Ministry of Fisheries
Kingdom of Tonga

No. 01

BASIC DESIGN STUDY REPORT

ON

THE PROJECT FOR

RENOVATION OF SEAWATER SUPPLY SYSTEM

IN

THE KINGDOM OF TONGA

MARCH 1999

Japan International Cooperation Agency

Fisheries Engineering Co., Ltd.

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PREFACE

In response to a request from the Government of the Kingdom of Tonga, the Government of Japan decided to conduct a basic design study on the Project for Renovation of Seawater Supply System and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Tonga a study team from September 26 to October 19, 1998.

The team held discussions with the officials concerned of the Government of Tonga, and conducted a field study at the study area. After the team returned to Japan, further studies were made. Then, a mission was sent to Tonga in order to discuss a draft basic design, and as this result, the present report was finalized.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Tonga for their close cooperation extended to the teams.

March, 1999

Kimio Fujita
President
Japan International Cooperation Agency

March, 1999

LETTER OF TRANSMITTAL

We are pleased to submit to you the basic design study report on the Project for Renovation of Seawater Supply System in the Kingdom of Tonga.

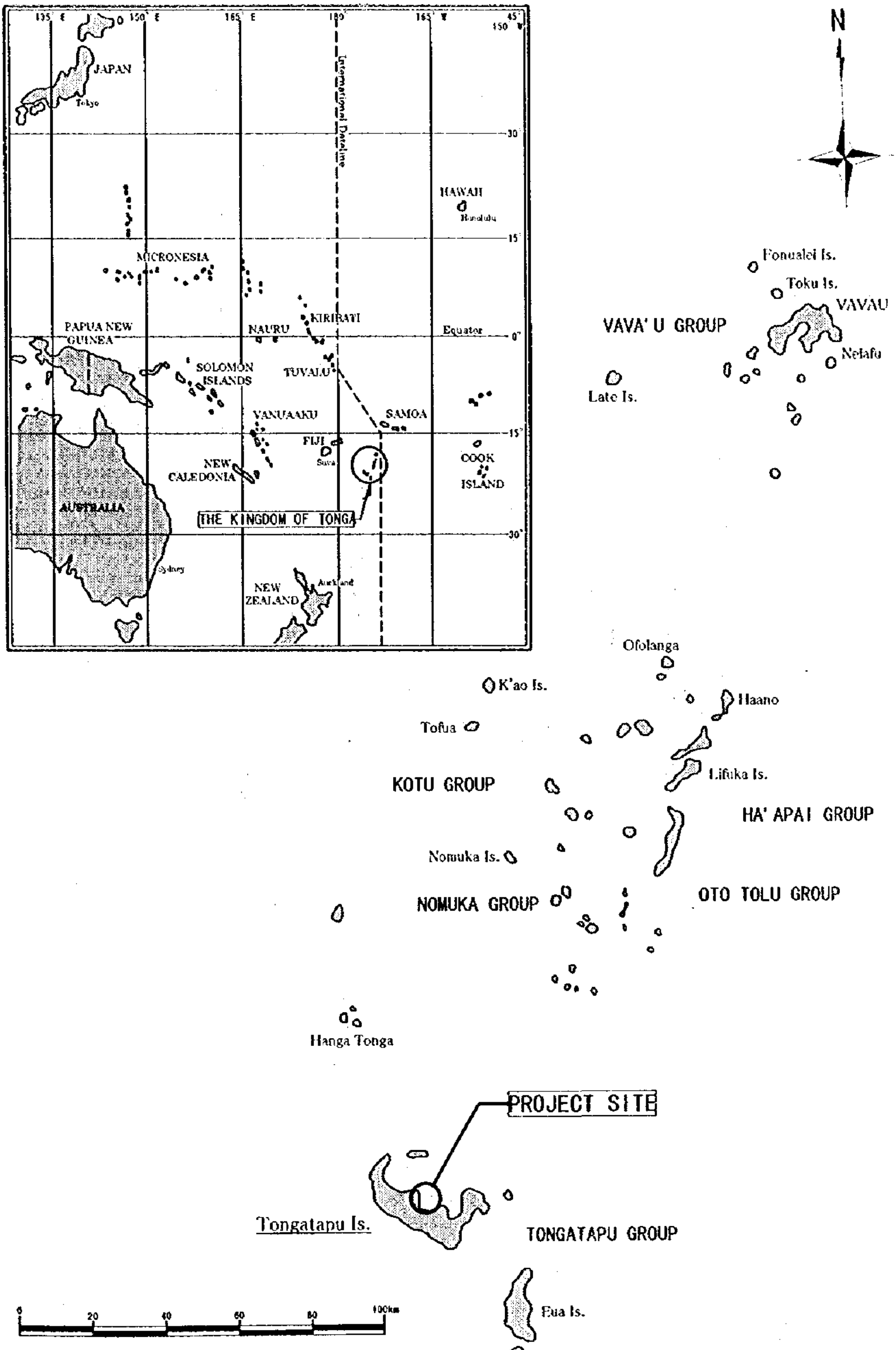
This study was conducted by Fisheries Engineering Co., Ltd. under a contract to JICA, during the period from September 18, 1998 to March 12, 1999. In conducting the study, we have examined the feasibility and rationale of the project with due consideration to the present situation of Tonga and formulated the most appropriate basic design for the project under Japan's grant aid scheme.

Finally, we hope that this report will contribute to further promotion of the project.

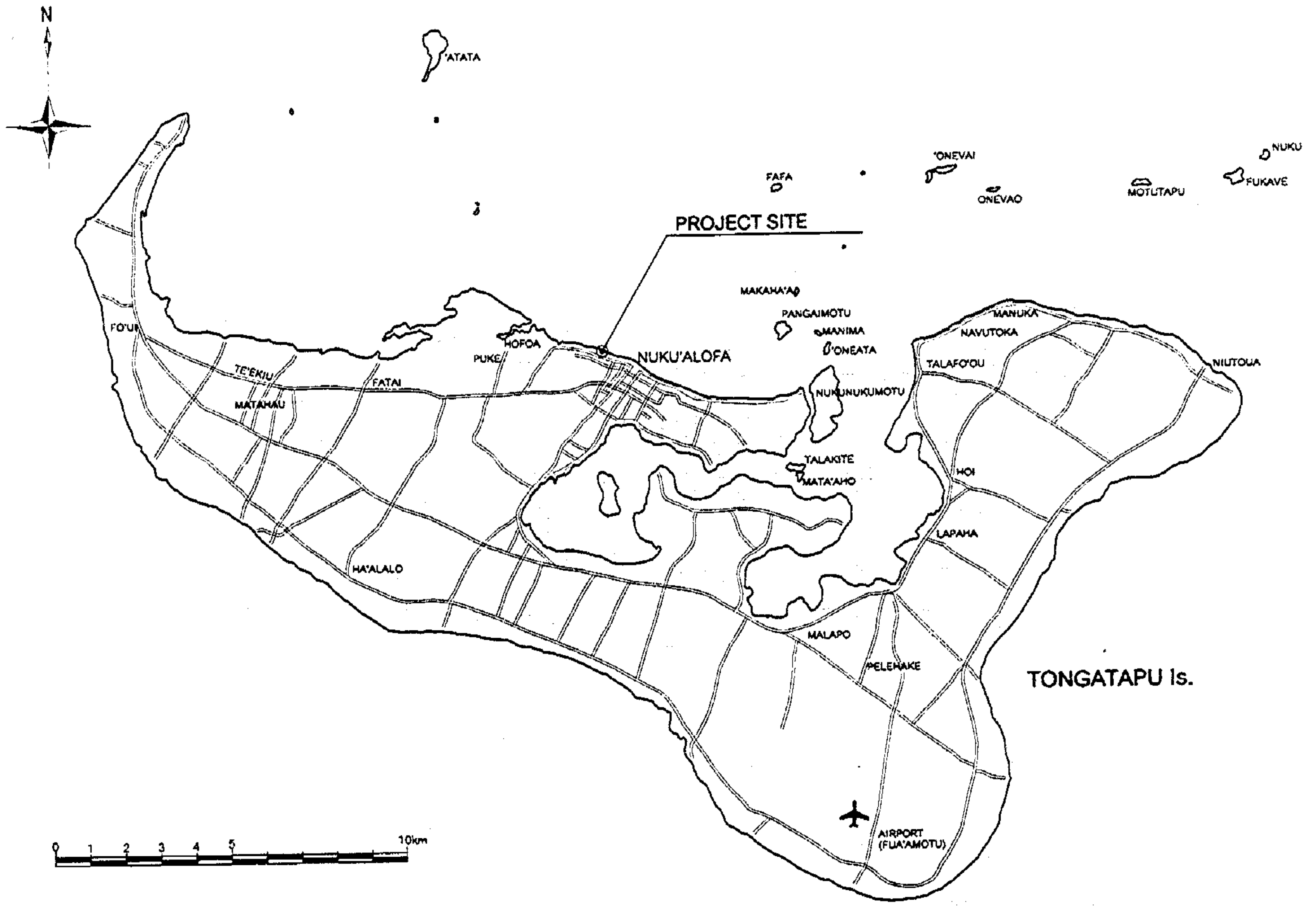
Very truly yours,

Toshiya OGASAWARA
Project Manager,
Basic design study team on
the Project for Renovation of Seawater Supply System in the Kingdom of Tonga

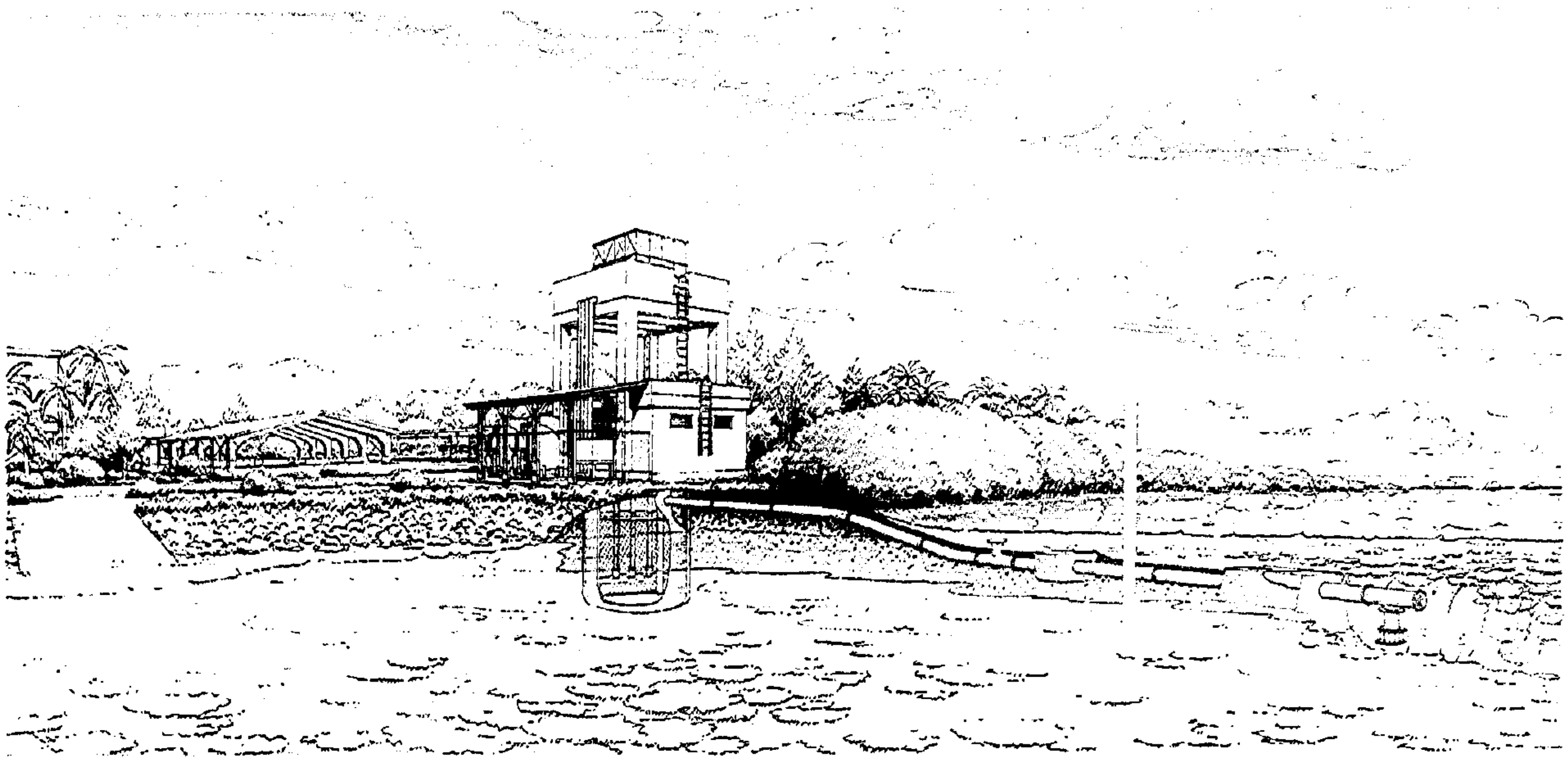
Fisheries Engineering Co., Ltd.



THE KINGDOM OF TONGA



PROJECT SITE MAP



PERSPECTIVE : THE PROJECT FOR RENOVATION OF SEAWATER SUPPLY SYSTEM IN THE KINGDOM OF TONGA

ABBREVIATIONS

ARDP	:	Aquaculture Research and Development Project
FAO	:	Food and Agriculture Organization of the United Nations
FFA	:	Forum Fisheries Agency
FRP	:	Fiber reinforced plastic
GDP	:	Gross Domestic Product
JICA	:	Japan International Cooperation Agency
PVC	:	Polyvinyl chloride
SPC	:	South Pacific Commission
SPADP	:	South Pacific Aquaculture Development Project
UNDP	:	United Nations Development Programme

CONTENTS

CHAPTER 1 BACKGROUND OF THE PROJECT

The Kingdom of Tonga is an island country, composed of about 170 islands located in virtually the center of the South Pacific and scattered along the western side of the International Date Line approximately between latitude 15° and 23° 30' S and longitude 173° and 177° W. The country's land area is only 748 km^2, but its coastline has a total length of 419 km, with an EEZ (Exclusive Economic Zone) covering some 720,000 km^2. Based on the 1996 Census, the total population was 97,446, of which 68.3% (66,577) lived on Tongatapu Island. Annual average population growth was about 0.3% over the 1986 - 1996 decade.

The Tonga economy is supported by primary industry, centered on agriculture, with agriculture, forestry and fishery contributing more than 30% of GDP, and accounting for over 90% of total export value. Thus, these sectors can be said to play a major role in terms of both employment creation and foreign exchange earnings. The primary export commodities to date have been coconuts, bananas and vanilla beans but, starting in 1987, a program to export squash pumpkins to the Japanese market began to bear fruit, contributing in a major way to Tonga's foreign exchange earnings. However, since the squash market is limited almost entirely to Japan, owing to recent competition from Vanuatu and New Caledonia as well as a series of other impediments, clouds have begun to develop over exporting squash.

Tonga's foreign trade balance, as with other South Pacific island states, is in chronic deficit, reflecting the country's geographic isolation as well as a paucity of natural resources. But an economic structure has developed wherein these trade deficits are largely covered by foreign aid and remittances from migrants. The Tonga government, with a view to reducing the economy's dependence on agriculture, which is so vulnerable to inclement weather, has been making a determined effort to sustain the nation's growth at past target levels by fostering and developing other industries, particularly tourism and fisheries.

The fishing industry in Tonga may be broadly divided into three categories: an export oriented commercial fishery directed at the abundant tuna resources in the EEZ; a small-scale inshore fishery, which operates chiefly in coastal waters and is an important source of fish for the domestic market; and a traditional artisanal fishery, operating on a subsistence basis in coral reef areas. The total fish catch in 1998, as reported by the Food and Agriculture Organization (FAO), came to 3,424 tons. According to the 1996 Census, direct employment in the fishing and fish processing industry totaled 1,067, accounting for 3.6% of the total labor force, but this share rises to 16% or more when persons indirectly involved with the fishing industry in some form are included. In addition, many individuals are said to be fishing on a part-time or subsistence basis, with such subsistence fishing providing a part of the people's livelihood, particularly in villages and on outlying islands. The share of the fishery sector in the country's total GDP has been steadily increasing, from an estimated 6.9% in fiscal 1992 / 93 to over 10% in fiscal 1996 / 97, while its share of export value has grown from 12.9% in 1992 / 93 to 23.2% in 1995 / 96. The fishing industry has thus consolidated its position as the nation's second largest industry after agriculture.

The coastal and reef fisheries play an important role as a key source of animal protein, while annual production by the artisanal fisheries is valued at the equivalent of T$ 2,500,000 per year (World Bank, 1996). However, catch pressures have been intensifying year by year, reflecting the general rise in purchasing power for fish products along with the modernization of fishing gear, and this has caused conspicuous resource depletion in such major species as giant clams, mullet, bêche de mer and lobsters. Yet, despite the imposition of catch restrictions, such as size limits, prohibition of diving gear, and closure of the bêche de mer fishery, there is no end of illegal fishing activity. It is hoped that drastic measures will be taken to bring about a recovery in fishery resources and that more effective use can be made of the reef areas, based on the seed restocking of such useful species as trochus, green snails, giant clams, and so on.

By way of support for fisheries development in Tonga as well as aquaculture research and resource conservation, a Marine Research Center was established in 1978 by a grant aid from the Japanese Government, as an experimental and research facility and, in 1991, implemented a program of project-type technical cooperation, based on this Center, with a view to further strengthening these activities. This technical cooperation, along with subsequent follow-up programs, has contributed to research and development on giant clams, green snails and trochus culture.

While the Marine Research Center has indeed achieved the desired results on the basis of this carefully linked program of grant aid and technical cooperation as well as efforts by the Government of Tonga, it has been saddled with a succession of problems, including unstable water quality resulting from water intake from the moat, superannuation of the seawater intake and drainage system, and inadequate water supply for cultivation. Now that the follow-up phase of the project-type technical cooperation program has come to an end, major uncertainties have developed over the future course of facility operations and management. In order to resolve these problems, the Government of Tonga has drawn up a renovation plan for the seawater supply system at the Marine Research Center and, in 1997, requested a grant aid from the Government of Japan for the Project implementation.

CHAPTER 2 CONTENTS OF THE PROJECT

2-1 Objectives of the Project

The economy of the Kingdom of Tonga is supported by primary industry, centering around agriculture, with the agriculture and fisheries sector playing a major role in generating employment and acquiring foreign exchange. While exports to Japan of squash, which began during the latter part of the 1980s, have been making an important contribution to the country's foreign exchange earnings, clouds have began to develop over this activity owing to a succession of impediments as well as the entry of other countries into the Japanese market for this product. With a view to breaking out of an economic structure dependent on agriculture, the Government of Tonga has been attempting to maintain the targeted rate of economic growth by nurturing and developing other industries, notably the twin pillars of tourism and fisheries.

The fishing industry offers many outstanding developmental opportunities not only because of its importance in supplying marine products for domestic consumption, but also because of the huge expanse of excellent fishing grounds in Tonga waters for tunas and other highly migratory species, while its coastal waters are ideal habitats for giant clams and valuable species of molluscs for use in ornaments and accessories. It is hoped that, on the basis of these fishery exports, the nation's chronic trade deficit can be improved.

In 1978, the Marine Research Center (hereinafter referred to as "the Center") was established with a grant aid from Japan as an experimental facility to support fishing development, and since the several grant aid programs have been implemented in the fishery sector. In 1991, a program of project-type technical cooperation was launched, by Japan International Cooperation Agency (JICA) based in the above Center, with a view toward further strengthening experimental research programs, and this cooperation has contributed to developmental research in breeding and cultivating such species as giant clams, green snails and trochus.

Based on the integration of grant aid projects and technical cooperation scheme as well as a series of effort by Tongan side, the Center has been steadily building on the results of its original research. However, several problems have recently developed: water quality has become unstable as a result of water intake from the reef moat, while the seawater intake facilities have aged, and a water shortage has also developed due to expanded Center activities. With the follow-up phase of the project-type technical cooperation now completed, these problems have given rise to grave concern over the future operation of the Center. The Project, accordingly, is intended to improve the seawater supply system at the Center so as to secure the requisite volume of quality seawater, which is a major problem at the facility, with a view toward contributing to the development of stronger operating capabilities along with a viable aquaculture industry in Tonga.

2-2 Basic Concept of the Project

Although the Marine Research Center was completed and handed over in 1978, the cyclone Issac in 1982 caused extensive damage to the intake facilities, rendering them unusable.

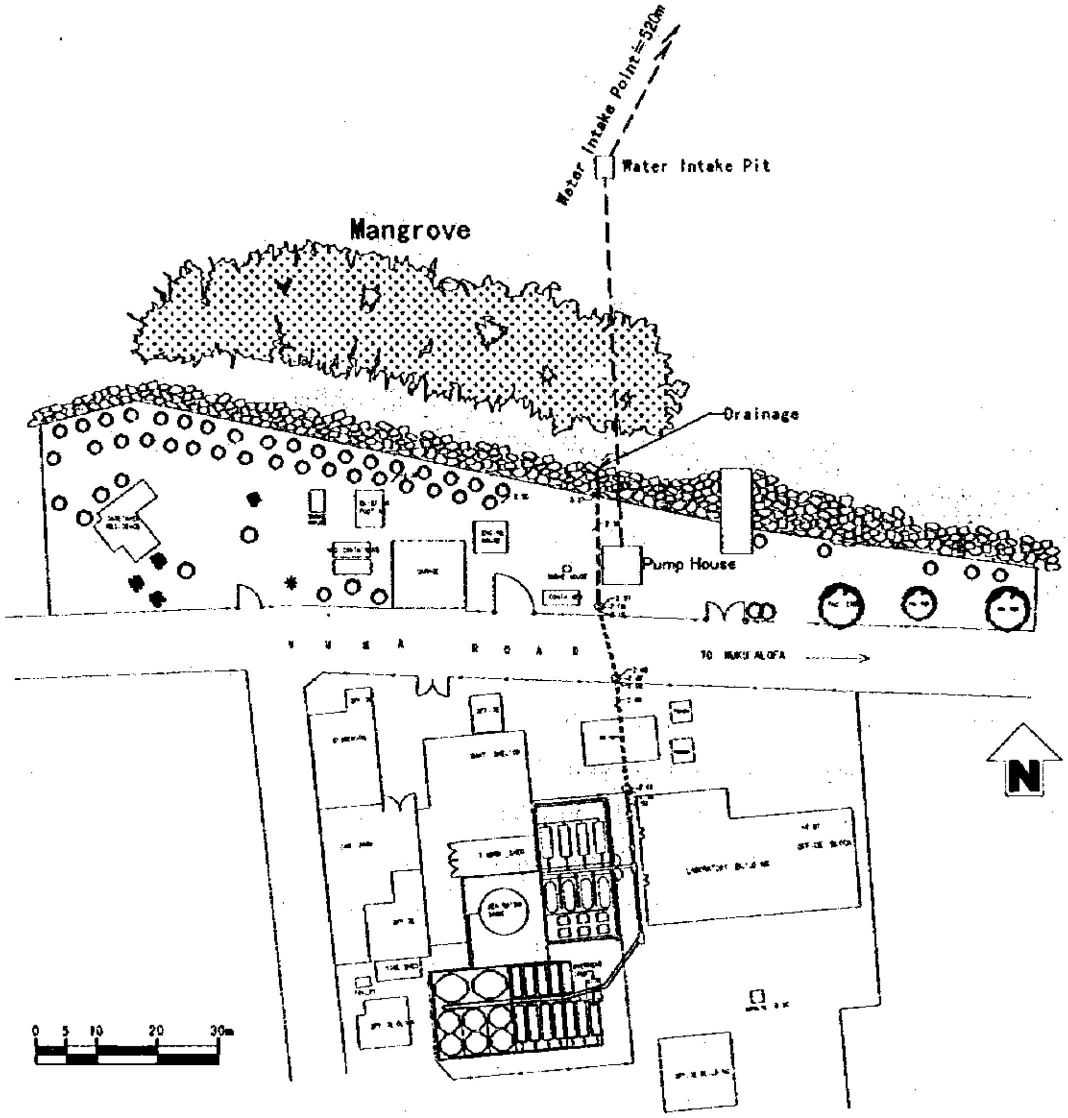


Figure 2-1 Layout of Present Facilities at the Marine Research Center

As the Aquaculture Research and Development Project (ARDP), a project-type technical cooperation by JICA, that began in 1991, Center functions were restored, at which time an attempt was also made to improve the facilities, including the seawater intake facilities. However, since complete renovation of the former intake system would have exceeded the scope of the ARDP, the work had to be restricted to makeshift repairs while using the old intake facilities. Furthermore, in the course of the ARDP, the rearing focus at the Center shifted from fin-fish to molluscs species, with a concomitant expansion of rearing tank capacity to meet the increased farming volume, leading in turn to heavier water usage. Under these circumstances, with the facilities already in use for some 20 years, Center activities have run up against a host of problems, such as the demise of culture organisms owing to a fall in salinity, water supply shortages for the rearing tanks, and frequent breakdowns of the superannuated pumps. The problems saddling the Center have been outlined as follows.

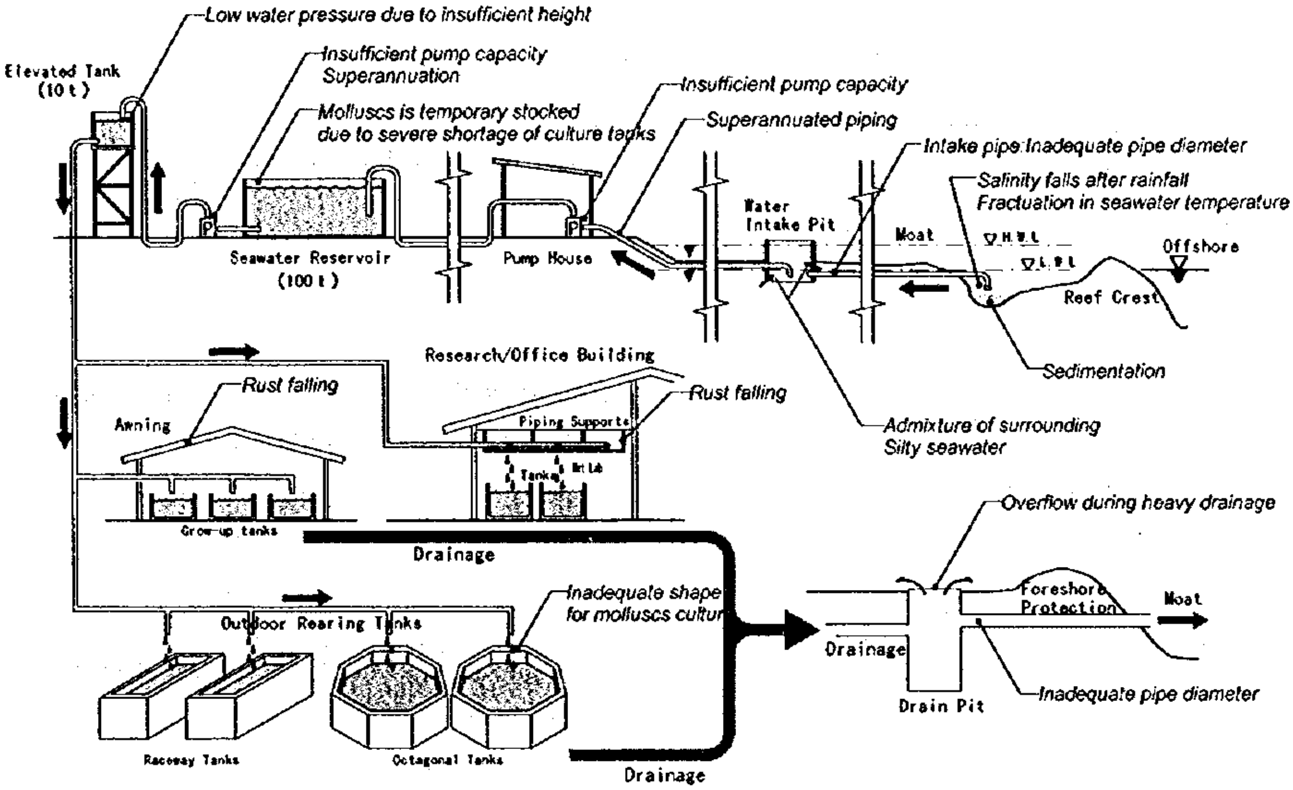


Figure 2-2 System Diagram of the Existing Seawater Supply System and Problem Areas

1) Unstable Water Quality

The intake point has been set inside the moat, which is subject to externally induced changes in water quality. Also, since seawater of undesirable quality penetrates from the intake pit installed near shore, owing to such factors as large fluctuations in water temperatures, a decline in salinity following rainfall, and the admixture of silt, water conducive to culture operations cannot be obtained. Water quality is also contaminated by rust falling into the rearing tanks from the superannuated owning.

2) Water Shortages

Part of the intake piping has been in use since the Center was established and so evidences marked superannuation. Since pipe diameter and pump capacity are too small to meet present water demand, the supply of water for culture use is inadequate.

3) Inadequate Drainage

With the expanded aquaculture capacity and a corollary increase in water consumption, since the drainage pipes have been in use in their present form since the opening of the Center, the sectional area has become inadequate, with drainage at times unable to keep pace, causing overflow from the drainage pit.

4) Complicated Control System

While gradual improvements have been made to the Center facilities and equipment during the ARDP phase, these measures were merely stopgap in nature to meet emergency situations. Thus, the present system lacks cohesion, resulting in considerable confusion during breakdowns.

5) Shortage of Rearing Tanks

While the research and development achievements at the Center have led to a growth in molluscs rearing volume, the installation of rearing tanks has not kept up with demand. Since only a limited area is available for additional tanks, the 100 m^3 seawater reservoir and octagonal tanks (the latter unsuitable for molluscs cultivation) remain in use, hampering efficient operations.

6) Lack of an Monitoring Function

In order to prevent fatal accidents to the culture organisms owing to breakdown of pumps, blowers, and other equipment, personnel at an aquaculture facility are normally deployed as monitors throughout the night and on non-working days. But the lack of a night-duty function at the Center has made it difficult to cope with emergencies, and this has also been a factor in the inability to prevent accidents.

Based on the above set of problems, the Center has been hard-pressed to conduct proper operation and research activities. It is essential, therefore, that Center activity be revitalized, if Tonga is to develop a viable aquaculture industry, and improvement of the seawater supply system is vital, since it constitutes the major obstacle to achieving this goal.

Since an intake system cannot function as an integrated unit if any its components are lacking, this Project will incorporate a comprehensive system, including water supply and drainage facilities. It has been also decided to add any other facilities which are found, during the course of the current study, to be indispensable to future activity. Based on the field survey, an appropriate plan framework has been established, as shown in Table 2-1 below.

Table 2-1 Plan Framework (Comparison with the Request Contents)

Function	Request Contents	Plan Contents	Remarks
Seawater intake	Intake pipe, intake pit, and piping to the elevated tank	As shown in the Request	Replacement required due to superannuation and inadequate capacity
Filtration	Reservoir cum filtration tank	Filtration tank	Needed to remove harmful organisms and other substances
On-site water supply	Intake pumps, elevated tanks, on-site distribution pipes, and wiring renewal	To include: intake pumps, elevated tanks, on-site distribution pipes, emergency generator, blowers, wiring and control panels	In conjunction with the new system, there is a need for : an emergency generator, blowers, and renewal of the control panel and wiring
Equipment storage	Machine house	Pump house	Required for equipment storage
Drainage	Drainage ditch and drainage piping	Drainage ditch, drainage piping, and settling pond	A settling pond is required from environmental considerations
Rearing		Replacement of owing for the culture area	Replacement is essential due to marked superannuation
		Rearing and seed production tanks	Need to expand the culture function
Monitoring	Night duty room (inside machine house)	Night worker's station	Needed to cope with emergencies
On-site preservation	Removal of elevated tank	Removal of reservoir tank, elevated tank, octagonal tanks, piping supports in wet lab	Removal is necessary to secure rearing space and for site preservation

The following basic concepts will be established in conducting the Project.

a. Based on a careful assessment of the present conditions, activities and problems at the Center, a design will be prepared of the appropriate facilities and equipment that are deemed necessary.

b. The operating plan will reflect facility design and equipment scale that minimizes maintenance costs and complication so that operation and maintenance can be performed independently by the Ministry of Fisheries.

c. As culture activities at the Center must continue even during the construction period, the Project will be organized so as to avoid interference with ongoing operations.

2-2-1 Present Conditions at the Center and the Necessity for Renovation

2-2-1-1 Seawater Intake Facilities

(1) Intake Point

An outline of the existing seawater intake system is shown in Figure 2-3.

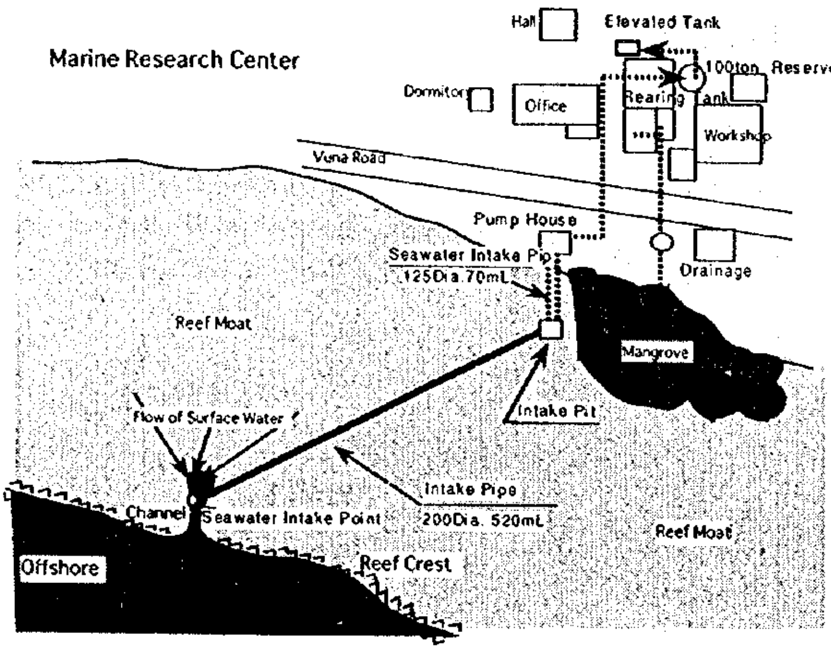


Figure 2-3 Outline of the Existing Seawater Intake System

The location of the existing intake point is near a small channel which has been cut through the edge of the reef crest about 520 m offshore from the existing intake pit. It is located inside a shallow moat which, at low tide, is completely isolated from the open sea by a reef crest which has developed some 500 m from shore. There are three key problems associated with the present water intake point:

a) It is susceptible to air temperature change and sunlight during low-tide periods.

b) Salinity falls after precipitation.

c) It is negatively affected by sedimentation and turbid water.

a) Fluctuation in seawater temperatures:

The water depth at the intake point is about -1.0m, with the actual depth at high tide (+1.50 m) maintained at about - 2.5 m, but the actual depth at low tide (+ 0.10m) becomes quite shallow, at about -1.1 m. During ebb tide periods, the seawater inside the reef, which is influenced by the air temperature and sunlight, flows toward the open sea through a channel which has cut out for passage. As a result, in winter, when the air temperature is low, low-temperature seawater is taken into the system, while, conversely, in summer, when the air temperature is high, there is an intake of high-temperature seawater, resulting in unstable water temperatures. Based on records of rearing water temperatures from January, 1997 to September 1998, the highest temperature recorded over this period was 36°C (on December 12, 1997), the lowest 17°C (on July 28, 1997 and 3 other days), and the largest daily fluctuation 7°C (on July 31, 1997 and 8 other days).

b) Fall in the salinity of the seawater:

At low tide, the water depth inside the reef becomes exceedingly shallow (approximately -20 cm), with some areas completely dry. As a result, after the rain, the salinity declines markedly. While the effect of inland water seeped out from shore is also said to continue for several days, in extreme cases, the normally 35‰ salinity is diluted by a heavy volume of rainwater to as low as 15‰. This drop in salinity has, on past occasions, precipitated the kinds of damage shown in the following table.

Table 2-2 Damage Resulting from a Decline in Salinity

August, 1993	Out of a population of 50 adult green snails brought in from Vanuatu, 9 individuals were destroyed.
End of January, 1997	8,000 giant clams, 400 green snails, and 400 trochus were destroyed.
February, 1998	More than 20,000 giant clams were destroyed.

c) Sedimentation and turbid water:

The reason for the turbid water is that (1) the intake point has been established in a shallow channel of about -1.0 m where sedimentation of mud and fine sand on the sea bottom are easily disturbed by wave action ; and (2) although the channel has been artificially excavated, sedimentation builds up year by year, while the opening of the intake pipe is half submerged in the silt and fine sands on the sea bottom, making it easy for this silt and sand to contaminate the seawater intake. Also, the silt and sand which have been introduced into the intake water contain rough grains which build up inside the pipe, thereby impeding the inward flow of seawater. The fine material, moreover, is carried to the rearing tanks, causing a deterioration of water quality therein.

(2) Intake pipe

The intake pipe is connected to the intake pit provided at a point about 70m from the shoreline, via a single PVC pipe of 200 mm diameter. Setting the water level differential from low tide at 0.5 m and the pipe length at 520 m, the flow volume of the intake pipe has been calculated at 650 liters / minute. Since the capacity of the intake pump is 500 liters / minute (5.5 kW), considering the loss of piping efficiency due to sedimentation in the pipe and sessile organisms, one can infer, that particularly during low-tide periods, when it is impossible to secure an adequate water head, water volume will be inadequate. The flow volume of the intake pipe to the pit has been estimated on the basis of the following formula:

Flow speed V = $\sqrt{2gh / 1.5 + f \times l / D} = \sqrt{2 \times 9.8 \times 0.5 / 1.5 + 0.031 \times 520 / 0.2} = 0.345$ m/s

Flow volume Q = AV = 3.14 x 0.01 x 0.345 = 0.011m³/s = 0.65m³/min

Diameter of the PVC intake pipe	D : 200 mm
Water level differential	h : 0.5m
Piping distance	l : 520m
Coefficient of friction loss	f : $8gn^2 / R^{1/3}$; 0.031
Kutta's coefficient of roughness	n : 0.012

In addition, since there is no maintenance access opening in the existing intake pipe, it is quite difficult to perform cleaning operations on the sediment and sessile organisms inside the pipe. From this standpoint, even if improvement work were undertaken, the fact that there is only a single piping to supply seawater to the existing culture facilities would inevitably stop the water supply during the improvement work, which would create an untenable situation in terms of coping with this problem.

(3) Intake Pit and Inlet Piping

The present condition of the intake pit and inlet piping is shown in Figure 2-4.

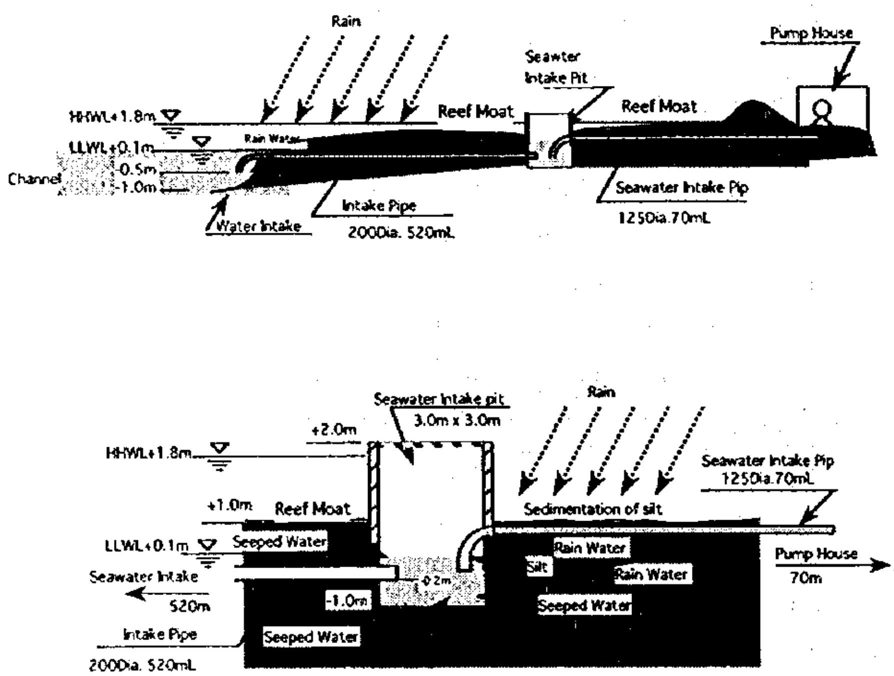


Figure 2-4 Present Condition of the Intake Pit and Inlet Piping

The original intake pit was planned on the premise that water intake would take place only during high-tide periods and so was located inside the reef with a foundation height of + 0.7 m and a distance of about 70 m from the shoreline. Subsequently, as required water volume increased, a need developed for water intake at low tide as well. Accordingly, in 1994, the intake pipe was extended to its present location from the intake pit, at which time improvement work in the intake pit was also carried out, involving construction of a concrete wall of +2.1m above the intake pit on all four sides, to prevent the pit from being submerged during high-tide periods. However, the lower section of the pit was left as an earthen structure, having been excavated down to a -1.0m level. A single PVC pipe, with a diameter of 125 mm connects this intake pit with the shore-based pumping facility.

The problem with the existing intake pit is that, since, owing to a poor connection between the extended side wall and the original section, gaps have now opened, while the bottom section remains an earthen structure. Thus, when water intake occurs during low-tide periods, seawater of deteriorating quality readily penetrates the circumference of the pit from the side wall and lower section. Most of the present problems with water quality, such as unstable water temperatures, a decline in salinity, and an admixture of silt, are believed to result from the existing intake pit.

The problems with the pipe from the intake pit to the pumping house are the result of noticeable superannuation over the 20 years that have elapsed since the facilities were built. Initially, 2 pipes were laid but, owing particularly to major deterioration, based on secular changes in the exposed section protruding above ground, along with a ready proclivity toward cracking in the flange and bend sections of the pipe which caused frequent leakage, intake operations have been discontinued in one pipe, which has been dismantled and diverted to miscellaneous drainage use in the vicinity of the pumping room. At present, the remaining pipe manages to supply intake water, but since it too has been exposed to damage and breakdowns, it has been determined that countermeasures are urgently needed.

2-2-1-2 Filtration Unit

Since seawater contains eggs and fry of fish and crustaceans that can grows as predators, along with various kinds of plankton and suspended matter which can impede the rearing of the target species under cultivation, filtered seawater is generally employed at seed production facilities. But filtration equipment has not been incorporated into the present seawater supply system, and although filtration cloth is fitted to the respective faucet to get rid of the above substances, because the mesh tend to be easily clogged with silt, replacement is quite complicated and troublesome. In addition, as the filtering cloth often became detached, owing to the resistance caused by clogging, the required volume of water cannot be maintained. Also, when the bags separate, predators are mixed in, while, during the coral spawning season, a large volume of coral eggs are also taken in but cannot be segregated for removal. Under these circumstances, there is no alternative but to divert culture operations to another location.

In this Project, it is expected that, by locating the water intake opening at an appropriate point, silt infiltration can be held to an absolute minimum. However, in order to prevent the admixture of living organisms, consideration should be given to the installation of filtration equipment.

2-2-1-3 Seawater Intake Facilities and Equipment

The existing piping system at the Marine Research Center is shown in Figure 2-5.

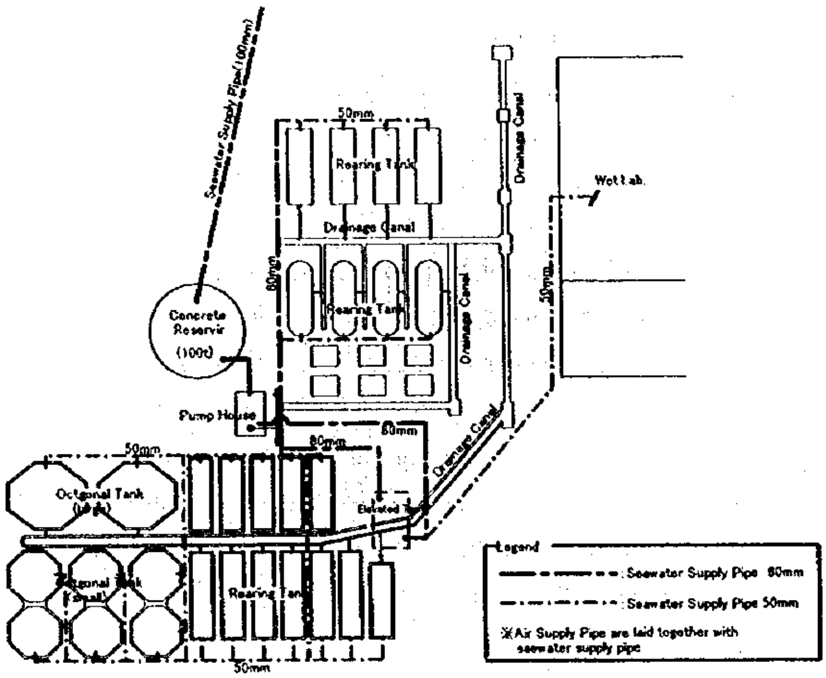


Figure 2-5 Internal Water Supply System (Present Condition)

(1) Elevated Tanks

The present facility contains two FRP elevated tanks, standing on concrete platform, with a combined capacity of 10 m^3 (5 m^3 x 2). Seawater is supplied from these tanks via a gravity flow system. The problem with the present elevated tank is that, with a base height of only 4 m, pressure is inadequate for delivering water particularly to the terminal tanks in the distribution network. In order to provide rearing water in adequate and stable quantities to all tanks in the system, it is essential that the platform height must be raised to obtain appropriate hydraulic pressure.

There are no particular problems with the capacity of these elevated tanks so long as water consumption does not exceed present levels. However, the fact is that water supply to the rearing tanks has been limited, owing to the installation of filter cloth at the water tap to prevent the admixture of silt and organisms as well as the inadequate delivery pressure. The present usage level, therefore, is not sufficient to maintain the proper volume required for culture purposes. Accordingly, in calculating the capacity of the elevated tank, the determining factor will be the requisite water volume for this Project.

(2) Water Distribution System

Seawater is first stored in a 100 m^3 reservoir tank via a 100 mm PVC pipe running from the pump room and is then transferred to a 10 m^3 elevated tank (with a base height of 4 m) via a 100 mm PVC pipe running from the transfer pumps. A main pipe, of 80 mm diameter, has been provided from the elevated tanks for subsequent delivery, as required, via branch pipes of 50 mm diameter. But, in addition to the inadequate installation height of the elevated tanks, since the distribution system is based on pipes branched from a main pipe with water flowing to one direction, supply pressure at the pipe terminals cannot be adequately maintained, creating a serious obstacle to the supply of culture water.

(3) Equipment

Table 2-3 Equipment for the Existing Facility

Type of Equipment	Capacity	Present Condition	Remarks
Intake pump (A)	0.5 m^3/min 5.5 kW/hr	Advanced corrosion in the foundation, exterior section, and exterior motor section	Replaced in 1996
Intake pump (B)	0.5 m^3/min 5.5 kW/hr	Not yet used but usable after inspection	Purchased in 1997
Transfer pump (A)	0.5 m^3/min 3.5 kW/hr	Advanced corrosion in the foundation, exterior and motor section	Installed in 1995
Transfer pump (B)	0.5 m^3/min 3.5 kW/hr	Advanced corrosion in the foundation, exterior, and motor section	Installed in 1995; motor section broke down during survey visit
Blower (A) (B)	2.8m^3/min 0.95 kW/hr	No particular external problems	Installed in 1995
Generator	20kVA, automatic starter type	No particular external problems	Installed in 1995

1) Intake Pumps

One of the two intake pumps is currently in operation, with the other unit stored in reserve at the storage area. The operating unit has been in use for over two years but, despite its seawater use specifications, corrosion is considerably advanced at the foundation and on the motor exterior, and so it would be difficult to include this unit in the plan equipment for continuous use. But the pump in storage is considered usable, subject to a planned inspection, assuming that its capacity presents no problem.

2) Transfer Pumps

The transfer pumps are operated on an alternating schedule. Some three years have passed since installation, and both units exhibit advanced corrosion on the pump exteriors, foundations and motor exteriors. During the field survey visit, a breakdown occurred in the electrical circuits, and so it has been determined that continued long-term usage of these pumps would be difficult.

3) Blowers

Although the blowers have been in use for some three years, since they are installed indoors, they are in relatively good shape, and so it has been determined that, assuming that their capacity presents no problems, they should remain usable in some form.

4) Generator

The present generator is an automatic starter type, with a 20 kVA capacity, serving as an emergency backup for the intake pumps, transfer pump, blowers, the culture tank area, JICA expert's office, and computers and air conditioners in the office bloc. The generator has been in service for about 6 years and is in excellent condition. It has accordingly been deemed continuously serviceable in the future, assuming that its capacity presents no problems.

(4) Control System

The present control system evidences superannuation in certain sections, such as the switchboard and overhead wiring. In addition, starting with the restoration work following high-tide flooding in 1983, a succession of repairs and expansions have been carried out, so that the control system has also not been maintained, causing confusion and disorder, particularly during repairs. It is deemed that there would be considerable merit, from the standpoint of facility operations, in simplifying the control system, with a view toward reducing labor input as well as accidents and breakdowns.

2-2-1-4 Pump House

Facilities are, of course, required for housing the various items of equipment at the Center. Should the intake system be renovated, however, the existing storage room for the intake pumps and generator (of wood construction with an area of some 35 m^2) as well as the room housing the transfer pumps and blowers (block construction, with an area of about 11 m^2) would not lend themselves to continued use under the Project, owing to changes in the nature of the equipment to be stored. It has been concluded, therefore, that new storage facilities will be required.

2-2-1-5 Drainage System

Drainage from the culture areas, after passing through a drainage ditch, is collected in a drainage pit outside the facility compound. It then crosses the road via 2 PVC drainage pipes of 125 mm diameter each, flowing into a drainage pit installed in front of the seawall, and is then finally discharged into the reef via a PVC pipe that passes through the foreshore protection (cf. Figure 2-1). The problem with the existing system is that, owing to the inadequate diameter of the PVC drainage pipes in the sections crossing the road, when a large amount of drainage is concentrated in a short period of time, as occurs during cleaning of the culture tanks, the drainage system cannot keep up with the load, resulting in overflowing through the drainage pit.

Site surveys reveal that, reflecting site elevation and tidal levels (principally at high tide), the drainage gradient can be maintained at about 1/500. While no particular problems are anticipated with this figure, along with maintaining an adequate sectional area, there is a need for conversion, wherever feasible, from the present culvert drainage method, which is subject to clogging with dust or other material, to an open conduit system, which is much easier to clean. Furthermore, as drainage is presently being released untreated, consideration should also be given to installing a settling pond to alleviate the burden on the local environment.

2-2-1-6 Awning

Although an awning now covers part of the rearing area, rust falling from the steel frame components has been contaminating the culture tanks, causing a deterioration in water quality. In addition, since the roof was completed in 1978, the main components (including some that have already been replaced), as well as the structural portions on the south side, which are particularly exposed to stiff sea breezes, are showing marked superannuation, giving rise to safety concerns. It has been determined, therefore, that, in order to prevent deterioration in water quality due to rust, as well as from a safety standpoint, renewal of the awning facility should be included in the Project.

2-2-1-7 Night Worker's Station

Though the Aquaculture and Research Section plays a major role at the Marine Research Center, at the present time, the Section's only exclusive facility is in the office building built for the JICA experts. In the absence of standby facilities to cope with emergencies, such as pump stoppages at night or on non-working days, frequent breakdowns occur which threaten the demise of culture species. In addition, cultivation has recently begun even on large-size giant clams, owing to their high commercial value, which has aggravated concern over possible theft. Considering also the need for standby facilities for night operations during the spawning season, it is understood a major requirement, even beyond regular maintenance, for a night worker's station to strengthen security while also doubling as a night-time rest area for the staff.

2-2-1-8 Removal of Existing Facilities

If this Project is implemented, a portion of the existing facilities, such as the intake pit, reservoir tank and elevated tank, will no longer be needed. In addition, the concrete octagonal tanks were installed for purposes of fin-fish cultivation and so, with cultivation now mainly focused on molluscs, they really serve no meaningful purpose. For this reason, the Tonga authorities have requested that consideration be given in the Project to their removal.

(1) Intake Pit

The intake pit will become superfluous following the improvement work on the overall intake system. However, on the grounds that this facility would still retain utility value in some form, as in cleaning the new intake pipe or as backup in the event of a breakdown, this facility will not be removed in connection with this Project.

(2) Seawater Reservoir Tank

Since the reservoir tank was originally installed to take in seawater at high-tide periods in order to stock seawater for use until replenishment became possible during the next high tide, a 100 m^3 circular reservoir tank was provided for this purpose. In 1994, however, the intake system was improved to permit water intake at all times, and so, at present, the subject reservoir tank is being used only as a reserve tank to cope with sedimentation of silt and other suspended particles as well as breakdowns of the intake pumps and sudden drops in salinity. Thus, when the intake system is renovated under the Project, this reservoir tank will become superfluous. However, trochus and green snails are presently being stocked in this tank as a means of alleviating, to some degree, the severe shortage of rearing tanks. Renovation of the seawater intake system is to be undertaken for the purpose of providing a suitable culture environment and strengthening of the culture function is an integral part of this Project. But, in order to accomplish this, it will be necessary to remove the reservoir tank so as to secure additional rearing space. The seawater intake system must be improved on a comprehensive, systematic basis, incorporating rearing tanks and water supply and drainage facilities and, as the existing reservoir tank would be a serious hindrance to the construction program, it would be appropriate to include removal of this tank in the construction work of the Project for which the Japanese side is to assume responsibility.

(3) Octagonal Culture Tanks

Among the various culture tanks, the concrete octagonal tanks ($15m^3$ x 2 units, $7m^3$ x 6 units) were originally installed for use in fin-fish culture experiments. But as they are neither efficient nor convenient, in terms of shape or water depth (about 1.5m) for molluscs culture, their utilization rates are quite low. In conjunction with replacement of owning, the molluscs under cultivation will have to be moved, tanks and all; however, since there is no space at the Center for this purpose, so as not to interrupt culture activity during the construction phase, a portion of the existing facilities will have to be dismantled to provide the alternate space required. Of course, since water supply and drainage facilities will be needed in the substitute area, it would arguably be proper to divert the underutilized octagonal tanks to this function. However, these preparations would have to be completed prior to the start of construction and, considering the stipulation that Center activity not be hindered by the construction work, it has been concluded that, in the interest of smooth Project implementation, these octagonal tanks should be removed as part of the construction work to be undertaken by the Japanese side.

(4) Overhead Piping Supports in the Wet Lab

The wet lab was installed as a research facility for aquatic life in general, but it has been in operation for close to 20 years, while the primary application target has shifted from aquaculture research on fish to molluscs varieties. In addition, owing to the superannuation of supports for the overhead piping, along with the inadequate water pressure, presently water supply is obtained via a different piping system. As the wet lab is being used mainly during spawning periods, the culture water must be of particularly high quality. However, corrosion of suspended piping supports is advancing at this facility, with rust falling into the tanks below, thereby causing serious deterioration of water quality. Seed production is one of the most important programs at the Center and so, as previously noted, when considering the need for a comprehensive, integrated renewal of the seawater supply system, it is appropriate that the Japanese side remove these severely superannuated overhead piping and supports.

2-2-2 Improvement Concept for the Facilities

Based on the above considerations, the problem areas and improvement targets at the Marine Research Center have been designated, as shown in Table 2-4, along with the necessary facilities and equipment to be provided to attain these objectives.

Table 2-4 Problem Areas at the Existing Facilities and Improvement Concepts

Scope	Outline of Current Problems	Improvement Concepts
Intake Point	- Water quality conditions Since the intake facility is located in the moat, it is subjected to the influences of inland water, rainwater, and ambient temperature. Salinity has fallen, and there is admixture of silt along with variations in seawater temperatures, leading to unstable water quality. - Topographical conditions The intake location is vulnerable to sedimentation, with the tip portion of the intake point already half submerged.	- Water quality conditions It will be secured an intake point which ensures intake of quality water equivalent to offshore water in terms of temperature, salinity, and silt. - Topographical conditions A point will be secured which will dispel concerns over silt accumulation, erosion, and navigation obstructions.
Intake pipe	- Owing to the small pipe diameter, the requisite water supply cannot be obtained. - In the absence of a maintenance access point, pipe cleaning becomes impossible.	- The requisite water volume will be secured. - Maintenance access points will be installed for cleaning purposes.
Intake Pit	- Surrounding silty seawater enters the pit from the side walls and bottom. - Seawater temperatures fluctuate under the influence of air temperature and sunlight. - Low salinity water penetrates the pit after a rainfall.	The effect of water penetrating through the circumference will be eliminated (but, since there is little advantage in continuing with the existing pit, it will not be used actively).
Filtration Unit	Since no filtration unit presently exists, harmful organisms and coral eggs enter the water, making it difficult, in certain cases, to sustain cultivation.	By equipping filtration unit, the intrusion of these organisms will be prevented.
Elevated Tank	- There is concern over inadequate capacity. - Installation height is too low, making it impossible to secure the required pressure.	- An appropriate capacity will be considered for meeting certain demand. - The tank platform will be given a proper height.
Reservoir Tank	- Not needed under new intake system. - Culture space is inadequate.	This tank will be dismantled and removed, with the vacated space allocated to culture operations.
Drainage System	Drainage pipe diameters are not suitable; during heavy drainage periods, drainage overflows through the drain pit.	A suitable scale of drainage will be provided.
Pump Operation System	A systematic control regime has not yet been established, causing disruption and confusion at site.	These activities will be simplified to meet the requirements of the new system.
Equipment	Many items of equipment are superannuated and/or have inadequate capacity.	Equipment will be upgraded to conform to the new system. While it will be, wherever possible, considered the possibility of continuing use, the great bulk of the items are superannuated or lacking in capacity, making it difficult to incorporate them into the new system.
Distribution Piping	Pipe diameters and distribution methods are not suitable.	Appropriate sizes and methods will be established.
Awning	- Water quality in the culture tank has deteriorated, owing to falling rust particles. - Danger of collapse due to superannuate.	A new awning will be installed and the old one taken down and removed.
Night Worker's Station	In the absence of such a facility, it is difficult to deal with night-time operations and emergencies.	A facility of appropriate scale will be built.
Octagonal Rearing Tanks	- Hard to use due to inadequate tank shape for molluscs rearing - Shortage of culture space	Items will be dismantled and removed, with the vacated space to be allocated to culture activities.
Supports in Wet Lab.	Water quality in the culture tank has deteriorated, owing to falling rust particles.	Will be removed.

2-2-3 Consideration of the Project Contents

The design of the various components will be based on the following sequence :

(1) In preparing the facility improvement plan, the following factors have to be governed.

a. Establishing basic guidelines for solving water quality problems.

b. Calculating the requisite water volume based on activity patterns at the Center.

(2) With respect to the location of the intake point for achieving the improvements targeted in (1)-a, various alternatives will be evaluated for selecting the appropriate plan from among them.

(3) Similarly, various alternatives will be evaluated with regard to the intake method, intake piping materials and filtration method which the optimum plan will be chosen.

(4) Based on the findings of the above evaluation, the incidental facilities and equipment will be determined which will be needed to complete the new seawater supply system.

2-2-3-1 Requirement of Water Quality and Supply Volume

(1) Quality of Water for Culture Use

The problem areas that must be improved in connection with water quality for culture use are as shown below :

1) Owing to the influence of air temperatures during low-tide periods, seawater temperatures are unstable.

2) Salinity drops after rainfall.

3) There is muddy water intake after rainfall.

In addition to the above problems, since the seawater contains eggs and fry of fish and crustacean species, which are a potential source of predators, as well as various types of plankton and suspended particles which impede the cultivation of target species, the need for corrective measures has been fully recognized. In order to correct these problems relating to water quality, plans have been developed for the seawater intake facilities in accordance with the following basic concepts and principles :

a. Variations in water temperature and declines in salinity, based on the influence of air temperature, rainfall, sunlight and land water, are characteristic phenomena in shallow moat areas. Accordingly, water will not be taken from inside the reef moat.

b. The influence of silt-induced turbidity, even within the moat, is strongest on the shore side; the closer one approaches the reef crest, the weaker this influence becomes. Moreover, even in the case of offshore seawater on the outer edge of the reef crest, while the degree of difference may vary, intake of turbid water is unavoidable, owing to the disturbance of bottom mud, including silt, during stormy weather. The problem of turbid water results from mingling action, chiefly from the existing intake pit. While it is believed that, if this pit is improved, the turbidity will be reduced to a virtually problem-free level, since it is vital that foreign organisms be eliminated, the seawater will, in principle, be treated via a filtration system.

c. As a slight trend of eutrophication is observed in the reef moat, the impact of waste water from household and industry is perhaps inescapable. However, for the meantime, this influence had not yet reached the molluscs at which the cultivation program is targeted. There is an atoll on the northern side of Tongatapu Island which largely surrounds this island and, owing to the poor seawater interchange, the seawater in front of the site, though called offshore water, has a low transparency, while the continued influence of land water is quite evident. Based on such facts, it is assumed that, in the Project, excepting salinity, silt, and water temperature, water quality comparable to present conditions will be secured.

(2) Requirement of Seawater Volume

1) Water Exchange Rate

Based on our interview survey with various specialists in charge of culture activities as well as our measurements of water volume at the water supply outlets in the culture tanks, the water exchange ratios under present conditions have been summarized, by individual tank, in the table 2-5. For reference purposes, case study data on culture operations in Japan's Okinawa Prefecture has also been given in the above table.

Under present conditions of water supply in the Center, filter cloth have been installed at the water discharge point to the tanks in order to eliminate silt. This, however, imposes limits on the volume of water supply, which is thus not at ideal levels. The low rate of water exchange, in turn, feeds a thick growth of green algae inside the tank while lowering growth rates of the target species. This algae growth not only greatly complicates the task of tank cleaning but is also believed to be one of the factors inhibiting the growth of giant clams as a result of the shade and competition for nutrient salts with symbiotic algae (zooxanthellae). In preliminary experiments by the experts, in the case of giant clams, for a water exchange rate of 5 times a day or less and 10 times a day or more, it was found that the "10 times or more" group to be clearly superior. In the case of green snails and trochus as well, growth was found to be faster at higher water exchange rates, with shell thickness and color approaching the natural state. Accordingly, at culture operations at the Center, water supply is geared, wherever possible, to a daily exchange rate of at least 10 times.

Table 2-5 Water Exchange Ratios per Tank, Based on Our Interview Survey.

Target Species	Tank Designation	Flooded Capacity (m^3)	Utilization Ratio (%)	Utilized Capacity (m^3)	Exchange Ratios in MRC (times/day)	Exchange Ratios in Okinawa case (times/day)
Green snail						4.0
Green snail Trochus	RW1~RW4	5.2	90.0%	4.680	4.0	4.0~10.0
	K1~K4	4.8	90.0%	4.320	4.0	4.0~10.0
	GREENSNAIL	3.6	90.0%	3.240	11.0	4.0~10.0
	NRW6	3.7	90.0%	3.330	11.0	4.0~10.0
	NRW1	3.4	90.0%	3.060	11.0	4.0~10.0
Giant clam	NRW2~NRW4	3.4	90.0%	3.060	11.0	5.0~10.0
	NRW5, NRW7 ~ NRW8	3.7	90.0%	3.330	11.0	5.0~10.0
	UP1	3.0	90.0%	2.700	6.0	5.0~10.0
	UP2~UP3	3.7	90.0%	3.330	6.0	5.0~10.0
	ML1~ML2	15.0	20.0%	3.000	6.0	5.0~10.0
	MS1~MS6	7.0	20.0%	1.400	6.0	5.0~10.0
	EXP1~EXP2	1.5	90.0%	1.350	6.0	5.0~10.0

Looking at the benchmark data for Okinawa Prefecture in Japan, the exchange rates are 4/day for green snails and 5~10/day for trochus and giant clams. In the case of Okinawa, since seawater temperatures drop in winter, if the water exchange rate is raised, the temperature of the culture water also falls, and so the exchange rate is held down in winter. However, in summer, when conditions are good, the rate rises to 10 exchanges per day.

In the case of Tonga, while winter air temperatures may fall to around 10°C, water temperatures in the offshore remain at about 20°C, so that a high exchange is preferable as a means of preventing a drop in water temperature as a result of air temperature and aeration. Moreover, in summer as well, when a rise in water temperature becomes a problem, this too can be prevented by raising the water exchange rate.

Further research studies must be awaited to determine the optimum water exchange rate but, for the time being, based on the knowledge gained to date, it would be appropriate to set water supply volume at a level that will permit 10 times/day exchange.

2) Required Water Volume

The primary species being presently cultivated at the Center are green snails, trochus and giant clams, plus a small number of other molluscs varieties. While the intent is to continue expanding seed production and cultivation of these species, in the case of fish species, which were the aquaculture targets when the facility was originally built, there are no plans for resuming this activity in the immediate future. Also, the octagonal concrete tanks, which were designed to be used for fin-fish culture, along with the 100 m³ reservoir tank, which will become redundant after the Project is implemented, will both be dismantled, and it is planned to use the vacated land to expand the cultivation area for molluscs.

Accordingly, in calculating the required water volume for this Project, it has been combined that the supply volume deemed suitable under present conditions with the additional supply for the expanded facilities, plus an extra margin for tank cleaning operations, which have hitherto not been feasible owing to insufficient intake capacity, as well as back-wash in the newly installed filtration facilities.

The water supply volume for the expanded sections has been calculated in proportion to their respective areas. The area available for expansion totals 375 m^2. Since the ratio of the tank installation area to effective tank volume becomes 0.16 m^3 per 1 m^2, it may be estimated that a tank of about 60 m^3 (375 m^2 x 0.16 = 60 m^3) can be accommodated (see Table 2-6 below).

Table 2-6 Forecasts of Future Tank Demand

Tank Designation	Target Species	No. of Tanks	Utilized Capacity (m^3)	Total Tank Capacity (m^3)	Installed Area (m^2)
<A. Present Tank Capacity and Installed Area>					
RW1~RW4	Trochus & green snail	4	4.680	18.72	264
K1~K4	Trochus & green snail	4	4.320	17.28	
GREENSNAIL	Trochus & green snail	1	3.240	3.24	210
NRW1~NRW4	G. clam & green snail	4	3.060	12.24	
NRW5~NRW8	G. clam & green snail	4	3.330	13.32	
UP1	Giant clam	1	2.700	2.70	
UP2~UP3	Giant clam	2	3.330	6.66	
EXP1~EXP2	Giant clam	2	1.350	2.70	
			Subtotal (A)	76.86	474
$76.86m^3 \div 474m^2 = 0.16m^3/m^2$ → Planned on the assumption that culture tanks of 0.16 m^3 per 1m^2 can be secured.					
<B. Potential Tank Capacity in Expanded Areas>					
Reservoir Tank Portion	$180\ m^2 \times 0.16m^3/m^2 = 29m^3$			29.00	180
Octagonal Tank Portion	$195\ m^2 \times 0.16m^3/m^2 = 31m^3$			31.00	195
			Subtotal (B)	60.00	375
			Grand Total (A) + (B)	136.86	849

Looked at from another angle, in terms of achieving a suitable tank capacity while maintaining existing activity patterns, based on production volume, production cycle, survival rates, and culture methods, the current tank capacity deficiency may be estimated at about 87 m^3 (refer to Table 2-7 following).

Table 2-7 Summery of Number of Major Tanks Required to Maintain Present Activities

Target Species	Stage of Use	No. of Required Tanks	No. of Existing Tanks	Tank Deficiency	Deficiency in Tank Capacity* (m^3)
Giant clam	Seed production and nursing	7	6	1	3
Giant clam	Temporary stock for preparation work	1	0	1	3
Giant clam	Stocking	7	3	4	12
Giant clam	Breed up	4	0	4	12
Trochus & G. snail	Brood stock rearing	1	1	0	0
Trochus & G. snail	Seed production	4	4	0	0
Trochus & G. snail	Intermediate culture (Phase I & II)	4	4	0	0
Trochus & G. snail	Intermediate culture (Phase III)	15	2	13	39
Trochus & G. snail	Intermediate culture (large size seed)	6	0	6	18
Total		49	20	29	87

*Capacity per tank converted at 3 m^2, equivalent to the existing RC raceway tanks.

Owing to the constraints of the plan site, it may be anticipated that it would, in actuality be quite difficult to expand the tank facility very much beyond a total capacity of $60m^3$. But even granting that a close to ideal culture environment would be hard to deliver, by introducing a tank shape conducive to molluscs cultivation, a considerable improvement in the culture environment can be expected over present conditions. In the Project, therefore, it would be appropriate to establish $60m^3$ as the target range of tank expansion.

Table 2- 8 Calculation of Required Water Volume

Tank Designation	Target Species	No. of Tanks	Utilized Capacity (m^3)	Water Exchange Rate (times/day)	Water Supply per Tank (l/min)	Total Water Supply Volume (l/min)
< A. Water supply to existing tanks (excluding octagonal tanks) >						
RW1~RW4	Trochus & green snail	4	4.68	10.0	32.50	130.00
K1~K4	Trochus & green snail	4	4.32	10.0	30.00	120.00
GREENSNAIL	Trochus & green snail	1	3.24	10.0	22.50	22.50
NRW1~NRW4	Trochus & green snail	4	3.06	10.0	21.25	85.00
NRW5~NRW8	Trochus & green snail	4	3.33	10.0	23.13	92.50
UP1	Giant clam	1	2.70	10.0	18.75	18.75
UP2~UP3	Giant clam	2	3.33	10.0	23.13	46.25
EXP1~EXP2	Giant clam	2	1.35	10.0	9.38	18.75
					Subtotal	533.75
<B. Water supply to expanded sections >		1	60.00	10.0	416.67	416.67
					Required Water Supply (A + B)	950.42
< C. Reserve volume > * Back-wash and cleaning requirement (20 ~ 30% of required water supply)						249.58
					Grand Total (A + B + C)	1,200.00

Based on the foregoing considerations, the requisite volume of water for culture use can be estimated at about 950.42 liters / minute. Allowing a 20~30 % safety margin for the water for tank cleaning purpose as well as the back-wash water for use in the filtration equipment, it has been determined that an appropriate target level for water supply would be in the order of $1.2m^3$ / minute (as per Table 2-8).

2-2-3-2 Seawater Intake System

(1) Selecting the Water Intake Point

Assuming that the water quality conditions and the requisite water volume are attained, the water intake should be set at a location that meets the following natural and social conditions:

a) For purposes of stable water intake, there should be no concern over sedimentation or erosion in the vicinity of the intake point.

b) There should be no concern about boat navigation.

c) There should be no impediments to continuance of culture operations even during the construction period.

Five locations have been selected as prospective sites for the water intake point. The winnowing process for the selection will involve an evaluation of construction conditions (construction period, ease of construction and construction costs) to determine the plan which fulfills the necessary conditions. The decision will be made on this basis on the following five options.

1) The present intake point (using the existing intake pipe in its present form at the same location)

2) A point offshore of the existing intake pipe (extending an offshore intake pipe from the existing intake pipe)

3) A point on the sea side of the ocean nursery site (new installation)

4) A point on the reef slope (new installation)

5) A spur-and-groove area of the reef crest (new installation)

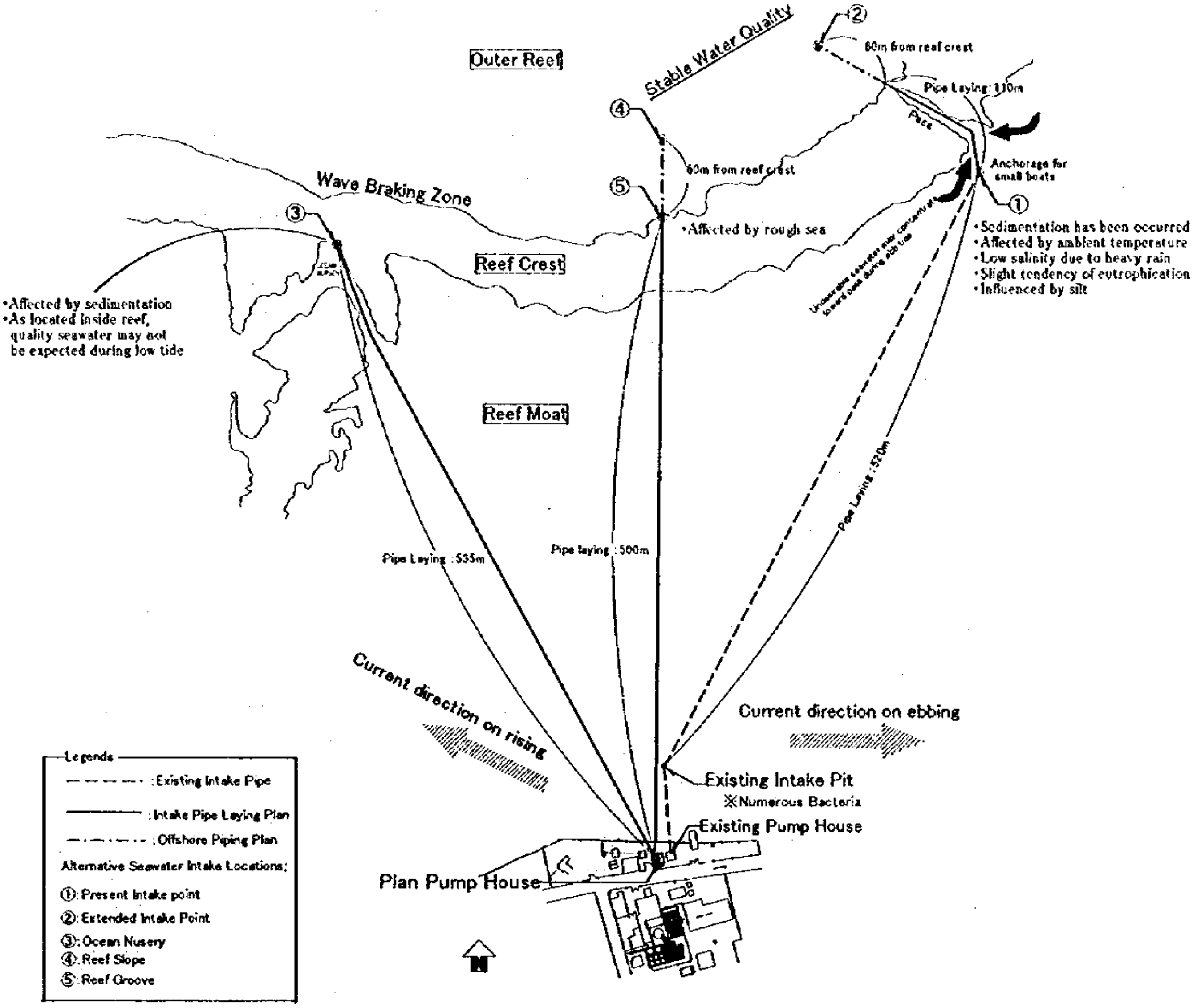


Figure 2-6 Candidate Intake Sites

1) Plan for Water Intake from the Existing Intake Point and Pipe

Since the existing water intake point is near the small channel inside the moat, according to our interview survey, it is influenced by such factors as a drop in salinity and a rise in water temperature. (Since no substantial rainfall was encountered during the survey period, no fall in salinity was witnessed.)

The diameter of the buried intake pipe is 200 mm so that, unless a new intake pipe with a larger diameter is installed, it will not be possible to satisfy the water requirement of 1.2 m^3 / minute. Viewed from the standpoint of natural and social conditions, silt accumulation is continuing year by year, owing to cyclones and other factors, while the mouth of the present intake pipe is partially buried.

In addition, since this location is on the channel and anchorage for small boats, it would not be proper to erect any permanent structures here.

In order to secure culture water during the construction period, it will be necessary to install a temporary pump on the outer edge of the reef crest and take in quality water from the offshore. However, in front of the facility, a fringing reef juts out considerably (about 450 m) from shore so that, from a topographical standpoint, it would be difficult to accomplish this. Furthermore, as to the possibility of supply via water wagons, with current usage running at about 620 m^3 per day, even to secure half that amount would require the equivalent of 78 4-ton wagons per day -- a huge operation-- and, in light of the difficulties of scheduling operations on off-days, this option would be clearly impractical. Considering the problems in securing rearing water via alternate means, it has been eliminated this option from the Project.

2) Plan to Extend the Existing Intake Pipe to the Outer Edge of the Reef Crest

Since, under this plan, the intake section would be extended to the outer edge of the reef crest, it would virtually eliminate such problems as low salinity, contamination by silt and fluctuations in seawater temperature. However, even with a larger pipe diameter for the new extension, since the diameter of the existing intake pipe is 200 mm, unless a new intake pipe of wide diameter were installed, the water supply requirement of 1.2 m^3 / minute could not be satisfied.

From the standpoint of natural and social conditions, it is true that such problems as silting and navigation obstruction would be resolved. With regard to securing a supply of culture water during construction, since, as in the case of the first candidate site (Plan 1), it has been concluded that it would be difficult to secure stable supplies of culture water on the basis of an alternate means, it would be appropriate to eliminate this option as well from the Project.

3) Plan to Establish the Intake Point at the Ocean Nursery Site

The Ocean Nursery site is a basin with a maximum depth of about -3 m, formed naturally on the inner side of the moat and used for raising giant clams. As the proposed site is located inside the reef crest, it is rarely affected by wave action, and since it is connected to the offshore by a small channel nearby, stable quality water would be readily available from the outside reef. This site is, therefore, endowed with excellent conditions for installing an intake point. On the other hand, as the location is inside the moat, it cannot be negated the possibility of a drop in salinity and changes in water temperature during low tide periods. In fact, analyses of total phosphate and total nitrogen show even higher values for the outer reef crest water, forcing us to conclude that the inside of the moat tends to be affected by sewage. No particular problems are foreseen with regard to securing the requisite volume of water, since a new intake pipe of appropriate scale would be installed.

From the standpoint of natural and social conditions, while no problems would be encountered with respect to boat navigation, the site has certain unfavorable aspects, such as the progressive accumulation (as observed) of sand and silt, owing to cyclones and other factors. No particular problems are anticipated in obtaining culture water during the construction period, since it would be possible to use and maintain the existing seawater supply system until completing of the work. While this location has certain unfavorable natural conditions as a candidate intake point, in view of the favorable construction conditions, it will be considered as an option for this Project.

4) Plan to Extend the Intake Point Out to the Reef Slope

By extending the intake point out to the reef slope on the outside of the reef crest, water would be taken from a depth that is hardly affected by waves even during stormy weather. By adopting this plan, as it would be possible to obtain outer sea water of stable quality at all times, unaffected by tides, an intake point could be chosen freely without concern over such problems as navigation, accumulation, or erosion.

Since the maximum design wave height at offshore of the Project site is 5.4 m, in which case the depth of wave breaking would be –4 m ~ –5 m, and since it would be dangerous to establish the intake point in a more shallow area, this must be avoided. Actually, since the wave breaking occurs roughly at the limit depth, it may be presumed that the breaking effect does not extend below –7 m. Accordingly, the plan depth of the intake point, including a safely margin, should be established at around –10m depth. Based on the results of the survey on sea bottom topography, the spot which would satisfy the above conditions would be about 60m from the edge of the reef crest.

In the aquaculture facility, the number one priority is to secure a stable supply of top-quality water. While, from a water quality standpoint as well as security of underwater structure, it has been determined that this option is one of the optimum among the candidate sites, there are also certain demerits. Since the site faces the offshore, the construction work would be directly affected by rough seas, and, given the need to work at sea, both on the surface and underwater, by utilizing a barge equipped with crane, construction would be relatively difficult, while construction costs would be the highest among the other candidate sites. Accordingly, it is recommended as an alternate plan, the fifth option (a spur-and-groove area), whereby a strainer would be established on reef edge to serve as the intake point.

5) Plan for a Spur-and-Groove Area on the Reef Edge

By selecting an appropriate point in spur and groove area of reef crest as water intake point, a relatively stable seawater could be obtained with only slight influence from the efflux of mud and sand from the moat, a drop in salinity after rainfall, or air temperature. Nor would there be any fear of navigation obstruction, accumulation, or erosion. And by using the low tide hours, the construction program could be carried out as the work on shore throughout all phases, eliminating the need for barges, providing greater ease of construction than under Plan 4, with low construction costs.

Nevertheless, even this option is by no means problem-free. Since the water intake would be at -2 m ~ -3 m deep, it would be easily affected by seawater inside the moat during ebb tide, while, as the intake point would be established in the wave breaking zone of the reef crest, it would be subjected to wave action during stormy weather. In addition, the intake water would contain silt churned up from the ocean floor along with drifting dust in the surface layer while air bubbles would also be sucked in. Accordingly, this option would not be suitable to either the siphon or pump-direct method.

Considering the various conditions from the standpoint of water quality, the locations of the intake points under the candidate plans may be ranked in the following sequence : (1) Reef slope plan, (2) Spur-and-groove plan, (3) Ocean Nursery plan.

Next, the optimum plan will be selected on an overall basis after evaluate each of these 3 plans from the standpoint of construction period, construction difficulty, and construction cost.

With regard to construction time, while there is very little difference among the candidate plans, if the fact is considered that the ocean nursery plan would require the longest stretch of buried intake piping, while the reef slope option would be influenced by weather conditions, then, ranking the candidates in the basis of shortness of construction distance, the plans may be ranked : (1) Spur-and-groove plan, (2) Ocean Nursery plan, (3) Reef slope plan.

On the basis of difficulty/ease of construction, simply because operations could be confined to the inner side of the reef crest, the ocean nursery option would offer the most favorable construction environment, while the reef slope plan would be most difficult, since the intake pipe would be laid offshore. Accordingly, the ranking in terms of construction ease, would be : (1) Ocean Nursery plan, (2) Spur-and-groove plan, (3) Reef slope plan.

Finally, in terms of construction cost, the spur-and-groove plan would be most advantageous, owing to the short piping distance, followed by the ocean nursery plan. The reef slope plan, which ranks lowest in terms of ease of construction, would also entail the highest cost, owing to the need to employ barges for sea operations as well as the underwater work requirements. The relative ranking on this count, therefore, shows : (1) Spur-and-groove plan, (2) Ocean Nursery plan, (3) Reef slope plan.

As discussed above, the comparative evaluations are summarized in Table 2-9.

Table 1-9 Comparative Evaluation of Intake Point Locations

Intake Point Locations	① Existing Intake	② Extending Intake	③ Ocean Nursery	④ Reef Slope	⑤ Spur-groove
Effect of Seawater from Inside the Moat	×	O	Δ	O	Δ
Effect of Sedimentation	×	O	×	O	O
Impact of Wave Breaking	O	O	O	O	Δ
Channel Obstruction	×	O	O	O	O
Effect on operations during Construction Period	×	×	O	O	O
Securing the Required Water Supply	×	×	O	O	O
Distance of Intake Pipe Extension*	0 m	B : 110m O : 60m	B : 535m	B : 500m O : 60m	B : 500m
Construction Difficulty (ranked by ease of construction)	-	-	1	3	2
Construction Period (ranked by shortness)	-	-	1	3	2
Construction Cost (ranked by lowest total cost)	-	-	2	3	1
Overall Evaluation	Rejected	Rejected	Numerous problems, but of limited merit	Optimum in terms of water quality conditions but poses construction difficulties	Usable from an overall standpoint i.e., both water quality and construction conditions

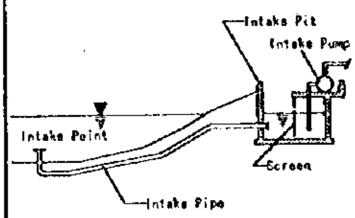
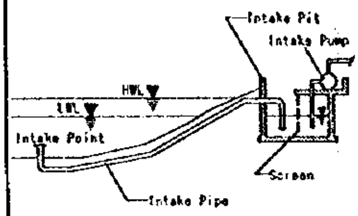
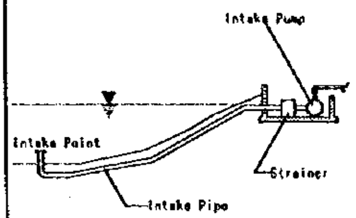
Remarks : * Approximate pipe length : B : Buried part O : Offshore part
O : No problem Δ : Minor problems but acceptable or can be solved
× : Not acceptable

The reef slope plan has been found to be optimum from the standpoint of water quality conditions, but construction would be relatively difficult, with construction costs the highest among the five options. With the spur-and-groove plan, on the other hand, the intake would be drawn from a relatively shallow area on the edge of the reef crest. While the possibility of taking in seawater of inferior quality from the moat, owing to the effect of air temperature and shore water, cannot be denied, there would be no danger of a significant drop in salinity. Moreover, the required quality of culture water could be obtained, while construction conditions would be superior to those for the reef slope plan, with maintenance also uncomplicated. Based on the above overall evaluation, it has been determined that the spur-and-groove plan would be most appropriate as the location for the water intake point.

(2) Intake Method and Intake Pit

The water intake methods that have been considered for this Project are : (1) natural conveyance method ; (2) Siphon method, and (3) pump-direct method. These methods are described in Table 2-10.

Table 2-10 Outline of Alternate Intake Methods

	Natural Conveyance Method	Siphon (Semi-siphon) Method	Pump-direct Method
Conceptual Drawing			
Description	Under this method, the seawater is conveyed by head, via pipe connecting the intake point offshore and the intake pit onshore. After debris and seaweed are removed using a screen inside the intake pit, the water is then pumped up.	Under this method, the intake pipe can be routed in a relatively shallow layer. The water is conveyed into the intake pit by way of a siphon (In the case of semi-siphon, the water is conveyed by head during high tide periods only).	Under this method, the intake point offshore is joined to an onshore pump, from which the water is supplied.
Strong Points	The condition of the debris and seaweed in the intake pit can be visually confirmed. Since the inflowing matter remains temporarily inside the intake pit, the pit functions as a settling pond for sand. Even in the event of intake pump breakdown, since the pipe is connected to the offshore, by using an underwater pump in the pit, it is relatively easy to secure water from the outer reef.	Just as with the natural conveyance method, the inflowing matter can be eliminated at the intake pit. And even when the pump breaks down, so long as the siphon has not been cut, by using an under-water pump, it is relatively easy to secure water from the offshore. As the location of the intake pipe is even shallower than with the natural conveyance method, to that extent, ease of construction is entranced, while construction costs are also low.	There is no need for an intake pit and, since the laying depth for the intake pipe is moderate, construction is both easy and low in cost.
Problem Areas	As the water intake mouth and the pipe must at all times be lower than the water surface, when there is wide tidal variation, the construction work becomes large-scale and difficult. Although the tidal variation at the Project site is a relatively modest 1.6 m, construction costs will be higher than with the other methods.	The exit level of the intake pipe must be lower throughout than the water surface and so, when the tidal variation is large, the construction becomes large-scale and difficult. In addition, for starting the siphon, a separate vacuum pump is necessary.	The strainer in the suction side of the intake pump is prone to clog up from seaweed and other inflowing materials, making frequent inspections mandatory. When the pump breaks down as a result of cavitation from the clogging, intake becomes impossible, while it is difficult to secure water from the offshore.

Since, under the pump-direct method, the intake pipe and the intake pump are directly connected, there is no need to construct an intake pit, making this method the cheapest of all. However, as maintenance frequency is high and this method is not as safe, it would not be suitable to conditions in the Project site. In the natural conveyance method, as with the existing system, an intake pit is built and, as soon as the water is received, it is pumped on. Under this method, there are two versions: a natural conveyance method, which is extremely safe, and a siphon (semi-siphon) method for which the construction work is relatively simple. Considering both construction costs and ease of construction in the Project site, it has been concluded that the semi-siphon method, which permits natural conveyance during high tide periods, would be most appropriate.

As to the location of the intake pit, subject to the precondition that the construction work must not interfere with ongoing Center operations, since the existing pit would be difficult to use, the new intake pit could be built. Taking into account maintenance requirements as well as the ability to cope with emergencies, a shore-based intake pit would be more suitable.

A comparative evaluation of the above methods is presented in Table 2-11, following. It has been determined that a new shore-based intake pit, based on the semi-siphon method, would be most appropriate for this Project.

Table 2-11 Comparative Evaluation of Intake Methods

Intake Methods	Pump-direct Method	Natural Conveyance Method	Semi-siphon Method
Intake pit	Not needed	Needed	Needed
Pump Load	Heavy	Low	Low
Effectiveness of sand settling and debris removal	None	Effective	Effective
Maintenance	Frequent	Easy	Easy
Accessibility	Best	Easy	Easy
Coping with emergencies	Difficult	Easiest	Easy
Difficulty/ease of construction (ranked in terms of ease)	1	3	2
Construction cost (ranked from low to high)	1	3	2
Overall evaluation	Unsuitable	Suitable	Optimum

(3) Intake Pipe

1) Pipe materials

Possible materials for an intake pipe would normally include concrete, steel, plastic and hybrid materials. However, in this Project, on the basis of the construction environment (including both ease of construction and economy), natural conditions, and durability, limited appraisal may be given to coated steel pipes and plastic ones. The characteristics of these materials are summarized in Table 2-12.

Although steel piping is superior in terms of watertightness and strength, it has the handicap of vulnerability to corrosion from salt water. This problem has, however, been rectified by the use of resin-coated steel piping, which has been used relatively often as intake piping, with excellent results. On the other hand, plastic piping, while excellent in terms of ease of construction and anti-corrosive properties and less expensive than resin-coated steel piping, poses serious strength problems, such as deterioration from ultraviolet rays and poor resistance to earth pressure and shock. However, such strength-related problems can be solved to some extent by suitably burying the pipes.

Table 2-12 Materials and Characteristics of Intake Pipes

Types		Characteristics
Coated steel piping	a) Polyethylene-coated steel piping b) Nylon-covered steel piping c) Other coated steel piping	Workability and watertightness are excellent. Water pipe cleaning by plastic pigs* is fairly straightforward. The coatings are used to improve the anti-corrosive properties of steel piping which is vulnerable to corrosion. The material cost is however higher than plastic pipes.
Plastic piping	d) PVC piping e) FRP piping f) Polyethylene piping	Vulnerable to earth pressure and shock, but superior in terms of ease of construction. PVC piping is the lowest cost material in this group.

(*) This is a maintenance technique in which epizoa or sessile organisms inside the pipe are removed by pressure-feeding a cannon-shaped pig through the pipe, using high-pressure water.

On the assumption that the water pipes will be cleaned by plastic pigs, the choice of material for the intake pipe narrows down essentially to one between coated steel piping and polyethylene piping. However, water pipe cleaning by pig is a rather complex process, which, even in Japan, must be entrusted to specialists. In Tonga, therefore, it would probably be somewhat difficult to have this done on a regular basis. Nonetheless, while future predictions are difficult, since, in the course of our field survey, epizoa or sessile organisms were not observed to an extent that might materially impede water intake, a plan of any water pipe cleaning by pig would not be undertaken in this Project.

Based on the above evaluation of piping materials, since the pipes for this Project will be located in the wave-breaking zone, it will be planed to use coated steel tubing in the intake point section, where adequate strength is called for, and in the siphon section, where watertightness is required, but will be installed PVC piping in the moat section.

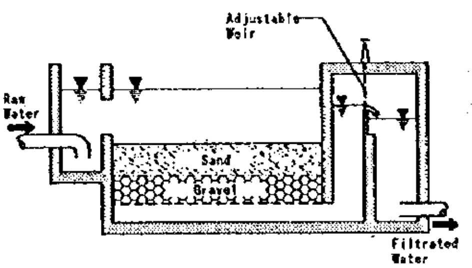
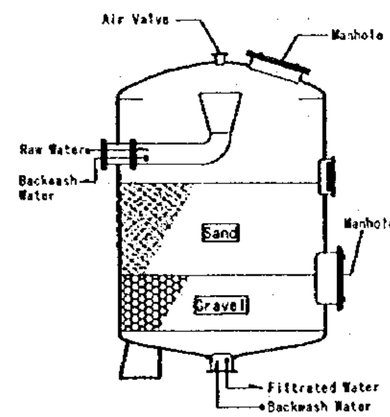
2) Pipe-laying Method and Pipe Diameter

There are two methods for laying pipes: exposed and buried piping. In the case of the Project, as the intake pipe is to be laid in the shallow moat, where the seabed will be partially exposed at low tide, the buried pipe method will be employed both to protect the intake pipe from wave action and ultraviolet rays and to ensure navigational safety for small boats in the area. After carefully considering the diameter required to handle the target water supply volume of 1.2 m^3 / minute, it has been deemed it appropriate to set the diameter of the intake pipe at 350 mm.

(4) Filtration Method

Seawater contains eggs and fry of certain harmful fish and crustacean species as well as a variety of plankton and suspended particles that hinder the rearing of target culture species. In order to eliminate these substances, filtered seawater is normally used, particularly in connection with seed production. Rapid filtration is commonly used as the primary treatment method for raw water at aquaculture facilities, and either a gravity or pressure method may be considered within this category. These methods are described in Table 2-13.

Table 2-13 Outline of Alternate Filtration Methods

Methods	Gravity-Type Filtration	Rapid-pressure Filtration
Conceptual Drawing		
Description	Under this method, the filtration process is accomplished by holding the free water surface to the upper side of the filter medium and passing raw water through the medium by means of the gravity differential between the water level in the tank and that of the effluence (outflow/efflux). This type of facility is commonly used where requires large-volume treatment, such as purification plant for municipal water.	Under this system, the filtration is accomplished by pressure-feeding the raw water with an intake pump and then passing it through the filter medium inside an airtight pressure vessel. It is geared to relatively low-volume treatment, with good results.
Strengths	Since the upper section of the tank is left open, dirt can be readily verified visually, so that maintenance is relatively simple (i.e., in terms of replacing the filter medium). And since the tank is of RC construction, it can treat a large volume of water. Thus, when large-volume treatment is required, construction is relatively inexpensive.	Since this method employs a pressure vessel, after filtration, water can be supplied, under residual pressure, to the elevated tank or various other facilities. In addition, local construction time is short for factory-built products, with good performance shown in low-volume treatment.
Problem Areas	A separate transfer pump is needed to supply water to the various facilities, while operation is complex. In addition, in the case of RC construction, the tank must be built locally, with precision work required for watertightness and other processes.	Since an airtight vessel is employed, visual inspection for dirt is difficult, making maintenance relatively difficult, such as in filter replacement. In addition, in terms of water supply, as the treatment capacity per tank is limited to a maximum of about 80 m^3/hr, when large-volume treatment is required, construction becomes relatively costly.

Gravity-type rapid filtration tanks include both an open-type and a back-wash water retention model. The latter performs automatic back-washing, in combination with a siphon pipe, when clogging develops on the filter medium. However, since the back-wash operation by compulsion is rather complicated, requiring at times the use of a separate vacuum pump, it is considered that this type would not be suitable for the Project.

The pressure-type rapid filtration unit comprises a manual and an automatic control model. The automatic type performs back-washing, based on the installation of a pressure-differential sensor and timer, with daily management quite simple. However, as it requires an automatic valve and an electric controller, it is thought over that coping with breakdowns would probably be beyond the independent capabilities of local staff.

In light of the above assessment, the choice is confined to the open gravity type and the manual pressure type methods.

There are major advantages to the gravity method, such as easy visual checking for dirt, and relatively simple maintenance, as with filter replacement. However, after the water pumped up to the filtration tank, the filtered water is retained briefly in the tank but then must be pumped up again to the elevated tank, created a requirement for a transfer pump, in addition to the intake pump, with an attendant risk of problems developing in the mechanical system. While it is possible to have a single tank serve as both a filtration and elevated tank, considering the flat ground in the Project site, a large capacity would be required for the elevated tank function, thereby adding considerable weight to the combined tank, so that construction costs would escalate while filter exchange would become cumbersome, introducing another negative for the gravity method.

With the pressure method, on the other hand, whereas the filtered water is sent on directly to the elevated tank, one pump would suffice, but, since the loss of head increases, a larger capacity intake pump would be needed than with the gravity method. Construction and maintenance would be simple and, with a treatment capability in the order of requirements for this Project, although there would be no particular advantage in construction cost over the gravity method, another merit of this method is that operating costs would be relatively economical.

On the other hand, dirt verification and filter exchange would be more difficult than with the gravity method. Nevertheless, if back-washing is done on a regular basis, the frequency of filter media replacement will fall and this operation can be performed locally. Thus, practically speaking, there is not anticipated any major problems arising in this connection. In either case, an initial supply of filter media would be procured from the respective manufacturer but, by utilizing sieved sand, which are locally available, as the filtration device, though filtration precision would be somewhat poorer, this medium, which is essentially problem-free, can be used.

Based on an overall evaluation, as presented in Table 2-14, it has been determined that the rapid-pressure filtration tank, manual operation type, would be most appropriate for the Project.

Table 2-14 Comparative Evaluation of Filtration Methods

Methods	Gravity-type Filtration		Rapid-pressure Filtration	
	Open type	Back-wash water retention type	Manual type	Automatic control type
Need for water receiving tank	Required	Required	Not required	Not required
No. of pumps required	2	2	1	1
Mechanism and component parts	Δ (Simple)	× (Complicated)	O (Simplest)	× (Complicated)
Relative difficulty of daily operations	Δ	O	Δ	O
Ability to cope with breakdowns locally	O	Δ	O	×
Local availability of filter medium	Δ	Δ	Δ	Δ
Construction cost (ranked from low to high)	1	3	1	2
Operating cost (ranked from low to high)	2	2	1	1
Overall Evaluation	Usable	Unsuitable	Optimum	Unusable

Legend : O Best Δ Satisfactory × Unsatisfactory

2-2-3-3 Incidental Facilities and Equipment

(1) Machinery and Equipment for Mariculture

1) Intake Pump and Filtration Unit

Seawater is supplied to the various rearing tanks through the intake pump, filtration tank, and elevated tank. The maximum volume of seawater usage will be 1.2 m^3 / min., with the capacities of the intake pump and filtration tank set to handle this requirement. However, considering the relatively long time required for component replacement along with the possibility of pump breakdowns, if single pump is installed, there is a danger of Center activities being impeded, and so it has been determined that it would be proper to use a dual system as a means of risk diversification. Since the maximum usage volume of 1.2 m^3 / min. will not always be required, if the capacity of the intake pump and filtration tank is each set at 0.6 m^3 / min., even during maintenance periods and emergencies, some 50% of maximum usage volume could still be provided. However, in the case of the intake pump, since, in addition to normal maintenance, consideration about wear and tear and breakdowns as well is needed, one spare pump will be provided to permit alternate operation of all 3 pumps.

2) Elevated Tank

If a pump resting time is allowed about 15 minutes, even during periods of maximum use, the required capacity of the elevated tank becomes : 1.2 m^3 x 15 min / 0.8 (effective water storage capacity) = 22.5m^3. On this basis, it will be planed to use the closest capacity standard of 24 m^3 for the elevated tank.

3) Blowers

Since the aeration volume for the existing blowers is about 30.07 liters / min per cubic meter of rearing water, the same scale is planned for the facility in this Project. Allowing for fluctuations in air supply volume, provision will be given to set several small-capacity blowers. It is estimated that 3 units would be collectively sufficient to satisfy maximum demand, so that, when demand is low, the unnecessary blower(s) would be turned off, thereby lowering running costs. The duct system will be a header-concentrated type, with 4 blowers to be provided (including 1 spare unit) for alternate operation.

4) Emergency Generator

The capacity of the emergency generator has been based on the need to provide backup for all of the powered electrical equipment required for culture activity, such as the pumps and blowers, along with the lighting fixtures and sockets in the culture-related facilities. The total load of the powered equipment, lighting, and sockets has been estimated at about 38.38 kVA. After adding an extra margin to cover the initial startup load for the powerful seawater intake pumps, a 50 kVA generator will be required.

a)	Load of power equipment :	29.83 kVA
b)	Load of lighting fixtures & sockets :	8.55 kVA
	Total	38.38 kVA

In determining the capacity of the fuel tank, consideration had to be given to the difficulty in the Project area of securing refueling service on Saturdays and Sundays, owing to local work patterns. On this basis, it has been set the fuel tank capacity at 1,000 liters, equivalent to two days' fuel consumption.

5) Control System

The automatic control system will be limited to the circuits controlling of water levels in the elevated tank and intake pit. The system will be designed for maximum simplicity and so readily understand able. A system chart for the planed facilities is shown in Figure 2-7.

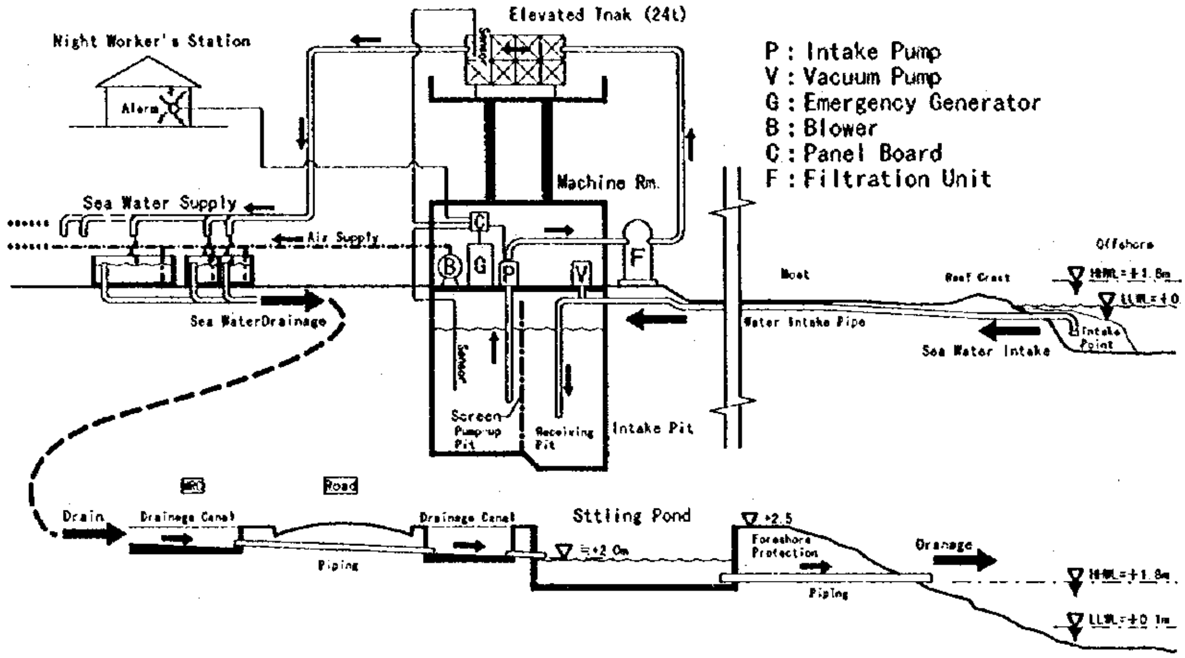
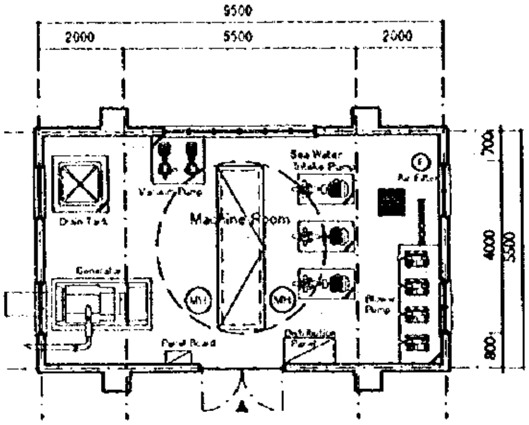


Figure 2-7 System Chart for the Plan Facilities

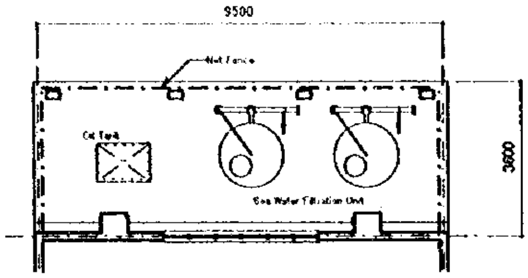
(2) Pump House

The pump house facility is intended to house the above equipment, comprising the intake pit receiving seawater from the water intake pipe; machinery room to install the various types of pump (seawater pump, vacuum pump and blowers), emergency generator and distribution panel; installation space for the filtration equipment and fuel tank; and a basement for the elevated tank.

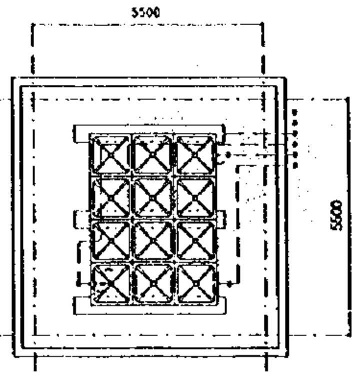
The intake pit comprises a receiving pit and a pumping pit, and its scale has been determined after allowing spaces for piping work and bottom cleaning operations. The requisite floor area for the machinery room, filtration equipment, as well as the elevated tank has been calculated, as shown below, giving due consideration to the specific equipment layout as well as working space for maintenance operations. The layout plan for the pump house is shown in Figure 2-8.



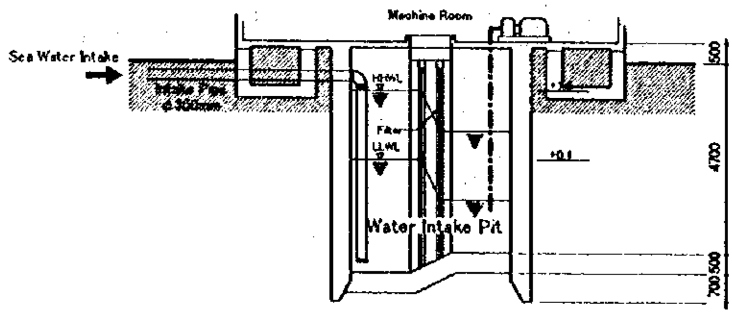
1. Machinery room
5.5 m x 9.5 m = 52.25 m²



2. Installation space for filtration
equipment and fuel tank
9.5 m x 3.6 m = 34.20 m²



3. Installation space for the elevated
tank 5.5 m x 5.5 m = 30.25 m²



4. Intake pit
(diameter:4.0m, depth:5.0 m)

Figure 2-8 Floor Plans for the Pump House

(3) Drainage Canal and Settling Pond

1) Drainage Canal

In principle, an open ditch system for the drainage facilities will be specified, since this method is quite simple to maintain. Drainage volume has been set at 63.2 liters/second on the basis of planed intake volume as well as the requirement for complete simultaneous drainage of 2 culture tanks.

a)	Plan intake volume	1.2 m³ / min	20.0 liters / sec
b)	Drainage from culture tanks	21.6 lit. / sec x 2 tanks	43.2 liters / sec
	Total		63.2 liters / sec

The flow gradient in the drainage canal has been set at 1/500, taking into account the distance from the existing drainage pit to the new settling pond as well as ground levels. Calculating the sectional area of the drainage canal, based on these conditions, the required sectional area becomes approximately: 0.4 m x 0.2 m = 0.08 m².

However, to provide adequate working space for cleaning operations, it has been planned a 40 cm width. In addition, since an open ditch cannot be used for the portion crossing the road, a culvert will be specified for this section.

2) Settling Pond

The scale of the settling pond should properly be established with a view to providing adequate settling time. However, owing to the constraints of the site area and ground level, in this Project, pond size will have to be limited to the usable area available.

The only site that can be secured for this pond is that lying between the front road and the foreshore protection, with an area of 8 m x 35 m (280 m^2). On the other hand, since the ground level capable of accommodating the inflow point is +2.0 m, with a high water level of +1.8 m, the effective water depth that can be secured for the settling pond would be a maximum of 20 cm. To function properly as a settling pond, with a pond bottom height of +1.4 m ~ +1.5 m, and assuming a water depth of about 50 cm, the scale of the settling pond becomes 140 m^3.

The pond will be surrounded by a concrete wall, with an earthen bottom. In this case, if the seawater surface exceeds +1.4 m, a counter flow will develop from the pond bottom. However, this would be appropriate in view of certain major advantages, such as the fact that the environmental burden would be less than with direct drainage, while drainage treatment would also be feasible even when new varieties are experimentally introduced.

(4) Awning

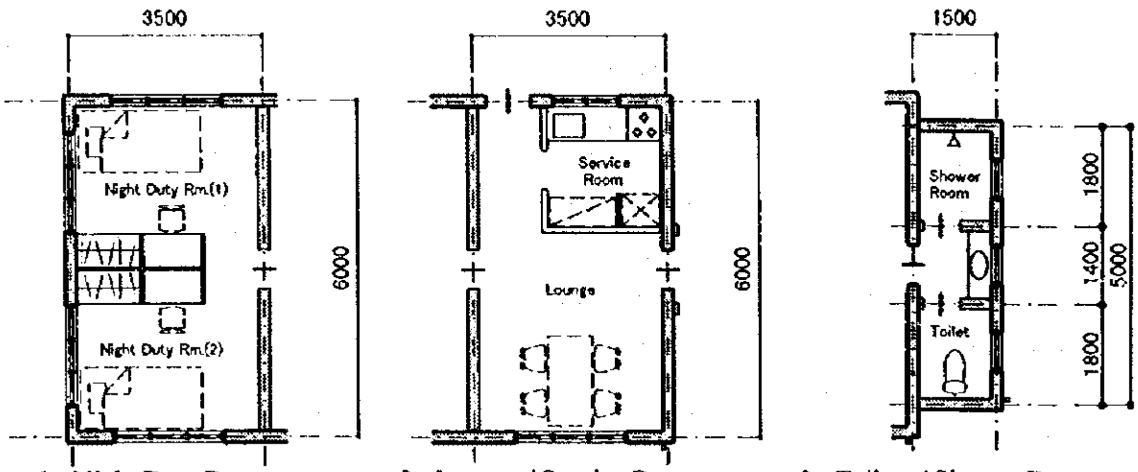
The existing awning structure uses H shaped steel (248 x 124 x 5 x 8 mm) for both the posts and beams. The independent foundation has been used with 12 m side spans and 4.5 m x 5 beam spans. The roof material is corrugated polycarbonate sheets. Although there is marked superannuation in the steel frame sections, which have been in use for over 20 years with prolonged exposure to sea breezes, since it has been determined that the concrete foundation section can stand up to continued use, it would be proper to limit the Project scope to the steel frame sections and roofing work, excluding the foundation structure.

As to the planning scale, inasmuch as there will be no major changes in the production plans for green snails and trochus, which are reared at the roofed facility, it has been concluded that there would be no particular problem in maintaining the awning area at the present scale : viz, 12 m x 22.5 m (4.5 m x 5 spans).

(5) Night Worker's Station

This facility will be provided for night operations, standby duty during emergencies, and as a regular post for night watchmen. While it will normally be occupied by one watchman during the night shift, it will have to accommodate 2 or more persons when cyclones or other severe storms are forecast. In addition, considering the fact that a team of 5 to 10 persons may be an night duty during spawning periods of the target species for reproduction, a night duty room accommodating two persons has been provided.

The facility will contain a night duty room, lounge / service room and toilets/shower room. In the floor plan, the night duty room has been designated as a private room, with the lounge / service room to share the same space. As shown below, the required floor space for this facility has been set at 49.5 m^2, after due allowance for the layout of furniture and fixtures as well as work space. The plan for the night worker's station is shown in Figure 2-9.



1. Night Duty Room 6.0m x 3.5m=21.0m^2

2. Lounge / Service Room 6.0m x 3.5m=21.0m^2

3. Toilets / Shower Room 5.0m x 1.5m=7.5m^2

Figure 2-9 Floor Plans for the Night Worker's Station

(6) Removal of Existing Facilities

The Project is intended to improve the quality and obtain the requisite supply of rearing water, which is a high-priority goal at the Center, with the new seawater supply system to be given a functional capacity in conformity with these objectives. This system is to be designed on a comprehensive and integrated basis, incorporating rearing tanks and water supply and drainage facilities. Based on careful consideration of the renovation plan, it has been determined that dismantling and removal of the 100 m^3 reservoir tank, the octagonal rearing tanks and the overhead piping and supports in the wet lab constitute an integral part of this Project. Accordingly, this removal work will be implemented as part of the construction responsibilities assumed by the Japanese side.

Although the existing intake pipe and intake pit will not have much utility after the new intake system comes on stream, they can still be used, after rehabilitation, as backup facilities. If, due to some reason, the removal work will become necessary, this removal work, however, will not be included in this Project but will be the responsibility of the Tonga government.

2-3 Basic Design

2-3-1 Design Concept

(1) Policy with respect to the Natural Environment.

The habitats in the reef moat facing the Project site of such organisms as mangroves, seaweed, seagrass, fish juveniles, bêche de mer, starfish, crustaceans, and molluscs will be carefully observed, along with coral, fish, and lobsters living on the reef slope facing the offshore. Since the seawater inside the moat loses salinity after rainstorms, while it will be necessary to install the intake point on the outer side of the reef crest in order to scrupulously avoid this effect, a portion of the construction work on the intake pipe will have to be carried out in the coral reef area. As the bulk of the work consists of simple digging and back filling inside the moat, the effect on the coral reef will be slight, though it would be nigh impossible to carry out the work without any damage whatsoever to these animals and plants.

In connection with the installation of the intake pipe, careful coordination will be maintained with the Ministry of Fisheries and other related authorities which are responsible for conservation and controls. The construction plan shall be prepared so as to minimize the scope of impact from the work. In this connection, certain areas will be placed off-limits during the construction phase, while excavating and refilling will be conducted, wherever feasible, during low tide periods so as to reduce seawater turbidity.

Since the mangrove areas which will have to be felled to lay the intake pipe are to be replanted, upon Project completion, by the Ministry of Fisheries, a plan will be given to readjust the site to present ground levels before turnover. In addition, since the December to April period is the cyclone season in Tonga, particular consideration must be given to completing the installation work for the intake point facing the offshore before the onset of this season.

(2) Policy with respect to Social Conditions

With the fiscal position of the Tonga government under continuous pressure, funds are hardly ample for operations and maintenance. Also, for religious reasons, work is, in principle, forbidden on

Sundays, while the custom is to take extended vacations at Christmas. This, in turn, makes it difficult to secure labor on Sundays and holidays. Accordingly, in this Project, consideration will be taken to hold operating expenses to the minimum, while designing the facilities with a view toward easy management.

(3) Policy with regard to Construction Conditions

While small-scale construction firms do exist in Tonga, primarily geared to the housing market, only a very few large-scale firms own such heavy construction equipment as cranes, bulldozers, and excavators. Even combining joint ventures with overseas firms, there are only a handful of companies in this class. Although the construction divisions of the Ministry of Works and the Commodity Board own construction equipment, the number of units is quite small, so that there is no assurance that equipment can be leased as required. In the Project, therefore, the principal items of equipment having a major impact on the construction period must be sourced from Japan or third countries, with only trucks and other general-use equipment to be procured locally.

Apart from aggregate, all of the construction materials have been imported, and prices have been figured on the high side owing to the small quantities required. A concrete plant operates in the Nuku'alofa area, and so concrete materials are available locally. With regard to the materials and equipment to be used in the construction of this Project, such as the intake pipe, water supply and drainage pipes, electrical materials, and pumps, in the present facilities, such items have been so far procured from Japan by the Center and so to continue using Japanese products will be planed, as they are also superior from a cost standpoint. As to the structural materials for the awning, laminated wood, which would eliminate concern over rusting as a result of sea breezes will be well advised. For the source of this laminated wood will be considered from a third country (e.g. New Zealand), which would be advantageous in terms of cost.

(4) Policy with regard to the Use of Local Firms and Materials

Local company(ies) is expected to employ as subcontractor of the Japanese contractor. However, since the construction called for under this Project requires experience as well as a relatively high level of technical skills, the potential field will be limited to only a few local companies. While domestic procurement possibilities will be confined largely to aggregate and concrete, it is planed to maximize the use of local labor and materials so as to provide a stimulus to the area economy.

(5) Policy with regard to the Maintenance Capabilities of the Implementing Organization

While there are many key problems to be solved, including that of obtaining staff for weekend and holiday work, in light of prevailing local customs, particularly of a religious nature, along with the level of maintenance skills among the organization staff and their ability to cope with chronic budgetary deficiencies, thanks to the technical cooperation programs conducted over the past seven years, there has certainly been a major improvement not only in aquaculture technology but in management skills as well. It has been thus concluded that a maintenance team can be assembled with at least the minimum level of required skills.

With due consideration of the above factors, a facility plan to put major priority on ease of operation along with economical operating costs will be developed. In this connection, it is planed to prepare displays diagramming operating procedures and install an alarm panel to alert the staff to equipment abnormalities.

(6) Policy regarding the Scope and Grades of Facilities and Equipment

In this Project, the location of the intake point and the diameter of the intake pipe have been set on the premise that, in the context of the present environment and ongoing Center activities, an adequate volume and quality of rearing water will be secured. Also, with respect to the quality of the materials for the intake piping and intake pumps, it will be planed to select grades incorporating corrosion-resistant properties for easy maintenance.

(7) Policy regarding Construction Period

In order to develop a plan that will not disrupt operations at the Marine Research Center, even during the construction phase, close collaboration with the Ministry of Fisheries will be indispensable in connection with the partial relocation of culture tanks prior to the start of construction and the dismantling and removal of the old seawater supply system after changeover to the new system. In making this intricate changeover, culture conditions must be carefully observed throughout the process, based on a program of adequate test runs. Moreover, as the construction period is strictly limited in projects implemented with grant aid program from Japan, making every effort will be required to ensure completion within the prescribed construction period on the basis of continuing cooperation with the Ministry of Fisheries.

2-3-2 Basic Design

2-3-2-1 Design Conditions

(1) Natural Conditions

1) Oceanographic Conditions

a) Tidal levels and wave conditions

Tidal levels and wave conditions in the plan area follow the date shown in the Basic Design Study Report on the Extension Project of Nuku'alofa Foreshore Protection (JICA, 1988):

Design highest water level	:	+ 1.80 m
High water level	:	+ 1.50 m
Low water level	:	+ 0.10 m
Equivalent Deepwater Wave Height	:	Ho' = 5.4 m (at offshore of the site)
Significant Wave Height	:	Hs = 1.01 m (within moat)
Period	:	Ts = 12.6 seconds

b) Tidal current

Tidal current will not be considered, since they can be ignored for design purposes.

2) Soil Conditions ; Shore and Sea Bottom Topography

Since the Project site was originally a swamp area with a low ground level, the site for the existing facilities was reclaimed by a fill using sandy soil. The structure of the existing facilities is of steel frame construction, while the foundation was designed by the independent foundation method (with a design load of 10 tons / m^2). Furthermore, from a knowledge of past well digging experience, it has been confirmed that the soil at the site within 1m ~ 2 m layer from the surface is a mixed layer of sandy soil originated from fill and marshland, while the next stratum down to 5 m ~ 7 m is a sediment of coral gravel.

Since a soil survey was not included in the field survey, it has been specified a soil bearing capacity of 10 tons / m^2 in the Basic Design, the same value as that used for the existing facilities. However, as the planed facilities include a pump house, equivalent to a 3-story concrete structure, which requires a high bearing capacity, it will be necessary, at the implementation stage, to conduct soil tests by boring or load tests to reconfirm bearing capacity.

The reef moat on the north side of the site, where the intake pipe is to be buried, has a width of about 500 m out from the shore line, while the soil is a lime-rock formation derived from a coral reef, essentially the same as found on shore. However, the 250 m stretch along the shore side has been found to be a sedimentary layer of coral gravel with a thickness of 1 m~2 m on lime rock, while an exposed coral rock formation extends 250 m on the offshore side.

3) Seismic Force

As Tonga, like Japan, is in an earthquake belt, seismic strength standards are based on those in Australia or New Zealand. Accordingly, in this Project as well, these standards will be applied in setting seismic force for the facility designs.

(2) Applicable Standards

Tonga has no building standards of its own, basing its designs generally on either Australian or New Zealand standards. Following local custom, therefore, Australian or New Zealand standards will be applied in the facility designs for this Project.

2-3-2-2 Facility Plan

(1) Layout Plan

The Project comprises, as its major facilities, the intake pipe, pump house, awning for the culture area, night worker's station and settling pond.

Since, in terms of achieving efficient seawater intake, the shorter the intake pipe, the more effective the intake system, the water intake strainer at the tip of the intake pipe is to be installed at the reef edge, which is the shortest distance from the pump house.

The pump house will be the core facility for water supply operations, housing such as the intake pit, intake pump and filtration tank. This facility will be placed on the north side of the site, adjoining the seaside area, where it will be easiest to bring in the intake pipe.

The night worker's station is designed to accommodate night guards and, since their patrol duty will center on the culture area, it is planned to locate this structure on the south side of the site, within easy range of the target facilities. In addition, in order to facilitate inspections for irregularities among the principal components of the water delivery system, a monitoring panel will be installed in the night worker's station.

Since the new awning for culture area will be a replacement for the existing one, the installation site will be unchanged from the present facility.

The settling pond is designed to settle suspended matter included in the drainage from the culture facilities and so will be installed at the terminal of the drainage canal. Accordingly, the pond will be located on the north side of the site adjacent to the seaside area. The layout plan is shown in Figure 2-10.

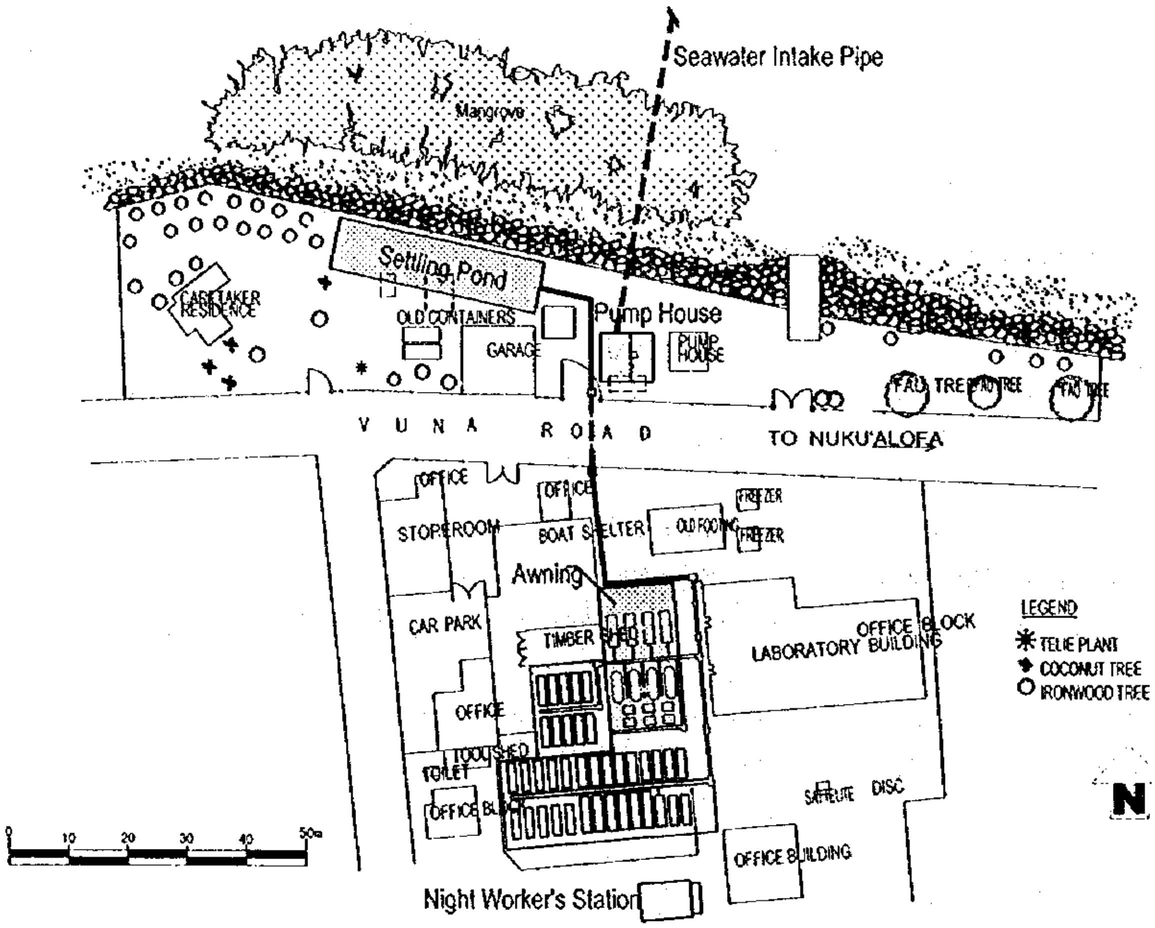


Figure 2-10 Facility Layout Plan

(2) Intake Pipe Plan

1) Intake Point Plan

In order to ensure efficient water intake, the intake location will be set at the reef edge, virtually due north of the Marine Research Center, which will minimize the length of the intake pipe. This area has a water depth of about 2.5 m. Since the bottom sand in this section is subject to turbulence from wave action, while garbage floating on the surface results in unstable water temperatures and salinity, the intake point will be installed in the center of this section so as to minimize these adverse influences. Particulars for the intake point set-up are given in figure 2-11.

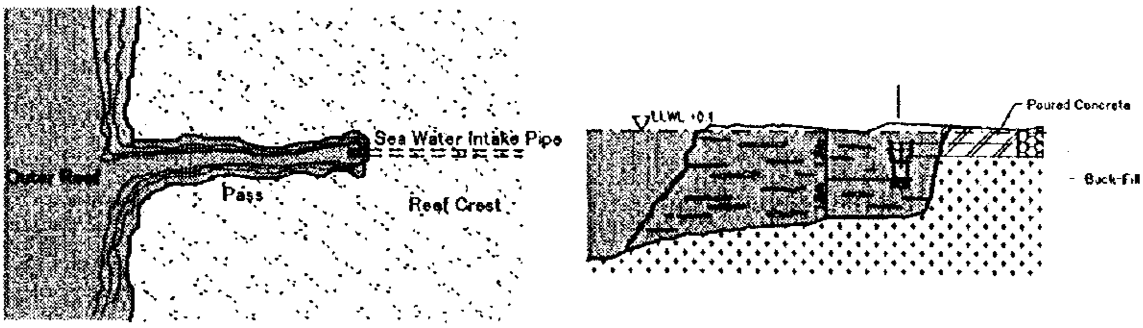


Figure 2-11 Intake Point

2) Installation Plan for the Intake Pipe

The diameter of the intake pipe has been set at 350 mm, based on the Manning formula. As to pipe materials, since the intake section will be installed in a wave-breaking zone, thereby necessitating high-strength material, while the land section, from the foreshore protection to the receiving pit, will utilize the semi-siphon method and so must be watertight, this portion of the pipe will be resin-coated steel piping. The moat section, on the other hand, where the physical load on the pipe is small, will be of PVC construction. In addition, maintenance access ducts with be installed at 50 m intervals to permit interior pipe cleaning and inspection.

Intake Pipe Sections	Material	Maintenance Ducts	Piping Length
Intake point section	Resin-coated steel piping	-	approx. 11.0 m
Moat portion	PVC piping	8	approx. 436.5 m
Shore section	Resin-coated steel piping	1	approx. 64.5 m
Total		9	approx. 512.0 m

3) Standard Sectional Plan

In order to prevent damage from edged protuberances, the intake pipe will be protected with a sand layer covered by a fill, using excavated sand, up to the present bottom levels. A typical section plan of the piping, as dictated by ease of laying work, is shown in figure 2-12 following.

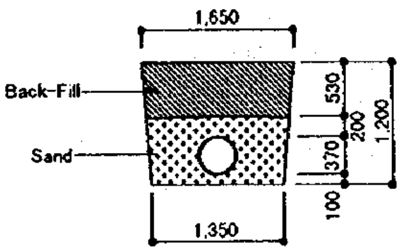
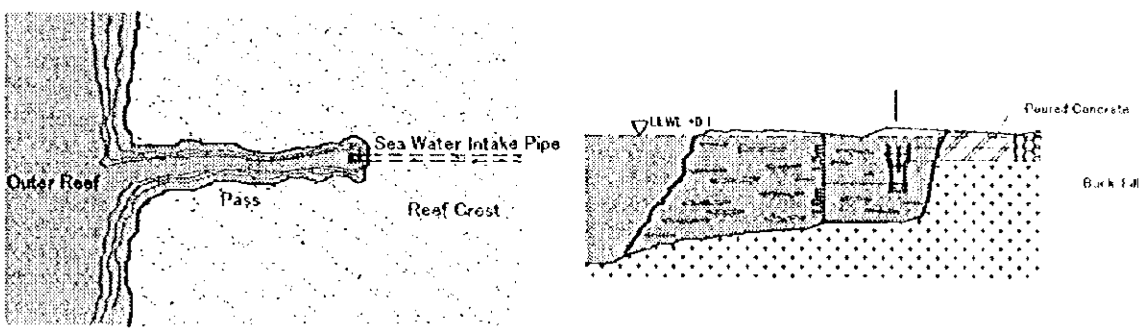


Figure 2-12 Typical Sectional Plan for the Intake Pipe



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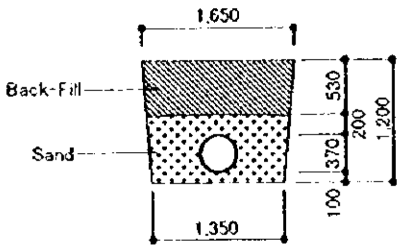


Figure 2-12 Typical Sectional Plan for the Intake Pipe

(3) Seawater Supply System

Water supply for culture use will be based on the use of a dual system to satisfy the maximum volume requirement (1.2 m^3 / min), with each of the two systems supplying half of the total requirement (i.e., 0.6 m^3 / min.) through its own intake pump and filtration unit. Rearing water will be distributed from the intake pump, via the filtration unit, to an elevated tank of 24 m^3 capacity and then supplied to the various tanks via a natural gravity system.

The plan is to have the intake pump start and stop automatically, based on the water levels in the intake pit and the elevated tank, but this automatic control system will be made as simple and easily understood as possible. The plan facility system is charted in Figure 2-13.

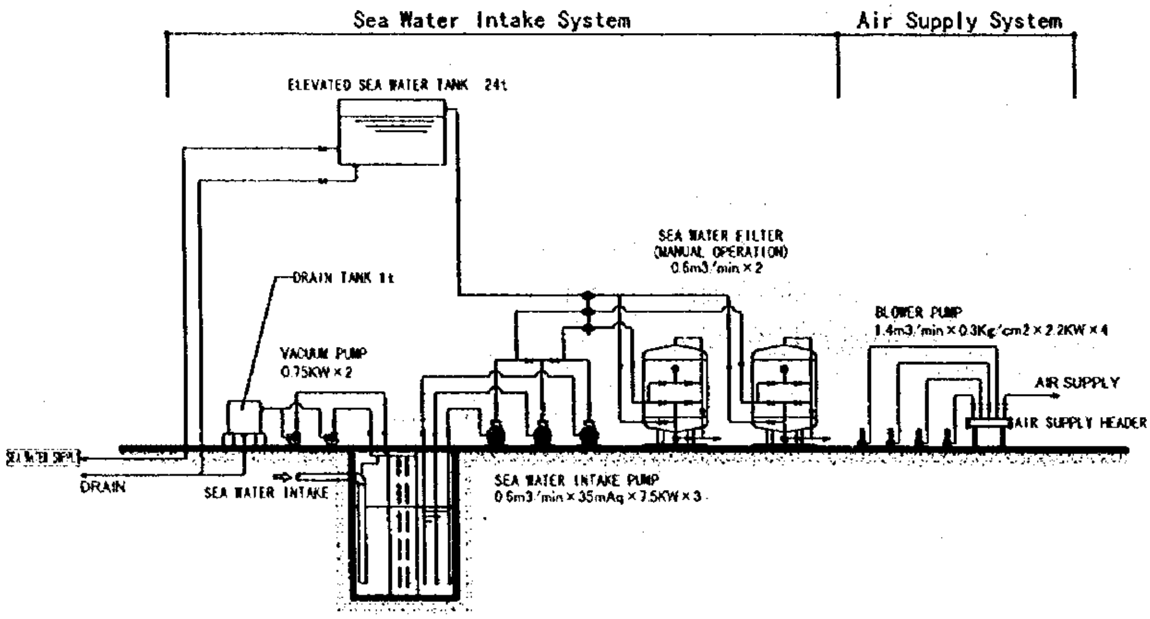


Figure 2-13 Plan Facility System

(3) Construction Plan

1) Pump House

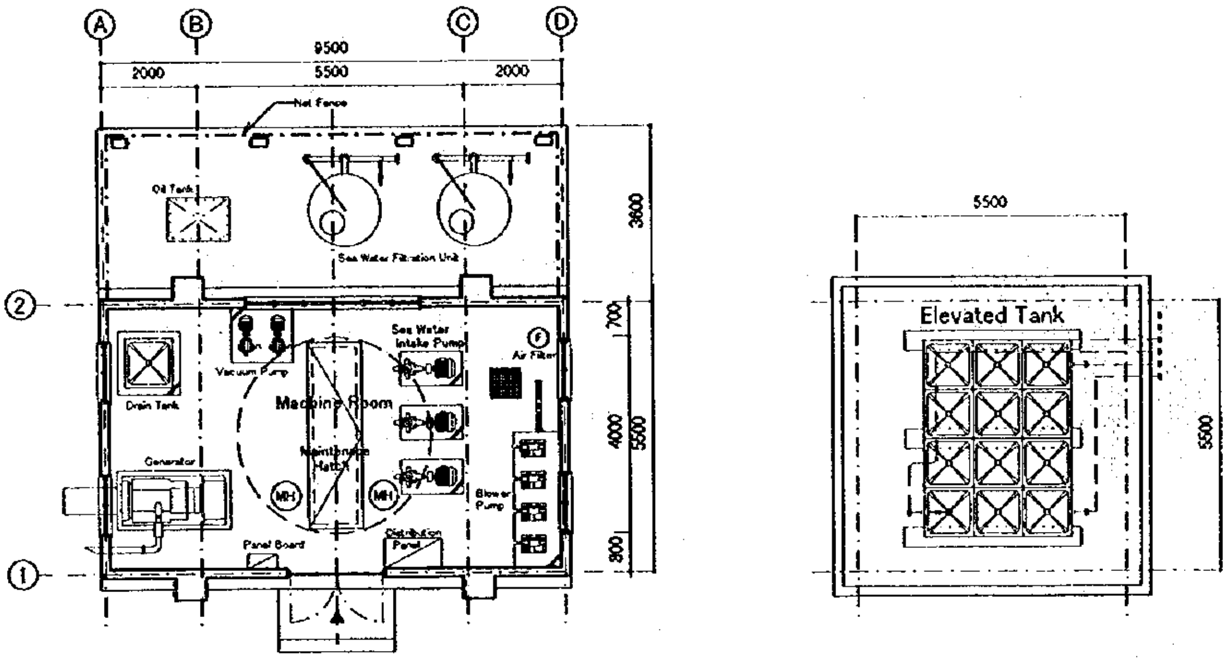
a. Floor Plan

The ground floor of the pump house will contain a machinery room for the main items of equipment and machinery, such as the intake pumps, vacuum pumps, blowers, generator, and control panel, and will also provide installation space for the filtration units and fuel tank, with the elevated tank to be installed directly on the roof above. The intake pit, which will receive the seawater, will be installed in the basement.

The floor area of the pump house, based on the span placement and the room layout plan, has been calculated as shown below:

1.	Machinery Room	5.5 m x 9.5 m =	52.25 m^2
2.	Installation space for the filtration system	9.5 m x 3.6 m =	34.20 m^2
3.	Installation space for the elevated tank	5.5 m x 5.5 m =	30.25 m^2
4.	Intake pit	(diameter: 4.0 m; depth: 5.0 m)	
	Total floor area		116.70m^2

The floor plan for the pump house is shown in Figure 2-14.



Ground Floor Plan

Roof Plan

Figure 2-14 Floor Plan for the Pump House

b. Sectional Plan

Exterior wall openings will be provided from the machinery room to facilitate maintenance on the installed equipment. The Project will also pay close attention to ventilation so as to minimize humidity. Ceiling height has been set at 3.0 m, allowing for adequate piping space and efficient maintenance operations.

c. Structural Plan

The pump house will accommodate a number of vibrating and heavy items, such as the generator and pumps, while the roof will have to support a 25 m^3 elevated tank. In order to afford proper durability and ruggedness, reinforced concrete has been chosen as the structural method.

The upper soil stratum at the planed construction site is understood to be a coral gravel layer descending about 6 m from the surface. Since, based on historical data, about 10 tons/m^2 bearing capacity can be anticipated as the long-term permissible stress, the direct foundation method will be adopted for the foundation structure. In addition, a geological survey will be conducted at the Implementation Stage to confirm bearing capacity.

2) Night Worker's Station

a. Floor Plan

This will be a night duty and lounge/service facility for the Center guards. Based on consideration of work space and efficient room placement, it will be planed to locate the lounge / service room in the center of the facility, with the night duty room and toilet/shower rooms to be placed on both sides.

Based on the span distribution and room layout plan, the floor area for the night worker's station has been calculated as follows :

1.	Night duty room	6.0 m x 3.5 m =	21.0 m^2
2.	Lounge/ Service room	6.0 m x 3.5 m =	21.0 m^2
3.	Toilet / Shower room	5.0 m x 1.5 m =	7.5 m^2
	Total floor area		49.5 m^2

The floor plan for this facility is shown in Figure 2-15.

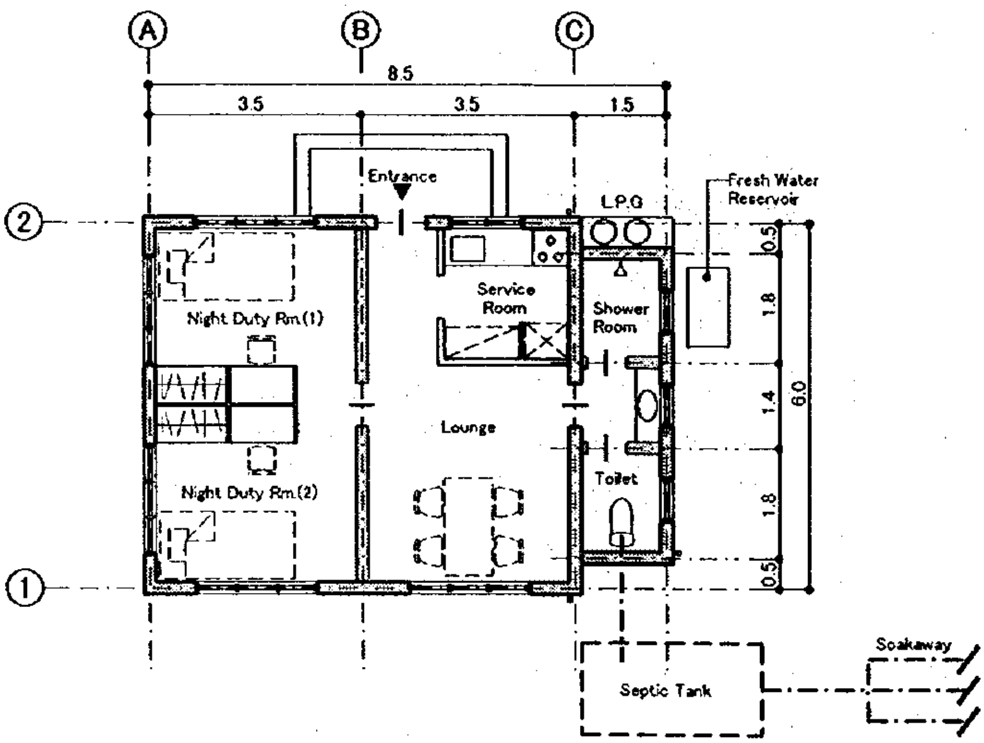


Figure 2.15 Floor Plan for the Night Worker's Station

b. Sectional Plan

All rooms in this facility will open to the outside, with special consideration given to natural ventilation and lighting. A pitched roof will be used, with insulation to be provided via an air layer in the attic. Natural ventilation will be introduced, while the general practice in the area is to provide high ceilings as a means of alleviating the heat. Ceiling heights in comparable buildings in the Project area run between 2.5 m~2.7 m. Accordingly, in deference to local custom and the practice in existing buildings, it has been set the ceiling height in the planed facility at 2.8 m.

c. Structural Plan

Concrete block will be used as the structural method for this facility, as it is highly popular throughout the planed area for its ease of maintenance and superior durability. Since the night worker's station will be a single-story building and, based on historical data, the long-term permissible stress can be expected to run about 10 tons/m^2, the foundation structure will employ the direct foundation method.

3) Awning for Culture Area

a. Floor and Sectional Plans

This will be a new awning, replacing the superannuated existing roof. Since there is no reason why the scale of the awning should not be the same as that of the present structure, it will be planed to adopt the identical shape: 12.0 m W x 22.5 m L x 3.0 m H.

b. Structural Plan

The awning facility will comprise posts and the roof structure. As the posts and beams will be directly exposed to sea breezes, the steel frame structure in the existing awning has had serious problems with rust damage. In the Project, therefore, as a means of preventing rust damage as well as for ease of maintenance, it has been concluded that it would be proper to specify laminated wood as the structural material.

It would be difficult to repair the existing foundation because neighboring facilities are too close to allow adequate working space. However, as the existing foundation is buried underground, structural damage is slight, and so that it can be used as the foundation for the plan awning. Accordingly, after reinforcement of the anchoring bolt section, it is planned to reuse the existing foundation structure for the plan awning.

(5) Finishing Plan

1) Exterior Finish

In Tonga, painted mortar is the most commonly used exterior finish. As this finish has been found to be both rugged and easy to maintain, it will be used on both the pump house and night worker's station.

2) Roof Finish

In the case of the pump house, since the roof type will be flat concrete, it will be given a mortar water-proof finish. In the night worker's station, painted corrugated sheets will be specified, as generally used in Tonga. It has been decided that the new awning over the culture facilities will be of translucent polycarbonate corrugated sheets, since they have been utilized in the existing facilities to date without particular difficulty.

3) Interior Finishes

In the interest of easy maintenance, it has been, in principle, decided on interior finishes that can be sourced locally. These materials will be as shown in Table 2-15 following.

Table 2-15 Interior Finishes Plan

Name of Facility	Floor Finishes	Wall Finishes	Ceiling Finish
Pump House	Mortar	Mortar with paint finish	Mortar with paint finish
Night Worker's Station	Tile	Mortar with paint finish	Paint finish on plywood
Awning	Mortar	-	-

(6) Plan for Electrical and Mechanical Equipment

1) Electrical Equipment

Since an 11 kV high-voltage overhead line has been built on the road in front of the site, power for the Plan facilities will be stepped down to 415 / 240 V via an on-pole transformer and then brought to the distribution board installed in the pump house for distribution to the night worker's station and the awning over the culture facilities.

In order to prevent salt damage, the trunk line will be buried, with power to be distributed indoors via PVC conduit pipes. To facilitate maintenance, the materials used will, wherever possible, be of standard local specifications and available locally.

The electrical system will be divided into two classes: lighting/sockets and power equipment, with maximum loads as shown in Table 2-16 below.

Table 2-16 Maximum Load Capacities

Facility Name	Lighting and Socket Load	Power Equipment Load	Total
Pump House	1.92 kVA	29.83 kVA	31.75 kVA
Night Worker's Station	3.72 kVA	-	3.72 kVA
Awning	2.91 kVA	-	2.91 kVA
Equipment load	8.55 kVA	29.83 kVA	38.38 kVA
Transformer capacity	38.38 kVA x 1.25 (safety margin) = 47.97 kVA		Rounded to 48 kVA

Based on the above calculations, and after allowing for the demand rate, the requisite transformer capacity may be estimated at around 50 kVA.

a. Lighting and Sockets

Both fluorescent and incandescent lighting are widely used in Tonga, with the bulk of these fixtures imported from Australia and New Zealand. In this Project, Japanese equipment will be used from the standpoint of safety and reliability. The load voltage will be 240 V, 50 Hz.

b. Power Equipment

Power will be supplied to the intake pumps, blowers, vacuum pumps, and other powered equipment. The load voltage will be 415 V, 50 Hz, but dedicated lines will be provided for equipment, such as the intake pumps, with high power consumption.

c. Emergency Generator

An electric generator will be installed in the pump house as a source of emergency back-up power for equipment directly connected to culture facilities, such as the intake pumps, blowers, and vacuum pumps. The generator will be an automatic starter model, with the following approximate specifications:

Engine:	Diesel engine	
Power supply:	3 phase, 3 lines	415 V / 240 V, 50 Hz
Generating capacity:	50 kVA	

2) Water-Supply and Drainage Equipment

a. Municipal Water Supply

Municipal water is supplied to the existing facilities via a water pipe laid along the road in front of the site. The water quality is hard, containing considerable lime, and is chiefly used for general non-potable purposes. Drinking water is obtained from rainwater, which is sterilized by boiling. During periods of heavy usage, as in the morning and evening, water pressure drops markedly, so that most consumers install receiving tanks, using a pump to boost pressure.

In supplying water to the plan facilities, the pump house and existing culture tanks will be served via a branch from the existing supply pipe, but it will be installed a receiving tank and booster pump in anticipation of shower consumption at the night worker's station.

b. Hot Water Supply

A water heater will be installed for shower use at the night worker's station.

c. Drainage Facilities

Drainage from the pump house and existing culture tanks will be drained via a drainage ditch on the premises. In the case of sewage and miscellaneous drainage from the night worker's station, a septic tank will be installed for combined treatment, after which the drainage will be soaked away in the ground via a soak-away pit.

d. Ventilating Equipment

In areas subject to high humidity, such as the service room and the toilets / shower room in the night worker's station and the machinery room in the pump house, a ventilating fan will be installed.

(7) Exterior Plan

The drainage ditch within the site will be used to drain both culture water and rainwater. Except for the portion crossing the road, the ditch will be an open concrete channel to facilitate maintenance.

The side wall of the settling pond will be of concrete construction, while the various heights will be: +2.0 m for the inlet point, + 1.95 m for the overflow outlet, and + 1.4m ~ +1.5 m for the pond bottom.

2-3-2-3 Equipment Plan

In addition to a serious shortage of culture tanks, the octagonal and reservoir tanks, which have been in temporary use, are to be dismantled and removed under this Project. Under the circumstances, a suitable number of new rearing tanks will be provided to compensate for those demolishing tanks. At the existing facility, the tank deemed most suitable for grow-up purposes is an FRP tank with a width of about 1.5 m and a length of about 5 m. A tank depth of 0.5 m is used in giant clam culture and 0.7 m for green snails and trochus. The scale of the culture tanks to be provided under the Project will be identical to that of the above tank.

While the rearing tank deficiency at the Center is estimated to be in the order of 29 units, comprising 10 tanks for giant clam use and 19 for green snail and trochus applications, owing to the limited potential area at the site for tank installation, a total of 20 tanks will be provided under the Project, divided equally (i.e., 10 units each) between giant clam and green snail/trochus use.

There is also a shortage of small-size trial tanks, used mainly in seed production and technical development experiments for giant clams, which prevents effective operation of these facilities. In this Project, therefore, a need has been recognized for providing trial tanks as well so as to further enrich research programs at the Center. Considering the concentration of giant clam spawning in a particular period of the year, 10 tanks will be provided to permit the conduct of 2 simultaneous experiments at each of five trials (5 trial tanks x 2 experiments). Half of these tanks will be of FRP construction, which offer superior durability, with the remaining units to be of transparent polycarbonate construction to facilitate observation activity.

A suitable tank capacity would be 500 liters, which covers a wide range of potential applications, from giant clam seed production to the culture of diatoms and in connection with the introduction testing of exotic species.

Table 2-17 Equipment Plan

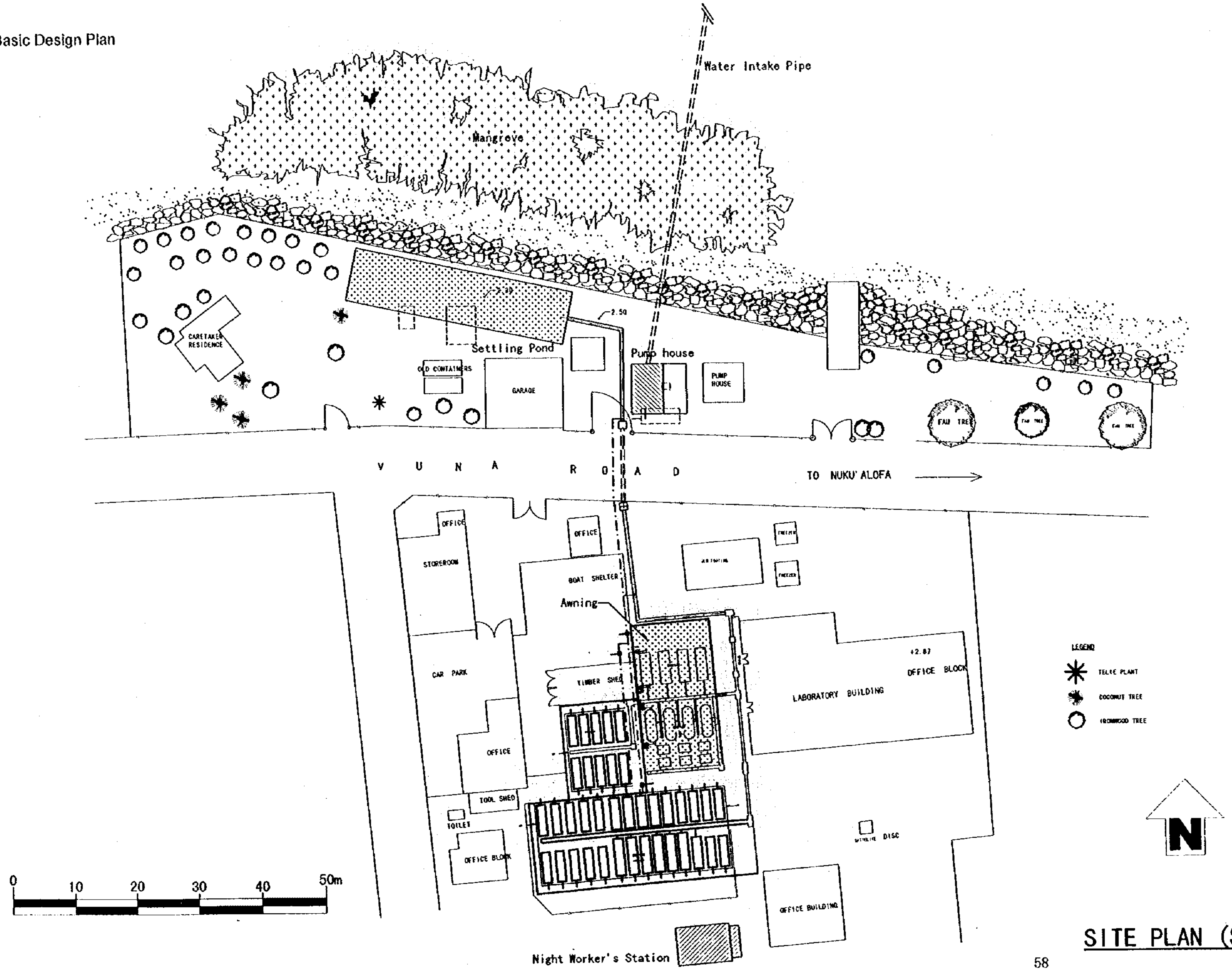
Name of Tank	Description	Quantity
(1) Culture tank for giant clam	FRP 1.5m x 5.0m x 0.5m	10 units
(2) Culture tank for green snail/trochus	FRP 1.5m x 5.0m x 0.7m	10 units
(3) Trial tank	FRP 500 liters	5 units
(4) Observation tank	Polycarbonate 500 liters	5 units

Based on the above considerations, the plan work has been determined as shown in Table 2-18.

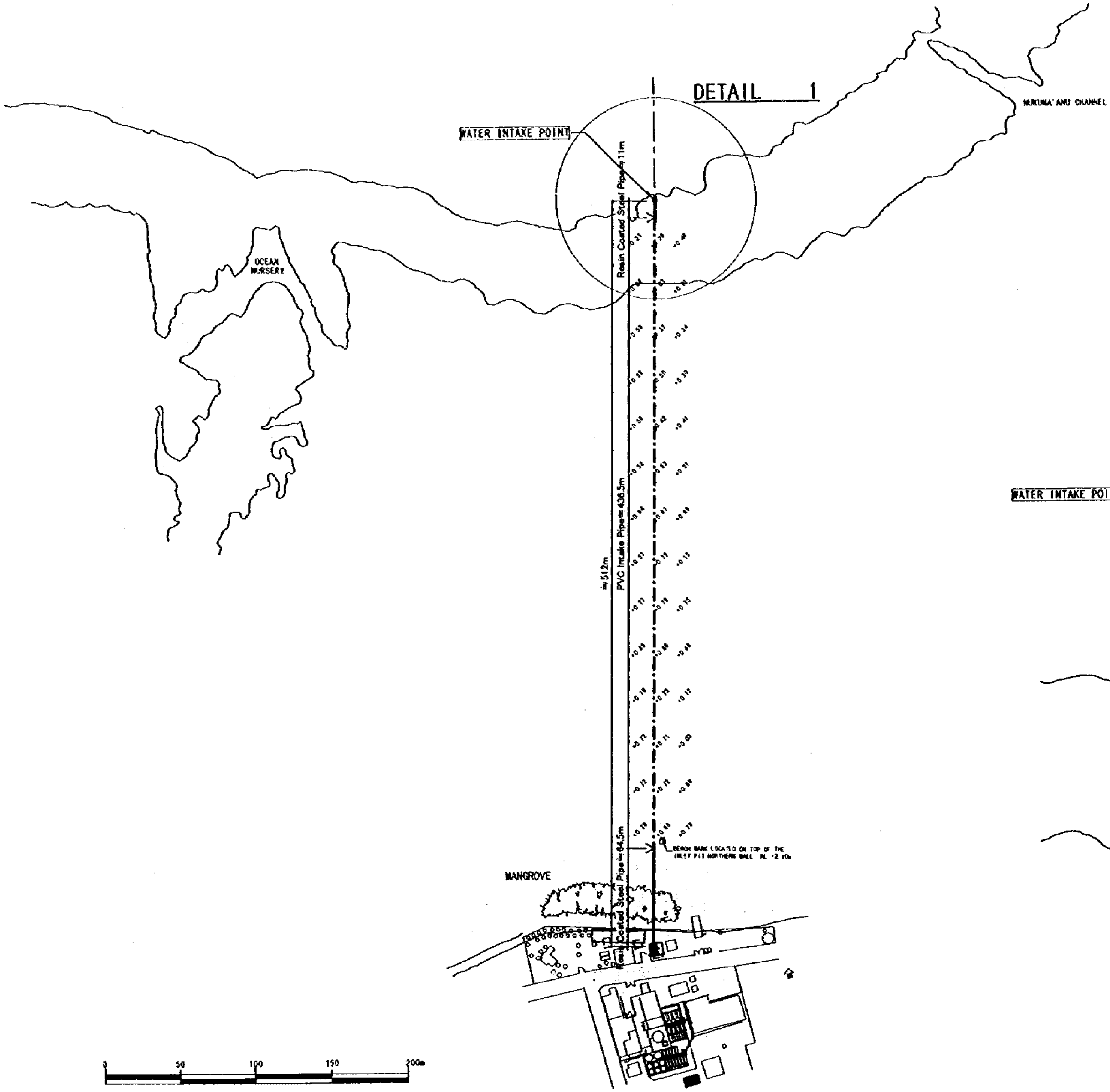
Table 2-17 Plan Component

Work Plan	Outline of Contents
1) Seawater Intake System	Intake point : Groove-and-spur of reef edge Intake capacity : 1.2m³/min Intake method : Semi-siphon Intake pipe : 350mm dia., 512m Pipe materials : Coated steel pipe and PVC pipe Filtration system : Rapid-pressure filtration system Key equipment : - Intake pump : 0.6m³/min x 3 units (inc. 1 x spare) - Blower : 1.4m³/min x 4 units (inc. 1 x spare) - Vacuum pump : 0.75kW x 2 units - Filtration unit : 0.6m³/min x 2 units - Elevated tank : 24m³, FRP - Piping renovation : For main supply lines in culture area
2) Pump House	Structure : Reinforced steel concrete Floor area : Machine room 52.25 m² Filtration unit space 34.20 m² Elevated tank space 30.25 m² Total (116.70 m²) Intake pit : 4m dia., 5m depth
3) Night Worker's Station	Structure : Concrete block Floor area : Night Duty Room 21.00 m² Lounge/Service room 21.00 m² Toilet /Shower room 7.50 m² Total (49.50 m²)
4) Awning	Structure : Glued laminated timber Floor area : Rearing space 270.00 m²
5) Drainage Canal and Settling Pond	- Drainage canal : 0.4m width Slope : 1/500 Structure : Reinforced concrete - Settling basin : 8m x 35m x 0.5m (depth) Structure : Gravel laying bottom, Reinforced concrete for retaining walls
6) Building Services	- Wiring, lighting and receptacle outlet : 1 lot - Emergency generator 50 kVA : 1 unit - Plumbing for city water supply and sewerage : 1 lot
7) Equipment	- FRP tank for giant clam : 1.5m x 5.0m x 0.5m 10 units - FRP tank for green snail/trochus : 1.5m x 5.0m x 0.7m 10 units - FRP trial tank : 500 liters 5 units - Polycarbonate observation tank : 500 liters 5 units
8) Demolish of Existing Facilities	- 100m³ reservoir - Octagonal tanks (2 x large tanks & 6 x small tanks) - Elevated tanks and basement - Overhead piping and supports in the Wet Laboratory - Awning

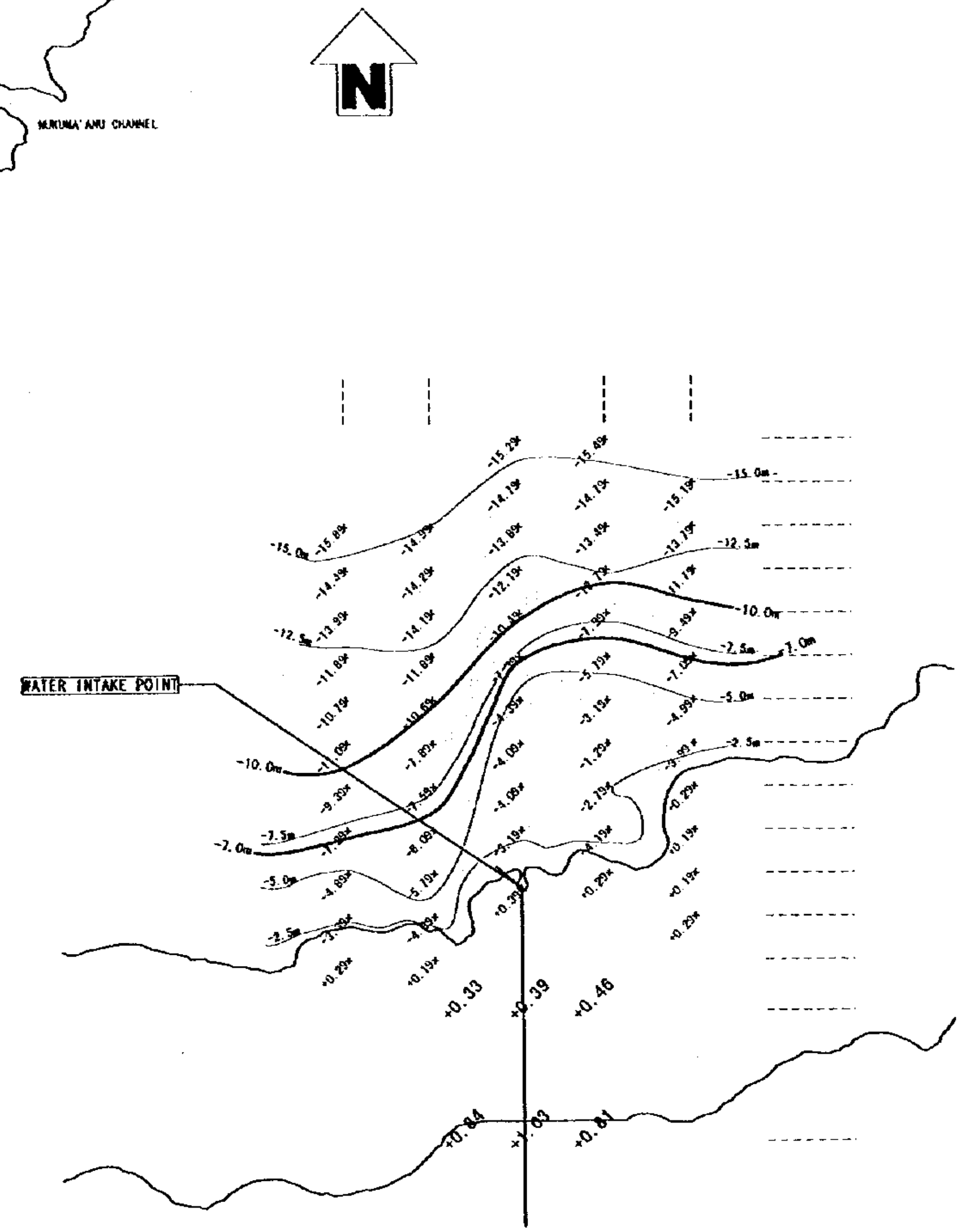
2-3-2-4 Basic Design Plan



SITE PLAN (S=1/600)

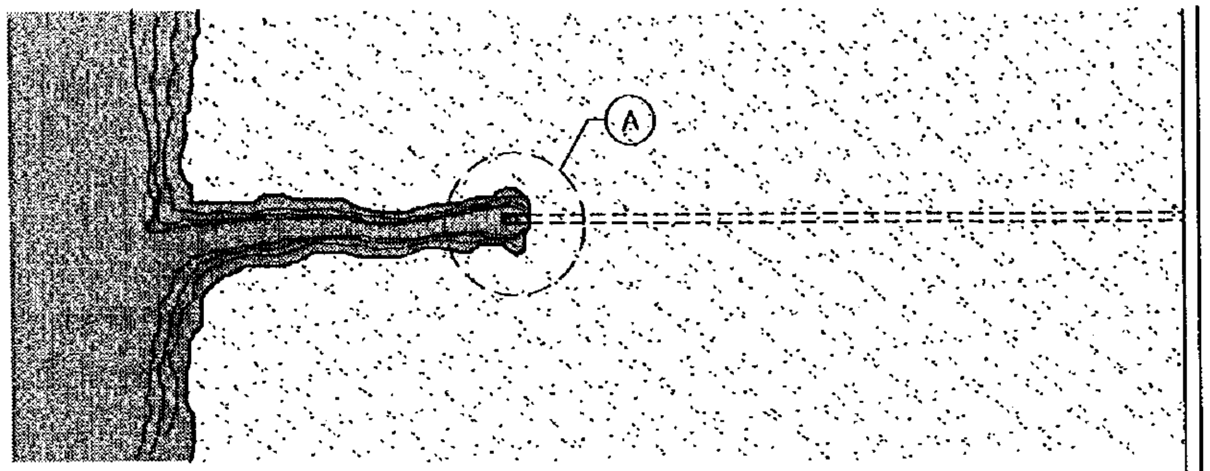


LOCATION PLAN

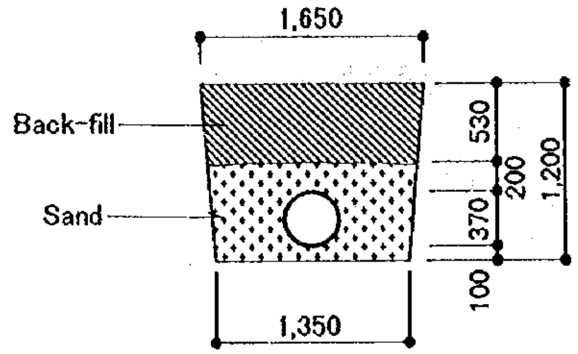


DETAIL 1

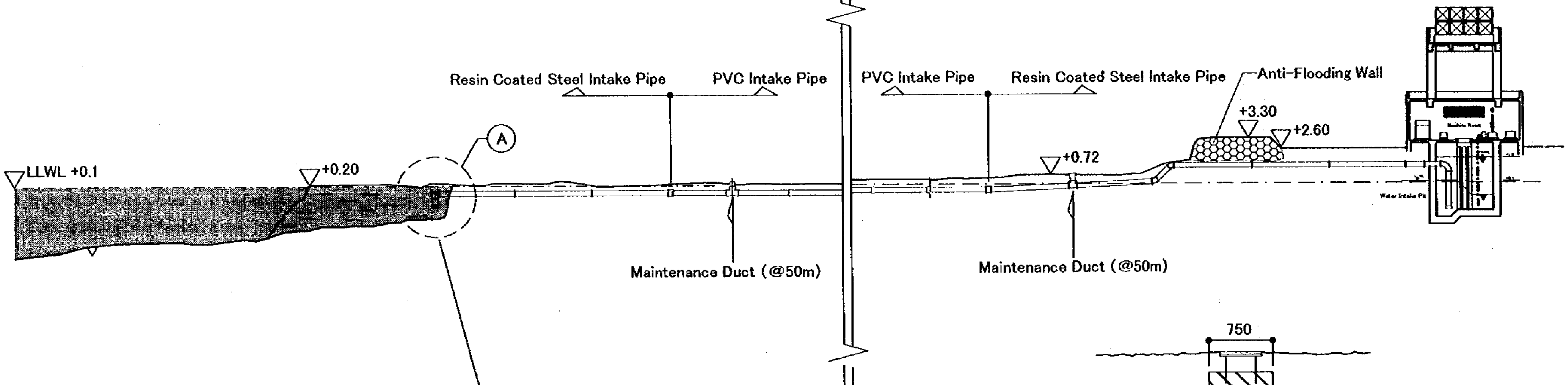
SEA WATER INTAKE PIPE

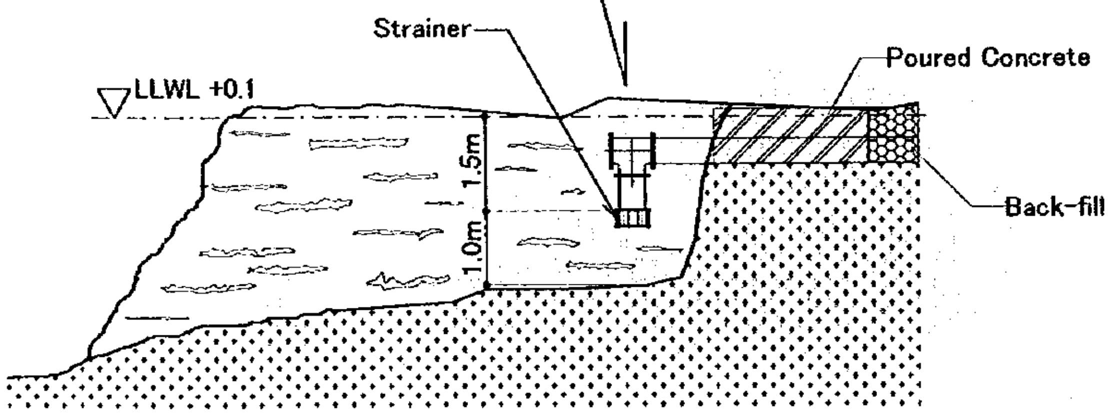


SEA WATER INTAKE PIPE PLAN

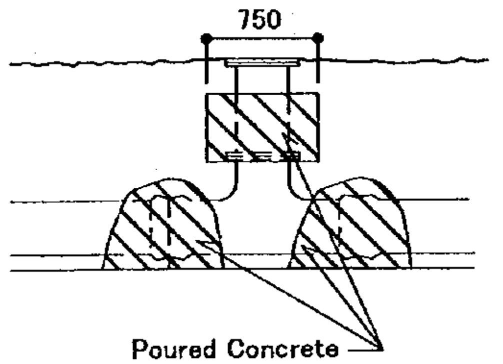


INTAKE PIPE TYPICAL SECTION



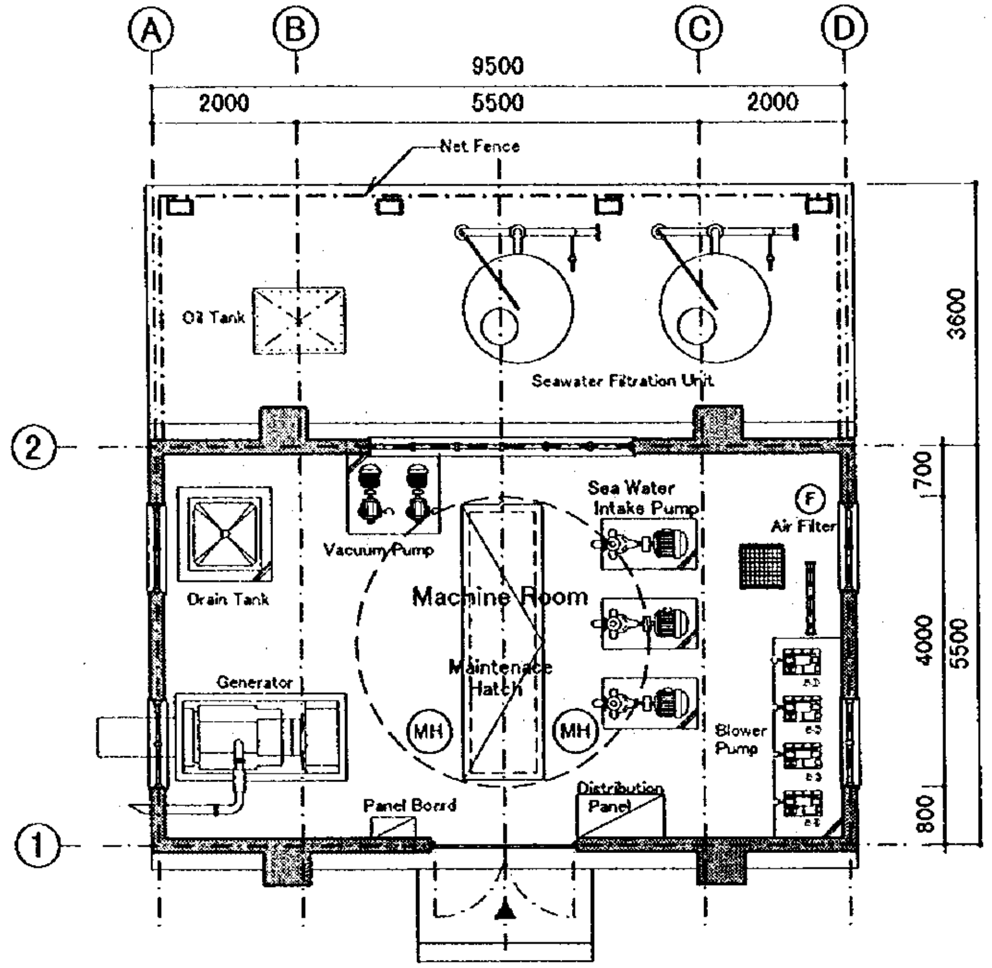


A: DETAIL

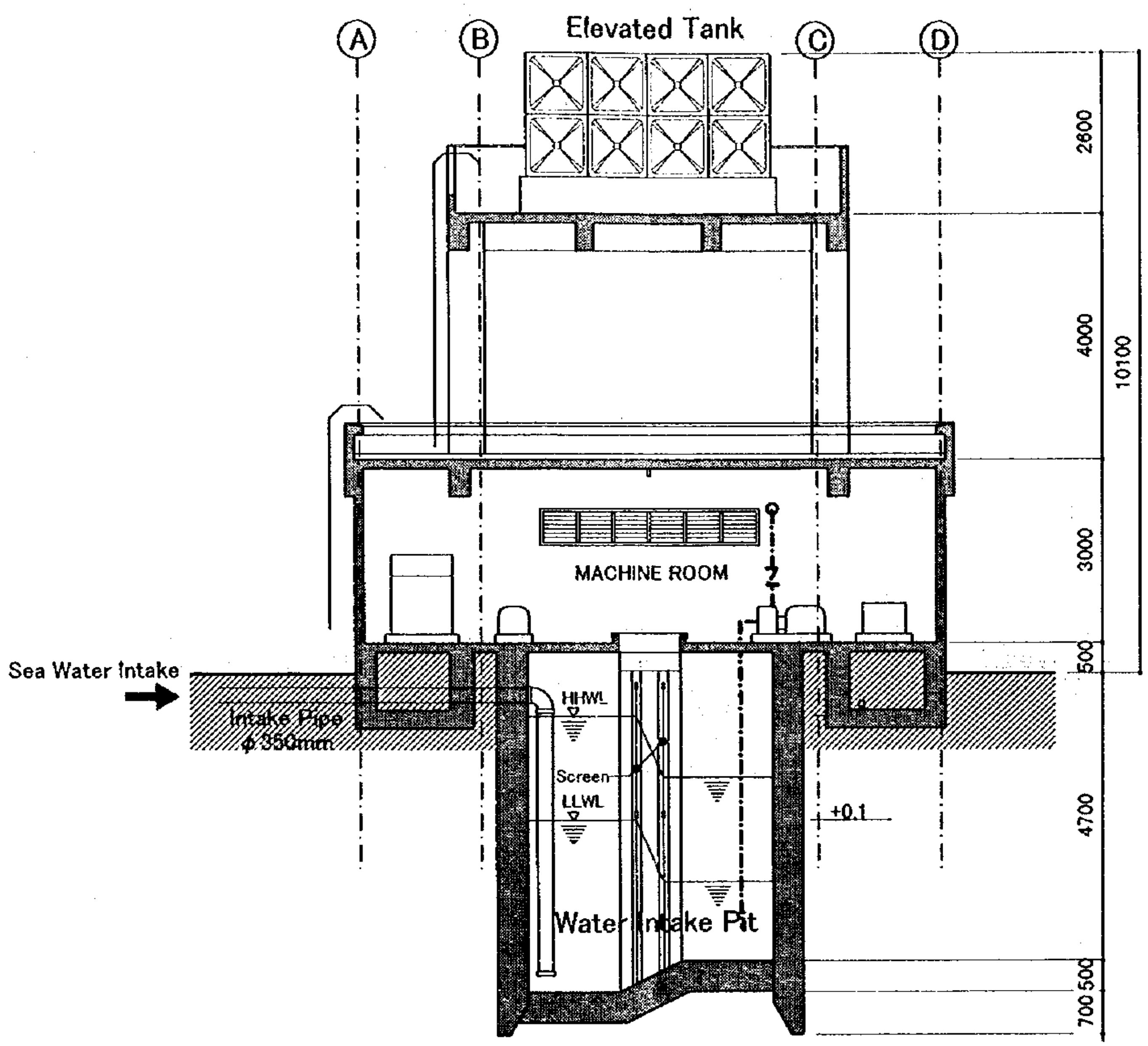


MAINTENANCE DUCT DETAIL

SEA WATER INTAKE PIPE

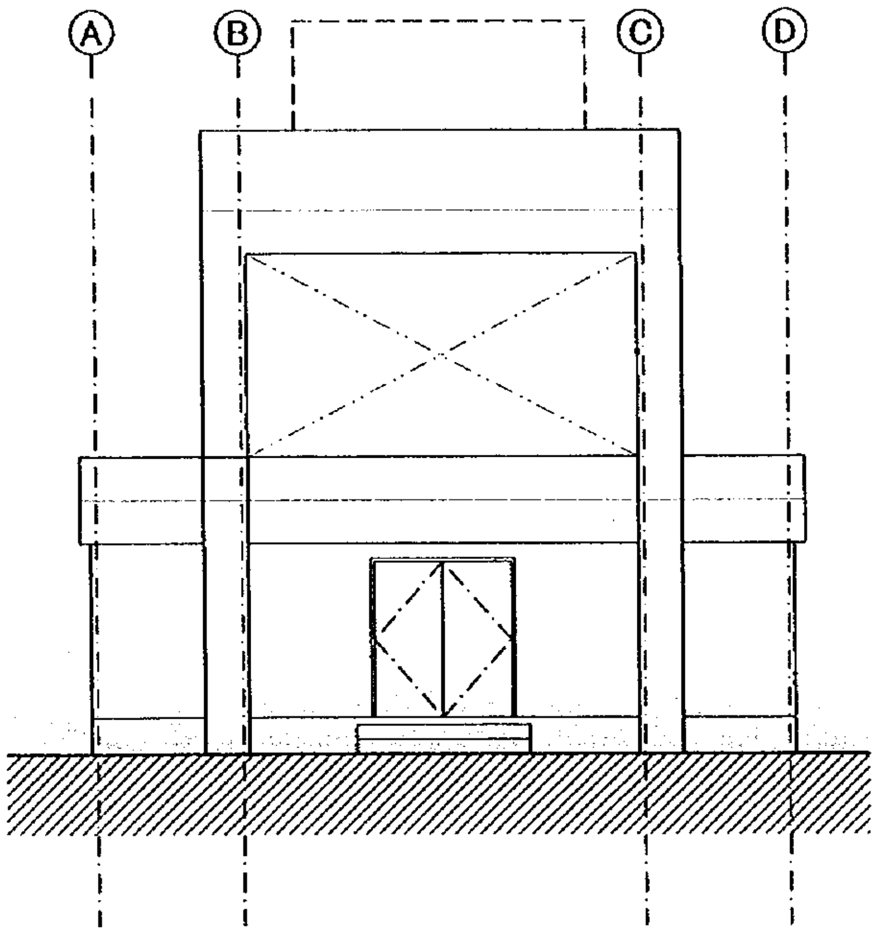


GROUND FLOOR PLAN

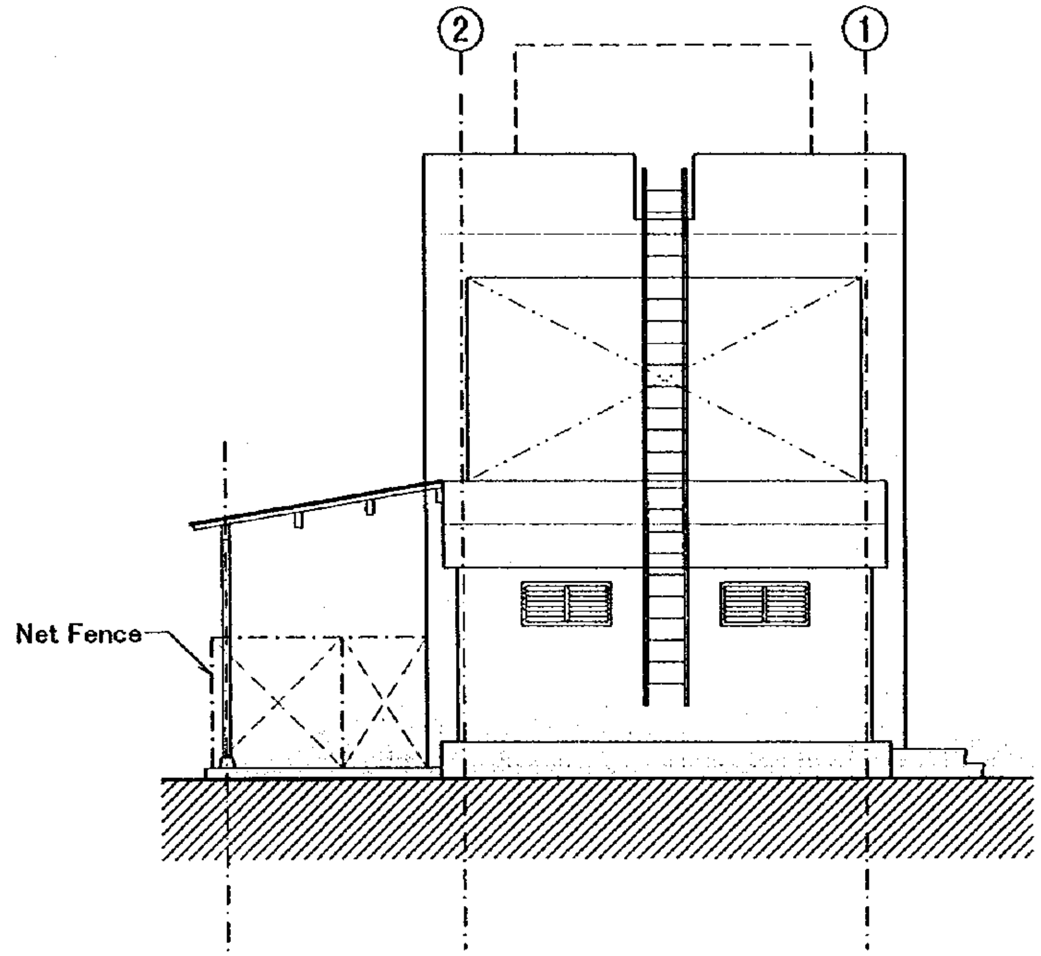


SECTION

PUMP HOUSE-1(S=1/100)

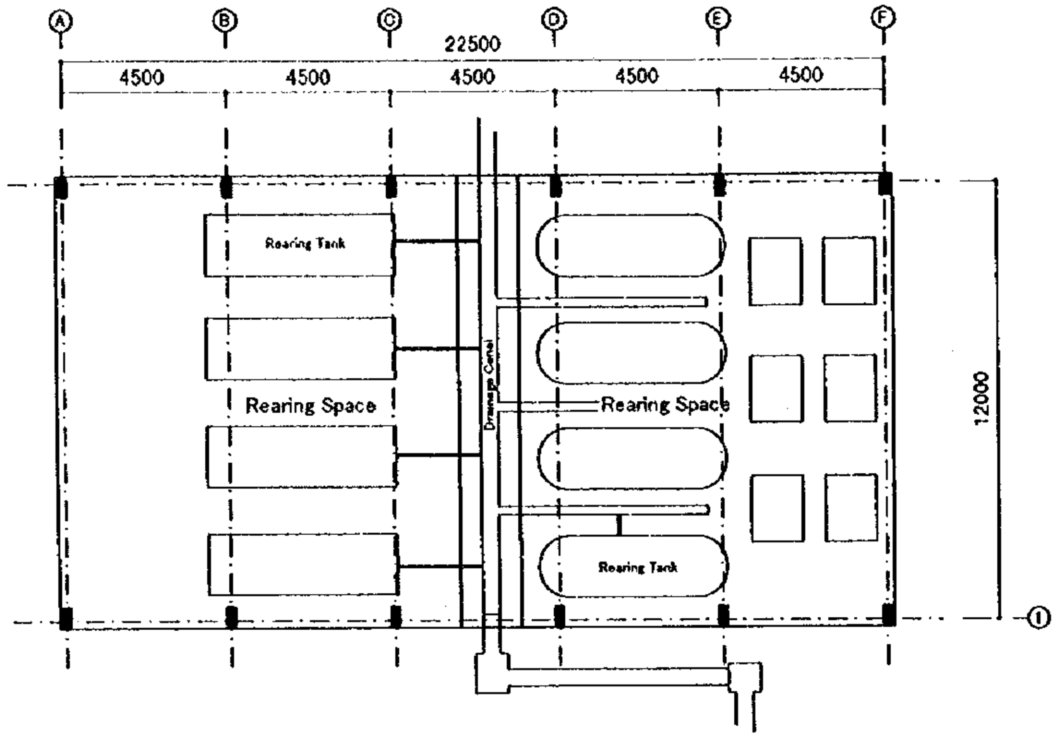


ELEVATION

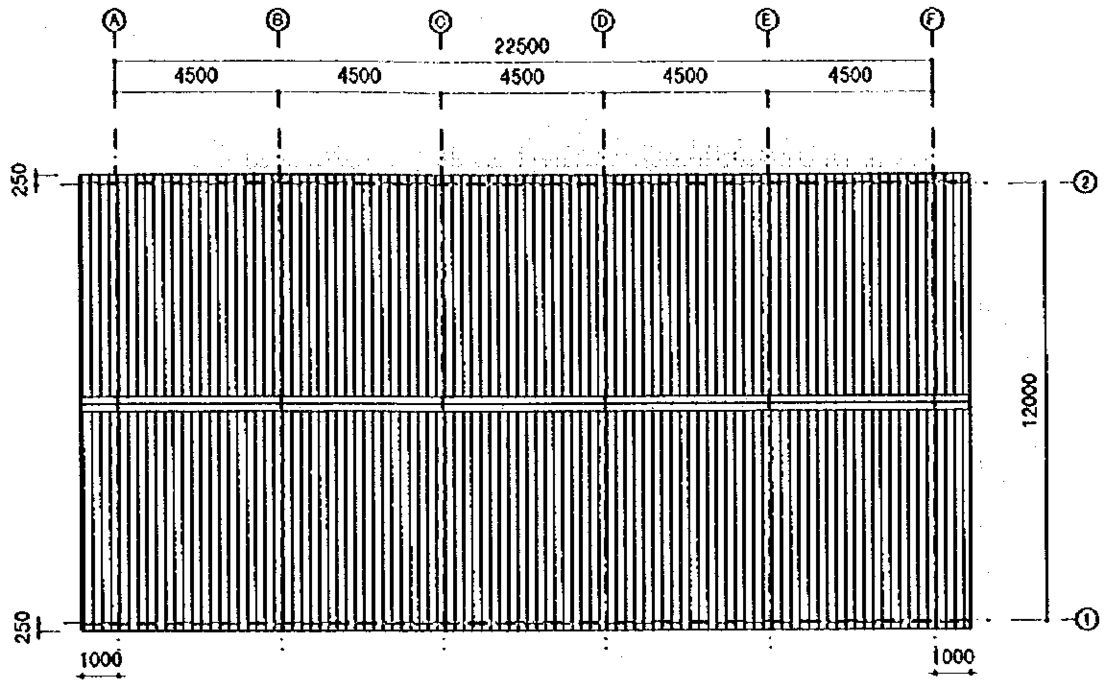


ELEVATION

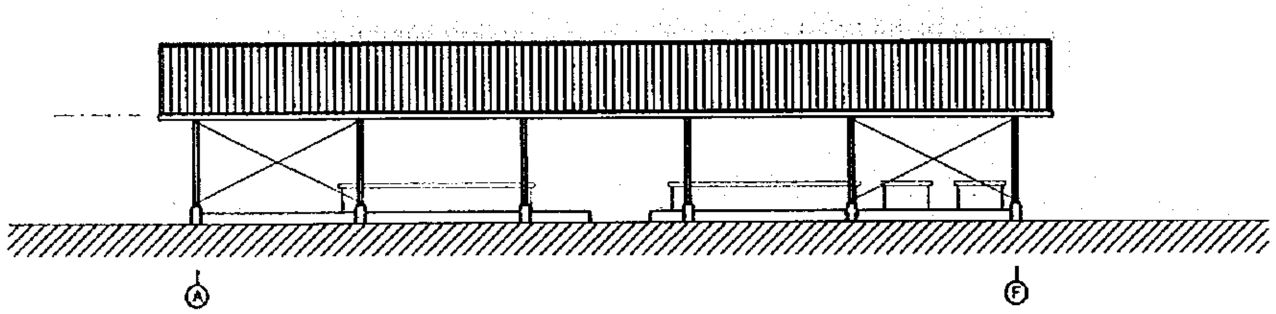
PUMP HOUSE-2(S=1/100)



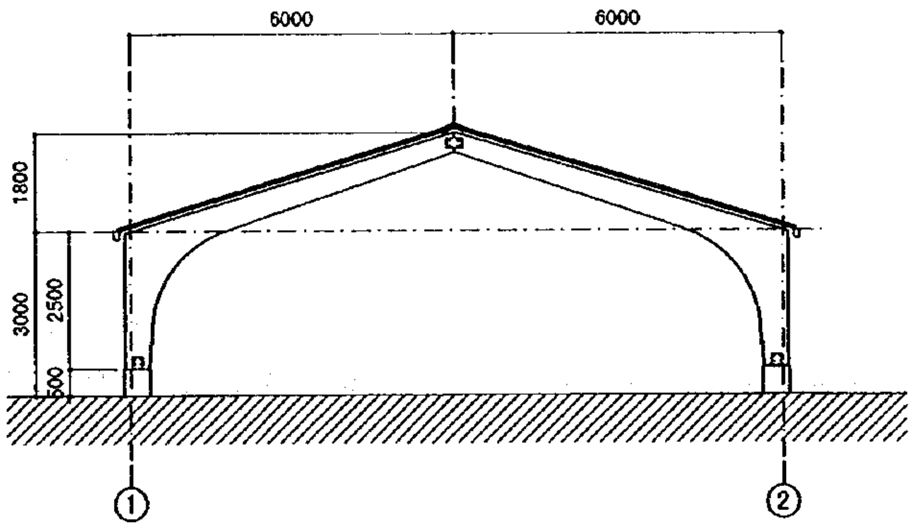
GROUND FLOOR PLAN (S=1/200)



ROOF PLAN (S=1/200)

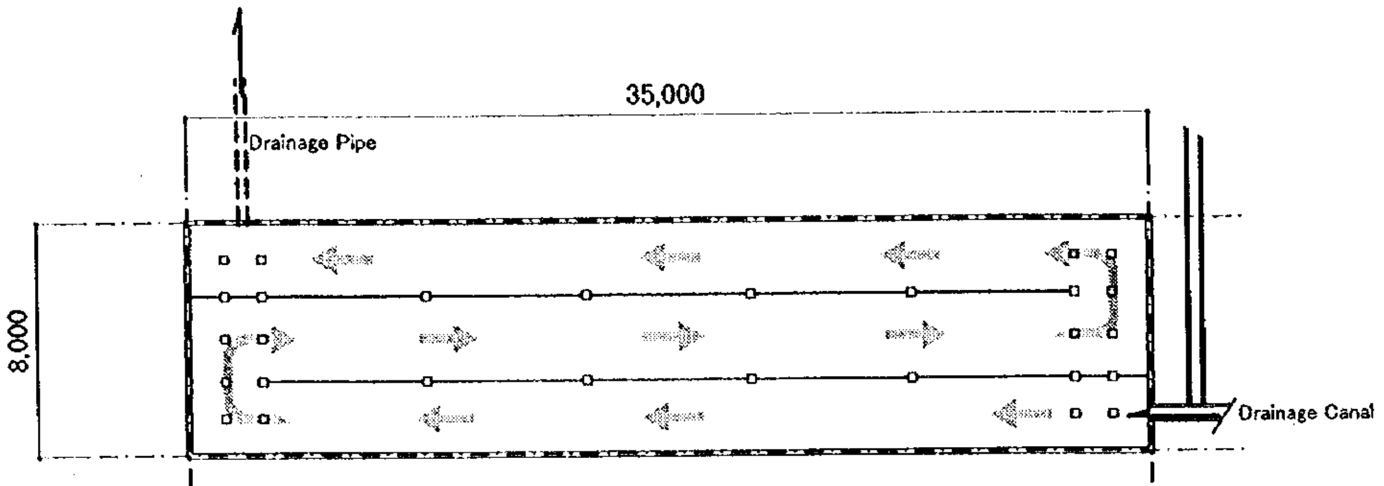


ELEVATION (S=1/200)

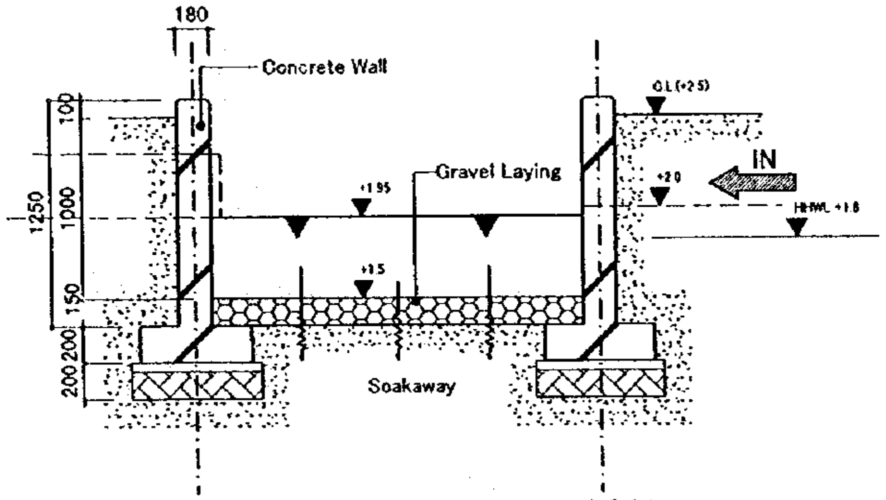


SECTION (S=1/150)

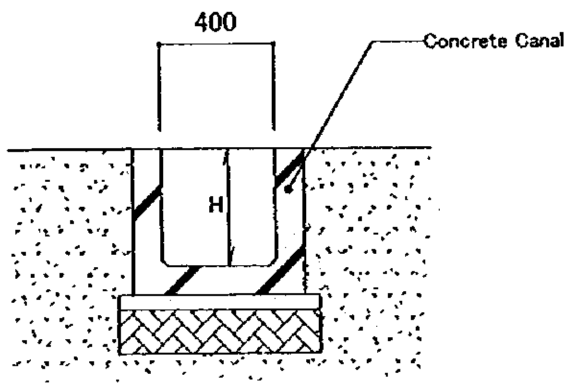
AWNING



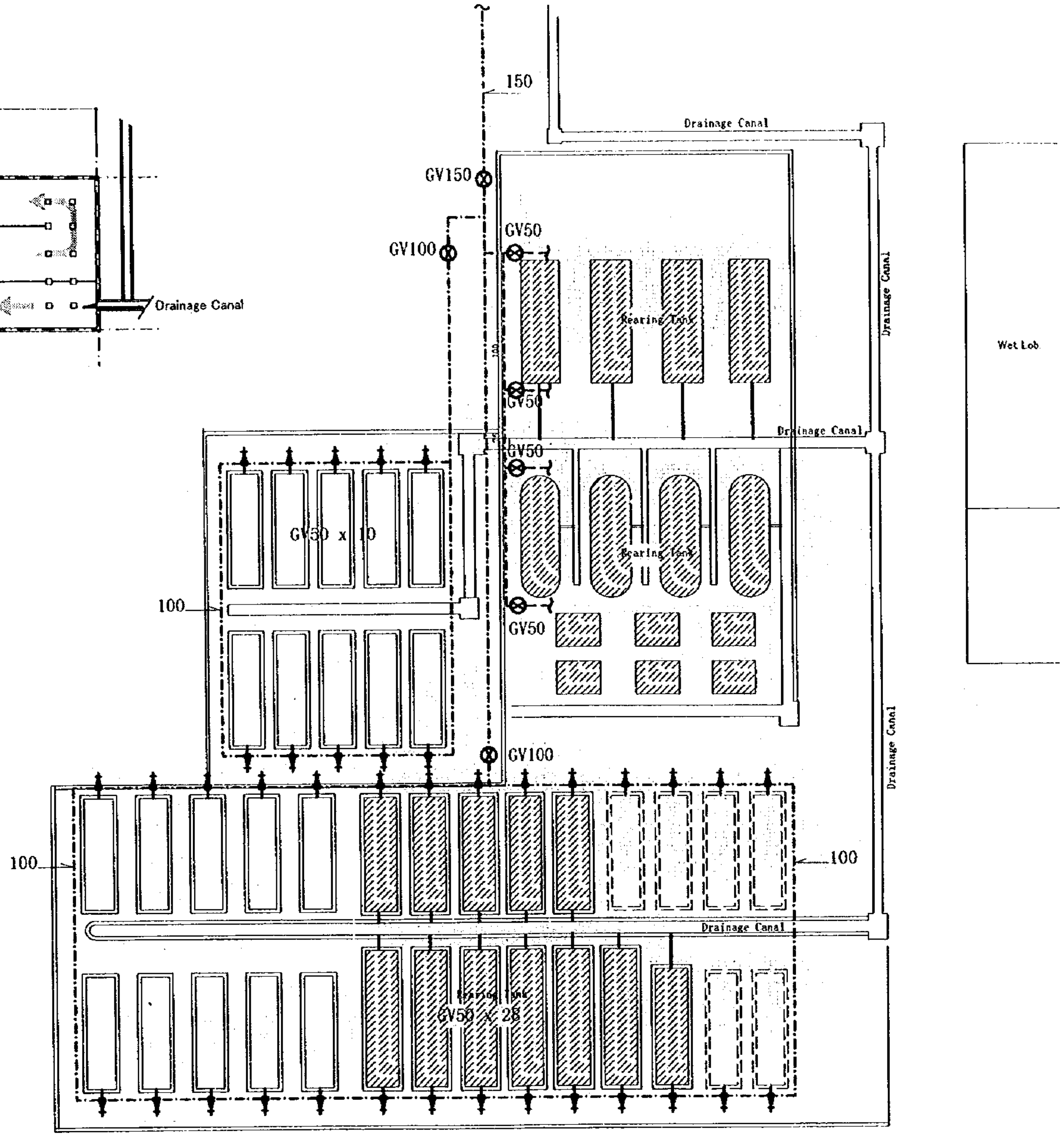
SETTLING POND PLAN



SETTLING POND SECTION

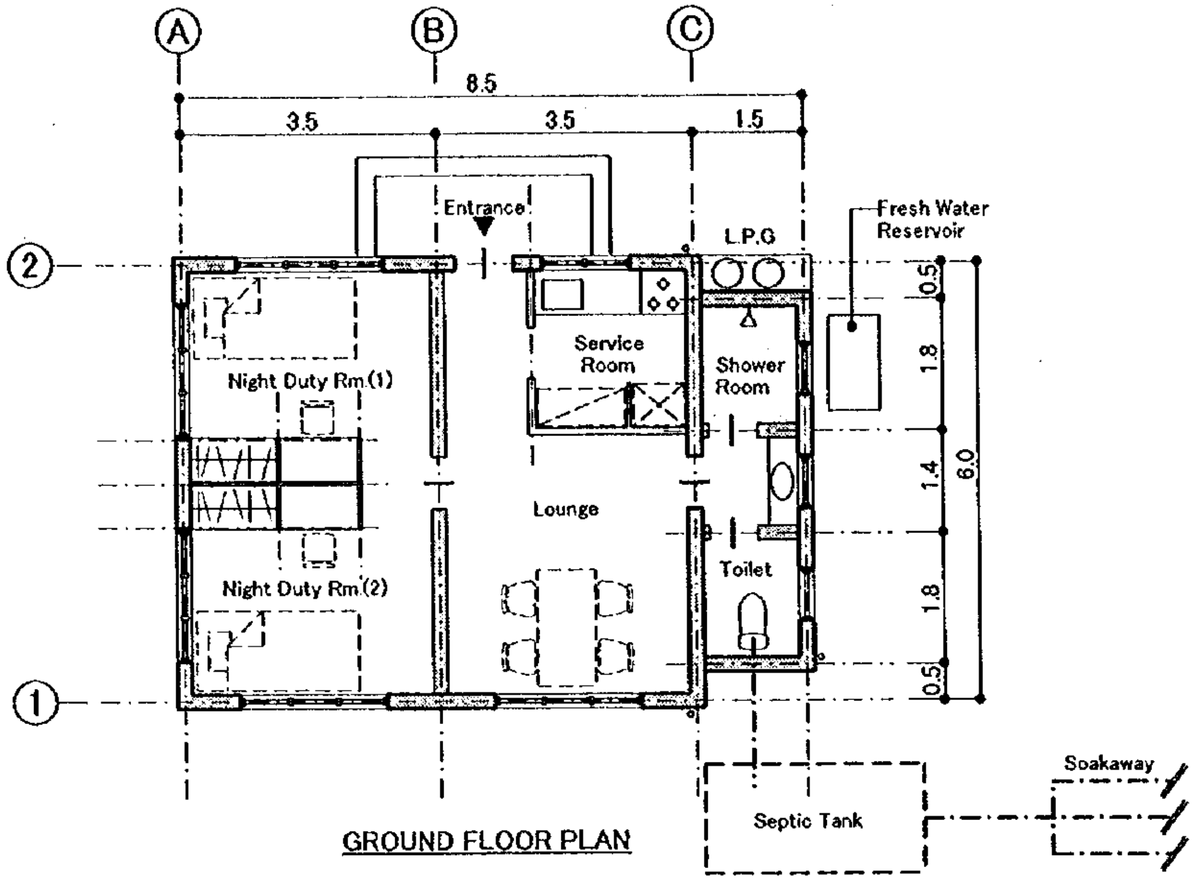


DRAINAGE CANAL SECTION

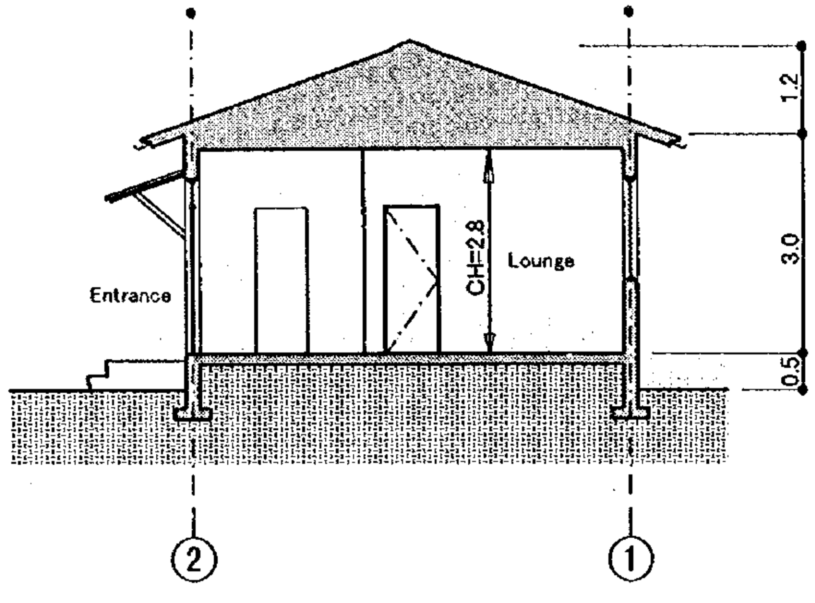


PLAN (S=1/200)

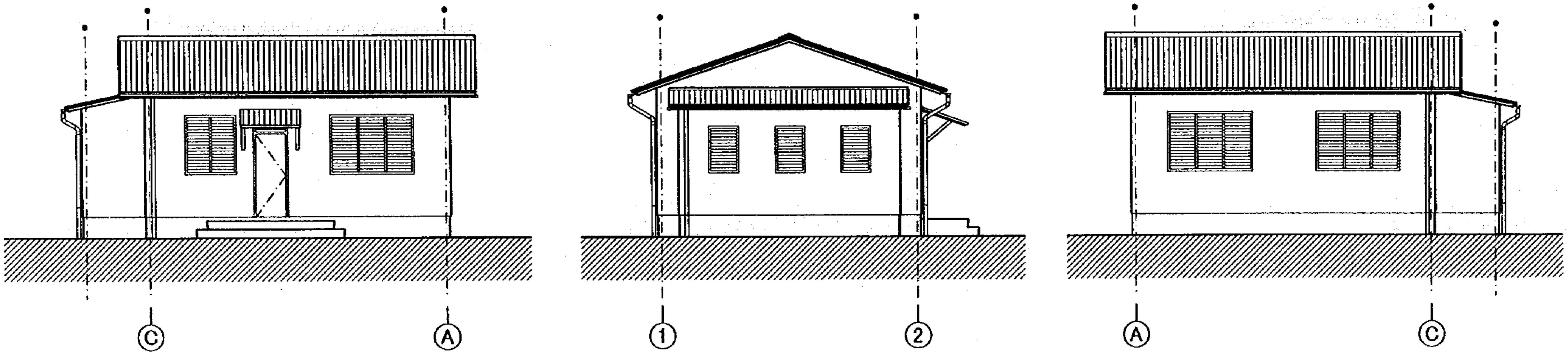
SEA WATER SUPPLY & DRAINAGE



GROUND FLOOR PLAN



SECTION



ELEVATION

NIGHT WORKER'S STATION (S=1/100)