Feasibility study for commercial underwater marine viewing facilities in Western Australian marine conservation reserves

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Abstract

This project investigated the feasibility of constructing underwater viewing facilities in marine parks in Western Australia. Existing structures in the world and their success were examined. An underwater observatory will attract many more visitors to the marine park to experience the spectacular underwater marine environment. The observatory will be used by people of all ages and all levels of mobility and will generate revenue to assist with the management of the park. Educational groups will be able to learn and study the marine life in their natural environment and not in an artificial aquarium.

The construction of a bridge or jetty out to the site of the observatory is required, unless one is already present. Construction of the observatory will be completed off site and towed to the location. The seafloor will need to be cleared, avoiding damage to the surrounding environment, to create a level site for the observatory. Reinforced concrete piles will be driven into the seabed and a concrete slab poured around and over the tops of the piles to form a level base that will support the observatory. Windows on the outer wall will enable marine life to be viewed from within.

The study established that construction of an underwater observatory will benefit and assist in the management of Western Australian marine parks.
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1.0 INTRODUCTION

1.1 Problem description

The beauty and uniqueness of underwater life in Western Australian marine parks and reserves, is currently only appreciated by divers and snorklers. Tourism only generates a small amount of revenue toward the management of these parks and reserves. Determining an appropriate and environmentally sensitive design for an underwater viewing facility is the primary objective of this feasibility study.

1.2 Affected parties

1.2.1 Government Agencies

The Federal, State and local government are important affected parties because of their potential for funding towards the project.

1.2.1.1 Department of Conservation and Land Management (CALM)

CALM is responsible for the management of all marine conservation reserves. A specialist Marine Conservation Branch has been established within CALM to address major issues of conservation. The Marine Conservation Branch provides policy, strategic and scientific advice for marine conservation and management, and advises marine reserves planning teams (CALM 2000).

1.2.1.2 The Marine Parks and Reserves Authority

The Authority is responsible for supervising the development of the marine reserve policy and management plans. It is also required to oversee the implementation of these by CALM.

1.2.1.3 Fisheries of Western Australia

Fishing in marine reserves is under the jurisdiction of Fisheries Western Australia
1.2.1.4 Department of Transport

All boating regulations, marker buoys, moorings and jetties are the responsibility of the Department of Transport.

1.2.1.5 Environmental Protection Authority (EPA)

The Environmental Protection Authority assesses, reports and makes recommendations on proposals that may significantly affect the marine environment (CALM 2000). The Department of Environmental Protection assists the EPA with these processes.

1.2.2 Private Sector

Donations from the private sector are another potential source of funding through business and corporate sponsorship. The services of certain private contracting companies and equipment suppliers will also be used.
2.0 CURRENT SITUATION

2.1 Observatories Types
There are currently many underwater observatories situated around the world. There are two types of observatories. The first must be built in a pristine environment where the water is clear and there is an abundance of life. To enter these observatories you must cross over a bridge and once inside experience marine life in their natural habitat.

The second type of observatory can be built at any sea front location. The idea of this observatory is that you view the marine life in a large tank whilst revolving around in underneath an acrylic tunnel. This observatory is not relevant to this study, as it is not situated in the open marine environment.

2.2 Marine and Coastal Ecosystems in Western Australia

Western Australia is blessed with a long and varied coastline, extending for 12 500km and hosting an amazing array of marine flora and fauna. The major marine ecosystems represented in Western Australia, are briefly classified into nine categories.

2.2.1 Saltmarshes
Saltmarshes are a coastal wetland usually found in temperate regions (latitudes above 30°). Mangroves dominate the associated shore lines in tropical regions (latitudes lower than 30°). However, mangroves and saltmarshes overlap and coexist in the subtropical/warm-temperate zone between latitudes 30° and 35° (CALM 1994).

Due to limited areas of freshwater inflow, saltmarshes are poorly developed in Western Australia. Depending on their level of maturity, saltmarshes may provide important habitat for birds, fish and invertebrates.
2.2.2 Rocky Shores

Rocky substrates of the littoral zone are of particular interest because the phenomenon of vertical zonation is pronounced (CALM 1994). The habitats of many of the animals and plants that live in this region are restricted to a narrow area around the shore.

2.2.2.1 Southern Western Australia

Two different types of rocky shores are found in the southern part of the State. Southward from Cape Naturaliste, granitic rock is dominant. This tends to weather into reasonably smooth slopes in areas exposed to heavy wave action, or forms boulder zones where the wave action is not as severe.

On the west coast, offshore limestone reefs have developed profiles that are very different to those of granitic shores. For the majority of the time rock platforms of such shores are covered by water however when the tide falls, they may quickly become bare and exposed to air and sunlight.

Lower in the intertidal zone, grazers such as limpets and chitons, are dominant. However, where there is a sufficient period of immersion, sessile filter-feeders like barnacles, mussels and tubiculous polychaete worms also establish distinctive zones (CALM 1994). In the mid-tidal zone, leafy green, brown and red algae and crabs appear.

2.2.2.2 Northern Western Australia

In the north of the Western Australia, the tidal range is generally larger than in the south, wave action is less severe, and there is a much greater variety of animal species (CALM 1994).

Littorinid and siphonarian grazers characterize the supra-littoral, the highest zone. In the upper and middle littoral zone, animals such as Saccostrea, Brachidontes, Lithophaga and Lithothyra can be found.
2.2.3 Seaweed-Kelp Beds

Shoreline and offshore reefs in temperate regions support a diversity of algal species, which form an important component of rocky shore and sublittoral ecosystems, (CALM 1994). A seaweed-kelp bed is a distinct ecosystem formed from dense algae.

A large biomass of detrital material is produced from the high biomass of plants and sessile animals, and the high productivity of the plants in the bed. This detrital material is found on the sea floor between the reefs and the shore and is deposited on the shore in large drifts, after storms. The decomposition and mechanical breakdown of drift material produces dissolved organic matter, and results in the release of plant nutrients and suspended particulate material into the water column (CALM 1994).

In southern Western Australia, the most abundant alga is the kelp *Ecklonia radiata* that, in many places, forms a complete cover from 2m to about 14m depth. Competitive interaction between the kelp and corals is a significant feature of this Western Australian ecosystem.

2.2.4 Seagrass Meadows

Seagrass is a flowering plant able to permanently live in the marine environment. Seagrass meadows in Western Australian cover immense areas of the seabed. The seagrass communities of southern Western Australia, from Shark Bay to the South Australian border, are possibly the most extensive in the world (CALM 1994). The largest seagrass beds are located in the open coast. They are situated in positions protected by offshore reefs. In southern Western Australia, bays protect the seagrass.

Seagrass usually occurs shallow, sand-silt, soft-bottom habitats. It can extend from the mid-intertidal zone to depths greater than 50m.

The reliability and productivity of seagrass communities are maintained through trophic interactions within seagrass communities and between associated ecosystems, such as mangroves or coral reefs. The total community represents a rich and highly dynamic food chain, which
sustains resident and migratory marine animals and birds (CALM 1994). Turtles and dugongs found in the north are consumers of the seagrass.

2.2.5 Coral Reefs

Coral reefs are found throughout the tropics and subtropics, usually between 30°N and 30°S, and are confined to regions where the annual mean water temperature is greater than about 18°C (CALM 1994). Coral reef systems are typically found in waters with low nutrient concentrations, as excessive nutrient loads can be harmful to the survival of coral.

Reef-building corals occur in water less than about 50m in depth. In water depths of less than 20m maximum growth will occur. This illustrates that the depth that light can penetrate in sufficient quantities, to maintain metabolism by zooxanthellae, is important in determining where optimum growth occurs. However, optimum coral growth also depends on temperature and salinity and will occur at 25-29°C and at normal ocean water salinity.

Reef-building coral species can be found along the entire coast of Western Australia, from the north Kimberley to the Great Australian Bight. There is however, an obvious reduction of species from the north to the south.

A wide variety of coral reef types are found along the tropical and subtropical coasts of the State (CALM 1994). Coral reefs are developed only as far south as the Houtman Abrolhos. Five coral reef provinces may be recognized in Western Australian coastal waters:

1) Platform reefs on the Sahul Shelf
2) North West Shelf shelf-edge atolls
3) West Kimberley and Pilbra fringing reefs
4) Ningaloo Reef
5) Houtman Abrolhos

2.2.6 Southern Estuaries

Southern estuaries are all partially enclosed coastal waters into which rivers flow. At one time or another, they are open to the sea. They do not however include coastal lakes that never open.
In southern Western Australia, estuaries are extremely variable in structure, hydrology and biology. Estuaries in the northern part of the State, however, are dominated by mangal habitats and are therefore classified as mangals.

Hydrologically the estuaries of the South West are seasonal estuaries. The estuary water alternates between nearly fresh in winter and brackish, marine, or hypersaline in summer-autumn (CALM 1994). The extreme rainfall and river flow, obstructing entrance bars and a small tidal range cause this. The hydrological and ecological status of the estuaries depends on how often the bars are penetrated. Three categories are documented:

1. Permanently open estuaries
2. Seasonally open/closed estuaries
3. Semi-permanently closed estuaries

There are usually extensive areas of shallow sand and mud flats and deeper water mud basins, but most estuaries have limited areas of natural solid substrates except in riverine parts (CALM 1994). Macrophytes are important substrates for epiphytes and fauna (CALM 1994). In the estuaries, which are permanently open, there may be development of extensive seagrass beds. The diversity of species within an estuary is predominantly related to the salinity regime, as massive mortality of fish and benthic fauna can occur when the water becomes hypersaline.

2.2.7 Mangals (Mangroves)

Mangrove communities grow along the edges of brackish and seawater shores, and occur in the intertidal zones. They consist of plants such as trees and shrubs, and are able to colonise waterlogged and saline soils (CALM 1994).

Competition from other plants is minimizes by saltwater inputs. The availability of silt and terrestrial sediments provides nutrients and substrates for the mangroves (CALM 1994). Extensive flora and fauna are associated with mangroves. Adult and juvenile fish frequently migrate to the mangroves, from offshore ecosystems to feed and seek shelter during their growth (CALM 1994).
2.2.8 Tidal Flats
Tidal flats occur predominantly in the coastal zones on northern Western Australia. This is where the tidal range is usually moderate to high. They consist of mud flats, sand flats, rock pavements and boulder or pebble flats and pavements (CALM 1994).

Tidal flats are generally temporary sinks for detritus. The detritus is transported into the system from adjoining areas such as mangals, samphire flats, or offshore seagrass meadows (CALM 1994). A variety of fish and invertebrates use tidal flats also function as nursery grounds for their young. Shallow water and tropical conditions promote the growth of seagrass, algae and diatoms and these, with material imported from other primary producing areas, form the basis of the trophic web (CALM 1994).

2.2.9 The Oceanic Environment
The term ‘oceanic’ usually refers to the offshore marine environment however in this circumstance it refers to the habitats within the water mass above and beyond the continental shelf. An immense number of marine plants and animals have habitats in the ocean water mass itself.

Three terms used for oceanic organisms are nekton, plankton and micronekton (CALM 1994). The nekton are the larger swimming animals, they live permanently in the water mass such as fish and squids. Plankton are plants or animals that float in the sea. As they drift, the water currents control their destination. Micronekton is a term used by biological oceanographers to describe marine swimming animals in the size range 10-100mm (CALM 1994).

2.3 Western Australian Marine Conservation Reserves

Marine conservation reserves are intended as places where plants, animals, and their habitats may be protected or managed to ensure long-term survival in natural conditions (CALM 1994). They help protect species and preserve the diversity of life. A structured multiple-use marine conservation reserve system has two primary roles. The first is to preserve ecosystems in the
marine environment and secondly to put a formal management framework in place. The marine conservation network comprises of several categories.

2.3.1 **Marine Nature Reserves**

They are created for conservation and scientific research. Hamelin Pool in Shark Bay currently the only one in Western Australia. The types of activities that may be permitted in a marine nature reserve are limited. The likelihood of requiring zoning, to separate activities, is therefore low (Government of Western Australia 1997). Low impact tourism is allowed in these areas.

2.3.2 **Marine Management Areas**

They provide a formal management plan over areas with high conservation value and intensive multiuse. They are selected because of their biological and recreational values and either existing or potential commercial activities. There is currently no Marine management Area in Western Australia. In marine management areas, the reserves are visibly multiple-use and there is a need for limited application of management zoning to constrain certain activities (Government of Western Australia 1997).

2.3.3 **Fish Habitat Protection Areas**

They are created to protect fish and their habitats. They cannot however co-exist with marine nature reserves. Therefore, if they exist in the same area then the marine nature reserve takes precedence.

2.3.4 **Rottnest Island Reserve**

The waters around Rottnest Island are reserved and managed by the Rottnest Island Authority Act.

2.3.5 **Marine Parks**

Marine parks and protected areas are acknowledged as an important means to prevent loss of marine and coastal biodiversity (Dixon *et al.* 1993). Western Australia has 6 marine parks, Rowley Shoals, Ningaloo, Shark Bay, Marmion, Shoalwater Islands and Swan Estuary. The
location of these marine parks is illustrated in Figure 1. They are created to protect natural features and aesthetic values while at the same time enabling recreational and commercial uses.

![Figure 1. Locations of Western Australian Marine Parks.](image)

2.3.5.1 Sanctuary Zones
They are managed only for nature conservation and low-impact recreation.

2.3.5.2 Recreation Zones
Recreation zones provide conservation and recreation for the marine environment.

2.3.5.3 Special Purpose Zones
These are managed for the use and issue of major environmental concerns. Activities that are compatible with the priority uses are permitted in these areas. It is used for wild life breeding, whale watching or protection of a habitat.
2.3.5.4 General Use Zones

These are areas not included in the other three zones. Conservation is still a priority in these areas but sustainable activities such as petroleum exploration, aquaculture and pearling may be permitted.

2.4 Activities is Marine Reserves

Figure 2 illustrates the activities that are permitted in Marine Conservation Reserves in Western Australia.

Figure 2    Possible activities in marine conservation reserves.
3.0 **SUCCESS FACTORS**

1) Revenue will be generated for the marine park through admissions, souvenirs and any other on site facilities

2) The construction of the observatory and walkway is implemented with minimal impact to the environment

3) The project is implemented with the least possible disruption to the current activities in the marine park

4) The community takes pride and enjoyment in the observatory

5) The community receives education on the importance of the conservation of the marine environment

6) Other revenue and job generating opportunities will arise from the construction of the observatory such as the leasing of amenities like the kiosk.

7) The observatory should be accessible to all people of all ages and all levels of mobility

8) Marine life in the area will increase with the conservation of the environment surrounding the observatory

9) There will be an abundance of marine life around the observatory so that there is a spectacular view through the windows

10) All aspects of the project support the particular cultural and social sensitivities of the region

11) The entire project is implemented and operational within an applicable period
12) The observatory and walkway require minimal maintenance

13) It attracts more tourists to the region, spending money within the local economy

14) The walkway and observatory should be aesthetically pleasing

15) The operational costs should not exceed the revenue generated

16) The observatory allows constant monitoring of the surrounding marine environment

17) During the construction and running of the facility some members of the local community should be employed

Success factors separated according to ‘what must get done’ (critical) and ‘what could be done’ (favoured).

**Critical Success Factors:**

1, 2, 3, 7, 9, 11, 12, 15.

**Favoured Success Factors:**

4, 5, 6, 8, 10, 13, 14, 16, 17.

### 3.1 Objectives to achieve success

The following is a set of objectives that must be achieved to reach a successful outcome.

#### 3.1.1 Critical Objectives:

1) Revenue will be generated for the marine park through admissions to the observatory, souvenirs and any other on site facilities.
2) The environmental impact of the design solution must be minimal. An in depth analysis of the factors that must be considered for each design are provided.

3) The project will be implemented with the least possible disruption to the current activities in the marine park.

7) The observatory will be accessible to all people of all ages and all levels of mobility.

9) There will be an abundance of marine life around the observatory so that there is a spectacular view through the windows.

11) The entire project will be implemented operational within an appropriate time frame.

12) The observatory must require minimal (specialised) maintenance. Design factors that are less susceptible to problems will be favoured.

15) The operational costs of the observatory do not exceed the revenue generated.

3.1.2 Favourable Objectives:

4) The people in the community should enjoy using and take pride in the recreation facilities. Ultimately, the community's high standard recreational facilities will lead to an improvement in social conditions.

5) A community education program to highlight the importance of conserving the marine environment would be a desirable initiative.

6) An increase in tourism in the region from the construction of the observatory will generate other revenue and employment opportunities.
8) The conservation of the environment surrounding the observatory will assist marine life in the area to increase.

10) All aspects of the project design must be aligned with the particular cultural and social sensitivities of the region. The design must not offend or impose outside ideologies that are unacceptable to the community.

13) The observatory will attract more tourists to the region, who in turn will spend money within the local community.

14) The walkway and observatory will be aesthetically pleasing.

16) The observatory allows constant monitoring of the surrounding marine environment.

17) During the construction and running of the facility some members of the local community will be employed.
4.0  **DESIGN OPTIONS**

4.1  **Orientation**

Direction of the waves and wind may have an effect on the type of dock selected. In general, the dock should not be parallel to the prevailing wave front. Therefore, if the structure is in an exposed location, and the wave front is generally parallel to the shore, the structure should be perpendicular to the shoreline. Sunlight will also have an effect on the orientation of the structure.

4.2  **Walkway**

4.2.1  **Floating**
A floating walkway floats on the water. It is held in place by piles that are driven into the seabed.

4.2.2  **Fixed**
A fixed walkway is mounted on permanent piles. The open type construction design of a fixed walkway is quite prevalent in the construction of piers in the Western hemisphere. Open construction docks may be subdivided into high-level decks and relieving-type platforms. In relieving type platforms, the main structural slab is below the finished deck and the space between is filled to provide additional weight for stability, as shown in Fig. 3. Whereas high-level decks usually have a solid deck slab.
4.2.3 Deck

The deck may be constructed of wood, reinforced concrete or a combination of concrete and steel or wood. The deck may be supported on piles, which may be wood, steel (H section or pipe), or reinforced concrete; or on large cylinders or caissons, which may be of steel or reinforced concrete. Figure 4 shows a typical type of poured-in-place concrete deck construction. Piles are located in slanting rows and are capped by concrete girders, which distribute the load from the deck framing to the piles. Longitudinal beams are placed at points of concentrated loads. Where concentrated loads do not exist and the bents are not spaced too far apart, the longitudinal beams may be omitted, and a flat slab may be used. In some designs, the pile cap will become a flat slab, when the piles are spaced closely together.

Figure 3 Relieving platform type wharf. (Quinn 1972)
4.2.3.1 Height
The height of the dock above the water will be determined by several factors. The tidal range will affect the height of the dock, as it is essential to keep the decking above the water at high tide.

4.2.3.2 Width
The width of the walkway will be influenced by its height above the water. The higher the walkway, the wider the deck needs to be to obtain a sense of stability. However, this width can be compensated for through the addition of handrails.

4.3 Piles

In designing a pile to carry a certain load, it is necessary to determine the condition of support at both the top and the bottom. If the pile ends are prevented from rotating, then it may be considered fixed. For fixity at the top of the pile, it is essential that the deck be of heavy construction. It is also essential that the pile be rigidly fastened to the deck either by embedding it or extending the reinforcing into the supporting cap (Quinn 1972). To fix the pile at a point not too far below the bottom, the soil must be a firm material such as compact sand or hard clay. The pile is then driven a substantial distance below the point of fixity, which in this case is assumed to be 10 to 15 feet below the bottom. If the seabed is a soft substrate, such as silt, a point of fixity would occur, not much above a depth of 20 to 25 feet below the seabed.
If the deck is of light construction such as wood or light steel, the top of the pile cannot be considered as fixed. The connection between the deck and the supporting piles is of considerable importance.

### 4.3.1 Precast-concrete Piles

These are more commonly used for dock construction than any other type of pile. Reinforced-concrete piles are sometimes driven or jetted to the specified grade; the piles do not need to be cut off (Quinn 1972).

### 4.3.2 Prestressed-concrete Piles

They are piles that have been prestressed before use. Piles of concrete should be cut off 4 inches above the bottom of the girder or cap, leaving the reinforcement projecting into the cap.

### 4.3.3 Steel H Piles

In recent years steel piling, particularly the H pile, has been used extensively. Steel H piles may be cut off 4 inches above the bottom of the concrete girder and capped with a steel plate or they may project into the girder sufficiently far to transfer the load to the piles in bond (Quinn 1972). If the deck is supported by steel beams and girders, the steel pile may be burned off at the elevation of the underside of the steel girder, and the connection made by welding or bolting (Quinn 1972).

### 4.3.4 Steel-pipe Piles and Cylinders

Pipe piles are driven either with open or closed ends depending upon soil conditions. They are usually driven with a single-acting steam hammer. The closed end method predominates in marine work and dock construction and where rock is usually not encountered, except at excessive depths. Except for temporary installations, pipe piles and cylinders are filled with concrete.

Pipe piles or steel cylinders, which are usually filled with concrete, are cut off 4 inches above the bottom of the girder and dowels inserted into the pile, which project into the cap (Quinn 1972).
4.3.5 **Wood Piles**

These have been used in the past more extensively for dock construction than any other type of pile. However, except for temporary use, these are gradually being replaced with stronger and more permanent types of materials. Virtually all wood piles used for permanent dock construction are creosoted. Wood piles are usually cut off 6 inches above the bottom of the girder or cap, and if they are to take uplift or tension, they are anchored into the concrete with a U-shaped strap, which is bolted to the pile (Quinn 1972). If the cap is timber, the pile will be connected to it with a drift pin and either wood or steel side plates. Wood piles may be driven with single or double-acting steam hammers.

4.4 **Observatory**

The design of the observatory can be many shapes. The stability of the shape in the marine environment will determine which one is chosen.

4.5 **Materials**

The selection of materials for an ocean structure is partly the problem of determining which of the many material characteristics are, most suitable to the specific structure. This process is a primary design consideration for marine structures.

The weight density of a material is very often a critical characteristic since structural weight is so often a major design consideration (Evans & Adamchak 1969). In many cases, it is not the absolute density itself, which is important, but strength to weight ratio. In most structures, it is desired to maintain a certain level of strength with minimum structural weight.

The most promising structural materials fall into three main categories; metals, nonmetals, and composites.
4.5.1 Metals
Steel, Aluminium, Titanium, and Copper-Nickel Alloys are metals that can be used in the construction of a marine structure.

4.5.2 Nonmetals
Plywood and concrete have been suggested for use in underwater structures. Glass and ceramics also show potential as a material for underwater construction.

4.5.3 Composite Materials
Composite materials are made of filaments of some material specifically positioned in a surrounding substance. The filaments may be either a metallic or non-metallic substance with glass and boron a common combination.

4.6 Dredging
Dredging is moving material submerged in water from one place to another either in the water or out with equipment called dredges. They are used to excavate the seabed for channels or structures. Dredges today come in two classifications-mechanical and hydraulic.

4.6.1 Mechanical Dredges
Mechanical types include the clamshell or grapple dredges. Larger dredges of that type are no longer used very often. The endless chain bucket (or bucket-ladder) dredge was used widely earlier in Europe but not in the United States.

The mechanical dipper dredge with its heavy bucket moved by a very strong arm and boom is still used for dredging relatively loose (usually not solid) rock (Bruun 1973). The bucket may be provided with special cast iron teeth.
4.6.2 Hydraulic Dredge

The hydraulic dredge is the most important piece of dredging equipment. The plain section dredge has no cutter but sucks material off the bottom and discharges it through a stern connected pipe leading to a spoil disposal area (Bruun 1973).

The cutterhead pipeline dredge has a rotating cutter on the end of the ladder. It excavates the material from in situ condition and discharges it through the stern to pontoon and shore pipe (Bruun 1973). The dredge is controlled on stern mounted spuds and is swung from one side of the channel to the other by means of a swing gear.

The self-propelled hopper dredge has a large hopper in which the dredged material is loaded for later dumping through doors in the bottom. This type of dredge is normally employed where the water is too deep for a pipeline dredge or where spoils areas for such a dredge are not available within economic distances. The self-propelled hopper dredge moves freely without any kind of mooring system. It can operate by pumping holes in the bottom side by side through a usually circular intake which is the reinforced end of the suction pipe, or it can trail along with its trailing suction head attached to the end of the suction pipe “vacuum cleaning” the bottom (Bruun 1973). This method is more practical and effective than the plain pipe sucking procedure where deep holes may become sediment traps for material which otherwise may have been flushed away (Bruun 1973).

A grader operation board is situated at the rear portion of the bridge where the gantry and the winches can be seen, and all kinds of adjustments can be made from the operation board which indicated depth, inclination of the grader and loads on winch and grader (Bruun 1973).

The cutterhead, pipeline, hydraulic dredge, with its supporting equipment, is essentially a floating power plant used to move material hydraulically to some other location without rehandling (Bruun 1973).
Presently, most hydraulic dredges will not be able to work in seas exceeding approximately 5 feet with wave periods of 5 to 10 seconds. If operation is to be economical, rehandling of material must be avoided to the extent possible, and mobilization should not require excessive costs.
5.0 POTENTIAL PROBLEMS AND SOLUTIONS FOR STRUCTURES

Different materials are affected in various ways by the marine environment. The most notable effects include the deterioration of materials, corrosion, fouling, decay and boring and, energy absorption by the materials.

5.1 Material Deterioration

Sea structures are subject to various deteriorating agents throughout their lifetime, the degree of deterioration depending upon the climate, the properties of the seawater and its seasonal variations, tide range, and the type of material in regard to the climatic conditions and with respect to its relative immersion (i.e. Splash zone, tidal zone, or continually immersed) (Gaythwaite 1981). Figure 5 illustrates the general effects of relative immersion on various materials with regard to vertical zonation.

Figure 5 Deterioration zones of various materials in the marine environment. (Gaythwaite 1981)
The marine atmosphere tends always to contain some small amount of salt, which increases the atmospheric rate of corrosion of marine structures over that of land structures (Gaythwaite 1981). In timber structures above the splash zone, freshwater may collect and stagnate, initiating rot (Gaythwaite 1981). The splash zone comprises of an area from the high water level to the upper levels attained by spray. This zone is subjected to intermittent wetting and drying as waves run up or break on the structure (Gaythwaite 1981). The tidal zone is the usual range between high and low water, which is periodically immersed. Above and below the tidal zone concrete should be quite serviceable in all climates. Below low tide to the seabed structures are continually immersed, and this is typically a zone of moderate to light attack of most materials except wood (Gaythwaite 1981). Below the mudline most materials are relatively protected as the lack of oxygen prohibits oxidation and the existence of organisms (Gaythwaite 1981).

Note that, in general, steel and concrete suffer the heaviest attack in the splash zone and the tidal zone, respectively, whereas timber is attacked below low water by marine organisms and is subject to decay above the splash zone (Gaythwaite 1981). Concrete that is continually submerged will usually perform quite well and gain strength with of time. In the tidal zone, however, it is subject to scratching.

The frequency and the degree of wave action are important to the rate of splash zone corrosion, owing to the frequency and extent of alternate wetting and drying (Gaythwaite 1981).

Tide range affects the distribution of corrosion rates on the structure, depending upon total water depth and exposure. In areas where the range is large, the trend seems to be for the greatest attack to be near or just above mean low water. In areas with a small tide, range the attack is greatest in the splash zone (Gaythwaite 1981). The distribution of corrosion in general is due to zones of differential aeration that are set up (Gaythwaite 1981).

5.2 Corrosion

Biological activity, such as the action of sulfate-reducing bacteria in a reducing environment, can greatly accelerate the corrosion of metal structures (Gaythwaite 1981). Increases in temperature,
salinity, and dissolved oxygen content all increase corrosion rates. Consideration should be given to the seasonal variations in these factors, as corrosion rates may vary throughout the year. There are many environmental factors that can influence corrosion in the marine environment as is seen in Figure 6.

![Figure 6](image)

**Figure 6** Environmental factors affecting the corrosion of materials in the marine environment. (Gaythwaite 1981)

5.2.1 **Classification**

Corrosion can be classified according to the conditions or type of electrochemical process.

5.2.1.1 **General and pitting corrosion**

The scaling or pitting of the surface of a metal exhibits this type of corrosion. This can occur either from a reaction with its surroundings or a difference in potential between different areas of the same metal (Gaythwaite 1981). Certain organisms that attach themselves to or move over the
surface of metal structures may cause pitting and erosion-corrosion. Figure 7 illustrates the processes that occur when the wall of a steel pipe is eroded.

![Figure 7: Corrosion of the wall of a steel pipe immersed in water. (Quinn 1972)](image_url)

5.2.1.2 Crevice corrosion
Crevice corrosion is formed in isolated areas where less oxygen is available for the repair of the oxide film. This results in a difference in potential being set up. Anaerobic conditions at the mudline can cause greatly increased corrosion due to bacterial activity.

5.2.1.3 Selective corrosion
This is a process whereby one particular metal of an alloy is attacked, and eventually destroys the metal’s alloyed properties. The dezincification of some brasses is an example of this.

5.2.1.4 Stress-corrosion cracking
Stress-corrosion cracking is a process where normal corrosion is accelerated by tensile stresses within the material (Gaythwaite 1981).
5.2.1.5 **Corrosion fatigue**

This type of corrosion occurs in cyclically loaded members or members subject to continual load reversals (Gaythwaite 1981). The working of the material accelerates the corrosion process.

5.2.1.6 **Galvanic corrosion**

Galvanic corrosion is caused by a difference in electric potential of two dissimilar metals in direct contact. Electric potential of various metals in seawater are known; so galvanic corrosion can generally be avoided by not using metals with large differences in electric potential in the same area (Gaythwaite 1981).

5.2.2 **Prevention**

Corrosion can be minimized by functional design, proper selection of material, protective coatings, claddings such as concrete encasements, rust inhibitors, and cathodic protection systems using impressed currents and sacrificial anodes (Gaythwaite 1981). When dissimilar metals are used, a galvanic series table should be consulted to verify the potential difference between them (Gaythwaite 1981). Functional design details would include such things as the avoidance of overlapping plates, discontinuous welds, and connection details that provide crevices or stress concentrations (Gaythwaite 1981).

Protection of corrosion from steel piling can be accomplished by encasing the pile with concrete from the underside of the deck to 2 feet below low-water level, which is the area where the most severe corrosion is expected to take place (Quinn 1972). Below low water, corrosion is usually slow, and except in very corrosive water, may be ignored providing an allowance is made in the design of the piles for loss of area, and the piles are given not less than two coats of bitumastic paint prior to driving (Quinn 1972).

All permanent steel structures must have some form of corrosion protection regardless of location (Gaythwaite 1981). Traditionally structures have been designed with extra metal thickness to account for the expected metal loss over the design life of the structure (Gaythwaite 1981). This practice is not wholly satisfactory because local pit growth can be many times the expected
average rate, and on large structures. There are a variety of protective coatings on the market with all kinds of claims and all kinds of prices (Gaythwaite 1981). Protective coatings and/or claddings are required in the splash zone and tidal zone (Gaythwaite 1981). Below low water, however, cathodic protection systems should be considered (Gaythwaite 1981).

5.2.2.1 Cathodic Protection
In order to reduce or practically eliminate loss from corrosion, many builders of steel structures are resorting to cathodic protection. By changing the direction of the flow of the electric current, protection of the steel from corrosion is accomplished. The electric current flows to the steel and not from it, thus preventing the iron ions from flowing out of the steel and causing its decomposition.

A sacrificial metal may be used for the anode as the source of the direct current. Metals such as aluminium zinc, cadmium, or magnesium maybe used. These are described as galvanic anodes.

Any structural steel member or steel pipeline, submerged below the surface of the water, can be protected when an adequate current density is supplied by a properly designed cathodic-protection system (Quinn 1972). However, because of the specialized problems involved and the additional considerations that must be given to the resistance, temperature, and dissolved oxygen content of the water, a comprehensive study of all conditions must be made in order to design a satisfactory and economical system (Quinn 1972).

The initial installed cost of cathodic protection, as applied to the underwater steel in a pier, trestle, or pipeline, is small compared to the cost of the structure being protected. The annual operating costs consisting of maintenance, power, and eventual replacement of the anodes have been found to be less than other methods of corrosion protection (Quinn 1972).

5.3 Fouling

When deciding what materials should be used for the piles, fouling should be considered.
Fouling is the accumulation of various plant growths and animal organisms on immersed and partially immersed structures in the marine environment. Fouling has several effects on marine structures.

1. Possible increase in corrosion rates due to destruction of protective coatings
2. General bio-deterioration due to the direct deteriorating effects of certain organisms on certain materials
3. Difficulty in inspection and maintenance of the structure (Gaythwaite 1981).

In the case of fixed and permanent structures, there is as yet not much a designer can do about fouling except to recognize that it will occur (Gaythwaite 1981).

In the tropics, hard mussel fouling may be a foot or more thick. This can be a problem as the apparent mass and projected area of a pile will have significantly increased. It is likely, however, that during severe wave action at least the outer layers of fouling will be washed away (Gaythwaite 1981).

It is generally observed that bacteria and algal slimes are the first life forms to accumulate on a newly immersed surface. This algal slim forms the base, for the attachment of successive organisms. The usual pattern of bio-succession can be generalized as follows: bacteria the first 1 to 3 days, algal slimes after 3 to 7 days, protozoans after 1 to 3 weeks, barnacles after 3 to 10 weeks, tunicates after 10 to 16 weeks, grasses after 3 to 6 months, and mussels after 6 to 12 months (Gaythwaite 1981).

5.3.1 Prevention

Fouling is a difficult problem to prevent. Although some metals exhibit a natural resistance to fouling, they are exotic materials not feasible for the general structure. Anti-fouling paints and inhibitors eventually must be reapplied, and whilst they are successful to a certain extent, they are not of use on fixed and permanent structures. In some instances, however, fouling may be beneficial, as in the case of a uniform coating of slime or weeds, which may effectively insulate the steel surface from corrosion.
5.4 Marine borers and decay

Certain marine organisms, primarily from the taxonomic groupings of mollusks and crustaceans, will bore into and destroy timber, soft concrete, and other materials immersed in seawater and in the tidal zone (Gaythwaite 1981). The pholads, known as rock borers, can bore into rock and porous concrete as well as into timber.

All types of borers respond to differences in environmental conditions however they are generally more active in the tropics, within the euphotic zone and within normal oceanic ranges of salinity (Gaythwaite 1981).

The use of timber for the immersed portions of structures should be avoided in the tropics and at sites where borers are known to be voracious (Gaythwaite 1981). Wherever timber is used in seawater, it should at the least be treated.

5.5 Energy absorption

Both ductility and notch toughness are measures of a material’s ability to absorb energy, without fracturing. The ability of a material to resist brittle fracture in the presence of metallurgical or physical cracks or notches is called notch toughness. In general, the more energy absorbed, the more ductile or tough the material is (Evans & Adamchak 1969). The material’s behaviour is described as “brittle” when little or no energy is absorbed. Many materials exhibit what is termed a “transition temperature”, a temperature below which the material’s behaviour changes quite rapidly from ductile to brittle, and its energy absorption capabilities fall off equally abruptly (Evans & Adamchak 1969). Since for many materials the transition temperatures are in the same range as certain ocean temperatures, this phenomenon is of particular concern to ocean structures (Evans & Adamchak 1969).
6.0 EVALUATION OF DESIGNS

6.1 Orientation

The structure should be perpendicular to the shoreline to avoid the effects of wave fronts. A comparison of how sunlight affects the orientation of the observatory and walkway is made with a north south oriented design and an east west oriented design.

6.1.1 North-South
With a north-south orientation, the marine life underneath the walkway will get maximum light exposure. This is because the shadow moves continuously throughout the day so no single portion is always in shadow.

6.1.2 East-West
An east west orientation is not feasible for the walkway and observatory, as some of the surrounding marine life will be continuously in its shadow. This will not promote growth as the marine life needs light.

6.2 Walkway

6.2.1 Floating
A floating walkway is held in place by piles so it no more beneficial than a fixed walkway. It is not a permanent structure as is will need to be removed during winter to avoid being damaged by the storms. There will be high maintenance costs with the removal and replacement of the walkway.

6.2.2 Fixed
A fixed walkway is mounted on permanent piles. It is strong enough to withstand winter storms and is a more permanent solution than the floating dock.
6.2.3 Deck

The deck may be constructed of wood, reinforced concrete or a combination of concrete and steel or wood.

6.2.3.1 Height

Unless a floating dock is chosen the height of the dock is variable, within reason. The amount of stress on the walkway will affect the height. Taller docks allow additional light to penetrate to the marine life underneath. This is beneficial because marine life depends on light to survive.

6.2.3.2 Width

As the width of the walkway is determined from its height, the higher the walkway is, the wider the deck must be. Handrails are required for docks that are a sufficient height above the water and can be added to one or both sides. The width also controls the amount of light filtering through to the marine life underneath the walkway. Therefore, you want to keep the width to a minimum to avoid the affects of shading to the ecosystem.

6.3 Piles

In selecting a pile to carry a certain load, it is necessary to determine the advantages and disadvantages of the pile in the marine environment.

6.3.1 Precast-concrete Piles

6.3.1.1 Advantages

When properly constructed and driven, they provide a very permanent type of construction, even in salt water, without the need of maintenance (Quinn 1972).

A precast-concrete pile with a steel H-pile lower section has proved very effective at certain locations. These are where concrete is required because of the severe corrosive condition of the water and where the bottom is of such a nature that it would prevent the required penetration of a displacement type of concrete pile. The concrete section should extend to a depth of 2 to 10 feet below the bottom, depending on the first a layer of the seabed.
In recent years, precast or prestressed concrete slabs and beams have come into use and have proved to be an economical form of construction when working in the marine environment. This is due to the large saving in cost.

6.3.1.2 Disadvantages
They have certain limitations, length being one of the more important ones. Since handling stresses and weight become excessive for very long piles length is a restricting factor. Given that a solid-concrete pile will displace an equal volume of soil, it will disturb and remould clay soils, which may result in a considerable loss in shearing strength and frictional resistance to support the pile (Quinn 1972).

It has been demonstrated that, fine cracks may appear in the surface of the concrete pile during handling unless the reinforcing stress is kept low. These cracks may close up and be almost invisible when the pile reaches an upright position ready to be driven, but they will usually become enlarged and plainly visible during the driving of the pile, because of the impact stresses set up by the hammer (Quinn 1972). These fine cracks are detrimental for piles in salt water. Therefore, the piles should be designed and handled carefully so that cracking will not occur.

6.3.2 Prestressed-concrete Piles
6.3.2.1 Advantages
These have become popular for marine structures where the length requirements make regular precast piles extremely difficult to handle and drive, and costly to use. Prestressing of concrete closes up cracks, offers relatively high strength and durability, and is generally desirable for applications in the marine environment (Gaythwaite 1981).

It can be argued that any cracks occurring will be fine and will be closed up by the prestress, as soon as the temporary handling load is relieved (Quinn 1972). It is preferential to have the pile free of cracks when driven, as this is one of the major advantages of the prestressed pile.
Recently, in soft bottom conditions that require long foundation supports, prestressed or post tensioned concrete piles and cylinders have been used with success. The prestressing or post tensioning simplifies the handling of long piles and reduces cracking. This is because the compression in the pile from prestressing is made sufficient to overcome the tensile bending stress in handling the pile or to reduce it to an amount, which will not cause the concrete to crack (Quinn 1972).

6.3.2.2 Disadvantages
The casting bed must be supported by unyielding ground or on piles and the anchorages at the ends must be unyielding when subjected to the prestressing loads (Quinn 1972).

6.3.3 Steel H Piles
6.3.3.1 Advantages
They are suitable for driving in extremely long lengths, as it is relatively light and can be easily spliced by butt-welding to develop its full strength (Quinn 1972). The H pile has a very small soil displacement. This makes it ideal to use in clay soils, which lose strength when they are remoulded. It can withstand very hard driving, and if the head is damaged it can simply be cut off, and driving resumed. It is one of the easiest piles to frame or fix to the deck of a dock. This is due to its large surface area enabling the pile to develop a large amount of bond when embedded in concrete. It can also be welded to steel pile-cap girders if the deck is of steel construction (Quinn 1972). It is easily adaptable to rigid-frame construction.

With respect to permanency, there is sufficient evidence that when embedded for is full length in soil, except loose fill, cinders, and peat bog, the H pile will suffer very little loss in area from corrosion over a many years. Fortunately, H piles can be protected from corrosion. Coating the piles with bitumastic paint before they are driven, and then removing any paint remaining above the low-water level may achieve this. Encasing the piles with concrete from the underside of the deck to 2 feet below low water will also combat corrosion. Cathodic protection may be used as well.
Open-end pipe and steel H piles, which do not displace, are favoured for use in clay soils as they lose their strength when remoulded.

6.3.3.2 Disadvantages
Steel H-pile sections are common in waterfront construction because of their availability, ease of splicing and driving, but from a corrosion point of view, they are clearly inferior other piles. When exposed to salt water, as is the case in most dock installations, the H pile, unless properly protected, it may be subjected to severe corrosion, particularly within the tidal range (Quinn 1972). When metal is removed from the flanges, and often this is where corrosion rates are highest in H-piles, the radius of gyration of the pile cross section may be drastically reduced as compared to the same amount of metal loss on an equivalent pile (Gaythwaite 1981).

Erosion must be considered in some areas as it may be severe where there is loose, shifting sand. The current or the waves can carry the sand and can cause erosion, so the surface of the piling should be protected with either a creosoted-wood plank or the pile encased in concrete. This however is an additional cost.

Pipe piles have the added advantage of being easier to maintain and inspect, and present a minimal surface area per weight of pile (Gaythwaite 1981).

6.3.4 Steel-pipe Piles and Cylinders
6.3.4.1 Advantages
Except for temporary installations, pipe piles and cylinders are filled with concrete. This increases the load-carrying capacity of the pile. It also protects the inside shell from corrosion. Steel-pipe piles, which are usually filled with concrete, are subject to corrosion on the exterior surface only. When severe corrosion is anticipated, particularly in the marine environment, cathodic protection may be employed.

6.3.4.2 Disadvantages
Severe corrosion can occur with steel-pipe piles, and even though they can be protected this can be a costly exercise.
6.3.5 **Wood Piles**

6.3.5.1 **Advantages**

In general, wood piles are still the most economical type of construction even though it lacks permanency. In certain locations, local hardwood or greenheart piles may be substituted for creosoted piles (Quinn 1972). Greenheart piles have been found to be highly resistant to marine organism attack and decay and have been used quite extensively for dock construction, particularly for fender piles, because of their very high strength in bending and crushing (Quinn 1972). In addition, to creosoting wood piles, recent practice has been to further protect them above the water level, particularly from fire, by encasing them with concrete pipe sleeves (Quinn 1972).

They may be protected from borers by guniting, which has been successfully accomplished without cracking the gunite protection in driving (Quinn 1972).

6.3.5.2 **Disadvantages**

They are only used in temporary constructions as stronger and more permanent materials are available. Greenheart is not suggested for deck construction because the wood is very hard to work (Quinn 1972). Wood piles are subjected to severe marine borer attacks.

6.4 **Observatory**

A comparison between the cylindrical and rectangular designs for the observatory is made.

6.4.1 **Cylindrical**

The cylindrical design has equal pressure on the whole circumference, making it extremely stable. This leads to a permanent structure with a negligible prospect of failure.
6.4.2 Rectangular / Square

The design of either a rectangular or square shaped observatory will have a structure with major forces on each of its corners. This leads to instability, which will cause the failure of the structure.

6.5 Materials

The selection of materials for an ocean structure is partly the problem of determining which of the many material characteristics are, most suitable to the specific structure. This process is a primary design consideration for marine structures.

6.5.1 Metals

6.5.1.1 Steel

Steels show promise mainly because of the extremely high strengths, which are made possible because of new heat treatment techniques. A tendency towards brittle behaviour and low notch toughness, in addition to only moderate enhancement of fatigue life are the major drawbacks of these high strength steels (Evans & Adamchak 1969).

In general, metals that are well suited to stagnant conditions are quickly eroded in the presence of increased velocities of aerated seawater. Similarly, metals such as the nickel-chromium-iron alloys perform well at high velocity. It does however crack and pit in stagnant conditions.

6.5.1.2 Aluminium

Due to its low density, the use of aluminium is significant. Some of the new aluminium alloys are a viable alternative instead of some steels, with the same yield and ultimate strength. The aluminium alloys also have better corrosion resistance. As strengths increase, aluminium alloys show the tendency towards increased brittleness, lower notch toughness, and questionable fatigue life (Evans & Adamchak 1969).
6.5.1.3 Titanium
Titanium combines a relatively low density with very high strength, excellent fatigue properties and corrosion resistance, and anti-magnetic properties (Evans & Adamchak 1969). A severe problem with titanium is stress-corrosion cracking. Titanium alloys are generally considered to be a promising material for deep applications in the field despite their high cost.

6.5.1.4 Copper-Nickel Alloys
Copper-Nickel alloys are valued in applications not requiring very great strength levels. They also have excellent corrosion resistance properties, at least under immobile conditions.

6.5.2 Nonmetals
6.5.2.1 Glass and Ceramics
The importance of glass and ceramics in the marine environment, are of because of their extremely high strengths in compression. They also demonstrate excellent corrosion resistance qualities. Glass also offers the advantage of transparency, which is required in an observatory. The principal drawbacks of glass and ceramics are their brittle behaviour and low fracture toughness.

6.5.2.2 Other Materials
The main advantage of both wood and concrete is their relatively low cost. In addition, concrete possesses good compressive strength, good availability, resistance to corrosion, and excellent formability (Evans & Adamchak 1969). Its chief disadvantage is its limited tensile strength.

Concrete when properly made and placed is an excellent material for ocean construction. However, if improperly made, it will deteriorate rapidly. Permeability in concrete is the most important property in obtaining a dense and durable finished product.

The chemical attack on concrete occurs primarily from the action of chlorides and sulfates in the seawater. It will occur more rapidly in warmer climates. Corrosion of reinforcing steel occurs at a pH lower than 11. Since the mean pH of seawater is slightly greater than 8, it is important that the concrete cover maintains a relatively high pH for the steel (Gaythwaite 1981).
In addition, aggregates should be as nonreactive and abrasion-resistant as possible, and sharp corners or edges on structural elements should be avoided (Gaythwaite 1981). Concrete actually poured in the water through a tremie pipe or lowered in individual sacks should also have a minimum amount of clay binder, such as bentonite, to keep the cement particles from leaching out (Gaythwaite 1981).

As a matter of material durability alone, concrete would be the material of choice for marine structures located in the tropics where steel suffers heavy corrosion and timber suffers from borer attack (Gaythwaite 1981). Marine concrete structures properly designed and constructed should have useful design lives of from 25 to 50 years, depending upon the location and exposure of the structure.

**6.5.3 Composite Materials**

Composite materials are made of filaments of some material specifically positioned in a surrounding substance. Such fiber composites are being developed with very high strength to weight ratios (Evans & Adamchak 1969). A major problem with the long-term use of composites is fastening and joining.
7.0 EVALUATION OF BENEFITS

7.1 Background Information

7.1.1 Reef-based Tourism

The increased demand for marine-based tourism is relatively new. This increase in demand can be attributed to the following factors:

1) A heightened awareness of environmental issues;
2) Greater media exposure to a wider public audience of the wonders of the underwater world;
3) The explosive growth of the tourism industry, particularly ecotourism (Downie et al. 1996).

7.1.2 Demand for high quality dive sites

The popularity of recreational scuba diving translates into an increase in demand for tourist destinations catering to divers and providing diver-friendly marine environments. The attraction for most divers is the great aesthetic beauty and rich diversity of marine life offered by coral reef ecosystems. These attributes are most impressive and pronounced in relatively pristine ecosystems (Downie et al. 1996). Survey results indicate that divers consider the quality of the dive site as the crucial factor affecting the quality of the dive (Downie et al. 1996). Quality of a dive site is a function of clear water (which enables better visibility), healthy reefs, and abundance and diversity of fish and other marine life (Downie et al. 1996). A recent study undertaken in Roatan, Honduras revealed that environmental quality (measured by percent live coral cover) is positively correlated with dive site visitation (Downie et al. 1996). This shows that demand for dive sites is a function of reef quality (Downie et al. 1996). Divers are “willing to pay a premium for environmental quality and good diving” (Downie et al. 1996).

Developing dive tourism presents obvious economic opportunities (Downie et al. 1996). High demand and willingness to pay for scuba diving in high quality coral reef ecosystems presents lucrative opportunities for countries, which possess such endowments (Downie et al. 1996).
7.1.3 Economic implications of reef degradation

The government recognizes the opportunities to be derived from marine tourism (Downie et al. 1996). As noted, however, a dilemma confounds a tourism industry based on fragile environmental resources; tourism can undermine its own viability unless carefully managed (Downie et al. 1996). The detrimental effect on coral reefs by uncontrolled development of popular dive destinations has been well documented (Downie et al. 1996). Primary threats include sedimentation, nutrient loading from runoff and sewage, trampling by divers and spear fishing (Downie et al. 1996). Degradation from uncontrolled tourism development would thereby detract substantially from its initial appeal, as the very environmental asset upon which the tourism depends would be threatened (Downie et al. 1996). As tourism develops and increasing numbers of tourists frequent an area, their increasing numbers negatively impact the ecosystem and may therefore reduce its amenity values (Downie et al. 1996). Because divers are primarily concerned with the quality of the dive site, “they will not continue to patronize destinations that do not have live, healthy reefs;” thus, considerable amounts of revenue from dive tourism would be forfeited should quality decline (Downie et al. 1996).

7.1.4 Carrying Capacity

While the impacts of tourism on terrestrial ecosystems have been well documented, comparatively few studies describe the full effect on coral reef environments (Downie et al. 1996). Although the biological existence of the reef is not as threatened by divers as it is by land-based pollution, its amenity value, the most important value in terms of economic returns from dive tourism, is significantly threatened (Downie et al. 1996).

7.2 Management Benefits

An underwater observatory will attract many more visitors to the marine park to experience the spectacular underwater marine environment. The observatory will be used by people of all ages and all levels of mobility and will generate revenue to assist with the management of the park. This use will generate revenue for the park. Revenue can also be generated through the rental of equipment. The demand for high quality dive sites is increasing so therefore if you protect the marine park through better management practices then clear water, healthy reefs and an
abundance of marine life will occur. This therefore translates into more potential revenue generation.

7.3 Educational Benefits

Educational groups will be able to learn and study the marine life in their natural environment and not in an artificial aquarium. When people are educated, they then are not afraid of conservation that occurs in their own backyard.

7.4 Recreational Benefits

Reef based tourists that are unable to dive or snorkel will be able to experience the underwater marine environment, such as young children, or people with restricted mobility.

7.5 Economic Benefits of Protection

Although subject to widely different interpretations, sustainable development requires harmonizing economic growth with environmental and social considerations. This can be achieved by implementing programs and policies that facilitate economic operations which generate stable income without degrading the environment (Downie et al. 1996). Long-term sustainable development must depend upon a balance between economics, the environment and social values and benefits.

Ecotourism has gained popularity as a driving force for sustainable development, providing both income and incentives for conservation. An important feature of ecotourism is that the generated income can be used to improve and protect the natural resource base that originally attracted tourists.

Conflicts between recreation and conservation have placed increasing pressures on marine resources with the continued growth of marine tourism. The appeal of the economic benefits available from tourism can encourage overzealous development without adequate measures to
protect the health and quality of the marine environment. With a decline in the quality of the marine environment, (the attraction drawing tourists in the first place), fewer tourists will be inclined to come and spend their time and money. Effectively, uncontrolled tourism development will eventually cause its own demise.

However, marine conservation reserves are not sufficient to ensure the protection of the marine environment. In order to maximize long-term economic benefits from marine protection, it is necessary to effectively manage activities outside of the marine conservation reserves, particularly onshore development (Downie et al. 1996). The infrastructure that accompanies growth of the tourism sector poses great threats to the marine environment. These threats must therefore be addressed. All coastal development projects should incorporate measures to minimize the potential negative impacts on the marine environment. In practice, this means implementing zoning and other regulations, controlling run-off from construction sites, hotels and golf-courses, and establishing systems of sewage treatment, trash collection and litter prevention (Downie et al. 1996). If implemented properly, onshore tourist developments that respect the marine environment can lead to significant long-term economic gains.

In sum, the potential economic benefits to be gained from sustained ecotourism present a convincing argument for protecting the environmental assets, which draw ecotourists (Downie et al. 1996).

Table 1 Benefits and costs of tourism and the marine environment

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Costs</th>
</tr>
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<tbody>
<tr>
<td>Economic/financial</td>
<td></td>
</tr>
<tr>
<td>• Foreign revenue for country</td>
<td>• Increased local cost of living</td>
</tr>
<tr>
<td>• Funds for region (e.g. taxes)</td>
<td>• Seasonality of income or employment unstable market</td>
</tr>
<tr>
<td>• Attraction of outside investment for local infrastructure/services</td>
<td>• Cost of enforcement/administration</td>
</tr>
<tr>
<td>• Diversification of local income</td>
<td>• Cost of training (guides,</td>
</tr>
<tr>
<td>• Service employment opportunities</td>
<td></td>
</tr>
<tr>
<td>Supports Employment Opportunities (e.g. agriculture, fisheries, handicrafts, cottage industry)</td>
<td>Liability of service providers</td>
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<td>-------------------------------------------</td>
<td>-------------------------------</td>
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<tr>
<td>Development of export markets for local products/foods, etc</td>
<td></td>
</tr>
<tr>
<td>Political</td>
<td></td>
</tr>
<tr>
<td>Maintenance of populations in political boundary areas</td>
<td>Exposure of global public to anti-humanitarian activities</td>
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<tr>
<td>Maintenance of future development options</td>
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<tr>
<td>Cultural/social</td>
<td></td>
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<tr>
<td>Exposure to new lifestyles</td>
<td>Disruption of culture</td>
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<tr>
<td>Maintenance of traditional knowledge/products</td>
<td>Loss of traditional knowledge</td>
</tr>
<tr>
<td>Environmental/conservation</td>
<td>Degradation of local products</td>
</tr>
<tr>
<td>Incentives/funds for park/resource management</td>
<td>Enhanced local expectations due to exposure to affluent visitors</td>
</tr>
<tr>
<td>Incentives/funds for resource management research</td>
<td></td>
</tr>
<tr>
<td>Improved environmental education</td>
<td></td>
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<tr>
<td>Accelerated development of an environmental ethic</td>
<td></td>
</tr>
<tr>
<td>Resource degradation due to numbers or activities of tourists</td>
<td></td>
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<tr>
<td>Resource degradation due to increased local demand</td>
<td></td>
</tr>
<tr>
<td>Resource degradation due to unsuitable facility/infrastructure development</td>
<td></td>
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<tr>
<td>Resource degradation due to improper waste management</td>
<td></td>
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</tbody>
</table>
Table 2: Environmental consequences of tourism (Auyong 1995)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consequences to Environment</th>
<th>Ecosystem Impacts</th>
<th>Human Impacts</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid waste disposal</td>
<td>Waste from human activities</td>
<td>Water and air quality reduced</td>
<td>Public health risk</td>
<td>Lots of trash cans</td>
</tr>
<tr>
<td></td>
<td>pollutes water and soil</td>
<td>Species/habitat poisoned</td>
<td>Economic loss (tourism)</td>
<td>Routine cleanup</td>
</tr>
<tr>
<td></td>
<td>Drainage from landfills or</td>
<td>Fish caught in trash</td>
<td>Aesthetics</td>
<td>Adequate treatment and disposal technology</td>
</tr>
<tr>
<td></td>
<td>dumps</td>
<td>Cleanup costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smoke and fumes from burning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage disposal</td>
<td>Suspended solids</td>
<td>Water quality decreased</td>
<td>Public health risk</td>
<td>Waste management</td>
</tr>
<tr>
<td></td>
<td>Reduced dissolved oxygen</td>
<td>Groundwater contamination</td>
<td>Welfare loss e.g.</td>
<td>User/impact fees</td>
</tr>
<tr>
<td></td>
<td>Bacteria and germs</td>
<td>Drainage from dumps and landfills</td>
<td>-subsistence</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chlorine</td>
<td>Smoke and fumes from burning</td>
<td>-recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freshwater demand</td>
<td></td>
<td>Increased local infrastructure</td>
<td></td>
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<tr>
<td></td>
<td>Toxic industrial waste</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Land use changes</td>
<td>Secondary development</td>
<td>Urbanization</td>
<td>Public health risk</td>
<td>Land use planning</td>
</tr>
<tr>
<td></td>
<td>Enhanced access/high density</td>
<td>Over-fishing/resource depletion</td>
<td>Welfare loss e.g.</td>
<td>Resource management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change in ecosystem structure</td>
<td>-quality of life</td>
<td>Appropriate site selection</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>-subsistence</td>
<td>avoiding sensitive areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-commercialisation of culture</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>or religious practices</td>
<td></td>
</tr>
<tr>
<td>Tourist activities</td>
<td>• More people in area</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• Increased conflict with different cultures and lifestyles</td>
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<tr>
<td>-sightseeing</td>
<td>• Resource depletion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-reef walks</td>
<td>• Changes in ecosystem structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-souvenir collection</td>
<td>• Degradation of important cultural historic or recreation areas</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>• Welfare loss e.g. quality of life</td>
<td></td>
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<tr>
<td></td>
<td>• subsistence</td>
<td></td>
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<tr>
<td></td>
<td>• Commercialization of culture or religious practices</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>• Education/information</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• Ensure compatibility with community</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Compensation in money or land</td>
<td></td>
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</tr>
</tbody>
</table>

| Construction activities   | • Noise                                                                               |
|                           | • Machinery                                                                          |
|                           | • Congestion or traffic                                                               |
|                           | • Structural addition to coast and landscape                                         |
|                           | • Disturbance of animals                                                              |
|                           | • Poison environment                                                                 |
|                           | • Water quality degradation                                                           |
|                           | • Worker safety                                                                       |
|                           | • Public health risk                                                                  |
|                           | • Aesthetics                                                                          |
|                           | • Respiratory irritation                                                               |
|                           | • Noise and emission control ordinances                                               |
|                           | • Toxic substance controls                                                            |
|                           | • Timing to avoid migratory/spawning                                                  |

Feasibility Study for commercial underwater viewing facilities

Alicia Rowse
8.0 ENVIRONMENTAL IMPACTS

8.1 Coral Reef

Due to their complexity, coral reef systems can show a variety of responses to stresses, such as storm damage, pollution, thermal effluents, or nutrient enrichment. A common response following such events is a progressive transformation from predominantly living coral to a dead substrate covered by macroalgae (CALM 1994).

8.1.1 Addition of predators

The infrequent outbreaks of the Crown-of-thorns starfish (*Acanthaster planci*) have caused localized destruction to coral reefs. The coral-eating gastropod *Drupella cornus* has caused widespread damage to back-reef communities of the Ningaloo Reef (CALM 1994). Such predator outbreaks are possibly due to some form of human interference with the natural ecosystem. The coral reef communities are usually slow to recover, even when the predator is removed.

There are occasional disastrous disturbances to coral reef communities when coral predators become excessively abundant. The crown-of-thorns starfish *Acanthaster planci* is large, 25 to 35 cm in diameter, and has 7 to 21 arms that are covered in spines (Mann 2000). It feeds primarily on coral and moves up to 4m per hour. Large areas of the coral cover can be lost, from 50% to nearly 100%, because of this.

After an outbreak in a particular area, it is common to find that acroporids have been selectively removed, leaving a mosaic of living and dead corals (Mann 2000). Hence, in places where acroporids previously dominated the community, total devastation is a very likely, and local areas of reefs will collapse.

Areas of dead coral are rapidly colonized by algae, and often later by sponges and soft corals. Increases in abundance of herbivorous fish and decreases in abundance of coral-feeding fishes accompany these changes (Mann 2000). However, coral larvae settle among the algae and eventually establish flourishing coral colonies. A similar percentage of coral cover will
potentially return in 10 to 15 years, whilst development of full species diversity takes about 20 years.

Strong freshwater runoff brings additional nutrients to the coastal waters, stimulating phytoplankton production and permitting more rapid development and better survival of the sea star larvae (Mann 2000). Destruction of coral by dredging, blasting, or by siltation resulting from bad land-use practice would reduce predation on sea star larvae and cause a feedback in which increase in sea star populations cause still further coral destruction (Mann 2000).

Some have suggested that the predators might have been killed off by pollution, whereas others have suggested that harvesting of vertebrate and invertebrate predators of the sea stars could have reduced mortality and caused increased abundance of adults (Mann 2000).

8.1.2 Eutrophication

Eutrophication is the addition of nutrients to a system. It will cause a substantial increase in primary production. This increase in primary production in coral reefs will lead to large increases in the quantity of algae, which will then overrun and replace the coral.

Eutrophication through sewage pollution has been associated with increased algal biomass, reduced coral species diversity, and reduced growth and reproduction in existing corals.

8.1.3 Sedimentation

Deposition of a thick layer of sediment on a coral colony can kill it almost immediately. Development in the coastal area will generate sediment from dredging. If currents carry the silt away from the reefs, minimal harm to the reefs will result. However, if the work is carried out in an area with restricted water circulation there can be profound mortality of the corals.

8.1.4 Coral Bleaching

When corals are stressed by exposure to extremes of temperature, salinity, or light irradiance, they commonly expel their zooxanthellae in a process known as bleaching (Mann 2000). If the stress lasts only for a short period and it is not too severe, the corals may recover their
complement of symbiotic algae, on the other hand if they do not, they will die. If not fatal, bleaching is accompanied by a decline in the protein, lipid, and carbohydrate content of the tissues, tissue necrosis, and reduced growth and reproductive output (Mann 2000).

8.2 Erosion and Accretion

8.2.1 Shore erosion
Shore erosion arises when more material is eroded away than deposited on the shoreline. The transfer of wind energy to the water generates waves causing this erosion. Waves may also be generated by other means, such as underwater earthquakes, but these seldom occur off the coast of Western Australia.

Usually there are two types of erosion. Natural erosion from natural causes such as storms, tides, and rise in sea level and man made erosion, resulting from improperly designed and incorrectly located coastal structures. Both result in the disturbance of the natural equilibrium between supply and loss of material. Man-made erosion is a process caused by man’s interference with natural shore processes, such as inlet improvement by dredging or the construction of jetties and structures which blocks the natural movement of sediment along the shore.

The coasts may be rocky and sandy however, rocky shores do not create any erosion problems. Sandy shores, on the other hand, are constantly in transitional movement and may have to be protected against erosion (Bruun 1973).

8.2.2 Shore accretion
Shore accretion is just the opposite of erosion because more material is deposited than eroded. The equilibrium forms associated with accretion may be computed, based on assumptions of material movements versus equilibrium configuration (Bruun 1973). Man made structures, such as the walkway, may influence the shoreline configuration considerably. This can create a build up of drift on the beach.
8.3 Seagrasses

If suitable sediment is at hand, the seagrasses will extend to the depths where the annual light flux is just enough to support a positive balance of photosynthesis over respiration (Mann 2000). If the water becomes turbid with suspended silt or mud, due to construction in the marine environment, light penetration will be reduced and the depth range of the dispersion of seagrasses will decline. The amount of light reaching the leaves will be reduced if high nutrient conditions, possibly caused by sewage discharge, cause a heavy growth of epiphytic algae on the seagrasses or a dense bloom of phytoplankton in the water column. If silt or phytoplankton settles on seagrass leaves, then the amount of light reaching the leaves will be still further reduced.

Like salt-marsh plants, seagrasses must be adapted to function with their roots in anoxic sediments (Mann 2000).

The subtropical species *Thalassia testudinum* (turtlegrass) demonstrates an interaction between salinity stress and temperature stress: The plants can withstand low salinities at low temperatures, although a combination of high temperatures and low salinity will be fatal.

8.3.1 Water Movement

If the leaves were in motionless water, their uptake of carbon dioxide and other nutrients would quickly deplete the water in their immediate vicinity (Mann 2000). A boundary layer would form in which carbon dioxide, nitrate, and phosphate were concentrated in a gradient that was low at the leaf surface and that increased to ambient level beyond the boundary layer (Mann 2000). Such a boundary layer would restrict the uptake of nutrients. The key to overcoming resistance to the boundary layer is the movement of water over the surface of the plant. This will reduce the thickness of the boundary layer (Mann 2000).

In nature, however water movement causes the shoots to bend and interlock and the canopy becomes more compact, thus reducing light penetration. Therefore, a change in water movement due to the structure may make the leaves intertwine significantly more, reducing the light and killing some of the seagrass community. They may also be indirectly affected by physical
development if this has the effect of diverting the flow of seawater bringing sediment and nutrients (Mann 2000).

8.3.2 Eutrophication
Fertilization of the water column through the input of nutrients causes the production of dense mats of free-floating green algae. The accumulation of algae will destroy seagrass beds by drastically reducing the light emitted to the beds.

In unpolluted situations, macroalgae may also be important in recovery of seagrass beds after a disturbance. An increase in nutrient levels from sewage discharge or from agriculture can lead to smothering of seagrasses by dense accumulations of unattached macroalgae (Mann 2000). It can also lead to the turbidity of the water column because of either suspended sewage solids or artificially high densities of phytoplankton. Finally, phytoplankton may settle on the leaf surfaces (Mann 2000). In all these ways, the seagrasses can die for lack of light.

Increase in nutrient levels can also lead to increase in the growth of algae attached to the leaves of the seagrass. In the natural habitat, an abundance of these epiphytes may lead to a development of dense populations of the animals that browse on them. Hence, a balance is achieved and the seagrasses are able to maintain their current growth patterns. If the water however, contains substances toxic to the animals that graze on the epiphytes, they will not be found in the habitat. This will lead to excessive growth of epiphytes and may lead to the demise of the seagrasses.

8.3.3 Restoration of Seagrass beds
Many areas have been identified where infilling, dredging, pollution, or a combination of these environmental factors, has led to the destruction of large areas of seagrass (Mann 2000). Considerable effort has been directed at finding cost-effective methods of replanting seagrasses, and determining whether the replanted areas fulfil the ecological functions presented by the natural seagrass beds. Some investigators have had limited success, whilst others have failed (Mann 2000).
It was concluded that *Thalassia* could be propagated with sprigs, and with seedlings in favourable locations. *Halodule* could also be propagated with sprigs, but that *Syringodium* showed poor survival rate regardless of the method that was used. Populations of penaeid and caridean shrimps and juvenile fish were considerably higher in a replanted *Thalassia* bed than in natural beds and were an order of magnitude higher than in nonvegetated areas (Mann 2000).

More recently, *Halodule* and *Syringodium* were successfully planted in clumps containing 15 to 25 shoots, anchored to metal staples, on 0.5 m centers (Mann 2000). Survival of the plants was considered relatively good, but bioturbation by large fish, caused 47% of the plantings to eventually fail (Mann 2000). Two to three times a year for 3 years, the development of both plant and animal components of the seagrass beds was monitored. Many plantings exhibited little spread in the first year but expanded rapidly in the second year. The overall assessment was that, with experience and care, seagrass communities can be re-established, provided that the development of the beds is monitored and a second planting is undertaken where necessary (Mann 2000). The costs of replanting are extremely expensive especially when there is no guaranteed success. However, it was concluded, that conservation provides a definite foundation for preserving the seagrasses than attempting to alleviate the problem through planting.

### 8.3.4 Sedimentation

High levels of suspended silt, resulting from the dredging and filing may not bury the seagrass beds but they will become smothered by the sediment.

Another impact of sediment discharge is increased turbidity in the water column (Brodie 1995). Turbidity reduces light penetration through the water. It also inhibits the growth of organisms that require light for survival. The effects are most severe on benthic communities where the viable depth range for a community, such as seagrass, may be narrowed by loss of light (Brodie 1995). Particulate matter in the water column also may interfere with the feeding behaviour of zooplankton.
8.3.5 Effects on Fisheries

Water pollution may affect fisheries adversely in a range of ways by. As previously noted, increased anoxic conditions will lead to restrictions in fish habitat especially, for inshore demersal fish although eutrophication, in some cases, leads to an initial increase in fish stocks as primary productivity increases (Brodie 1995). As eutrophication continues, the problems causing reductions in the fisheries resources, such as anoxia, toxic red tides, shellfish poisoning and non-food phytoplankton blooms continue.

Although seagrasses may be relatively resilient to some natural and human impacts, such as storms or anchor and propeller damage, other activities such as coastal engineering projects, landfilling, dredging and sand mining can cause the complete destruction of a seagrass community. Thermal pollution, sedimentation, nutrient enrichment, sewage discharge, oil and chemicals have been shown to also deplete seagrass communities (CALM 1994). Toxic elements from agricultural run-off can also have marked effects on seagrass systems in estuaries and landlocked bays (CALM 1994).

8.4 Southern Estuaries

If the construction of the underwater observatory is near or in one of the southern estuaries then a variety of impacts may be experienced by the ecosystem. Sometimes these impacts may benefit the estuaries by creating a more equable environment that permits a higher diversity of aquatic species to live there. More often, though the impacts have detrimental results on the estuary, from activities such as increased discharge of industrial wastes and sewage. Probably the most serious long-term threat is from clearing in catchments for more construction purposes and the consequent eutrophication and sedimentation in estuaries that will follow.

Given the high aesthetic and commercial values of the southern estuaries there is no doubt that they require management. However, this is a very difficult thing to achieve and will require the management of the catchments beyond the limits of the estuaries as well as management of the estuaries themselves (CALM 1994).
8.5 Mangals

Mangroves may be disturbed or destroyed by natural events such as cyclones, tidal waves, or coastal erosion (CALM 1994). Human activities from the construction of structures in the marine environment may also have comprehensive impacts. Dredging can cause changes in the drainage patterns within the mangroves, deforestation can increase sediment runoff and deposition in the mangals, and changes in coastal development can adversely change the environment and deplete mangroves. Water pollution by additional refuse dumps, sewage, oil and chemicals can be detrimental to mangroves and associated food chains important to people (CALM 1994).

8.6 Tidal flats

Tidal flats are susceptible to natural and human-induced disturbances in the environment. Natural disturbances may include cyclone-induced erosion, sediment transport, or flood-induced blanketing of substrates by different sediment types (CALM 1994). Human-induced disturbances that will negatively affect these areas are, dredging and soil dumping, and the discharge of toxic materials into the water column. The first will create turbid water along the tidal flat and the second will release harmful substances into the ecosystem that will harm the marine life and then seep into the substrate.
9.0 OTHER IMPACTS

9.1 Infrastructure Impacts

The most obvious components of tourism development are the actual structures that house and support this influx of visitors. Associated to these may be various service and recreational amenities such as restaurants, swimming pools, golf courses, and tennis courts. This growth in tourism requires the provision of basic utility and service infrastructure such as water, sewage and solid waste disposal, and power. Efficient access to and from major tourist destinations through major airports, roads, or ports is vital also to the success of a major tourism development. The need for physical infrastructure that normal growth would not require, is an argument used against the construction of structures in marine environments. Furthermore, these large-scale developments are particularly stressful on coastal and marine environments.

9.1.1 Infrastructure Requirements

Necessary comforts for visiting tourists through the provision of infrastructure, is a major development requirement. Generally, operational activities, especially for resort complexes, require a certain level of infrastructure and public services. If this does not take place sewer and waste disposal facilities could overflow, water could be diverted from existing uses, or there may be periods where power-generating plants are unable to provide sufficient energy capacities (Auyong 1995).

9.1.2 Fresh Water Needs

Depending upon the type of facilities made available, potable water requirements could vary greatly from the current usage.

9.1.3 The Aquatic Environment

Water traditionally has attracted tourists, and water resources and near shore habitats are often the most severely affected (Auyong 1995). Construction of hotels and other tourist infrastructure has led to various impacts, such as erosion, loss of habitat, increased siltation and degradation of near-shore habitats.
These impacts can be direct, indirect, or interrelated. A hotel might build a dock for its dive boat, which results in sand eroding from the altered beach and being deposited elsewhere in the marine environment.

### 9.1.4 Recreational Use

Impacts also result from additional tourist activities, generally revolving around recreational and cultural events. A wide range of environmental concerns related to recreational uses such as trampling of vegetation on tidal areas, collecting of fish, shells and corals are of major concern (Auyong 1995).

Although small-scale camping facilities would be of interest to local communities, investment by the public sector in campground facilities does not generally yield economic returns and therefore would not likely be supported by the governments.

### 9.2 Socio-Economic Impacts

Preliminary assessment of the project suggests that the observatory will offer a number of local and regional opportunities. With the construction of the observatory, there will be a creation of several employment opportunities. These will be associated with the construction, maintenance and daily running of the observatory. An increase in tourism in the region will generate spending in the local community.
10.0 PROJECT IMPLEMENTATION

Implementation of this project will occur in several stages. Preliminary surveys of the sea floor will be carried out before any of the final design or construction phases begin. This is to determine the composition of the seabed and marine habitat of the chosen site.

The first phase will be the construction of the observatory at a specified site. This site is not at the location of the observatory in the marine park but a site in another place. This is to minimise the environmental impacts whilst constructing the observatory. As it the proposed site is in a marine protected area, damage to the surrounding environment must be kept to a minimum. This also must be done, as the whole attraction of the observatory is the marine life and hence damaging it will be detrimental to the success of the observatory.

The site of the observatory and walkway needs to be prepared before construction can begin. Dredging of the site occurs to create a level surface for the beginning of the stages of construction. The site will be dredged using a self-propelled hopper dredge. The seabed is also excavated with the intention that the foot of the observatory will sit in the seabed. By doing this, no viewing space is lost from the 1m thick solid concrete base.

Once the site is prepared, cores will be drilled into the seabed for the piles for the observatory. The piles will be driven and then the concrete slab for the base of the observatory will be poured. After the base for the observatory is complete, the main structure will be floated out to the site. It will then undergo a controlled flood to sink the structure into its correct position over the base slab. The structure will be anchored to the base using anchor bolts. They are rods protruding from the top of the piles. These bolts are narrow at the top and the structure ‘screws down’ on top of them.

The body will then be pumped out and the top half of the structure attached. Once the observatory has been securely placed in the correct position, the construction of the walkway out to the observatory will begin. Again, cores will be drilled into the seabed for the piles that support the walkway. The piles will then be driven and the deck completed.
Once these construction stages have finished, the interior of the observatory will be completed and reading to be used.
11.0 QUANTITATIVE ANALYSIS

Once a site has been chosen for the observatory a more definitive quantitative analysis can be conducted, however the major issues that need addressing have been outline here. Many analysts increasingly target marine ecotourism as a vehicle for both economic development and coral reef conservation goals (Downie et al. 1996). The economic gains from reef-based tourism are evident throughout the world. However, the paradox of marine tourism is that the economic activity it generates can jeopardize the existence of the environmental assets from which these revenues derive. Therefore, to maintain the integrity of the resources, the economic goals of marine-based tourism must be harmonized with environmental protection. Balanced use of marine resources for both economic and ecological functions, rather than the extremes of strict preservation or unmanaged development, is central to their sustainable management (Downie et al. 1996). Marine protected areas represent viable means of successfully managing the ecosystem to extract economic benefits while simultaneously protecting the environment. Despite the cost, analysts find that the economic benefits of marine protection outweigh the costs, often by more than an order of magnitude (Downie et al. 1996).

The working hypothesis in the marine park is attractive because its unique resources are protected. However, if protection of the marine ecosystem is not maintained, much of the marine park’s attraction would be lost, along with it the associated revenues.

11.1 Economic Benefits of Protection

The main categories of economic benefits included in the economic analysis are gross revenues to the private sector and government revenues associated with activities related to the marine park. The primary uses of the waters contained in the marine park are:

I. The observatory
II. Dive-based tourism
III. Small-scale and recreational fisheries
IV. Yachting and other water sports
V. Cruise tourism
VI. Ocean transport

Of these, only revenues from the observatory are considered, as the other uses of the marine park waters are less dependent on the protection afforded by the Park. Land-based supporting activities to the observatory include hotels, restaurants, souvenir sales, and car rental.

11.2 Cost Benefit Methodology

Cost benefit analysis embodies intuitive rationality, in that any course of action is judged acceptable if it confers a net advantage – that is, if benefits outweigh costs. Here we estimate the revenues (direct, indirect and tax) and costs (direct, indirect and opportunity) that would flow from human use of the observatory under scenarios with and without protection in order to estimate the benefit that could be derived from effective reef protection (Downie et al. 1996).

11.2.1 Benefits calculation – Direct revenue

The sources of direct revenue are entrance fees to the Park, admission fees, concessions, cafeteria revenue and donations collected by the park itself.

11.2.2 Indirect Revenues from Park protection

Indirect revenue is that revenue generated in the local economy, which can be attributed, to use of the reef and accrues but is not collected by the park administration. There are a variety of flows, which yield indirect revenue. Revenues can be obtained through including hotel, and diving expenses as well as expenses for other activities related to the reef. There are however, several factors, which in combination, tend to limit the amount of these revenues, which remains in the local economy.

Observatory based tourists were also projected to participate in other activities, including rental of dive gear and tours.

11.2.3 Benefits Calculation- Tax Revenues

The Government collects several direct and indirect taxes. Those for the observatory based tourism component are difficult to desegregate include: personal income tax, wage tax, business
profit tax, use tax and land tax. Even if the portion of this revenue attributable to observatory-based tourism could be easily calculated, for the most part these should be considered as transfers of benefits rather than additional benefits generated by use of the park (Dixon et al. 1993). Tax revenues can be calculated on a base consisting of the indirect revenues and direct revenues from concessions and the shop.

11.2.4 Cost Calculation – Direct Costs
The direct initial costs of establishing the Park have been obtained (Downie et al. 1996). These costs include capital expenditures, which include marking boundaries, installing moorings and construction of administration buildings and recurring costs for staff and operations (Downie et al. 1996).

Employment, in an economic sense, is a cost of generating total gross revenue. Nevertheless, employment, particularly of locals, is probably the most long lasting benefit to the local economy in the marine park. In addition, because of the dominance of tourism in the economy, employment in support activities such as construction, banking, trade and even government are indirectly related to the activities in the Park.

11.2.5 Indirect Costs
Indirect costs of marine protection include all costs, which are incurred to protect the marine park outside of the costs of park establishment and administration. Accordingly, indirect costs associated with protection of the marine environment, amount to modification of existing development plans and costs of compliance with protective regulations (Downie et al. 1996).

11.2.6 Opportunity Costs
In order to determine the total cost of preserving marine environment, an inclusive view of the costs must consider opportunity costs; and in calculating the opportunity costs of protecting the marine environment, it is necessary to identify and assign values for alternative uses of that resource. In opportunity costs, it includes those tangible assets that are foregone due to the preservation of marine environment. Yet, we have determined that tourist development will proceed as planned, regardless of whether marine protection is pursued. The protection of the
marine environment precluded certain extractive activities such as mining, coral collecting, and certain types of fishing therefore with the exception of coral collecting; these activities are incompatible with development of the zone for tourism. For this reason, the use of the marine environment for other purposes is rather limited. We therefore project that opportunity costs from keeping the marine environment undamaged are negligible.

While the opportunity cost of having a pristine marine environment are negligible, however, that of the money spent in preservation of the park is not. This money could easily be spent elsewhere in the economy. This cost can be accounted for through use of discounting. The discount rate is of concern in calculating the net benefits of marine environment protection because costs for protection are incurred up front, while benefits will not arrive until some years into the future (Downie et al. 1996).

11.2.7 Range of outcomes

Clearly, if excessive damage to the marine environment occurs more quickly than expected, the benefits to be derived from the marine resource will fall much more quickly, making protection much more appealing (Downie et al. 1996). Since the benefits of protection of the marine environment accrue in the future and most of the associated costs are up-front, the discount rate has a significant effect on outcomes (Downie et al. 1996).

Other important considerations include the relative weight placed on marine environment quality by prospective tourists.
12.0 CONCLUSIONS

The study established that construction of an underwater observatory would be beneficial in the management of Western Australian marine parks. There will be many advantages from building such a structure. Some of these include the generation of revenue to assist with the management of the marine park, creating permanent employment for local residents, and educating the community on the benefits of conservation. There is the potential for severe environmental impacts to occur from the construction of the observatory, however these can be avoided if stringent preventative measures are followed.
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