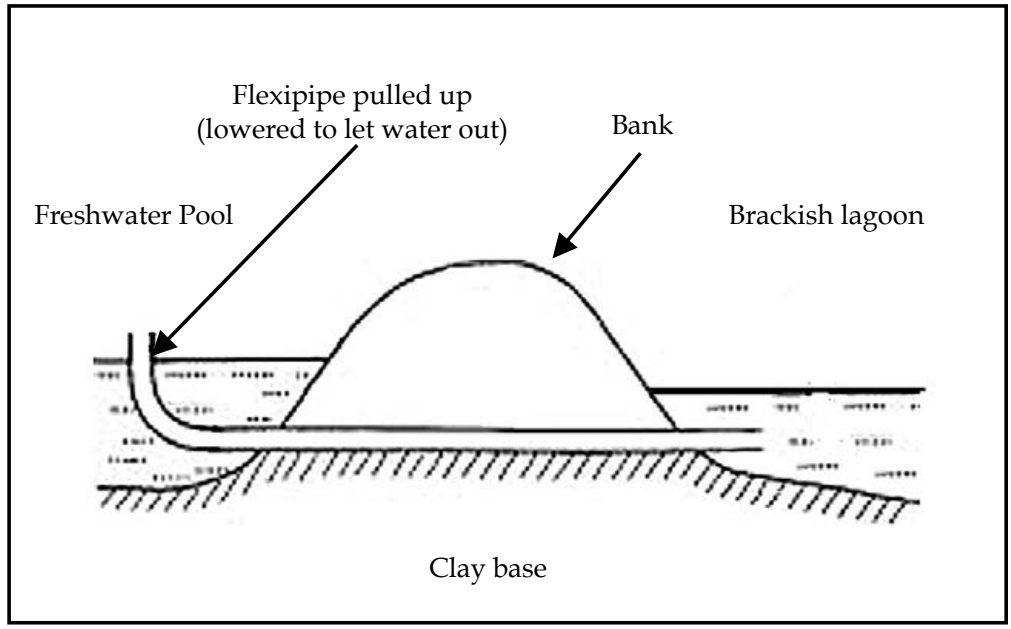


Figure 3.1 Design of Nature Trail. Section A refers to Figure 4.1.

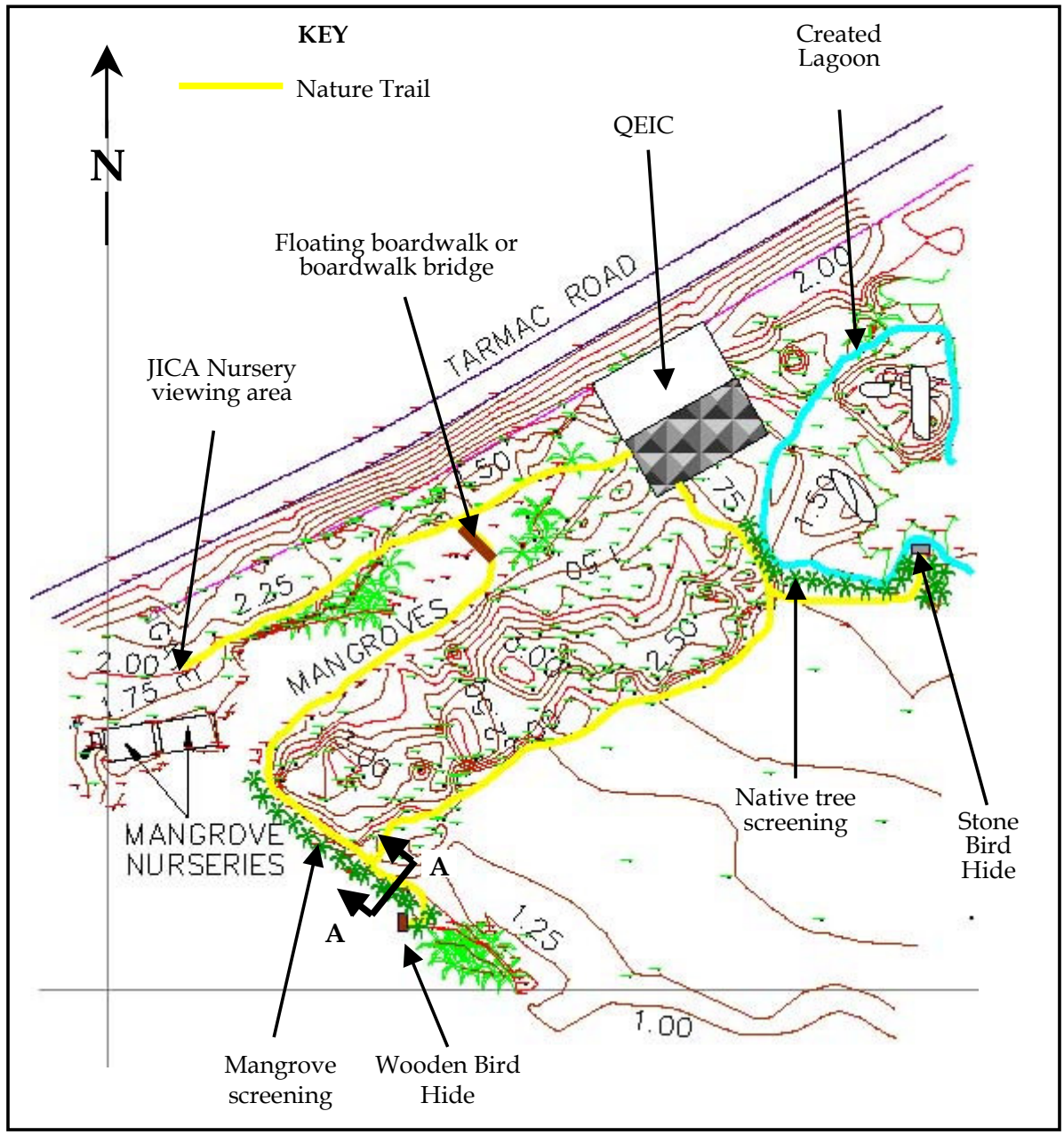


Figure 3.2 Design of Nature Trail path.

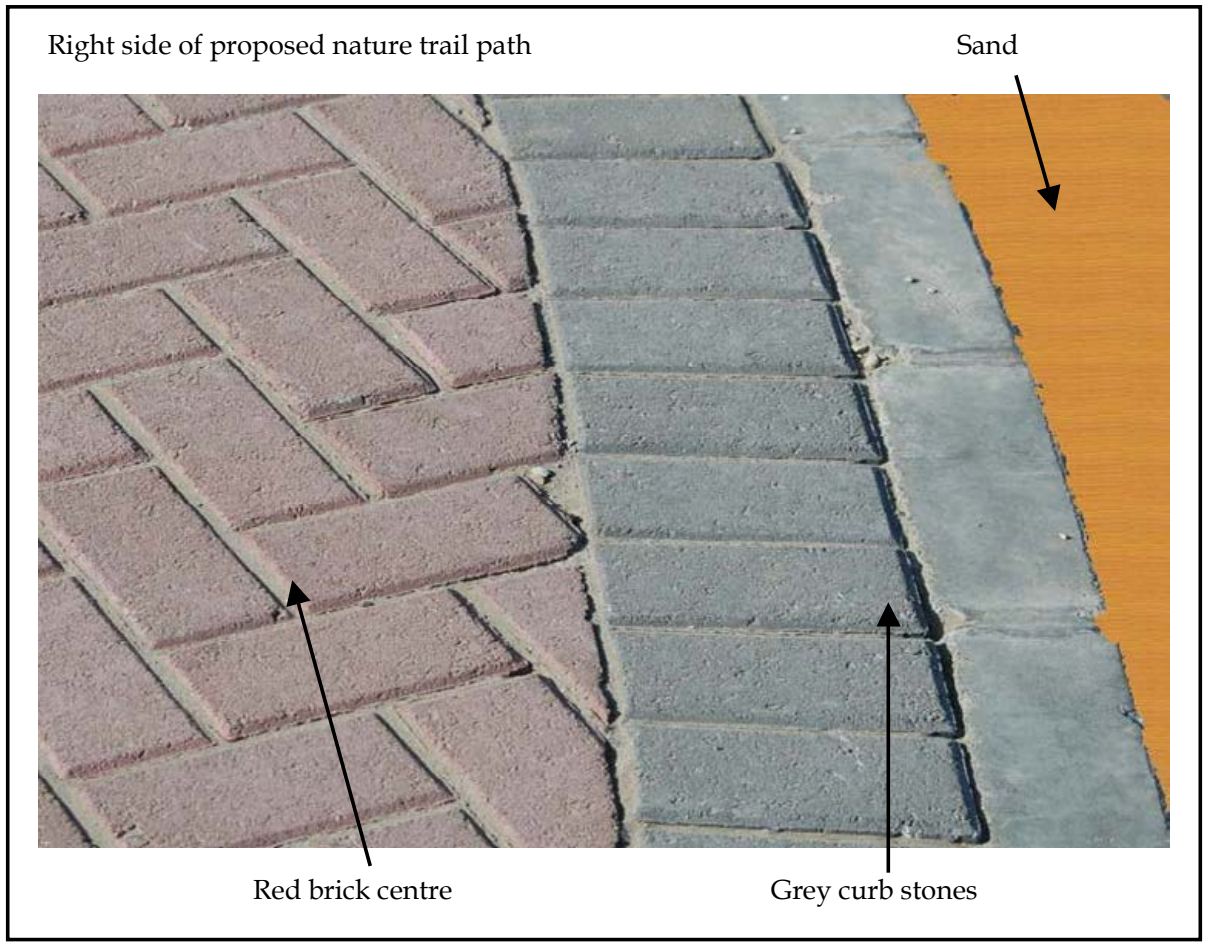


Figure 3.3 Example of a floating boardwalk through mangrove

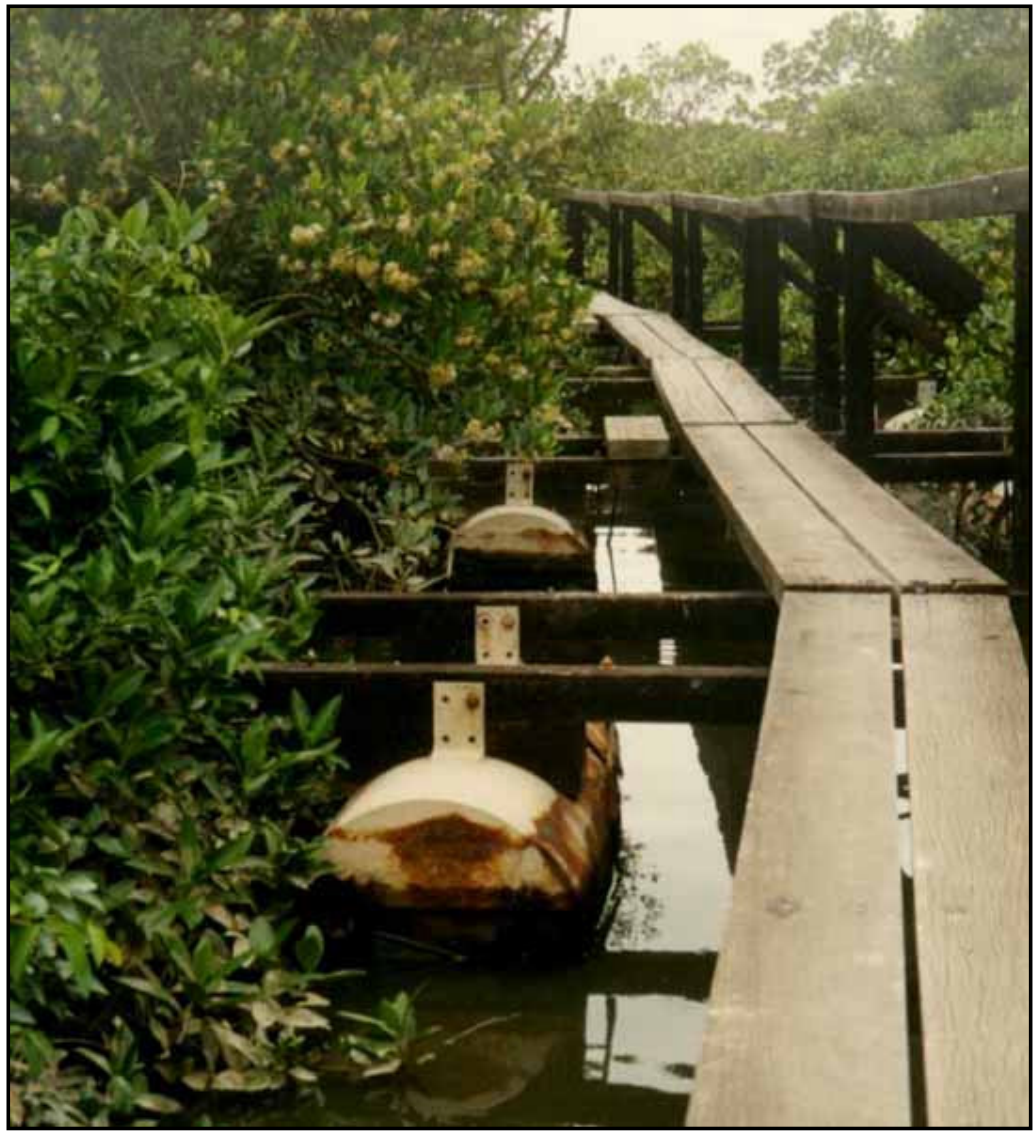
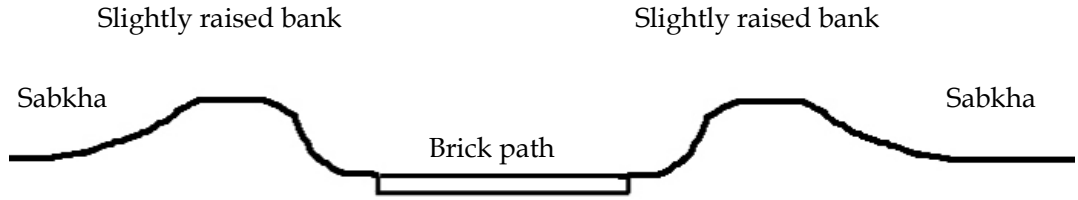


Figure 3.4 Design of Nature Trail path (a) when crossing the sabkha, and (b) when adjoining the created natural lagoon

(a)



(b)

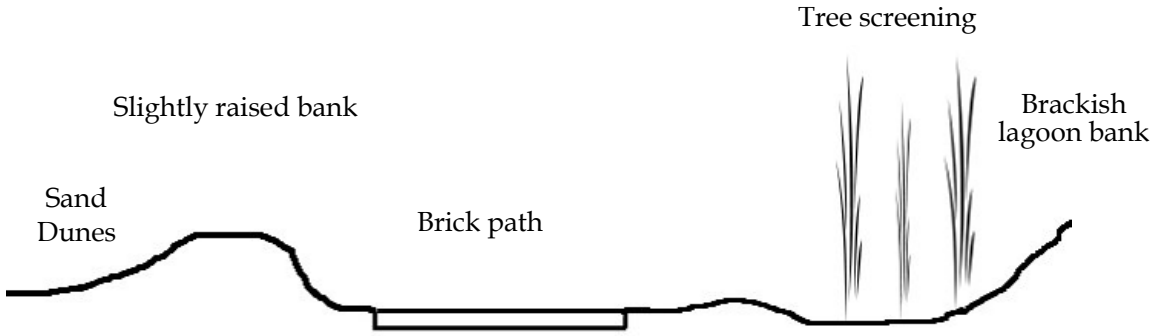


Figure 3.5 Diagrammatic example of a basic hide design

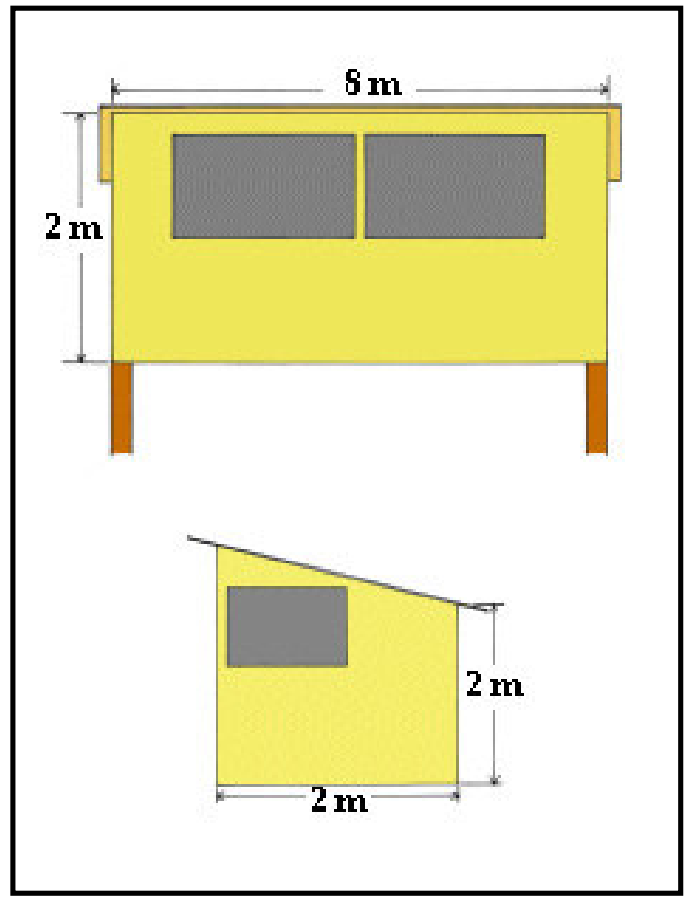


Figure 3.6 Examples of Pond-dipping Platforms

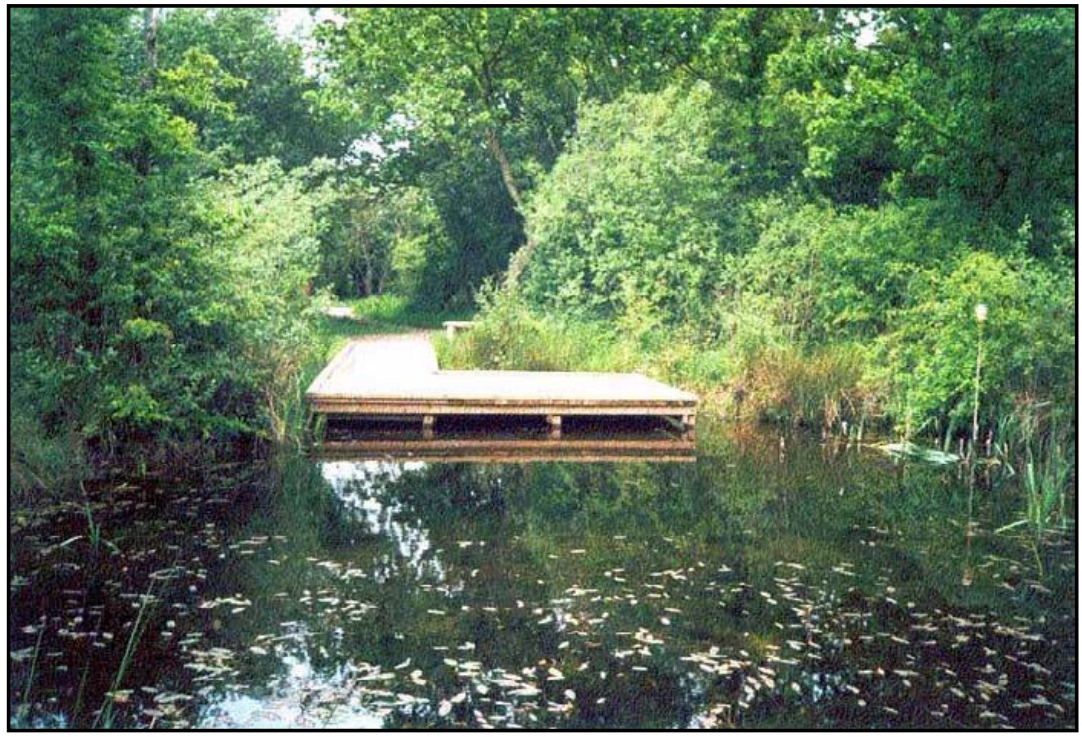


Figure 4.1 Design of mangrove planting beside JICA Nursery Lagoon. See Figure 3.1 for location of Section A – A.

Section A - A

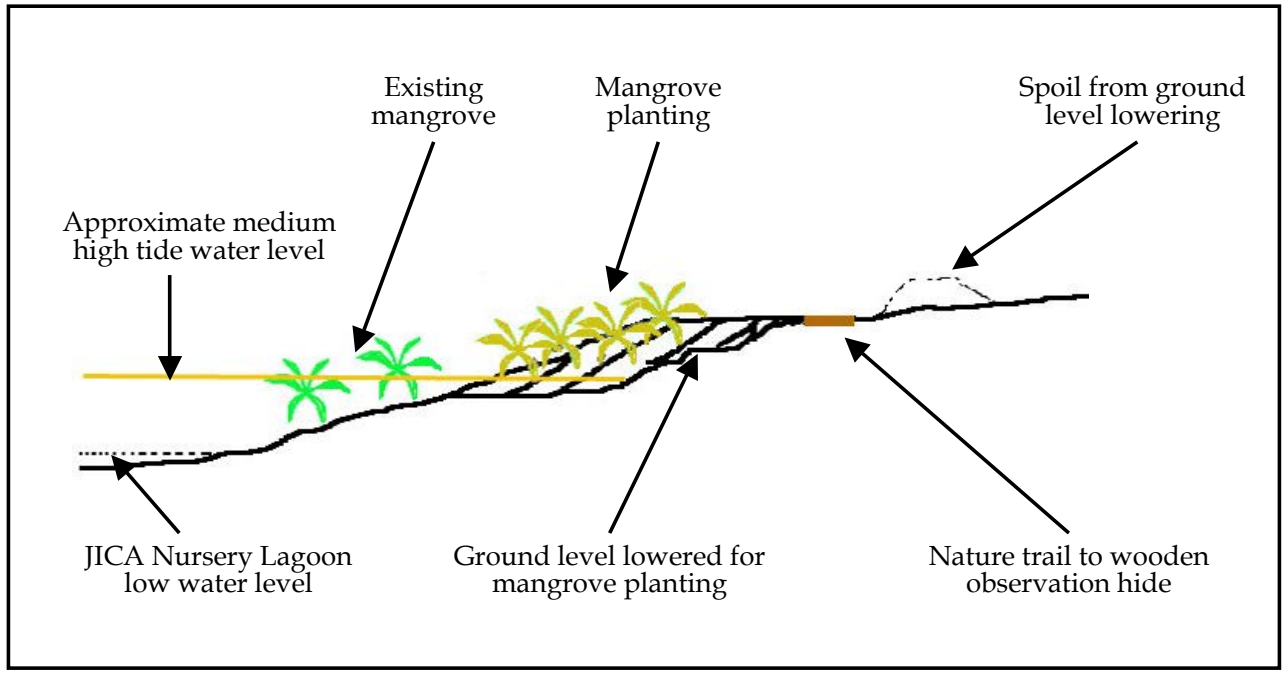


Figure 4.2 Example of temporary reed screen