CHAPTER 6 Numerical simulation

6.1 Study objectives

There are following environmental and social considerations that seem to be lacking in the feasibility study on Star wharf development.

- To understand present status of water circulation in Port Villa harbor
- Quantitative evaluation of impact on circulation by the project development
- Quantitative prediction of silt dispersion and deposition that affect coral reef ecosystem
- Impact on water exchange in a long term point of view

To meet above requirements, a hydrodynamics model to represent real characteristics of water circulation in Port Villa harbor is constructed based on water current data newly acquired in this field survey. Changes of water circulation and exchange between parts in Port Villa harbor are predicted using the hydrodynamics model. A silt diffusion and deposition model using the results of the hydrodynamics model is constructed to predict impact area of turbidity and deposition induced by activities in the construction phase of the project.

6.1.1 Procedures of numerical simulation

The procedures of numerical simulation are shown in Figure 6.1.1-1. In the preparation stage of this study in Japan, tentative numerical models are constructed so that validation of these models is performed soon after the acquisition of field data.

The simulation model consists of two parts. The first one is a hydrodynamics model that represents the flow field of Port Vila harbor and predicts the change of water flow by Star Wharf development, and the second one is advection-diffusion model that simulates distribution of suspended solids concentrations and their deposition.

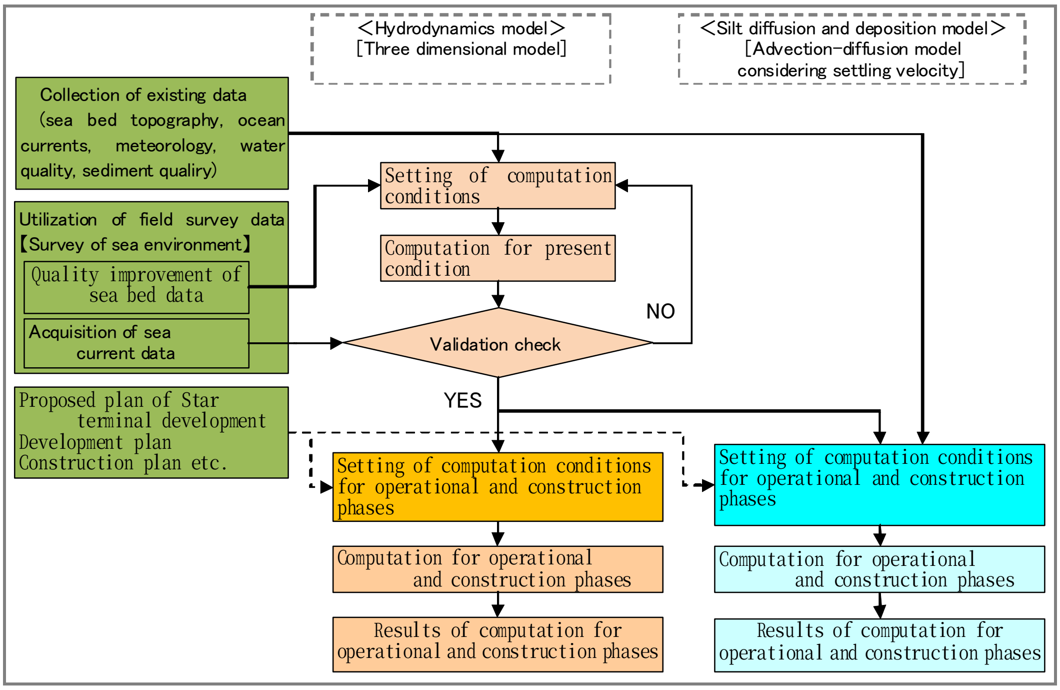


Figure 6.1.1-1 Procedures of Numerical Simulation

6.1.2 Selection of numerical models

(1) Hydrodynamics model

Fundamental equations of the hydrodynamics model are composed of momentum equations, continuity equations and conservation equations of water temperature and salinity. Requirements for the model used in this study are presented below.

- Three dimensional model(Multi-level model)

Since the topography of Port Vila harbor is complicated, it is substantially probable that sea currents in the surface layer are different with those in the bed layer. To model these situations, it is crucial to adopt the three dimensional model.

- Nested grid model

To accurately predict the impact of Star Wharf development, the nested grid model is adopted (See Figure 6.1.2-1). This model consists of multi-domains which have different grid sizes. Therefore, the model is able to represent the whole area of Port Vila harbor with a relatively rough grid length and cover near area of Star Wharf with a small grid length simultaneously.

(2) Silt Diffusion and deposition model

Advection-diffusion model taking settling velocity of sediment into account is selected. In the model, advection diffusion processes are taken into consideration as well as gravitational settling effects of silt particles. The settling velocities of silt particles are set through the Stokes formula based on information of particle sizes.

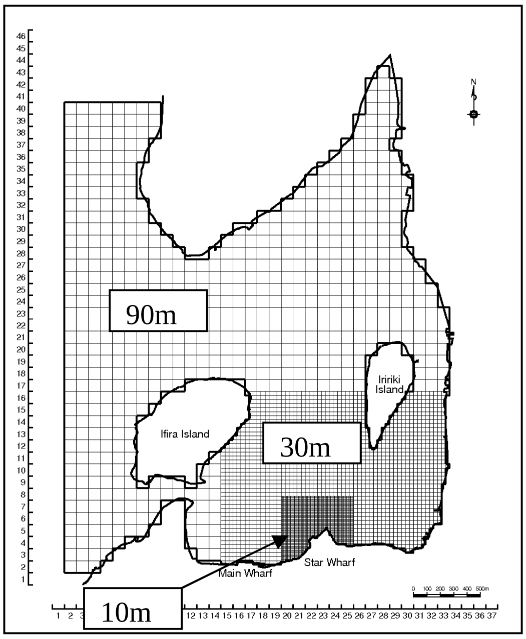


Figure 6.1.2-1 Computation grid of Port Villa harbor

6.1.3 Construction of models

(1) Hydrodynamics model

Tentative depth data for the simulation made on information of charts are improved based on the new depth data acquired in this field survey. Present case hydrodynamics simulations are conducted for the model validation using the improved depth data.

Validation of hydrodynamics model is performed through comparisons of the current ellipses and the mean currents between the simulation and the observations.

(2) Silt diffusion and deposition model

Estimation of turbidity generation induced by activities in the construction phase of the project is improved in its accuracy taking sediment analysis data obtained in this field survey into consideration. A silt diffusion and deposition model is constructed using the improved estimation of turbidity generation and the flow data produced by the validated hydrodynamics model.

(3) Analysis of simulation results

Simulation results are analyzed as follows.

(a) Change of magnitude and direction of current field

To understand impact on the flow field by the Star wharf development, magnitude differences of current velocity between the present and future cases are computed and velocity vectors of both cases are overwrapped to see change of flow direction

(b) Change of water exchange in Port Villa Harbor

Port Vila harbor can be divided into 4 parts of the bay mouth, Vatumaru bay, Paray bay and Pontoon bay. Changes of water exchange between these parts by the project development are computed and tabled.

(c) Spread of suspended solids

Results of silt diffusion and deposition model are plotted in daily average and maximum concentration distributions.

(d) Deposition thickness of silt

Deposition thickness of silt is computed and plotted based on the results of silt diffusion and deposition model.

6.2 Hydrodynamics

6.2.1 Model description

Fundamental equations of the hydrodynamics model are composed of momentum, continuity and conservation equations of water temperature and salinity. These equations are solved numerically by the finite difference method. The model is a multi-level model which is able to resolve vertical structure of velocity and salinity field. The basic concept of the model and definition locations of model variables (velocity components and water surface elevation) are presented in Figure 6.2.1-1. This model is able to take meteorological conditions (winds, solar radiation etc.) and tidal conditions as external forces and represent water current factors such as wind induced, density driven and tidally forced currents seen generally in coastal regions.

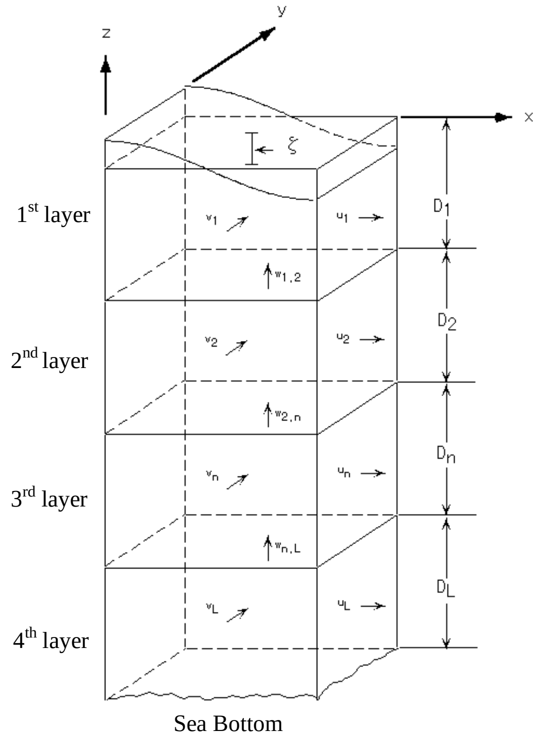


Figure 6.2.1-1 Basic concept of model and definition locations of model variables

Governing equations for hydrodynamics are as follows.

＜Continuity＞

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

＜Momentum＞

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\partial}{\partial z}\left(K_M\frac{\partial u}{\partial z}\right)+F_x$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\partial}{\partial z}\left(K_M\frac{\partial v}{\partial z}\right)+F_y$$

$$\rho g=-\frac{\partial p}{\partial z}$$

＜Conservation of Salinity＞

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{\partial}{\partial z}\left(K_H\frac{\partial T}{\partial z}\right)+F_T$$

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=\frac{\partial}{\partial z}\left(K_H\frac{\partial S}{\partial z}\right)+F_S$$

The last term in the right-hand side of the above equations, *F*, represent the mixing effects due to the short-term fluctuation of velocity components for momentum, heat, and salinity, and are given by

$$F_x=\frac{\partial}{\partial x}\left[A_M\frac{\partial u}{\partial x}\right]+\frac{\partial}{\partial y}\left[A_M\frac{\partial u}{\partial y}\right] \qquad F_y=\frac{\partial}{\partial y}\left[A_M\frac{\partial v}{\partial y}\right]+\frac{\partial}{\partial x}\left[A_M\frac{\partial v}{\partial x}\right]$$

$$F_{T,S}=\frac{\partial}{\partial x}\left[A_H\frac{\partial(T,S)}{\partial x}\right]+\frac{\partial}{\partial y}\left[A_H\frac{\partial(T,S)}{\partial y}\right]$$

in which

x, y, z : orthogonal coordinate system, *z*: positive upward

u, v, w : velocity components

p : pressure

S : salinity

f : Corioli's parameter

ρ_0 : reference density

ρ : local density

K_M, K_H : vertical eddy viscosity and diffusivity

A_M A_H : horizontal eddy viscosity and diffusivity

g : gravitational acceleration

t : time.

The surface boundary conditions are as follows.

$$\rho K_M \left(\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z} \right) = (\tau_{sx}, \tau_{sy}) \qquad \rho K_H \left(\frac{\partial T}{\partial z}, \frac{\partial S}{\partial z} \right) = (Q_{suf} / C_v, 0)$$

$$w = \frac{\partial \eta}{\partial t} + u \frac{\partial \eta}{\partial x} + v \frac{\partial \eta}{\partial y}$$

where,

Q_{suf} : heat flux at the sea surface

C_v : specific heat

w : vertical velocity

η : surface elevation,

Surface friction represents the effect of moving air dragging the water surface and is expressed in a manner proportional to the square of wind speed as shown below.

$$\vec{\tau}_s = (\tau_{sx}, \tau_{sy}) = \rho_a C_a \vec{\mathbf{W}} \left| \vec{\mathbf{W}} \right|$$
$$\vec{\mathbf{W}} = (W_x, W_y), \left| \vec{\mathbf{W}} \right| = \sqrt{W_x^2 + W_y^2}$$

C_a : wind drag coefficient

ρ_a : density of air

W_x, W_y : wind vector in X,Y-direction

τ_{sx}, τ_{sy} : wind stress in X,Y-direction.

Heat exchange between the atmosphere and the sea surface is expressed in the conservation equation of temperature. This heat flux is defined as: follows when heat flow to warm sea water is positive.

$$Q_{suf} = Q_s - (Q_b + Q_c + Q_e) \quad \text{(cal/cm}^2\text{/s)}$$

Q_S : shortwave radiation from the sun

Q_b : long-wave radiation from the ocean

Q_c : sensible heat transfer by conduction and convection

Q_e : latent heat transfer by evaporation of seawater

The bottom bpundary consitions are as follows.

$$\rho K_M \left(\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z} \right) = (\tau_{bx}, \tau_{by}) \qquad \rho K_H \left(\frac{\partial T}{\partial z}, \frac{\partial S}{\partial z} \right) = (0,0)$$

$$w_b = -u_b \frac{\partial h}{\partial x} - v_b \frac{\partial h}{\partial y}$$

$$\vec{\tau}_b = (\tau_{bx}, \tau_{by}) = \rho C_D \left| \vec{\mathbf{V}}_\mathbf{b} \right| \vec{\mathbf{V}}$$

$$\vec{\mathbf{V}}_\mathbf{b} = (u_b, v_b), \left| \vec{\mathbf{V}}_\mathbf{b} \right| = \sqrt{u_b^2 + v_b^2}$$

$\vec{\mathbf{V}}_\mathbf{b}$: horizontal velocity vector at the bottom

$\vec{\tau}_b$: bottom shear stress

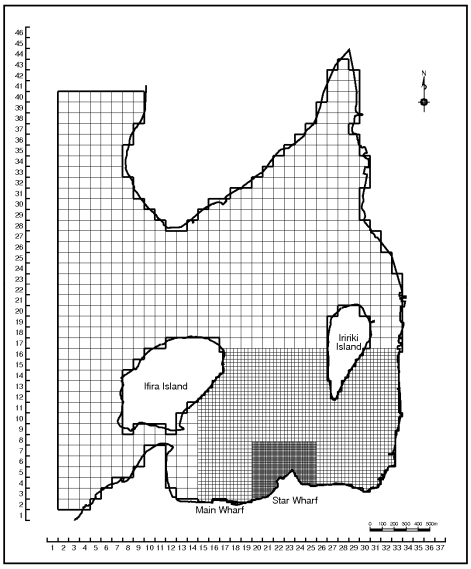
C_D : bottom friction coefficient

6.2.2 Computational conditions

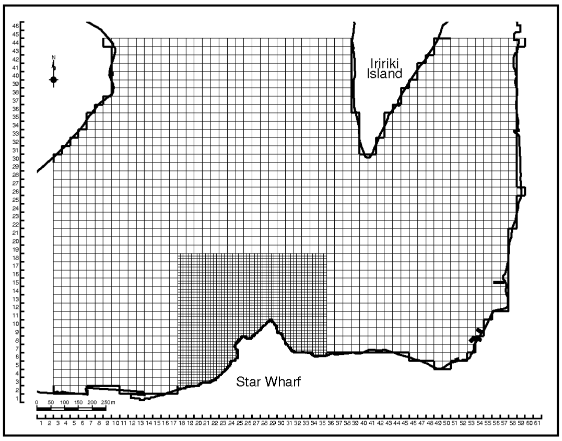
(1) Computational domains

To accurately predict the impact of Star Wharf development, the nested grid model is adopted (See Figure 6.2.2-1). This model consists of multi-domains which have different grid sizes. Therefore, the model is able to represent the whole area of Port Vila harbor with a relatively rough grid length and cover near area of Star Wharf with a small grid length simultaneously.

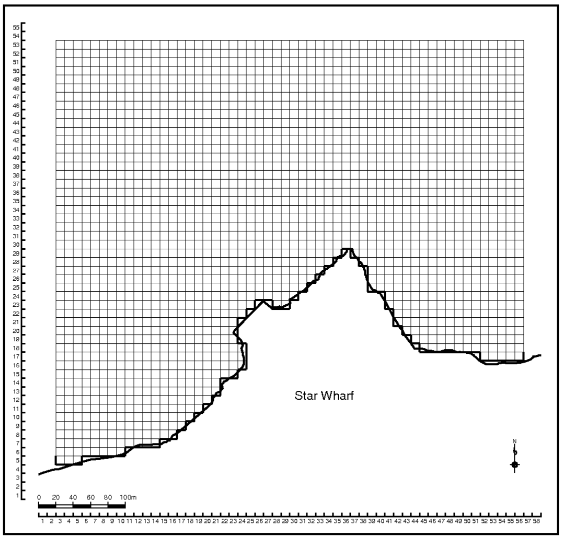
Whole area
(Grid length 90m,Present condition)



Intermediate area
(Grid length 30m,Present condition)



Detailed area
(Grid length 10m,Present condition)



Detailed area
(Grid length 10m,Future condition)

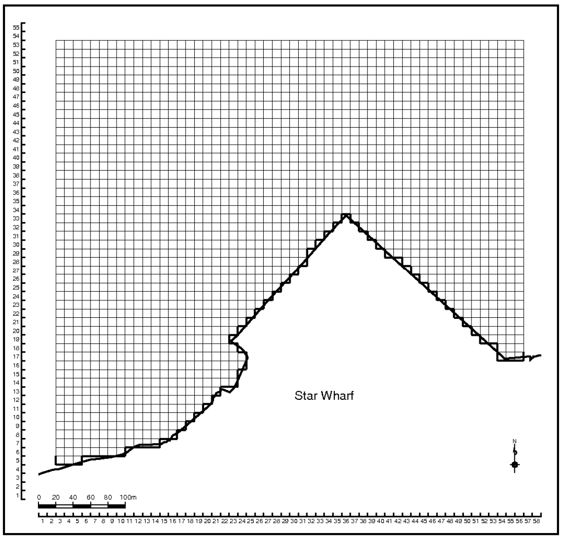


Figure 6.2.2-1 Computation area and grids

(2) Sea bed topography

Sea bed topography of the computation area is set base on the chart and measured data obtained in the field survey. The sea bed topography used in the simulation is presented in Figure 6.2.2-2.

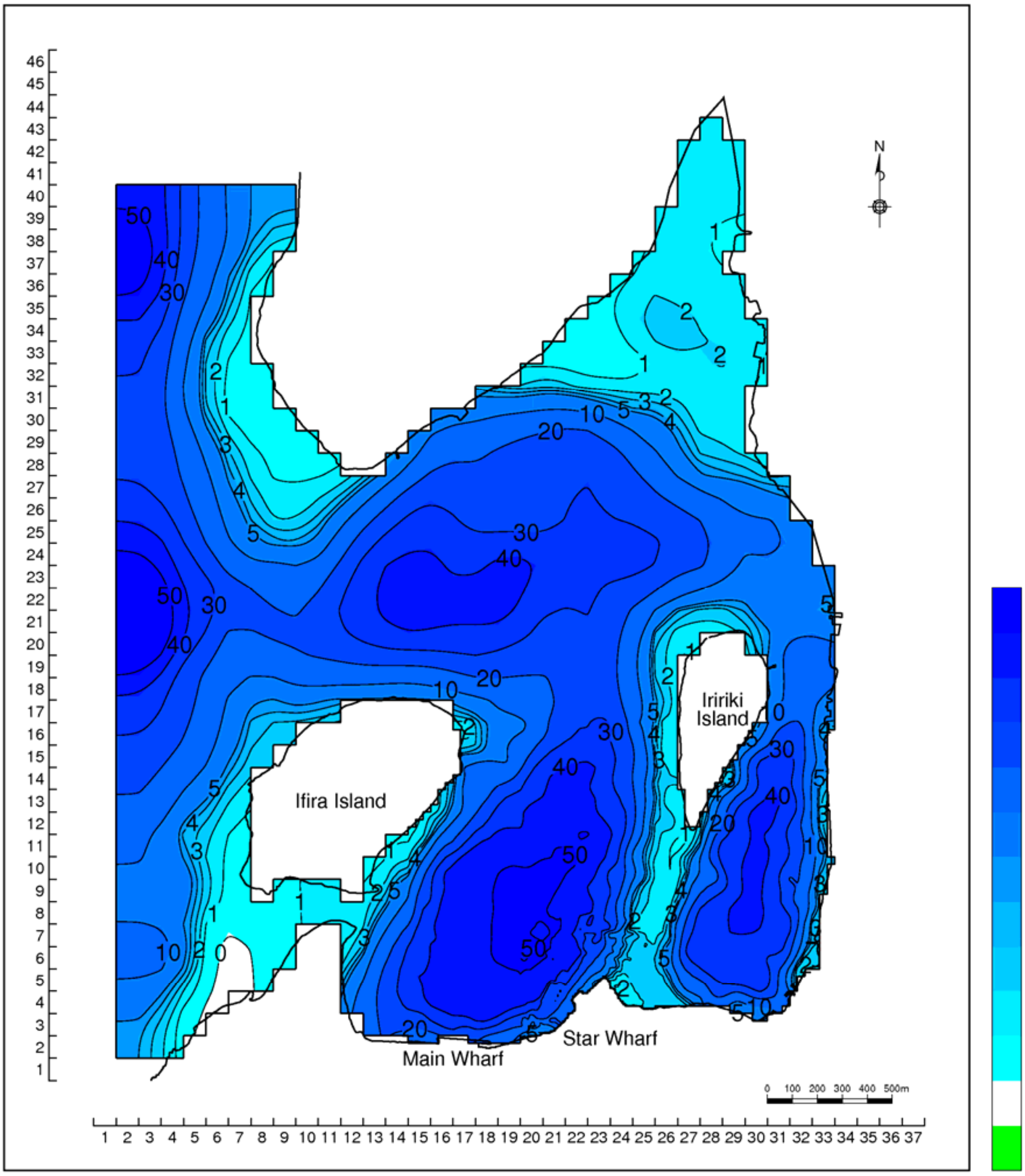


Figure 6.2.2-2(1) Sea bed topography (grid length 90m, present, datum : mean sea level)

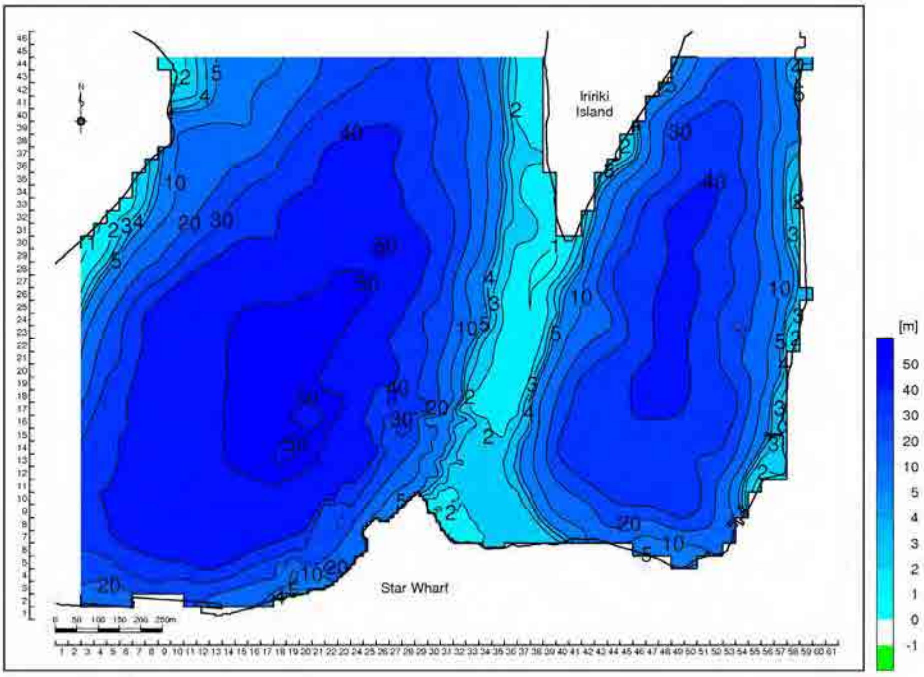


Figure 6.2.2-2(2) Sea bed topography (grid length 30m, present, datum : mean sea level)

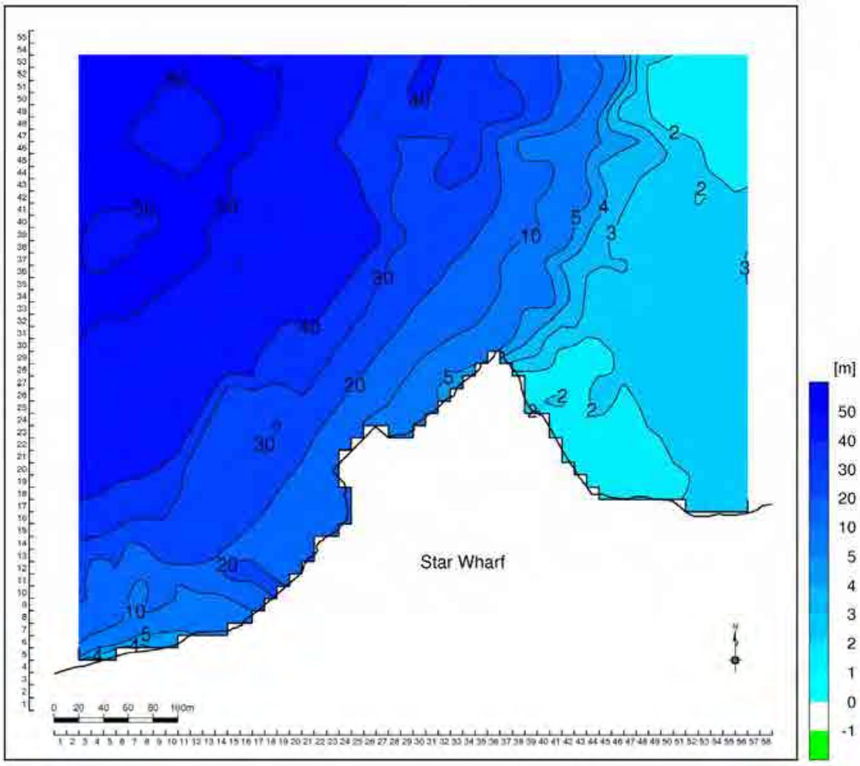


Figure 6.2.2-2(3) Sea bed topography (grid length 10m, present, datum : mean sea level)

(3) Vertical grid

Number of layers is set 4 levels. Layers shallower than 5 meters in which reefs exist are set relatively small in its thickness, namely the location of the first layer is 0-2m, the second layer 2-5m, the third layer 5-10m and the firth layer is 10m deeper. The vertical grid is summarized in Table 6.2.2-1.

Table 6.2.2-1 Vertical grid

Layer	Depth range
First	0-2m
Second	2-5m
Third	5-10m
Forth	10m deeper

(4) Boundary conditions

(a) Tides

Tide observation of Port Villa harbor has been conducted by the Australia meteorological agency. The harmonic constants of the main 4 tide constituents provided by the authority are listed in Table 6.2.2-2. This shows that M_2 constituent with a period of nearly 12 hours dominates in the tidal motion of Port Villa harbor.

Therefore, the boundary conditions of tides are set as shown in Table 6.2.2-3 for the boundary locations shown in Figure 6.2.2-3

Table 6.2.2-2 Harmonic constants of the main 4 tide constituents in Port Villa harbor

Constituent	Amplitude(cm)	Phase(degree)
K_1	16.29	205.5
O_1	8.36	171.7
M_2	36.51	164.1
S_2	10.84	183.1

Table 6.2.2-3 Tidal boundary conditions set at each location

Location	Amplitude(cm)	Phase(degree)
A	36.51	0.5
B	36.51	0.0
C	36.51	0.0

Tidal period is set just 12 hours to approximate the M_2 tide dominated in Port Villa harbor

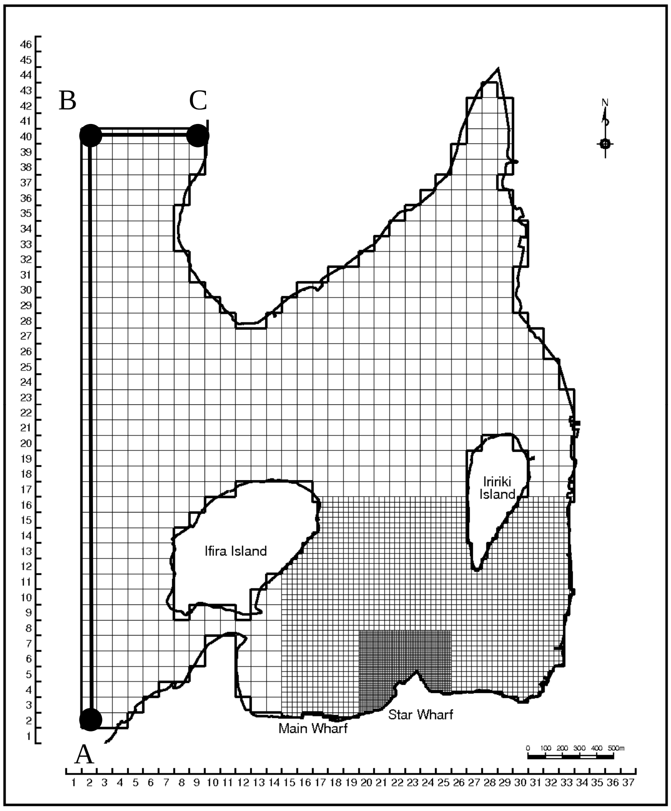


Figure 6.2.2-3 Locations where tidal boundary conditions are set

(b) Water temperature and salinity

Water temperature and salinity at the open boundaries are set as Table 6.2.2-4 based on the vertical profiles obtained at St.C1 in the field survey.

Table 6.2.2-4 Boundary conditions of water temperature and salinity

Layers	Water temperature(℃)	Salinity(PSU)
First(0-2m)	26.8	34.7
Second(2-5m)	26.7	34.8
Third(5-10m)	26.7	34.8
Forth(10m deeper)	26.6	34.9

※These are set based on the mean values of the vertical profiles obtained from three times of field survey.

(5) Initial conditions

Initial surface elevations are set as high tide and initial velocities are zero. Initial values of water temperature and salinity are same as Table 6.2.2-4.

(6) Computation period

Computation period (integration time) is 6 days (144 hours) and the results for the last 12 hours are used for the analysis.

(7) Meteorological Conditions

The meteorology in Port Villa harbor has been observed by Vanuatu and Australia meteorological agencies. Based on the data collected from these authorities, necessary meteorological conditions for the hydrodynamics simulation such as winds, air temperature, humidity, cloudiness and solar radiation are set.

Wind data are collected every hour for a period of 2008-2010 from Australia meteorological agency. Wind roses for the same periods are shown in Figure 6.2.2-4. This shows that wind directions from north-east prevail throughout years. Therefore wind direction used in the simulation is set from north-east. The magnitude of wind velocity is set as the mean value in October in the three years.

The meteorological data collected from Vanuatu meteorological agency are air temperature, relative humidity and cloudiness as shown in Table 6.2.2-6.

The conditions used in the simulation are set as the mean values in October of 2008-2010. Solar radiation data required for the simulation are calculated as follows.

Solar radiation under the clear sky in Port Villa harbor is calculated to be 30.8 (MJ/m^2/day) under the condition that latitude of Port Villa is -17.75 ° and the day is 15th October based on the following formula.

$$H_{MX} = 30.0 E_0 \left[\omega T_{SR} \sin\delta \sin\phi + \cos\delta \cos\phi \sin(\omega T_{SR})\right]$$

$$E_0 = \left(r_0 / r\right)^2 = 1 + 0.033\cos\left[2\pi d_n / 365\right]$$

$$\delta = \sin^{-1}\left\{0.4\sin\left[\frac{2\pi}{365}(d_n - 82)\right]\right\}$$

E_0 : Eccentricity correction factor of the Earth's orbit

ϕ : Latitude of relevant point

r_0 : Mean distance between the Sun and Earth

r : Distance between the Sun and Earth in the present season

d_n : Julian day that takes values of 1-365

ω : Angular velocity of Earth rotation(15 deg/ *hour*)

T_{SR} : Sun rise time in terms of local time. For example, T_{SR} =6 on Spring Equinox Day

δ : Solar declination angle

Solar radiation on a cloudy day is calculated based on the following formula.

$$S_d = H_{MX} \times y$$

$$y = 1.70\log_{10}(1.22 - 1.02x) + 0.521x + 0.846$$

$$x = n - \alpha \exp(-3n_L)$$

where, n is cloudiness with 0-1, α 0.4, n_L is mean cloudiness in low altitude. Based onTable 6.2.1-6(2), n=0.5, and n_L is also set 0.5, because its value is unclear, so that y=0.9 and S_d=27.7(MJ/m^2/day) is obtained.

Meteorological conditions used in the simulation are summarized in Table 6.2.2-5.

Table 6.2.2-5 Meteorological conditions

Parameters		Values
Wind	Direction	From north-east
	Velocity	2.6(m/s)
Air temperature		25.1(℃)
Relative humidity		82.3(%)
Cloudiness		5.7
Solar radiation		27.7(MJ/m^2/day)

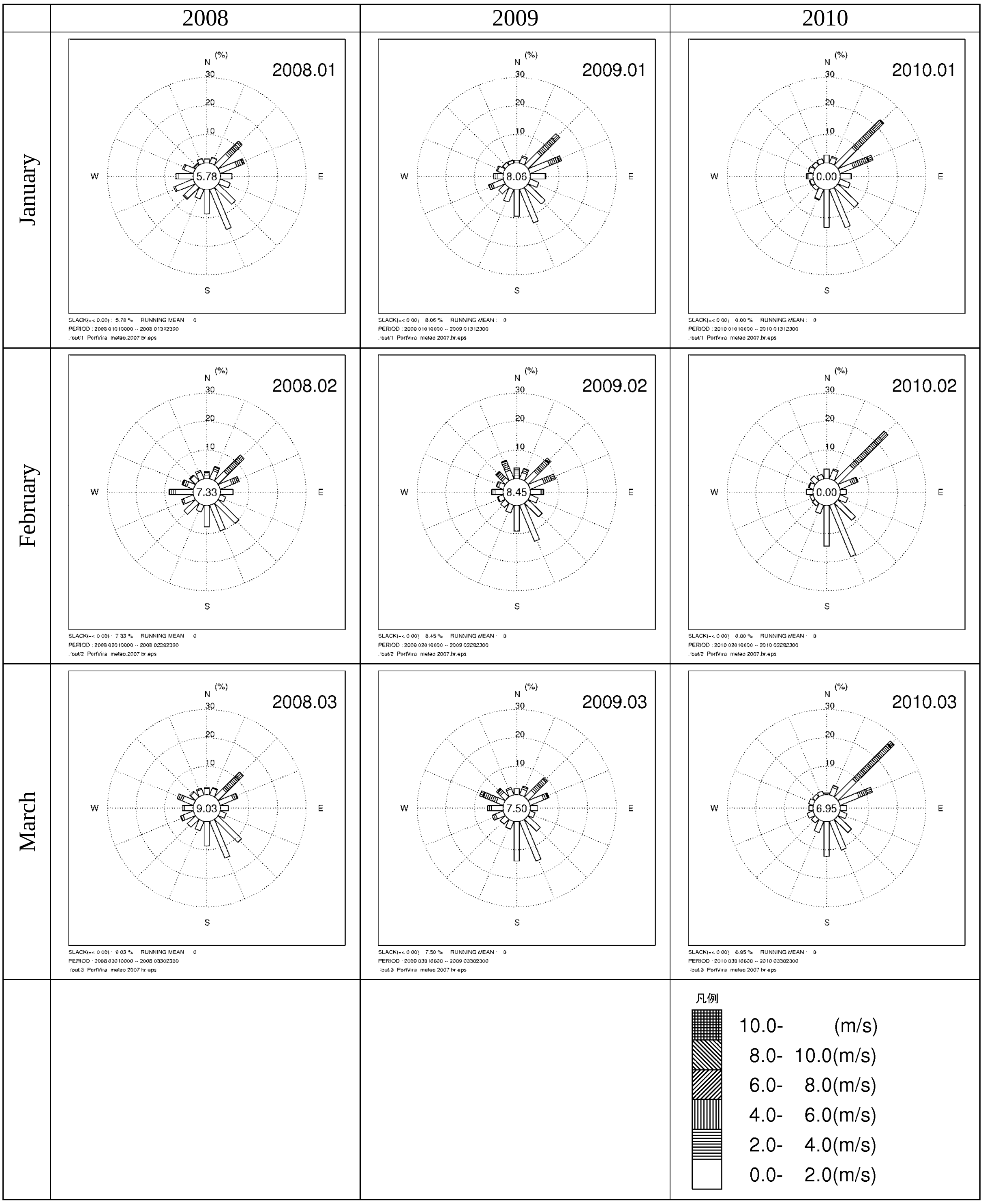


Figure 6.2.2-4(1) Wind rose (Port Villa, January-March)

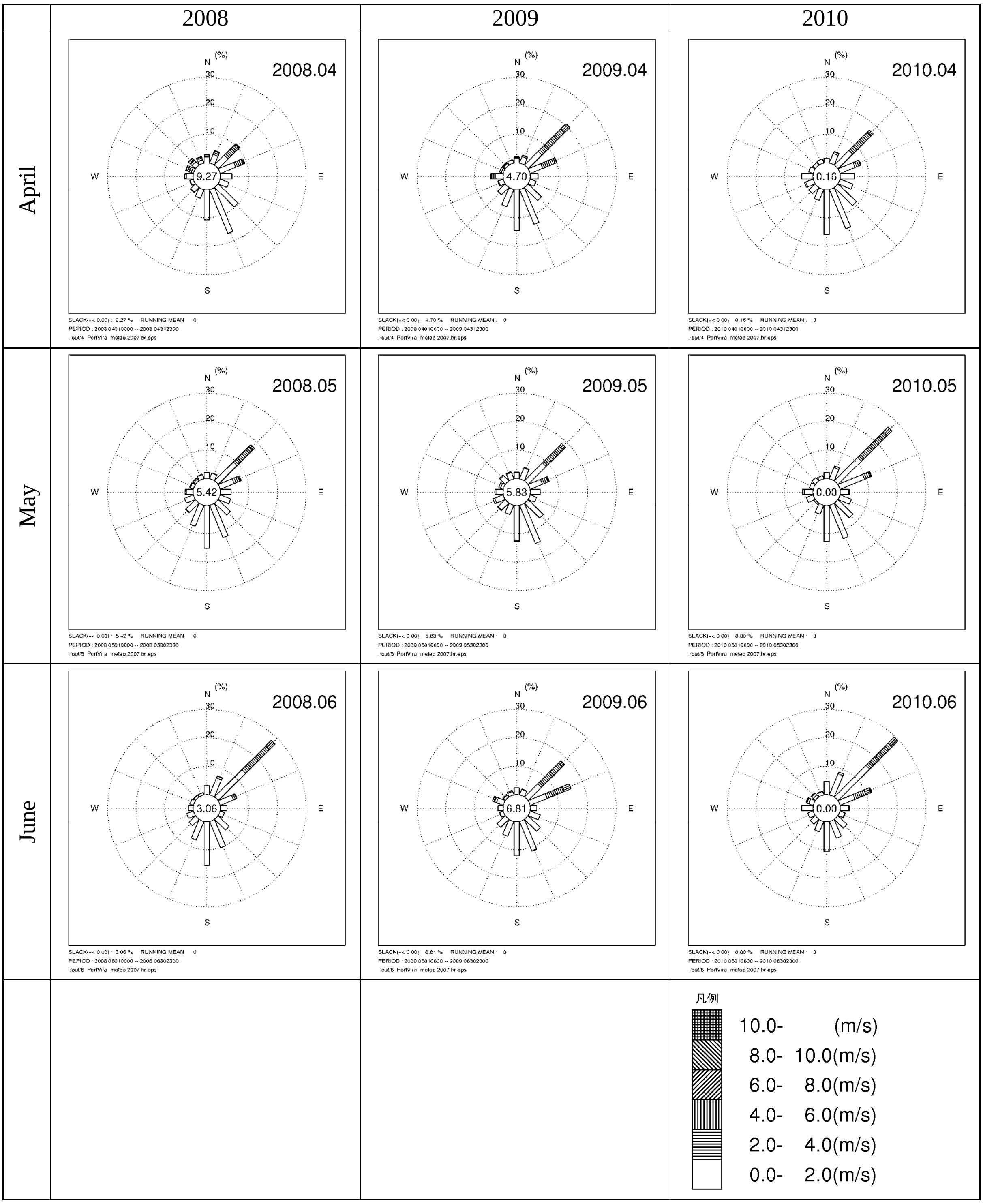


Figure 6.2.2-4(2) Wind rose (Port Villa, April-June)

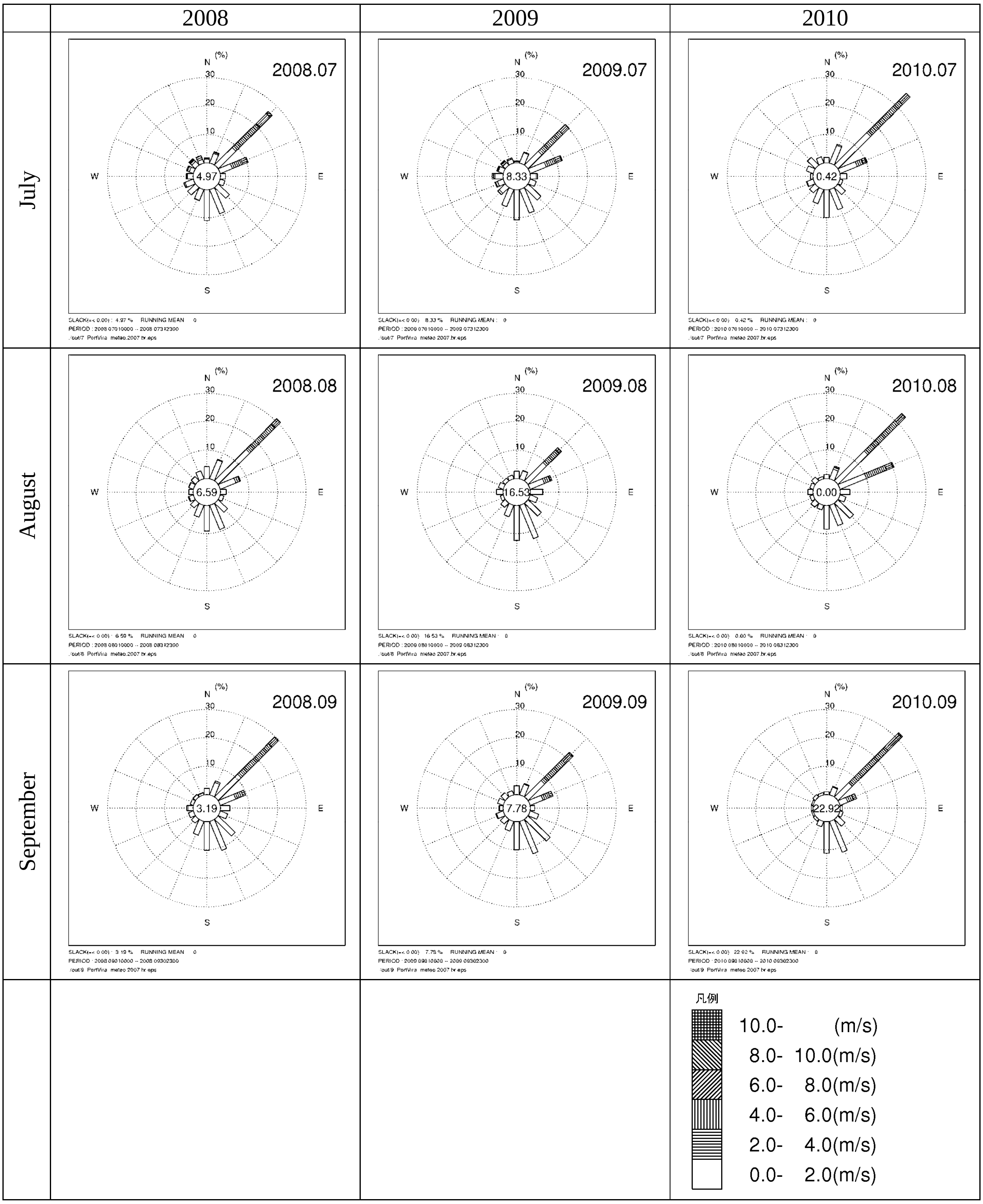


Figure 6.2.2-4(3) Wind rose (Port Villa, July-September)

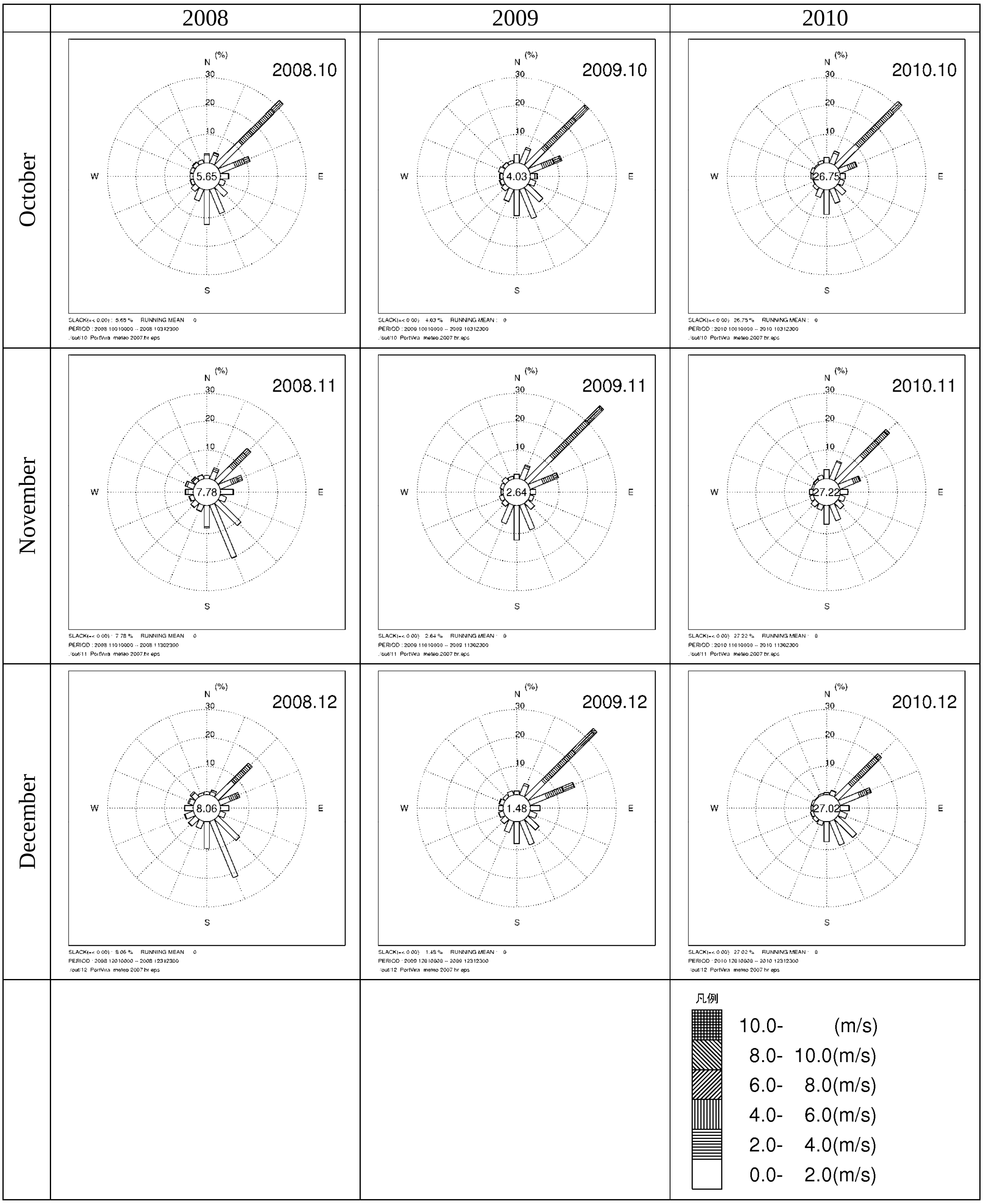


Figure 6.2.2-4(4) Wind rose (Port Villa, October-December)

Table 6.2.2-6(1) Meteorological data (Air temperature, degree-C)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2008	26.6	26.2	25.5	24.2	23.9	23.3	22.6	23.3	25.9	26.2	27.0	26.6
2009	26.9	27.2	27.0	25.9	23.5	23.4	23.0	21.7	22.9	23.9	25.0	23.5
2010	26.9	26.8	26.6	24.7	25.1	25.2	22.9	23.8	24.8	25.1	23.6	26.3

Table 6.2.2-6(2) Meteorological data (Cloudiness, 0-10)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2008	5	5	6	6	5	6	6	6	5	6	4	5
2009	4	6	6	5	5	5	5	5	4	5	6	6
2010	6	5	6	5	6	7	5	5	4	6	5	5

Table 6.2.2-6(3) Meteorological data (Relative humidity, %)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2008	86	86	87	88	84	—	83	86	83	85	85	84
2009	86	86	87	87	83	86	83	84	82	79	81	81
2010	83	83	87	87	89	88	82	87	82	83	84	86

(8) Computational Parameters

Computation parameters etc. other than stated so far are listed in Table 6.2.2-7.

Table 6.2.2-7(1) Parameters used in the hydrodynamics simulation

Parameters	Values set etc.
Time step	$\Delta t < \dfrac{\Delta s}{\sqrt{2 \cdot g \cdot h_{\max}}}$ Δs : Grid length(m) g : Gravitational acceleration(m/s^2) h_{max} : Maximum depth in the computation area(m) Computation stability is evaluated under the above condition. Based on the above formula, time steps are 0.9 sec for the whole domain, 0.3 sec for the intermediate domain, and 0.1 sec for the detailed domain.
Friction coefficient at sea surface	Wind stress transfers momentum from air motion (wind) to sea surface. The wind stress is proportional to wind velocity squared as follows $\tau_a = C_a \cdot \rho_a \cdot W^2$ τ_a : Wind stress(N/m^2)　ρ_a : Air density (Kg/m^3) C_a : Friction coefficient (=0.0013)　W : Wind velocity(m/s)
Friction coefficient at sea bed	Friction coefficient at sea bed is calculated by the following formula under the assumption that the logarithmic boundary layer near the sea bottom is formed. $C_D = \left[\dfrac{1}{\kappa} \ln \dfrac{h + z_b}{z_0} \right]^{-2}$ h : Water depth z_b : Vertical coordinate of the lowest velocity defined grid measured downward negative from the sea surface z_0 : roughness length(＝1.0cm) κ : Karman constant(＝0.4)

Table 6.2.2-7(2) Parameters used in the hydrodynamics simulation

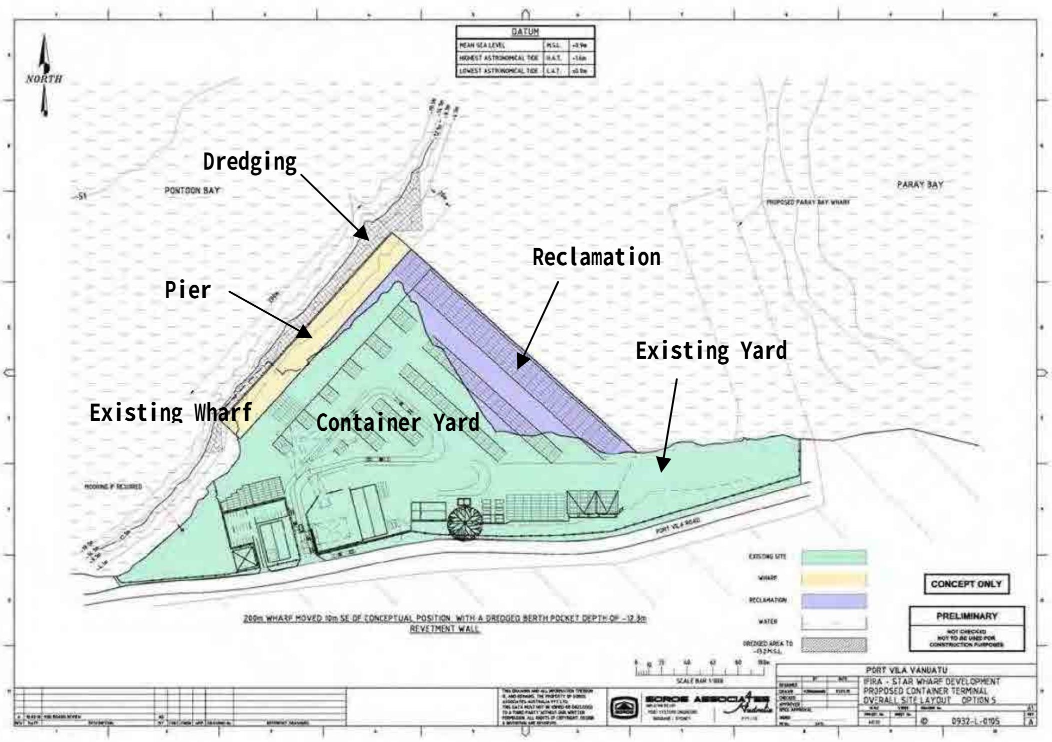
Parameters	Values set etc.
Horizontal eddy viscosity (A_M) Horizontal eddy diffusivity (A_H)	The following empirical formula by Smagorinsky(1963)[1] is used. Where a constant $C_{M,H}$ is 0.1 and back ground value $A_{MB,HB}$ is 10^4 cm²/s. $A_{M,H} = C_{M,H}(\Delta x \times \Delta y)\left[\frac{1}{2}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2\right]^{1/2}+A_{MB,HB}$
Vertical eddy viscosity (K_M) Vertical eddy diffusivity (K_H)	Stability functions by Pacanowski and Philander(1981)[2] are used. A minimum value of 1.0(cm²/s) and a maximum value of 50.0(cm²/s) are set. $K_M = \frac{K_{M0}}{(1+\alpha R_i)^n} + K_{MB}$ $K_H = \frac{K_M}{(1+\alpha R_i)^n} + K_{HB}$ $R_i = \frac{-\frac{g}{\rho}\left(\frac{\partial \rho}{\partial z}\right)}{\left(\frac{\partial U}{\partial z}\right)^2}$ K_{MB} : Back ground vertical eddy viscosity (=1.0 cm²/s) K_{HB} : Back ground vertical eddy diffusivity (=1.0 cm²/s) K_{M0} : A parameter(=50.0 cm²/s) α : A parameter(α=5) n : A parameter(n=2) z : Vertical coordinate from a reference U : Horizontal velocity(cm/s)
Coriolis parameter	Coriolis term represents a apparent force acting objects in motion which arises from the Earth rotation and the coriolis parameter is formulated by the following formula. $f=2\omega\sin\phi$. ω : Angular velocity of the Earth rotation ϕ : Latitude of the relevant area(=-17.75 °)

[1] J.Smagorinsky(1963) : General Circulation Experiments with the Primitive Equations Ⅰ. The Basic Experiment, Monthly Weather Review, 91, 99-164.

[2] R. C. Pacanowski and S. G. H. Philander(1981):Parameterization of Vertical Mixing in Numerical Models of Tropical Oceans. J. Phys. Oceanogr.,11,1443-1451.

(9) Conditions for future prediction

Future conditions of topography after Star Wharf development are shown in Figure 6.2.2-5. The details in the development are reclamation (0.33ha) and dredging (0.94ha, 12.3m depth) in front of Star Wharf. Figure 6.2.2-6 shows a comparison of present and future grids and sea bed topographies.



Source：Star Terminal Construction Project, Bankable Feasibility Study, Final Report (2010)

Figure 6.2.2-5 Plan view of Star Wharf development

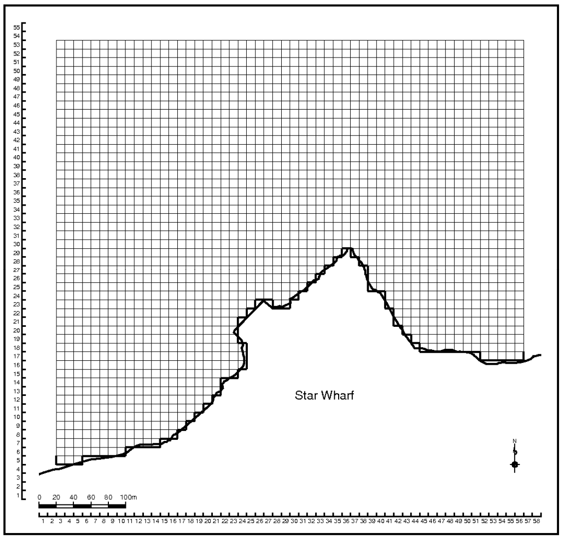
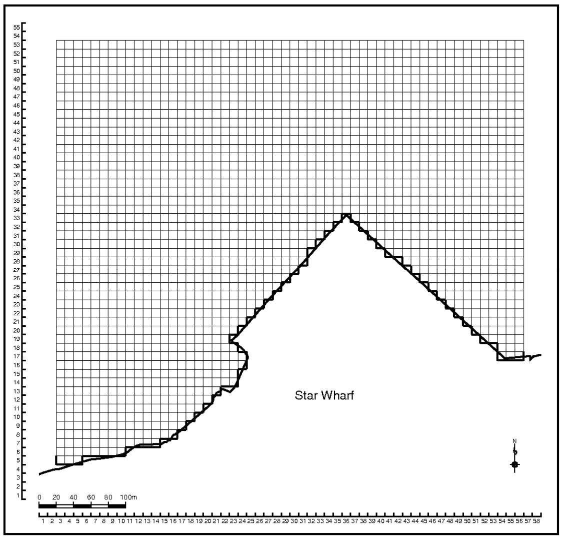
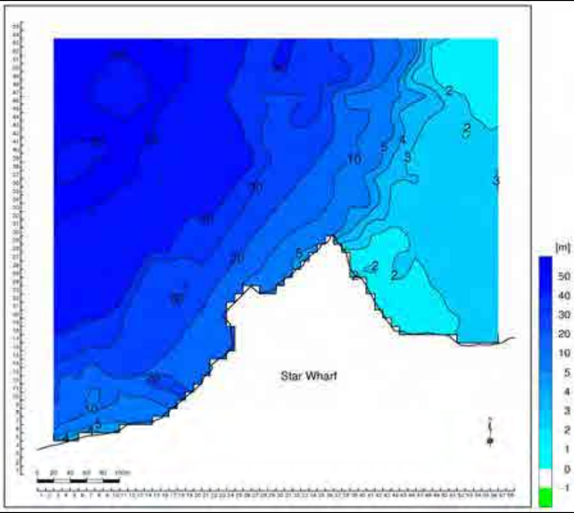
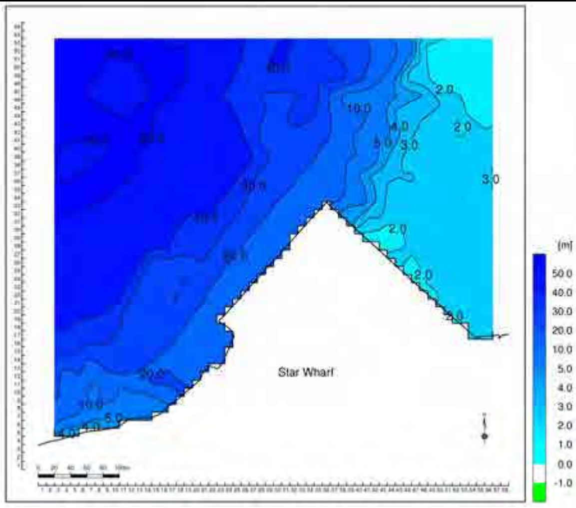
Present grid	Future grid
	
Present sea bed	Future sea bed
	

Figure 6.2.2-6 Comparison between present and future grid and sea bed

6.2.3 Validation of hydrodynamics model

Validation of hydrodynamics model is performed through comparisons between the simulation results and the current observations

The current survey is conducted at two points shown in Figure 6.2.3-1. St.C1 is located at the bay mouth and the observation layers are two, the upper layer is 3.1m deep below the surface and the lower layer is 1.8m above the sea bed. St.C2 is located near Star wharf and the observation layer is 0.3m above the sea bed. One day current surveys are performed three times of spring, neap and intermediate tides.

One day harmonic analysis is adopted for these observations to obtain current ellipses and mean currents. Validation of hydrodynamics model is performed through comparisons of the current ellipses and the mean currents between the simulation and the observations.

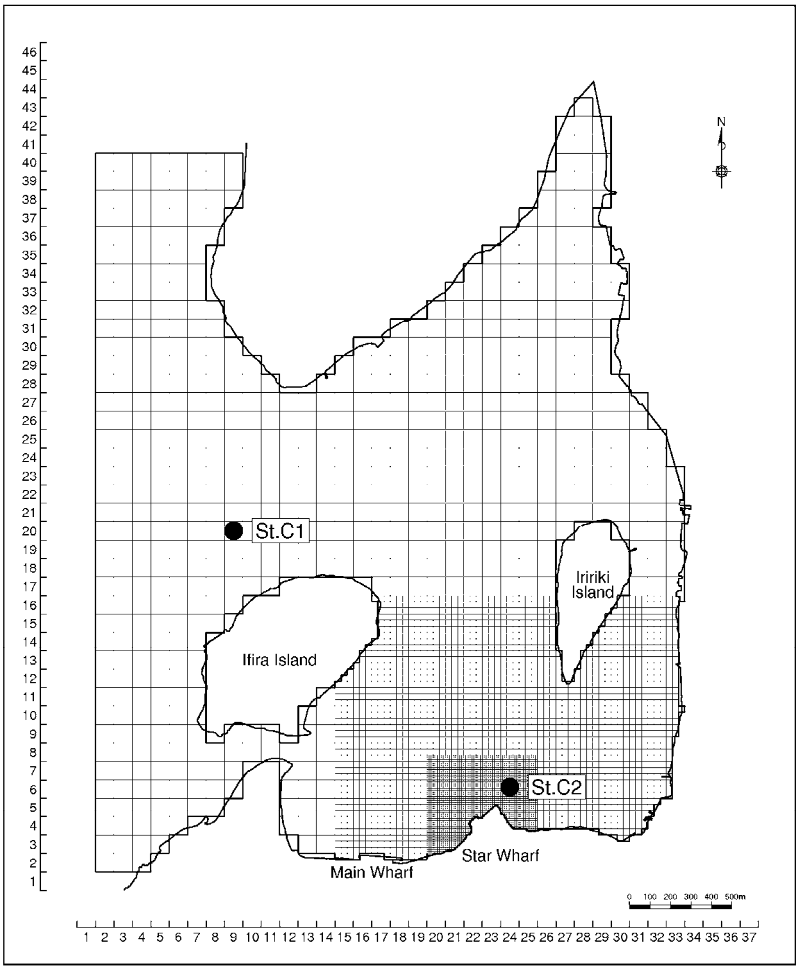


Figure 6.2.3-1 Current survey points

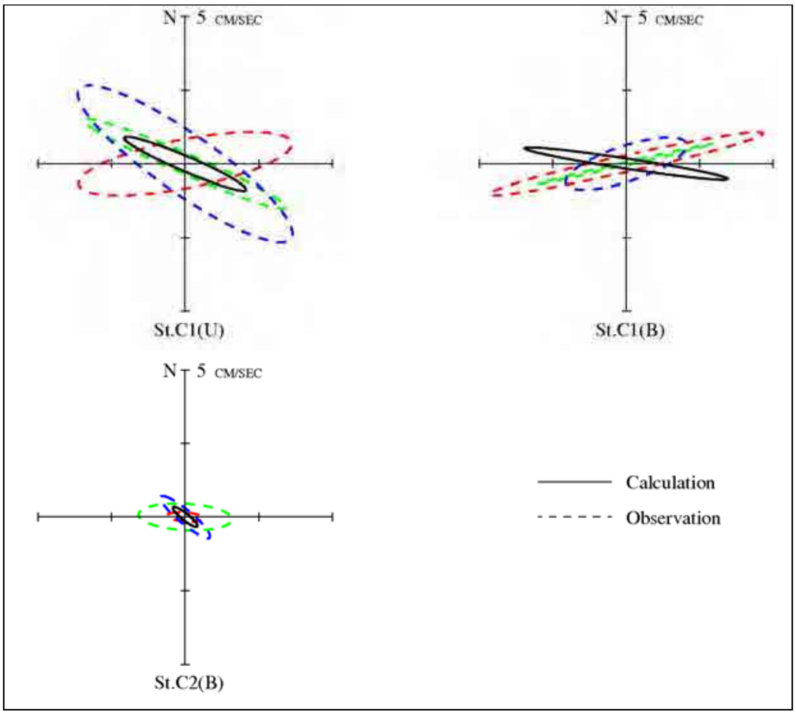
(1) Comparison of current ellipse

Comparison of current ellipse between simulation and observation is shown in Figure 6.2.3-2.

Long axes of semi-diurnal current ellipses of three times observations in St.C1 are almost directed east-west despite some fluctuations and the magnitudes of long axes are smaller than 5cm/s. On the other hand, magnitudes of current ellipses in St.C2 are considerably smaller than St.C1 and direction of long axes also is of east-west dominance.

Forced tide at open boundaries in the simulation is the principal lunar constituent (M_2) which has a tidal period of 12.42 hours. Strictly speaking, therefore, current ellipse by the simulation should be compared with semi-diurnal current ellipse of intermediate tide, not spring or neap tide. Comparing the current ellipses of the simulation and the observation, the magnitudes and directions of simulation almost resemble those of observation in spite of some difference in magnitude in the upper layer. In St.C2, both the current ellipses of the simulation and observation are small in velocity.

Based on above considerations, it is evaluated that the hydrodynamics model is validated through the comparison of current ellipses.



Red：2011/10/27/00:00-10/28/00:00 (Spring tide)
Blue：2011/11/01/00:00-11/02/00:00 (Neap tide)
Green：2011/11/06/06:00-11/07/06:00 (Intermediate)

(U)：Upper
(B)：Lower

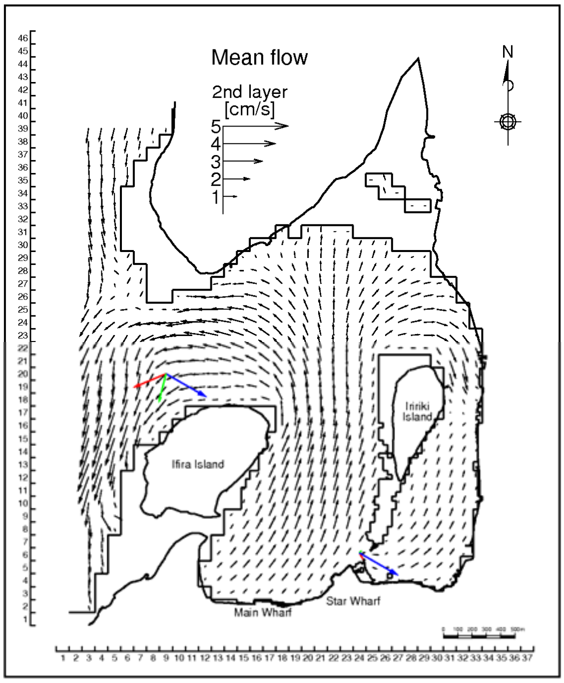
Figure 6.2.3-2 Comparison of current ellipse between simulation and observation

(2) Comparison of mean currents

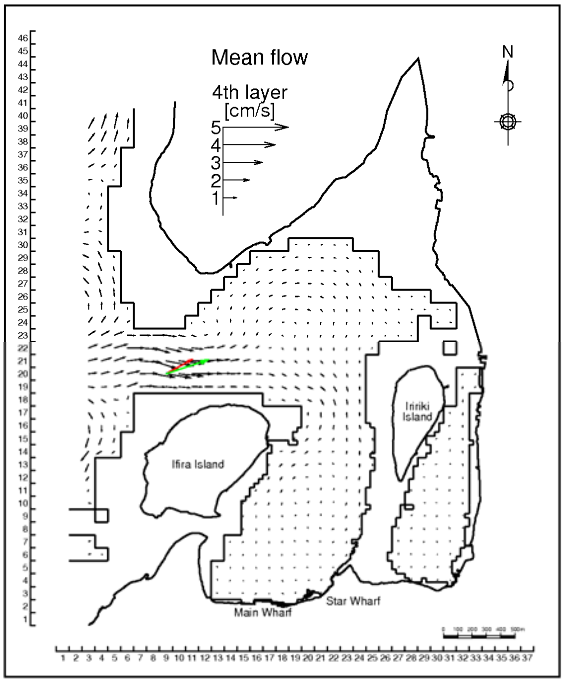
Comparison of mean current between simulation and observation is shown in Figure 6.2.3-3.

In the mean currents of three times, flow direction of St.C1 located at the bay mouth is outflow in the upper layer and inflow in the lower layer except the results in the intermediate tide of 2011/11/05 to 07. In St.C2, on the other hand, velocities are very small except the data of intermediate tide and flows direct almost eastward throughout three times observations. The mean flow on 2011/11/05 to 07 shows a different tendency due to an atmospheric disturbance with the other two observations. It is evaluated that simulation mean flow shown in Figure 6.2.3-3 represents tendencies of the observation described above.

Second layer (2-5m)



Forth layer (10m deeper)



Red arrow：2011/10/27/00:00-10/28/00:00 (Spring tide)
Blue arrow：2011/11/01/00:00-11/02/00:00 (Neap tide)
Green arrow：2011/11/06/06:00-11/07/06:00 (Intermediate tide)

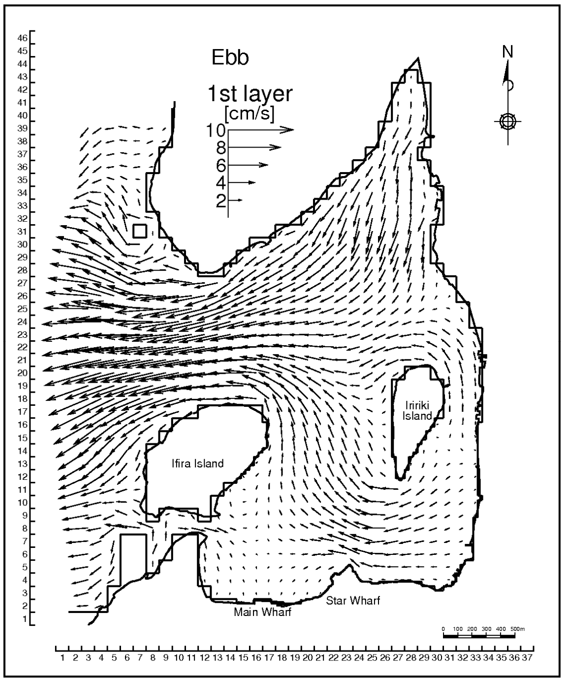
Figure 6.2.3-3 Comparison of mean currents between simulation and observation

(3) Summary of validation

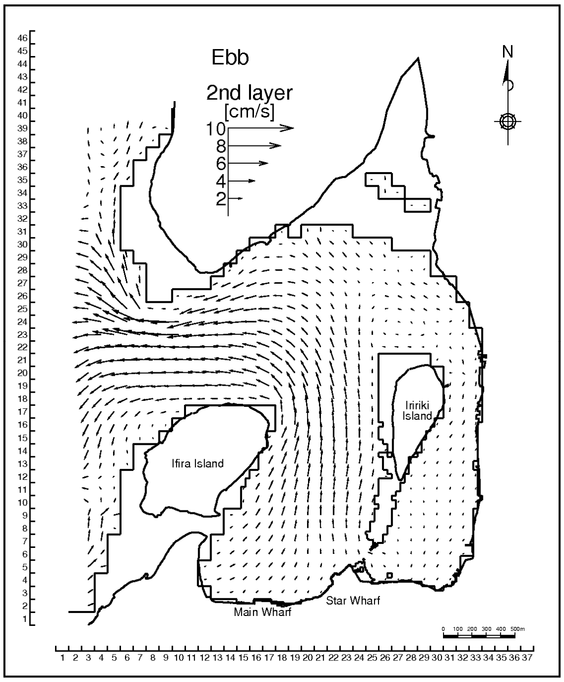
Validation of hydrodynamics model is performed through comparisons of the current ellipses and the mean currents between the simulation and the observations. Through the comparisons of current ellipses and mean currents, it is evaluated that the hydrodynamics model represents real characteristics of water circulation in Port Villa harbor. Therefore, it is considered that this model can be utilized to predict change of water flow by the project development and the simulated flows by the model can be used as flow conditions of the diffusion and deposition model of silt.

Figure 6.2.3-4 presents simulated current vector fields in ebb, low, flood, high tides and mean flow.

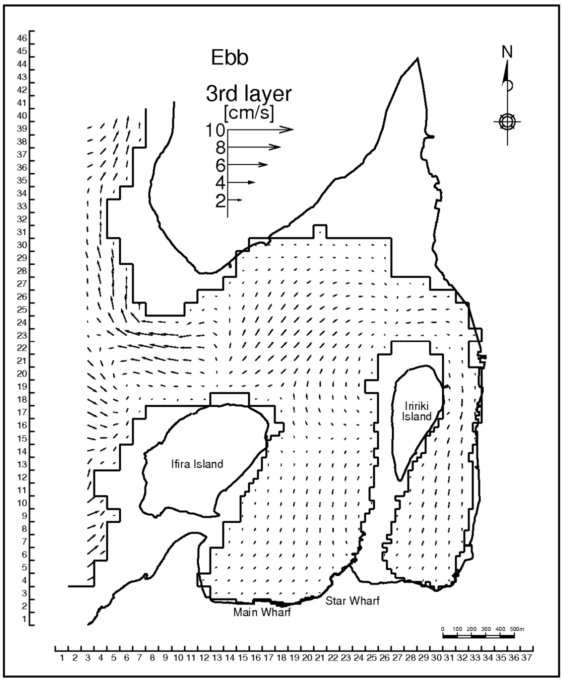
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

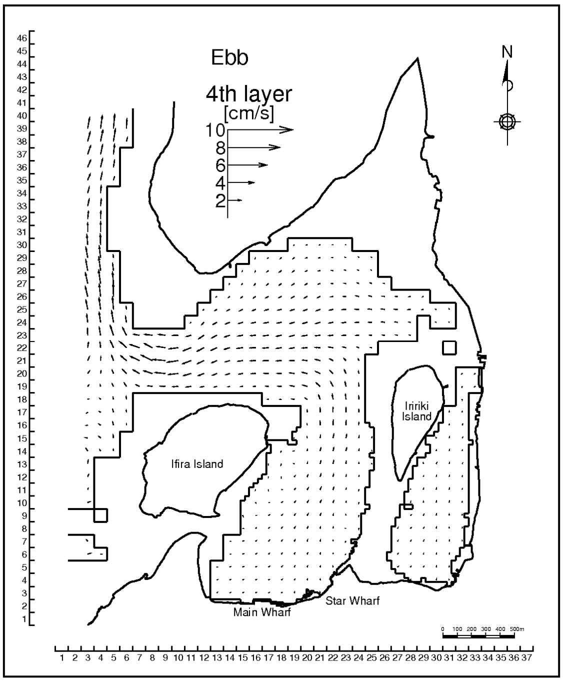


Figure 6.2.3-4(1) Simulated current field (present, ebb tide)

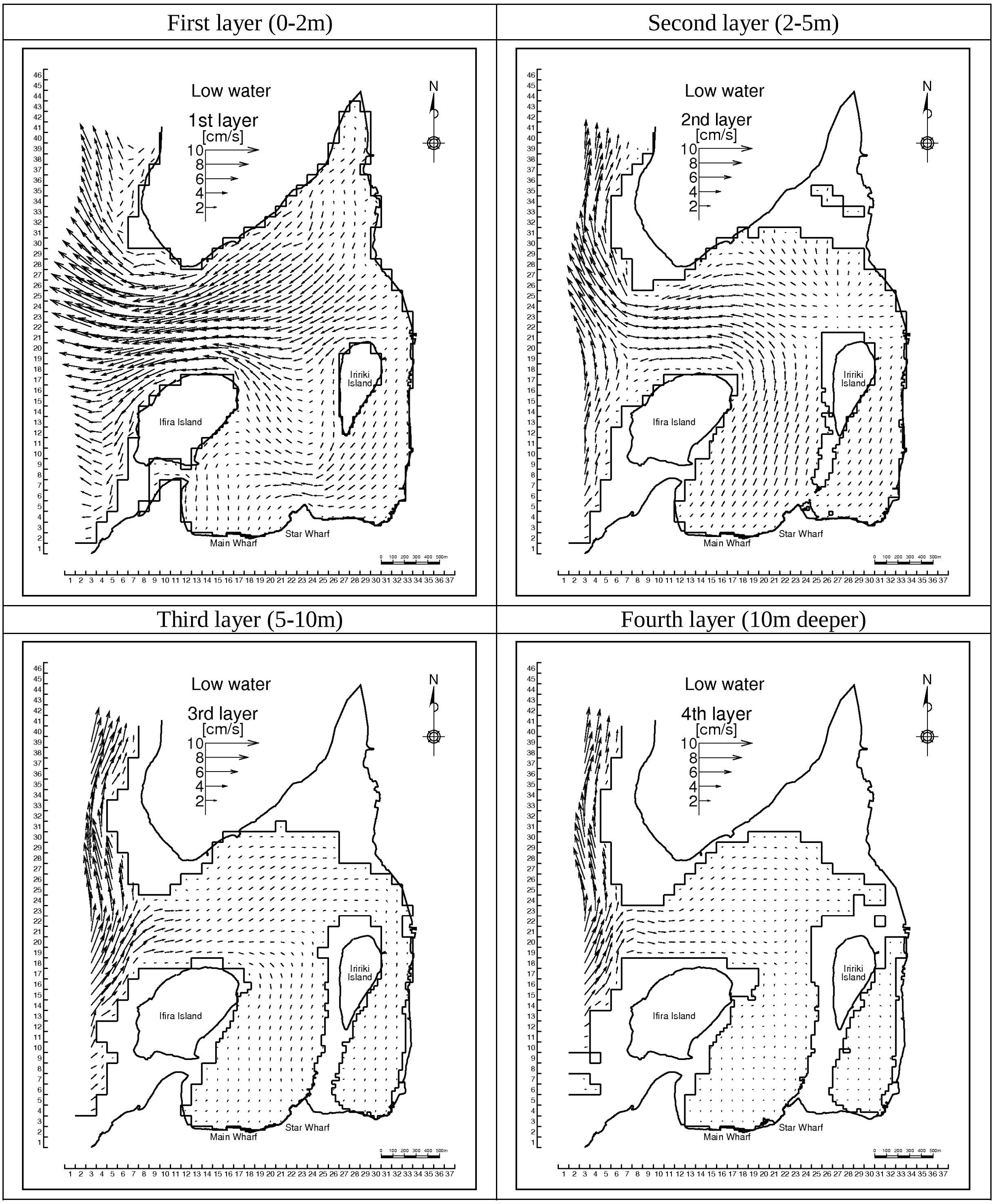


Figure 6.2.3-4(2) Simulated current field (present, low tide)

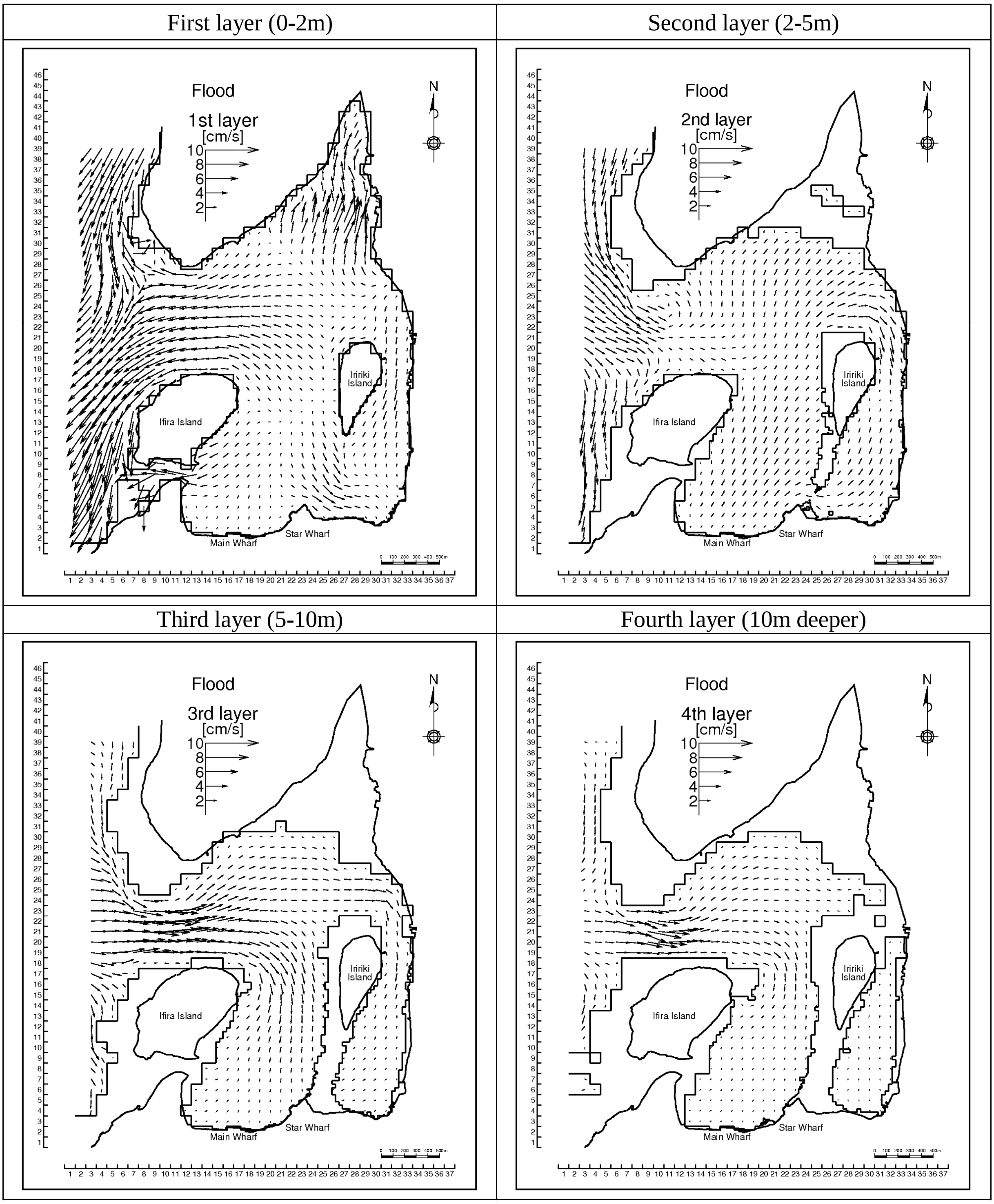


Figure 6.2.3-4(3) Simulated current field (present, flood tide)

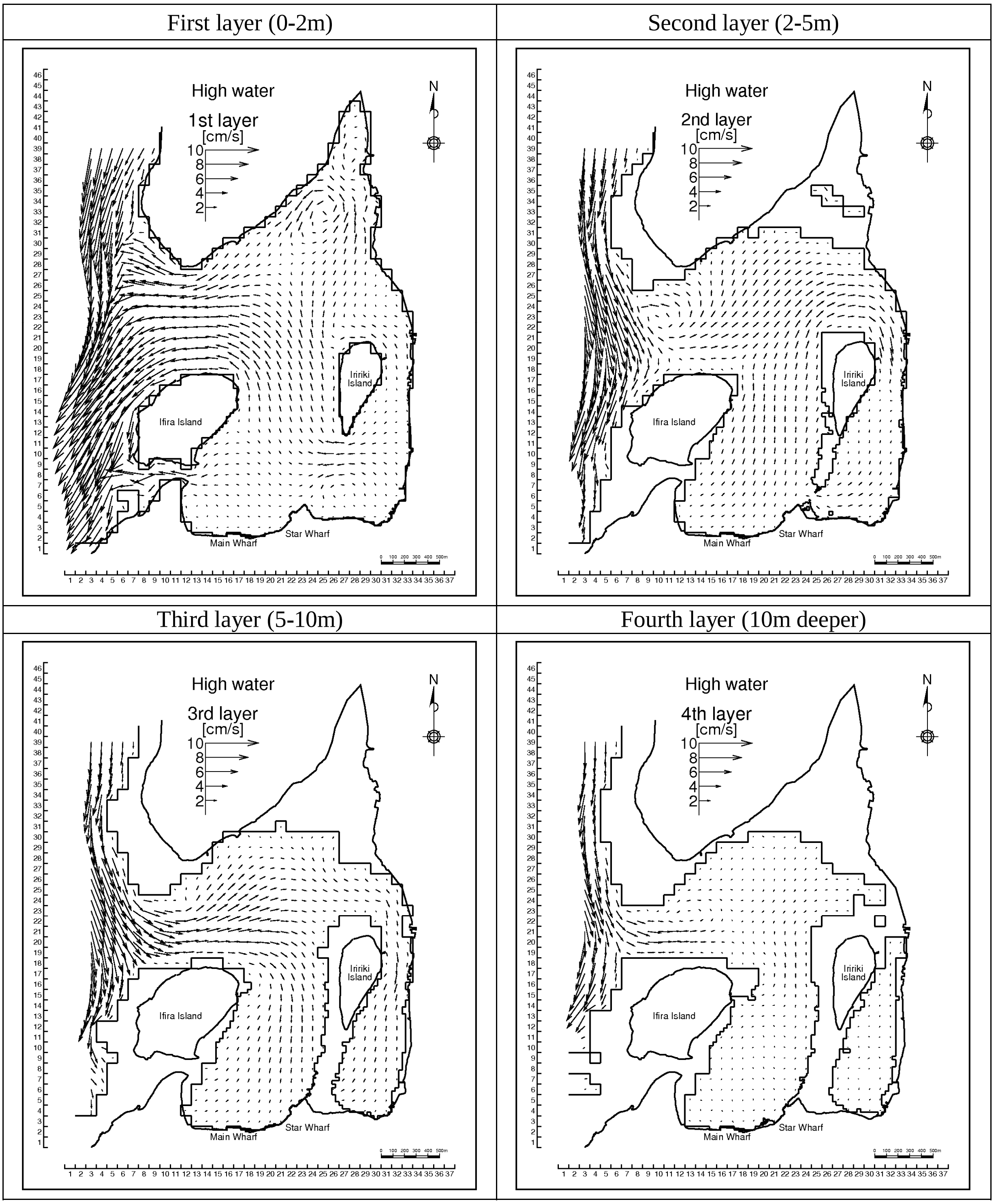
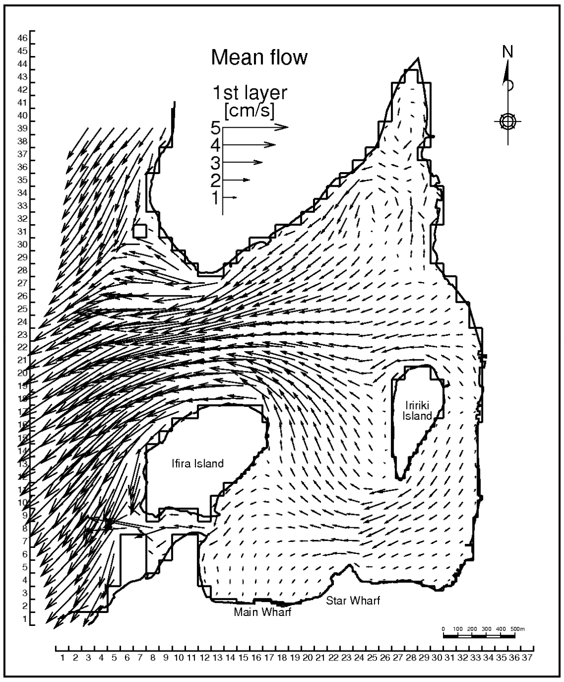
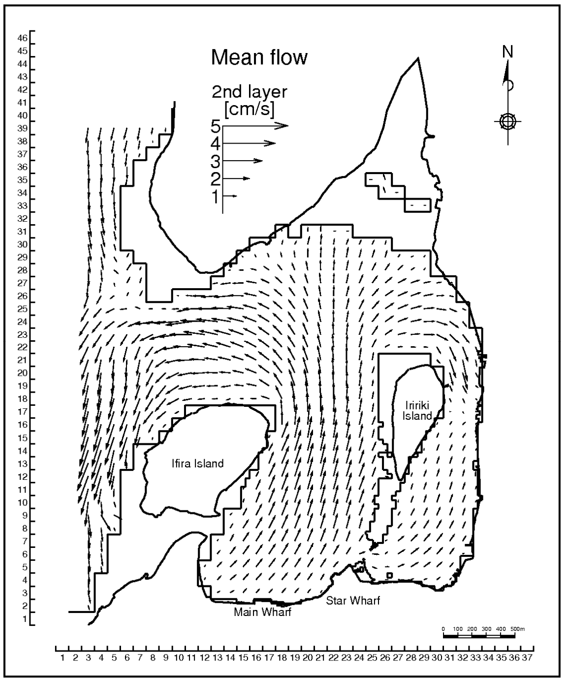


Figure 6.2.3-4(4) Simulated current field (present, high tide)

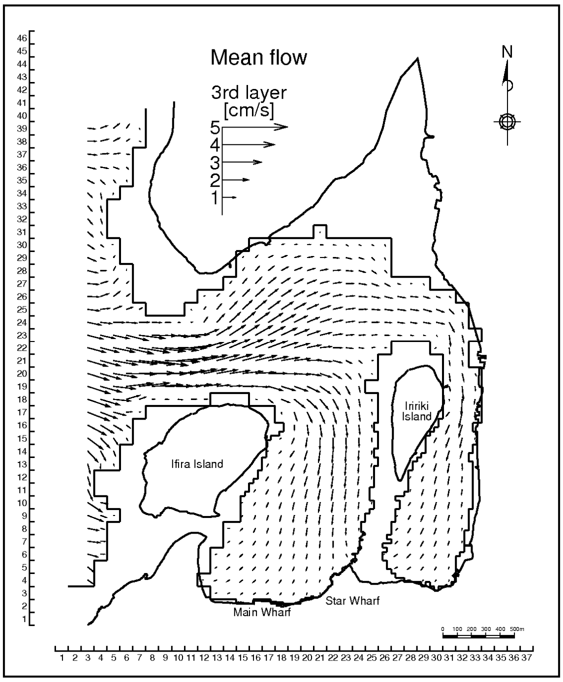
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Fourth layer (10m deeper)

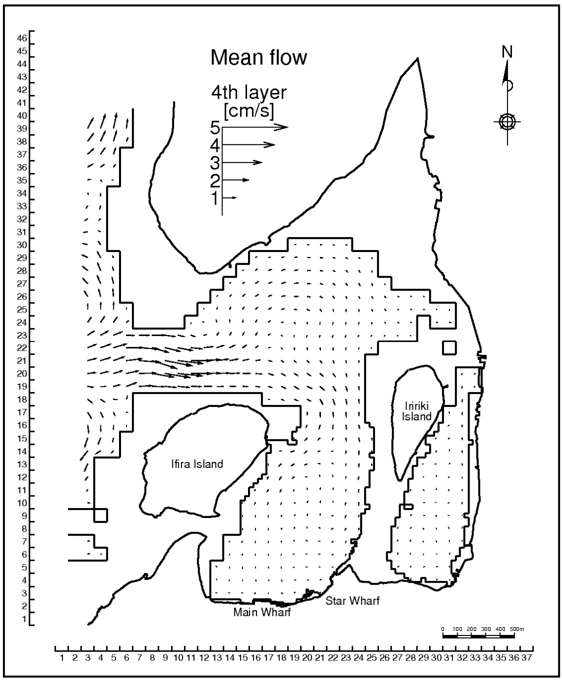


Figure 6.2.3-4(5) Simulated current field (present, mean currents)

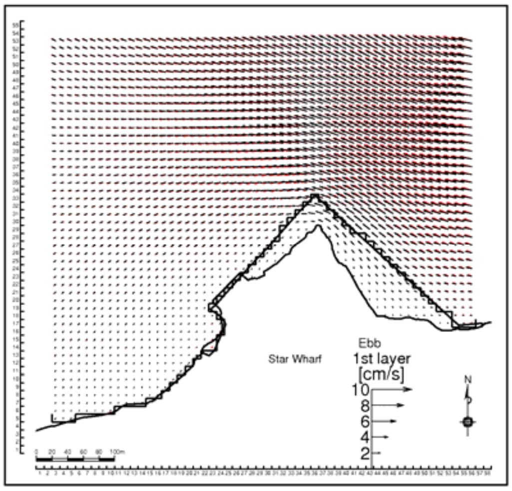
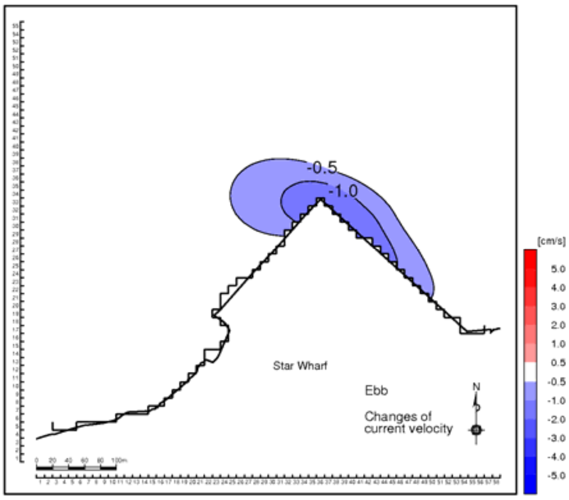
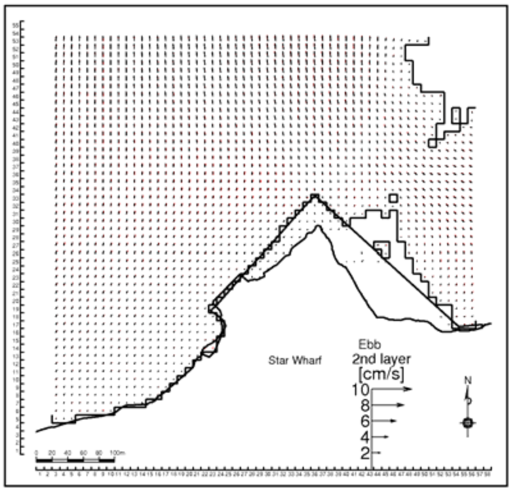
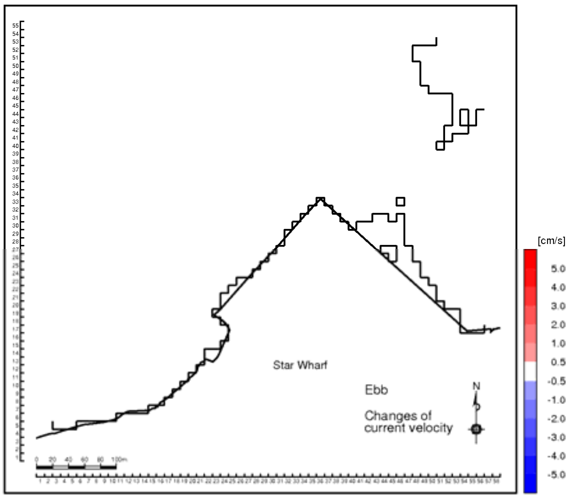
6.2.4 Future prediction

(1) Velocity and direction change

To understand impact on the flow field by the Star wharf development, velocity vectors of the present and future cases are overwrapped to see change of flow direction and magnitude differences of current velocity between the present and future cases are computed to grasp change of velocity. These are plotted for the first and second layers of the detailed domain in Figure 6.2.4-1.

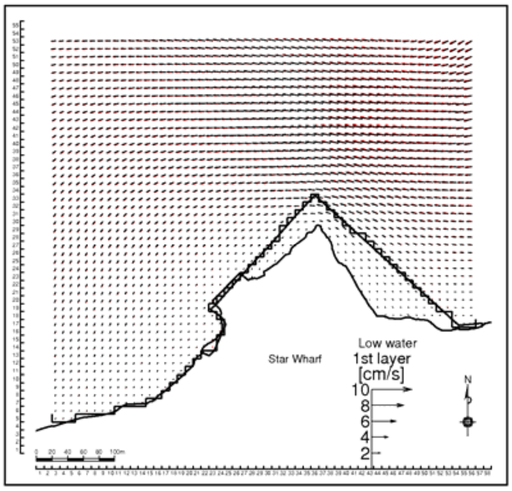
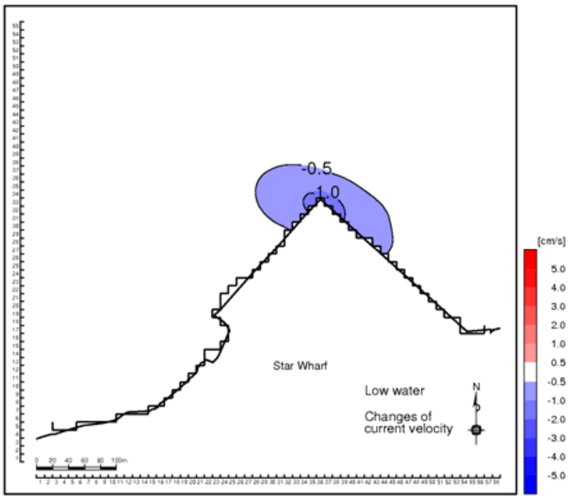
Velocity changes are restricted near the reclamation of Star wharf and the magnitudes of velocity change are approximately -1cm/s (velocity decrease). The area of velocity change is wider in ebb and low tides than flood and high tides, and no area of velocity change greater than 0.5cm/s can be seen in the high tide. In the velocity change of mean flow, a restricted area of velocity change greater than 0.5cm/s can be seen locally near the reclamation.

As for the flow direction change, no large scale flow pattern change can be seen in spite of some direction change near the reclamation.

	Current vector	Velocity change
First layer (0-2m)		
Second layer (2-5m)		

(black arrow: present, red arrow: future)

Figure 6.2.4-1(1) Current velocity change (ebb tide, detailed domain, first and second layer)

<table>
<tr><th></th><th>Current vector</th><th>Velocity change</th></tr>
<tr><td>First layer (0-2m)</td><td>
</td><td>
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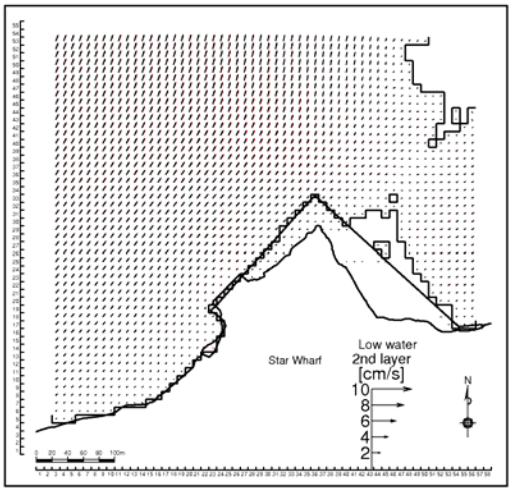
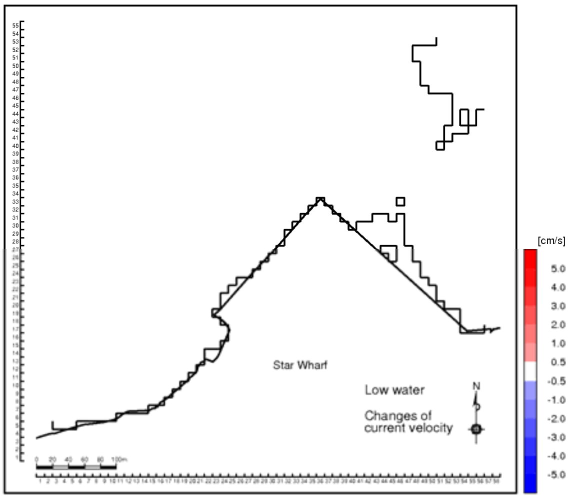
<tr><td>Second layer (2-5m)</td><td>
</td><td>
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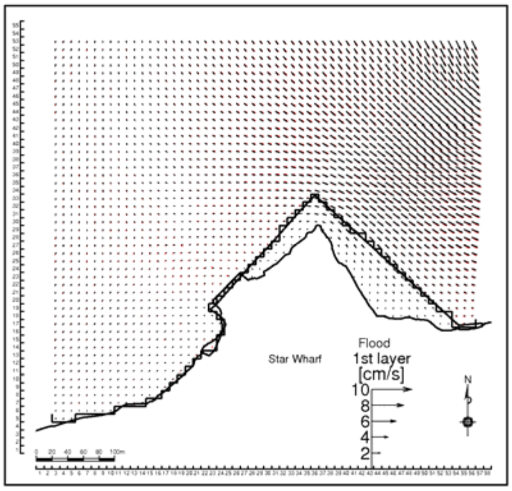
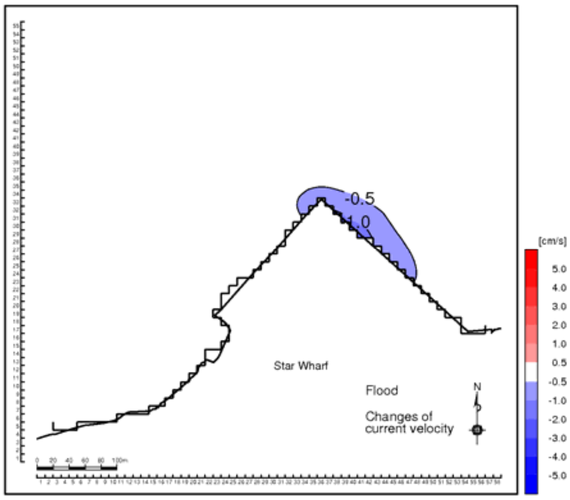
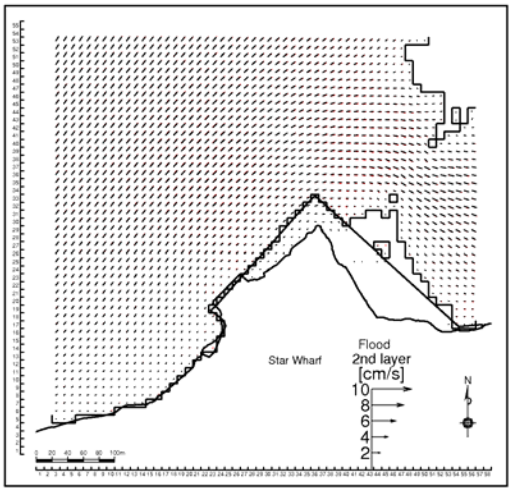
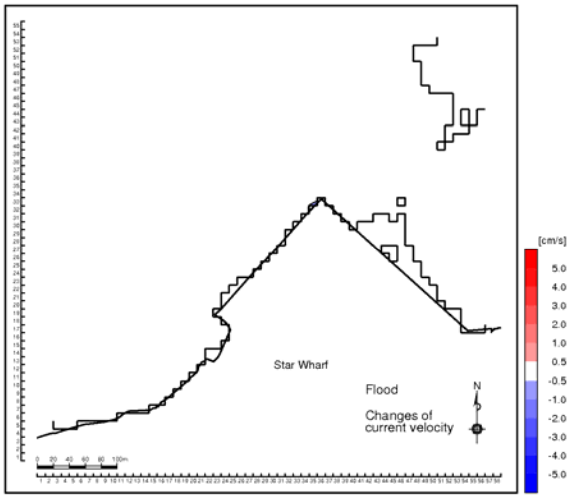
</table>

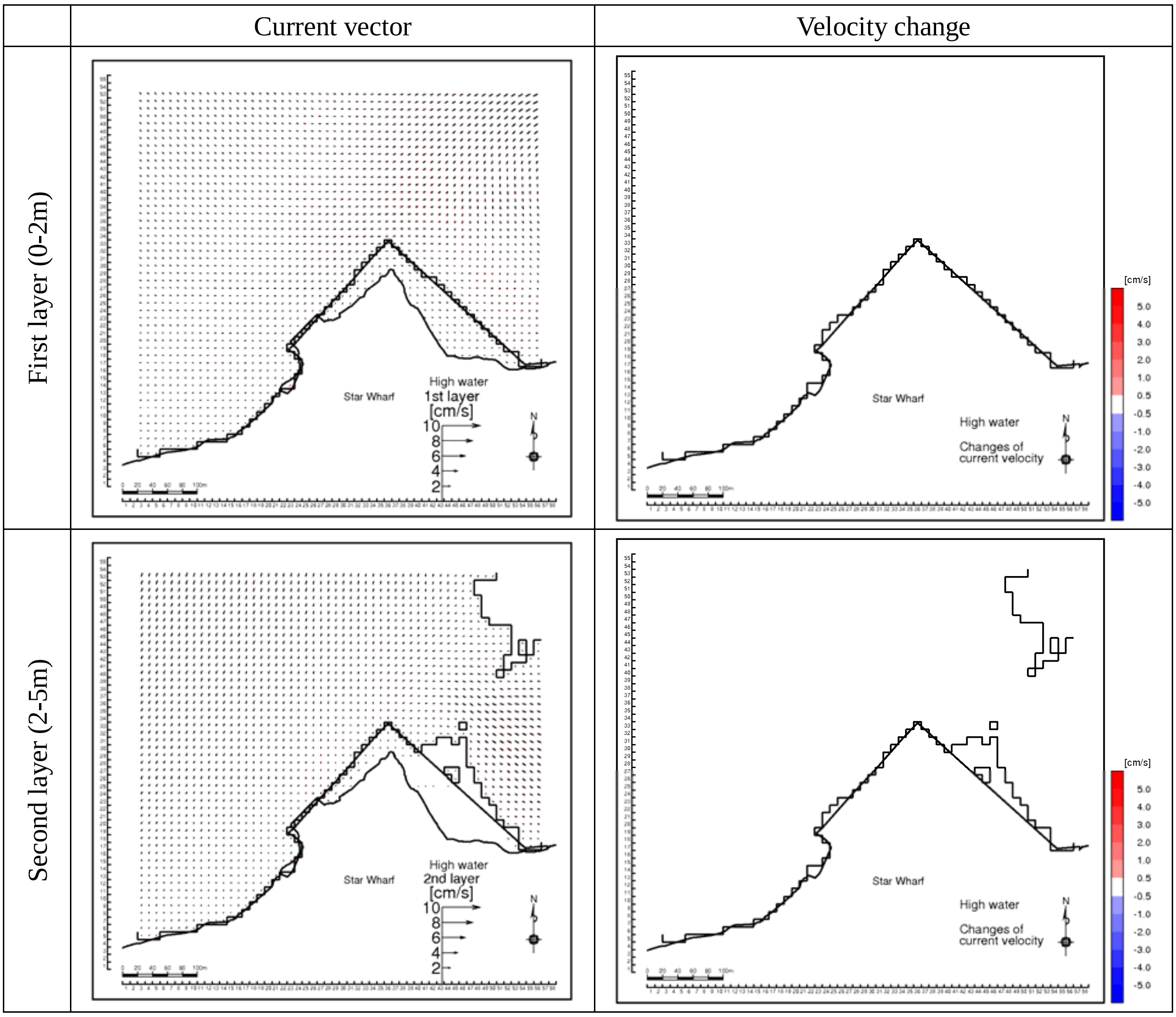
(black arrow: present, red arrow: future)

Figure 6.2.4-1(2) Current velocity change
(low tide, detailed domain, first and second layer)

	Current vector	Velocity change
First layer (0-2m)		
Second layer (2-5m)		

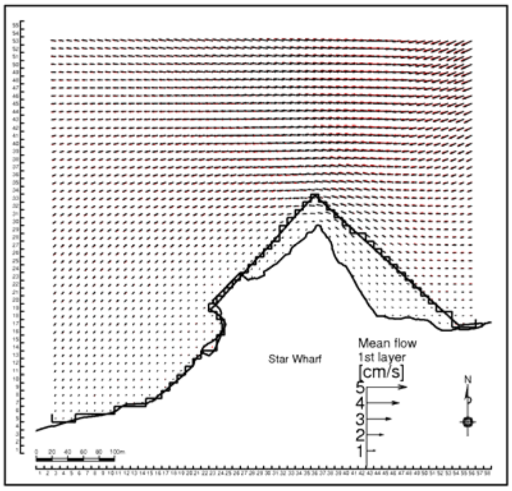
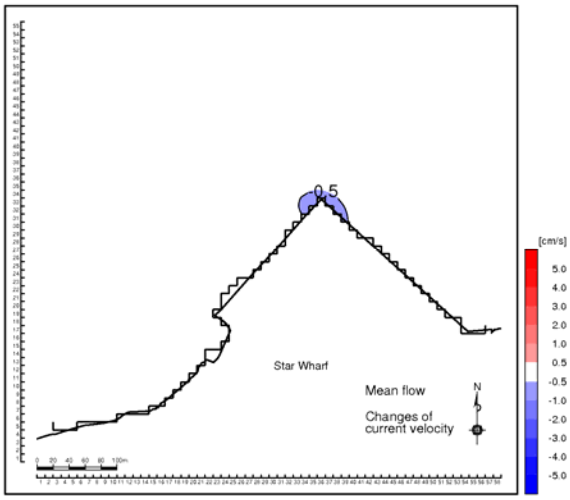
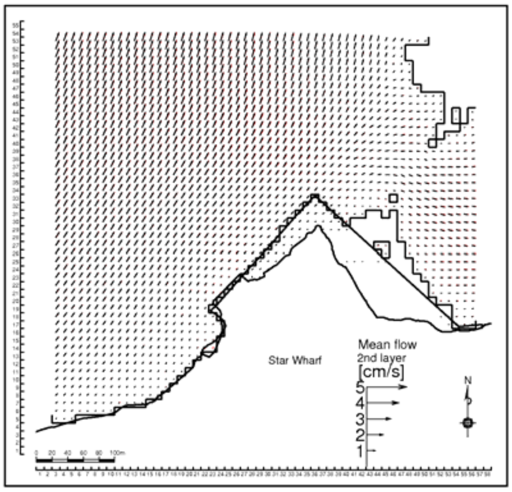
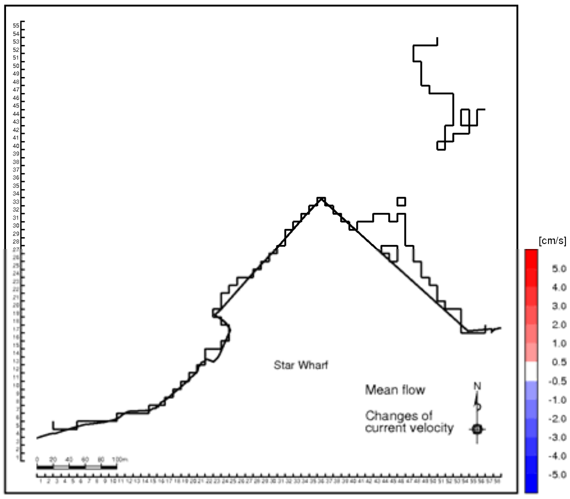
(black arrow: present, red arrow: future)

Figure 6.2.4-1(3) Current velocity change
(flood tide, detailed domain, first and second layer)



(black arrow: present, red arrow: future)

Figure 6.2.4-1(4) Current velocity change
(high tide, detailed domain, first and second layer)

	Current vector	Velocity change
First layer (0-2m)		
Second layer (2-5m)		

(black arrow: present, red arrow: future)

Figure 6.2.4-1(5) Current velocity change
(mean currents, detailed domain, first and second layer)

(2) Change of water exchange

To understand impact on the whole flow pattern in Port Villa harbor by the project development, changes of volume transport through representative sections shown in Figure 6.2.4-2 during a tidal cycle are investigated. The results are presented in Figure 6.2.4-3.

According to these figures, a pattern of outflow in the upper layers and inflow in the lower layers dominates as a whole. The changes of volume transport through sections by the project development are very much smaller than the volume transport itself.

Based on the considerations mentioned above, it is evaluated that the water exchanges between parts in Port Villa harbor preserve unchanged even after the project development.

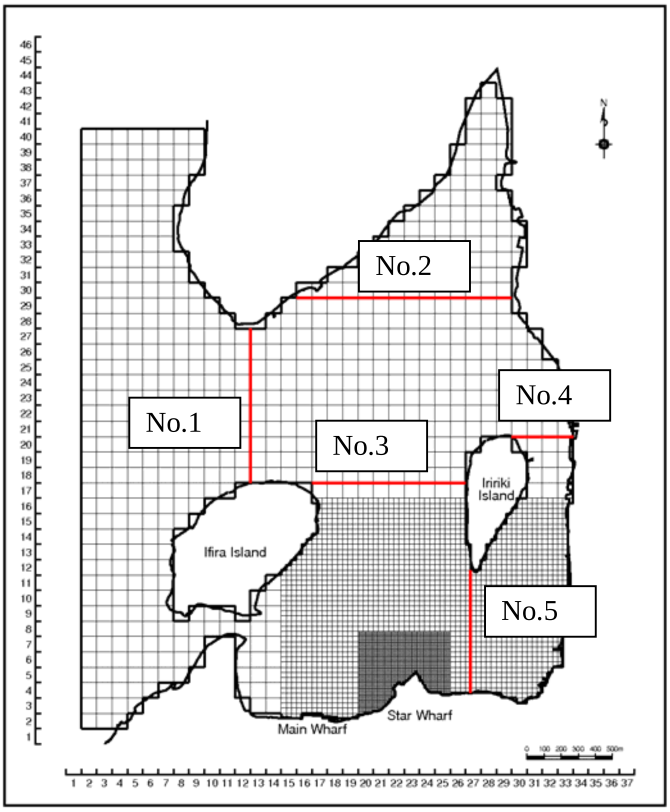
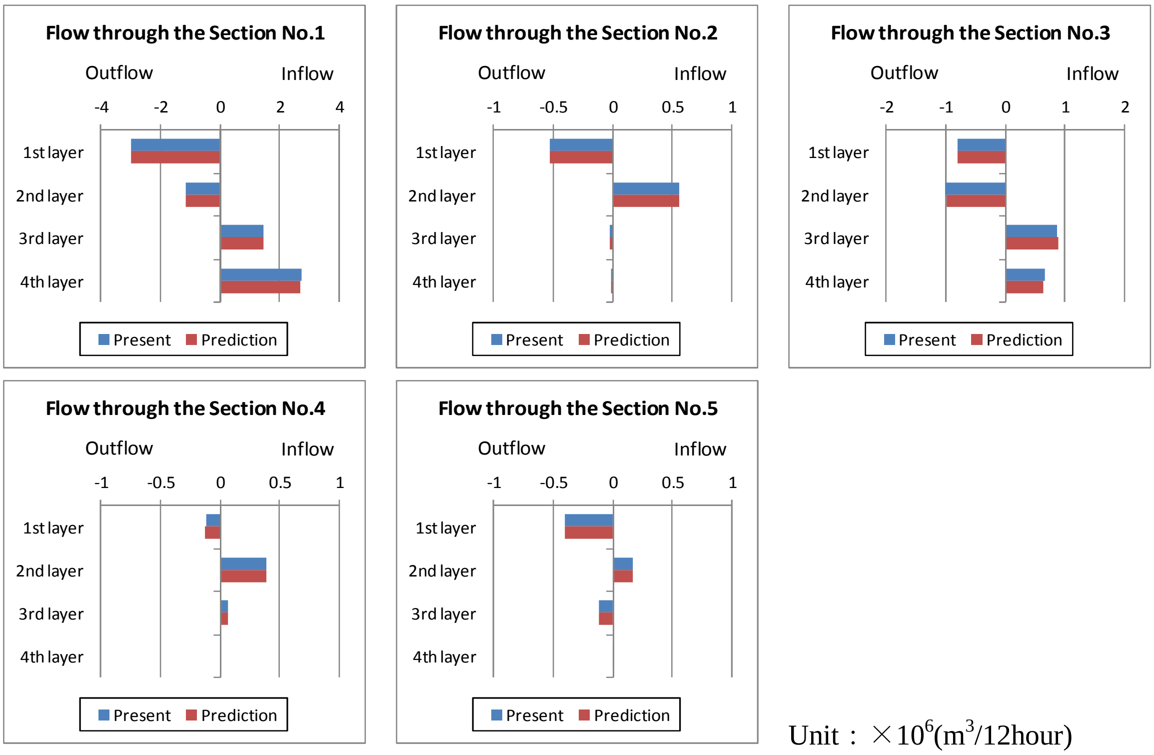


Figure 6.2.4-2 Location of sections



Unit : $\times 10^6$(m^3/12hour)

※Flow into the bay is represented inflow and positive. Outflow from the bay is represented outflow and negative.

Figure 6.2.4-3 Volume transport through sections

6.3 Silt Diffusion and deposition model

6.3.1 Model description

Advection-diffusion model taking settling velocity of sediment into account is adopted. In the model, advection diffusion processes are taken into consideration as well as gravitational settling effects of silt particles. Fundamental equations adopted are as follows.

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+(w-W_S)\frac{\partial S}{\partial z}=\frac{\partial}{\partial x}\left(K_x\frac{\partial S}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial S}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial S}{\partial z}\right)+q$$

S : Suspended solids concentration (mg/L)

x,y,z : 3-dimensional coordinates (m)

u,v,w : Velocity components in x,y,z-direction, respectively (m/s)

t : Time (s)

Kx,Ky : Horizontal eddy viscosity (m^2/s)

Kz : Vertical eddy viscosity (m^2/s)

q : Load(g/s)

W_s : Settling velocity(m/s)

Deposit weight of suspended solids is converted to height by the following formula.

$$\text{Deposit weight (g/m}^2\text{)} = \sum_{i=1}^{m}\int_0^T W_S \cdot S_i \cdot dt$$

$$\text{Deposit height(m)}=\text{Deposit weight(g/m}^2\text{)}\times\left(\frac{1}{\rho_s}+\frac{1}{\rho_w}\frac{R_w}{1-R_w}\right)$$

W_s : Settling velocity(m/s)

S_i : Suspended solids concentration with i-th particle size (mg/L)

T : Accumulation time(T=24hours)

ρ_s : sediment density of deposit(g/m^3)

ρ_w : Sea water density(g/m^3)

R_w : Water content in the sediment(0-1)

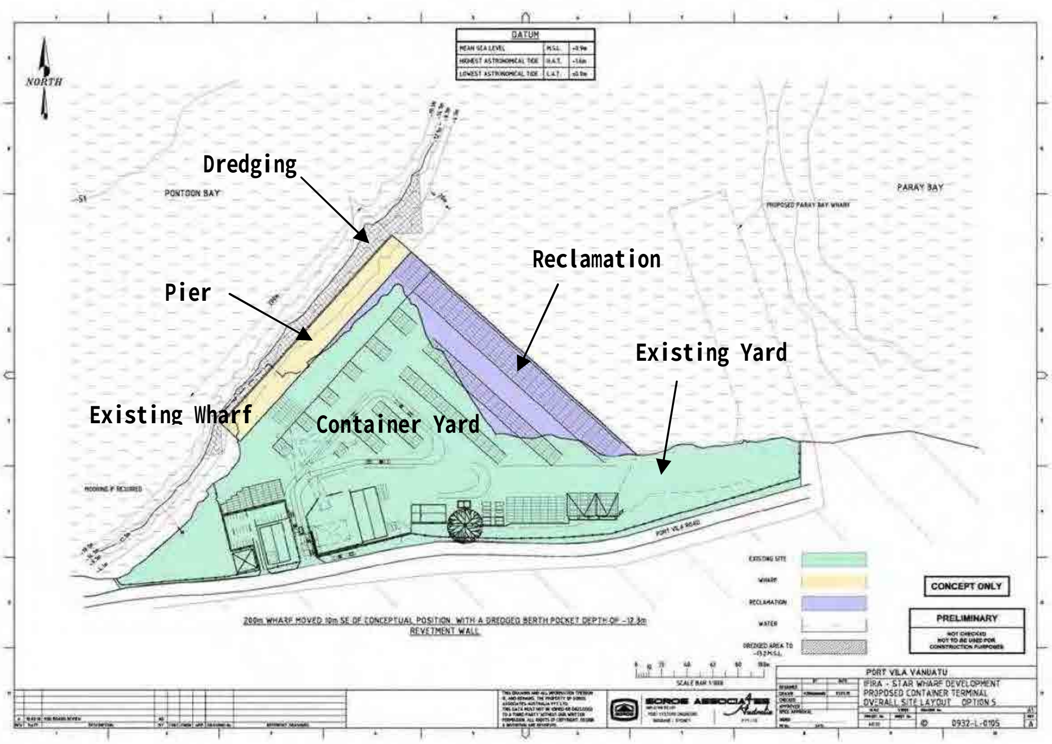
6.3.2 Computation conditions

(1) Generation of turbidity

(a) Activities generating turbidity

According to the plan of constructing Star Wharf, activities possible to generate turbidity in the construction phase are removal of existing wharf, dredging and reclamation. Among these activities, the reclamation is considered to barely contribute turbidity generation, because it is done after the construction of revetment surrounding the reclamation area. Removal of the existing wharf is also considered to generate little turbidity because the activity does not directly affect bed sediment. It is thought that the dredging most generates turbidity among these activities, because of the activity directly affecting bed sediment.

Based on above considerations, spreading of turbidity is simulated for the dredging.



Source：Star Terminal Construction Project, Bankable Feasibility Study, Final Report (2010)

Figure 6.3.2-1 Plan view of Star Wharf development

(b) Outline of dredging

According to the plan of constructing Star Wharf, it is planned that sea area in front of Star Wharf is dredged as shown in Figure 6.3.2-1. The outline of dredging is shown in Table 6.3.2-1.

Table 6.3.2-1 Outline of dredging

Duration	30days
Area	0.33 ha
Amount of dredged sediment	62,000 m^3
Target depth	12.3 m
Method	Cutter-suction or grab dredge

(c) Environmental conditions related to turbidity generation

(i) Flow velocity in the field

Flow velocities in the dredging area are set based on the results of 3 times current surveys in St.C2. Velocity near the dredging area is tabulated in Table 6.3.2-2.

Table 6.3.2-2 Velocity near the dredging area

	Mean velocity(cm/s)	Maximum velocity(cm/s)
Spring tide	2.6	7.5
Neap tide	2.8	10.3
Intermediate tide	3.6	8.8

(ii) Setting of threshold particle size

Threshold particle size of sediment is necessary to be determined because it controls particle size range of sediment that contributes turbidity generation. The threshold particle size is determined using a relation between field flow velocity and threshold particle size as shown in Figure 6.3.2-2. The field flow velocity is set 10.3 cm/s taking the maximum velocity in Table 6.3.2-2. The threshold particle size is determined to be 0.183mm using the velocity through the Camp formula shown below.

Ingersol formula： $V_c = \frac{1}{1.2} V \sqrt{\frac{8}{f}}$ Camp formula： $V_c = 1.86 \sqrt{\frac{(\rho_S - \rho)}{\rho} gd}$

Vc：Field flow velocity (cm/s) f：Drag coefficient(=0.025)

g：Gravity acceleration(980cm/s^2) ρ_S：Sediment density(=2.78)

ρ : sea water density(=1.024) μ : Viscosity

d : Sediment diameter(cm) V : Settling velocity(cm/s)

Settling velocity is calculated through the Stokes formula.

Stokes formula $V = \frac{1}{18}\frac{g(\rho_S - \rho)}{\mu}d^2$

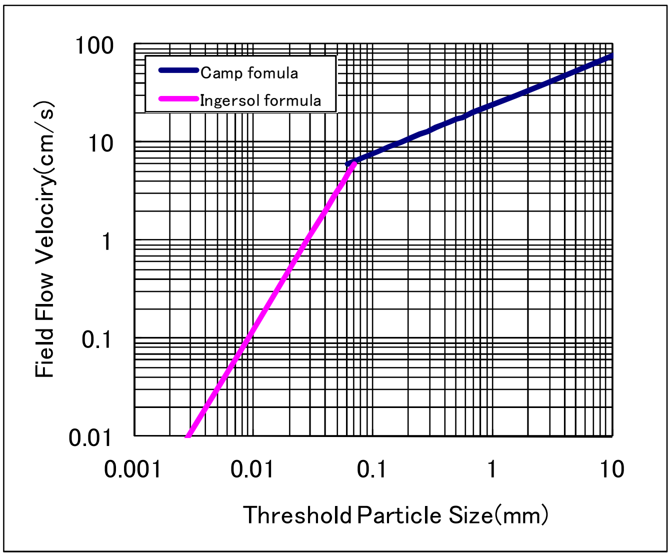


Figure 6.3.2-2 Relation between field flow velocity and threshold particle size

(iii) Sediment property of dredged material

Sediment property of dredged material is surveyed in this project to calculate generation amount of turbidity by the construction activity. The survey results are shown in Table 6.3.2-3 and Figure 6.3.2-3.

Since the threshold particle size is determined as 0.183mm, the cumulative finer weight percentage, R corresponding to the threshold particle size is found to be 13.5% as average of 3 points in Figure 6.3.2-3.

Among the sediments finer than the threshold particle size which are considered to contribute turbidity generation, composition of silt and clay is 22% and sand 78%, because composition of silt and clay is 3% and sand 10.5% among sediments finer than 13.5%.

Table 6.3.2-3 Sediment particle analysis

Class (mm)	Clay	Silt	Sand			Gravel	
			Fine	Medium	Coarse	Fine	Medium
	-0.005	0.005 -0.075	0.075 -0.250	0.250 -0.850	0.850 -2.0	2.0 -4.75	4.75 -19
St.S1	3.0		9.4	33.8	19.0	21.4	13.4
St.S2	4.1		28.4	47.0	13.9	5.0	1.6
St.S3	1.8		9.9	55.2	23.7	8.1	1.3
Average	3.0		15.9	45.3	18.9	11.5	5.4

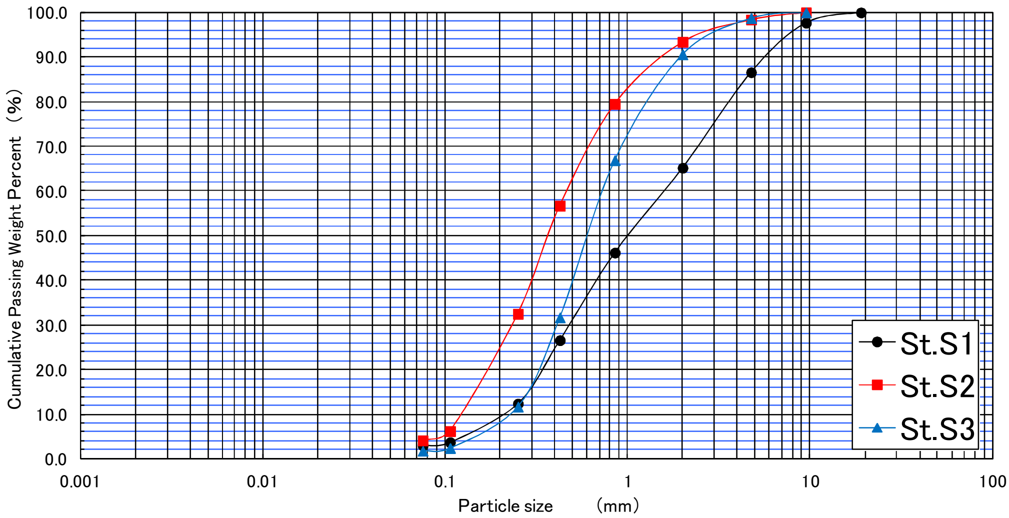


Figure 6.3.2-3 Sediment size distribution

(d) Calculation of turbidity generation

According to the method for calculation of turbidity generation presented in 「Guide line for evaluation of turbidity impact in port and harbor construction, 2004.04, Ministry of Land, Infrastructure, Transport and Tourism of Japan, Bureau of ports and harbors」, amount of turbidity generation induced by the dredging activity is computed based on the planned dredged amount. The calculated results are shown in Table 6.3.2-4.

The load of suspended solids calculated here is dumped at a location shown in Figure 6.3.2-4. The schedule of dredging in a day is that there is the dredging activity in 8 hours and no activity in the other 16 hours.

$$w = \frac{R}{R_{75}} w_0$$

$$W = w \times Q_s$$

w : Unit turbidity productivity in the planned area (kg/m^3)

w_0 : Standard turbidity productivity in the guide line (kg/m^3)

R : Cumulative finer weight percentage corresponding to the threshold particle size(%)

R_{75} : Cumulative weight percentage finer than 0.075mm in sediment when the standard turbidity productivity is investigated. (%)

W : Amount of turbidity generation (kg/day)

Q_s : Amount of dredged sediment(m^3/day)

Table 6.3.2-4 Calculation of turbidity generation

Existing standard turbidity productivity etc.			R(%)	W (kg/m^3)	Dredged sediment, Q_s (m^3/day)	Turbidity generation, W (ton/day)
Method	R_{75}(%)	w_0(kg/m^3)				
Cutter-suction	21.6	1.63	13.5	1.02	2,067	2.1
Grab	18.4	7.68	13.5	5.62	2,067	11.6

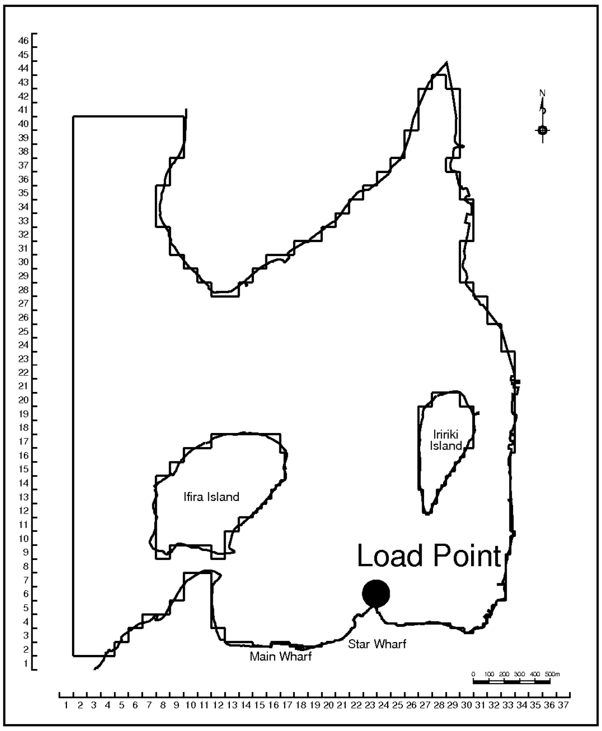
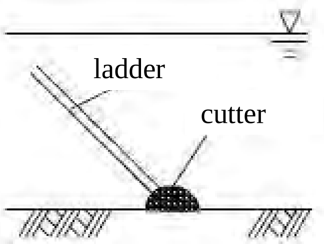
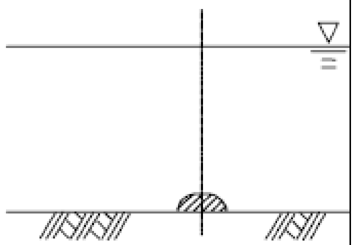
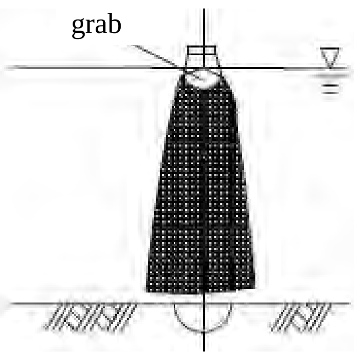
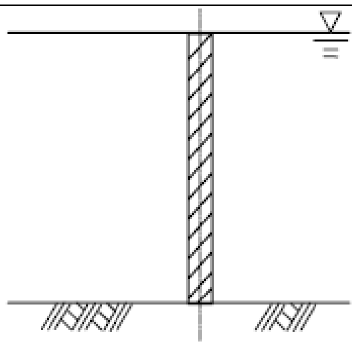


Figure 6.3.2-4 Location of SS generation

(e) Model of turbidity generation

It is necessary to determine model of turbidity generation for each dredging method to simulate turbidity spreading. Models of turbidity generation of cutter-suction and grab dredger are shown inTable 6.3.2-1 according to 「Guide line for evaluation of turbidity impact in port and harbor construction, 2004.04, Ministry of Land, Infrastructure, Transport and Tourism of Japan, Bureau of ports and harbors.

Table 6.3.2-5 Turbidity spreading and model of turbidity generation

Methods	Turbidity spreading	Model of turbidity generation	Explanation
Cutter-suction dredge			Turbidity is generated at the sea bed when cutter swings. Therefore location of turbidity generation is the sea bed.
Grab dredge			Turbidity is generated due to various causes such as rolling up of sediment when grabbing, release of attached sediment into water when pull-up and seepage of water/sediment mixture above the sea surface. Therefore location of turbidity generation is through all water columns from sea bed to surface.

(f) Setting of settling velocity

Settling velocities of suspended solids are calculated through the Stokes or Allen formulas (shown below) used depending on the particle Reynolds number for each representative particle size which is logarithmic mean of edge values of the sediment class. The results are shown in Table 6.3.2-6.

Stokes formula : $V = \frac{1}{18} \cdot \frac{g(\rho_s - \rho)}{\mu} \cdot d^2$

Allen formula : $V = 0.223\{g^2(\rho_s - \rho)^2 \rho\mu\}^{1/3} \cdot d$

V : Settling velocity (cm/s)

d : Particle diameter (cm)

ρ_s : Sediment density (=2.78)

ρ : Sea water density (=1.024)

g : Gravity acceleration (=980cm/s^2)

μ : Viscosity (=0.0089poise : at 25℃)

Table 6.3.2-6 Settling velocity for each sediment class

Class of sediment	Size range(mm)	Representative size(mm)	Settling velocity(m/day)	Remarks
Sand	0.075-0.183	0.117	200.0	Allen formula
Silt/clay	(0.001)-0.075	0.009	7.5	Stokes formula

(g) Silt Protector as a counter measure against turbidity spreading

In the plan of Star Wharf development, setting of silt protector is planned in construction activities such as dredging and reclamation.

In the SS simulation, both cases with and without silt protectors are conducted to see the difference between the two cases. The load of turbidity generation in the case with silt protectors is set 40% of that of without case shown in Table 6.3.2-4. This draws upon example cases in which removal ratios of turbidity by silt protectors are 40-80%. These examples are presented in 「Guide line for evaluation of turbidity impact in port and harbor construction, 2004.04, Ministry of Land, Infrastructure, Transport and Tourism of Japan, Bureau of ports and harbors」

(2) Initial and boundary conditions

Initial and boundary concentrations of suspended solids are set zero to evaluate just impact by construction activities.

(3) Horizontal and vertical diffusivity

It is necessary to set horizontal and vertical diffusivity to perform advection diffusion simulation. These coefficients are derived from the hydrodynamics simulation.

(4) Time step

Time steps are set 3 seconds for all three domains considering computational stability.

(5) Integration time

Integration time of the simulation is 240 hours (10 days). SS concentrations in the computation domains approach periodic stationary within the integration time. The last 24 hours results of simulation are used for the analysis to compute daily average and maximum concentrations.

(6) Parameters necessary for conversion from deposition weight to thickness

Parameters necessary for conversion from deposition weight to thickness are water content and sediment density. These parameters values come from the field surveys in this project. The results of field surveys are shown inTable 6.3.2-7, and values of water content and sediment density are set 21.4% and 2.78 g/cm^3 respectively as average of three points. Sea water density is 1.024 g/cm^3.

Table 6.3.2-7 Results of sediment survey

Parameter	St.S1	St.S2	St.S3	Average
Water content (%)	22.4	20.1	21.8	21.4
Sediment density (g/cm^3)	2.738	2.792	2.810	2.780

6.3.3 Results of prediction

Computation cases are listed in Table 6.3.3-1. Case1 and 2 are cases without and with silt protectors adopting cutter-suction dredger. Case 3 and 4 are cases without and with silt protectors adopting grab dredger.

Table 6.3.3-1 SS simylation cases

Case name	Dredge method	Silt protector
Case1	Cutter-suction	Without
Case 2	Cutter-suction	With
Case 3	Grab	Without
Case 4	Grab	With

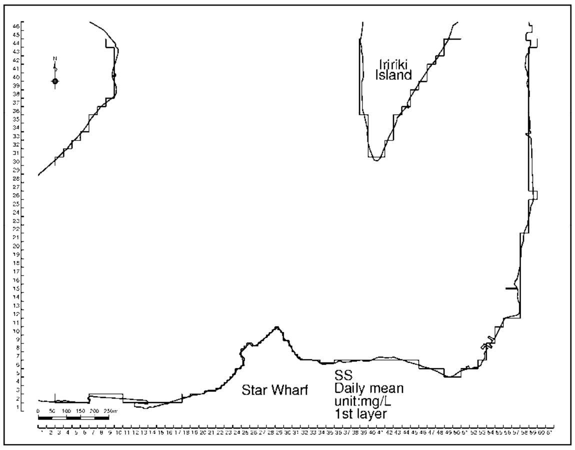
(1) SS concentrations

(a) Case 1 and 2(Cutter-suction dredge)

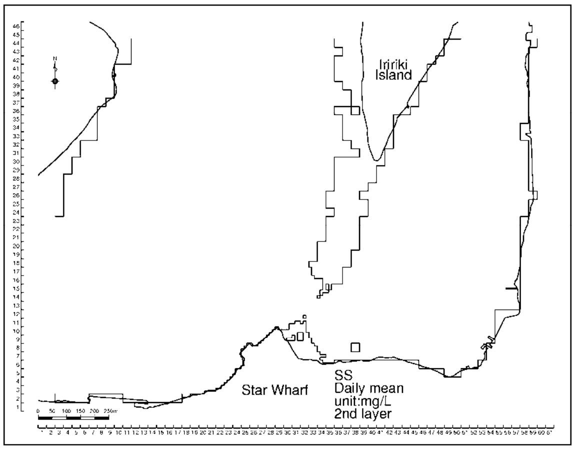
Results of case1 and 2 are presented in Figure 6.3.3-1 and Figure 6.3.3-2 respectively. Daily average and maximum concentrations are shown for each case. In case1, SS concentrations over 1mg/L are seen only in the third layer (5-10m depth). In the daily maximum concentrations, a contour of 2 mg/L is within a sector with a radius of 100m centered the load point.

In case 2 (with silt protector), SS spreading is suppressed compared with case1, and a daily maximum concentration contour of 2 mg/L is within a sector with a radius of 60m centered the load point.

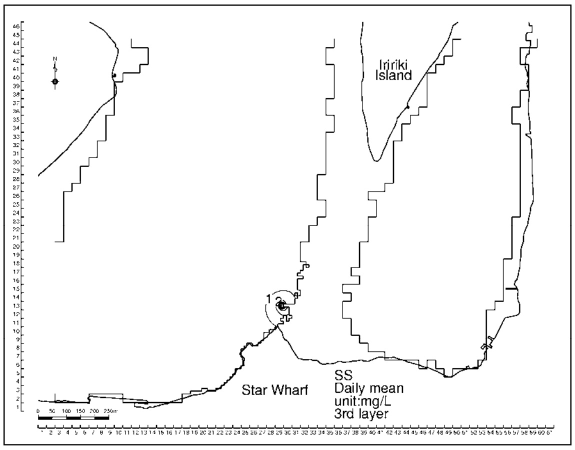
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

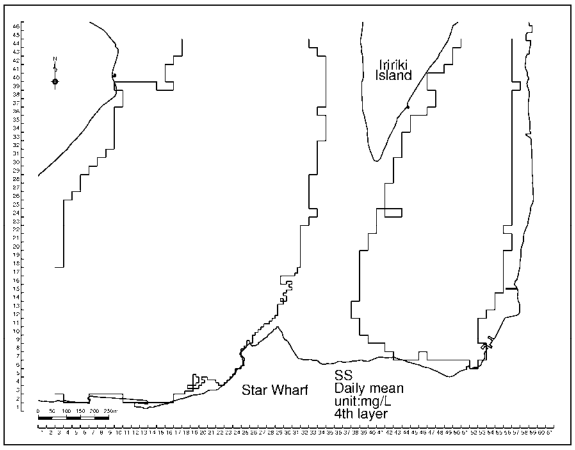
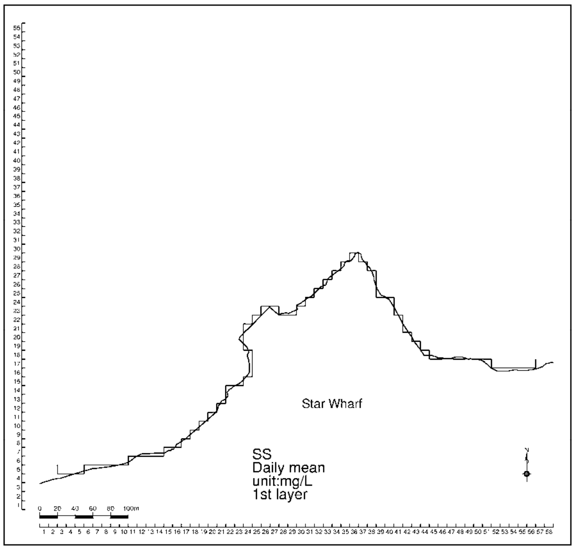
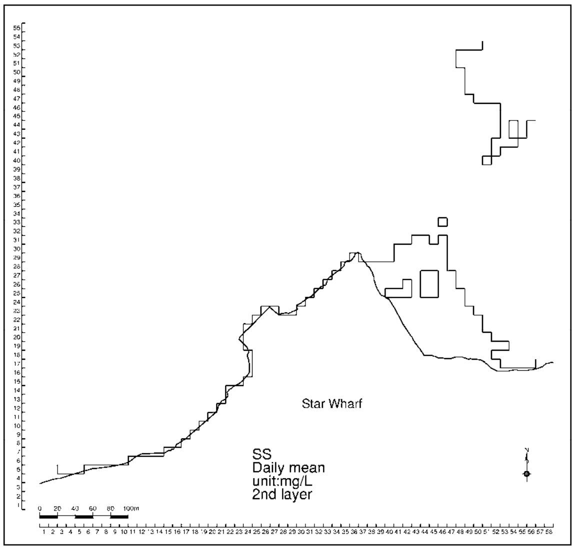


Figure 6.3.3-1(1) SS concentration
(Case1：Cutter-suction dredge[Without silt protector],intermediate domain, daily average)

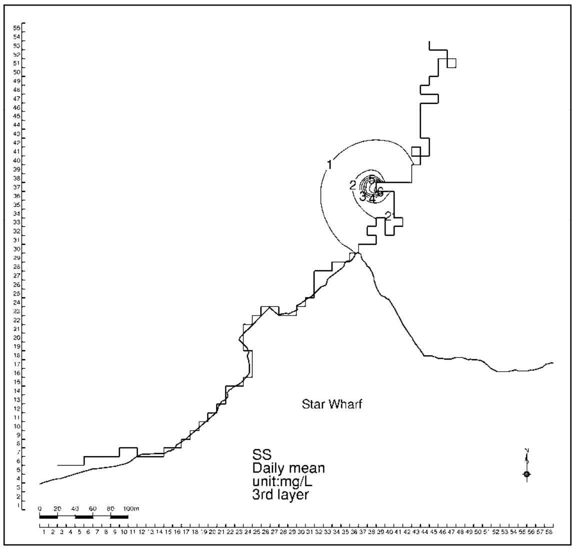
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Fourth layer (10m deeper)

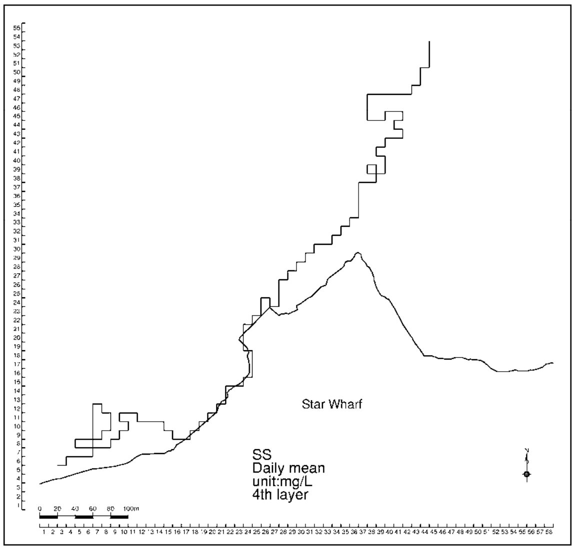
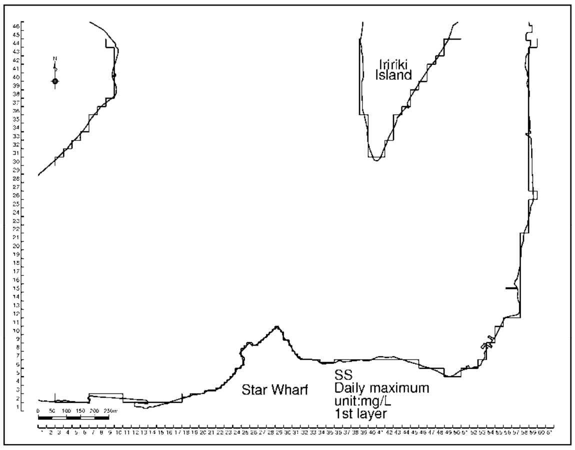
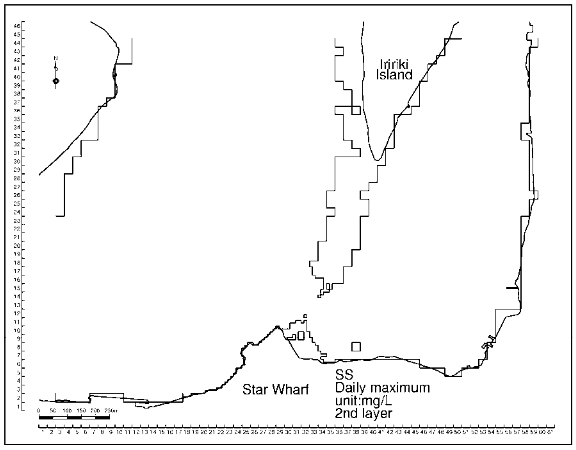


Figure 6.3.3-1(2) SS concentration
(Case1：Cutter-suction dredge[Without silt protector], detailed domain, daily average)

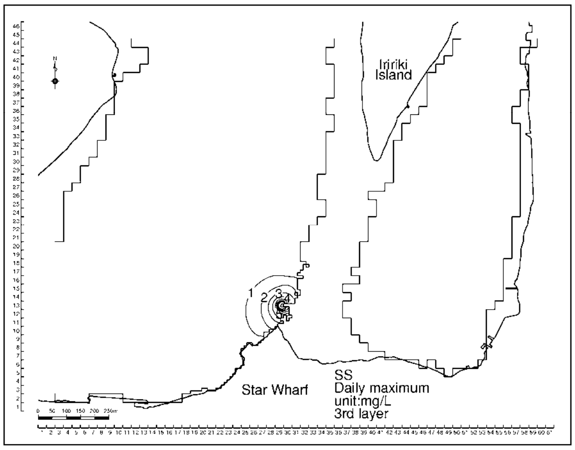
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

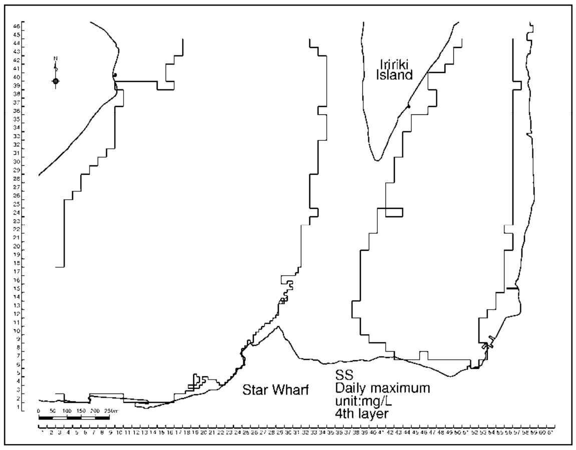
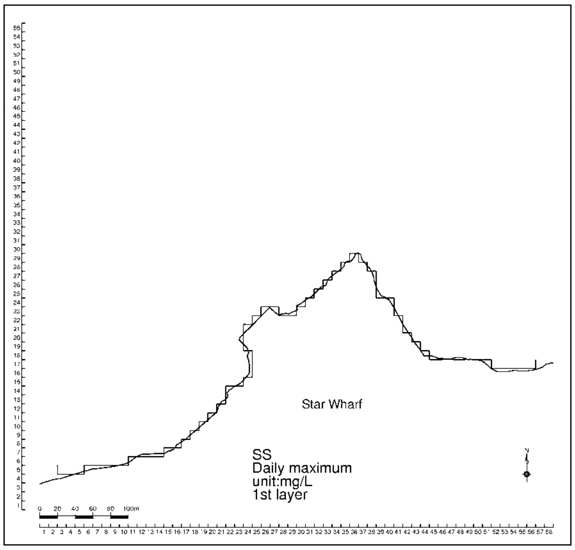


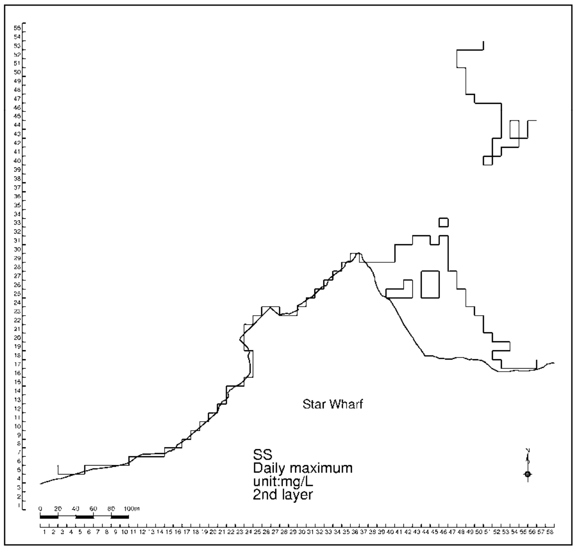
Figure 6.3.3-1(3) SS concentration

(Case1：Cutter-suction dredge[Without silt protector],intermediate domain, daily maximum)

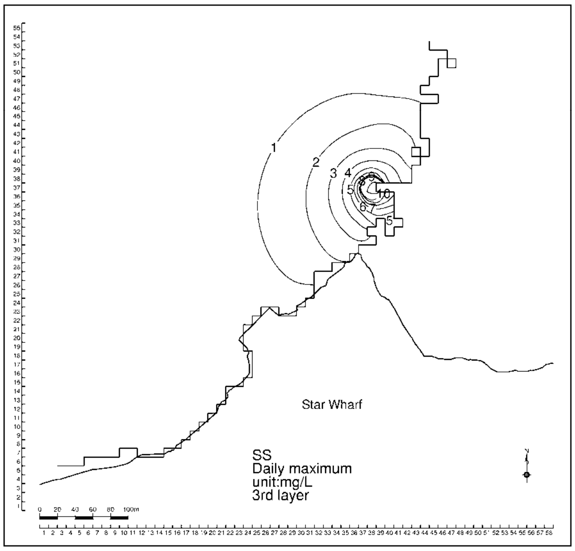
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

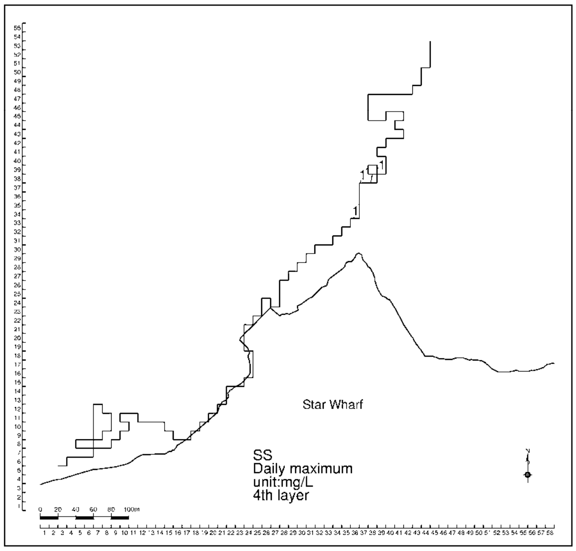
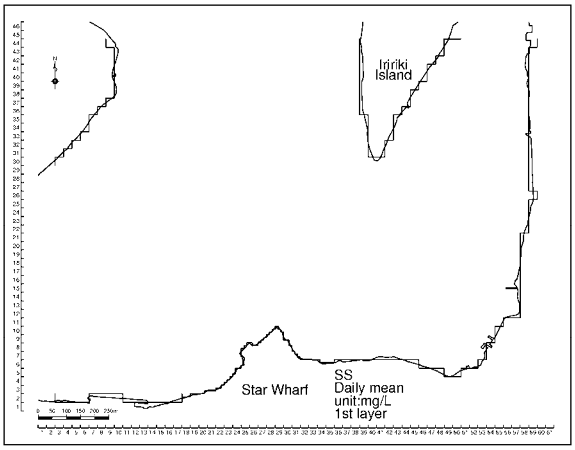
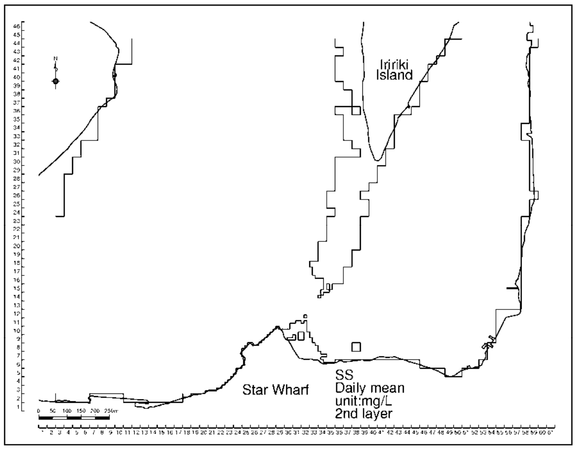


Figure 6.3.3-1(4) SS concentration
(Case1：Cutter-suction dredge[Without silt protector], detailed domain, daily maximum)

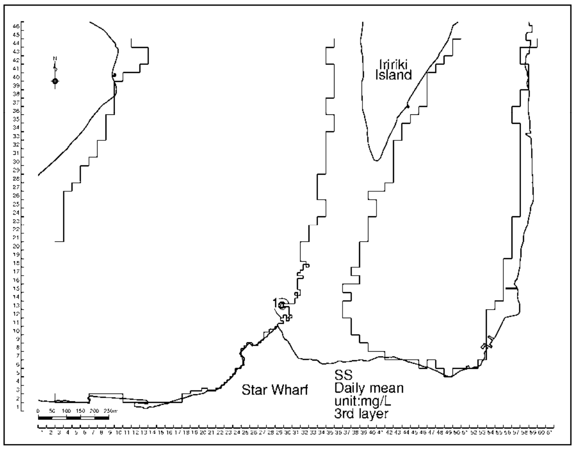
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

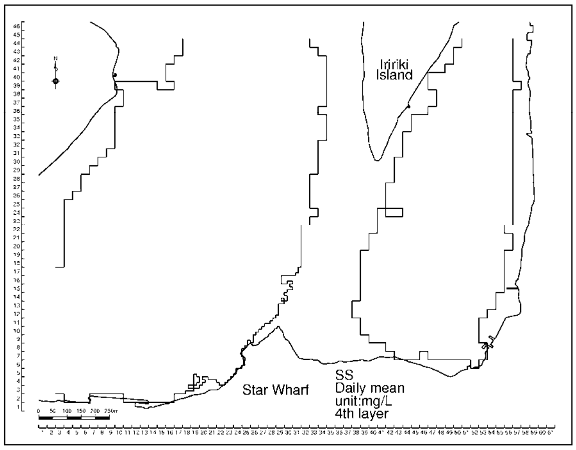


Figure 6.3.3-2(1) SS concentration
(Case2：Cutter-suction dredge[With silt protector],intermediate domain, daily average)

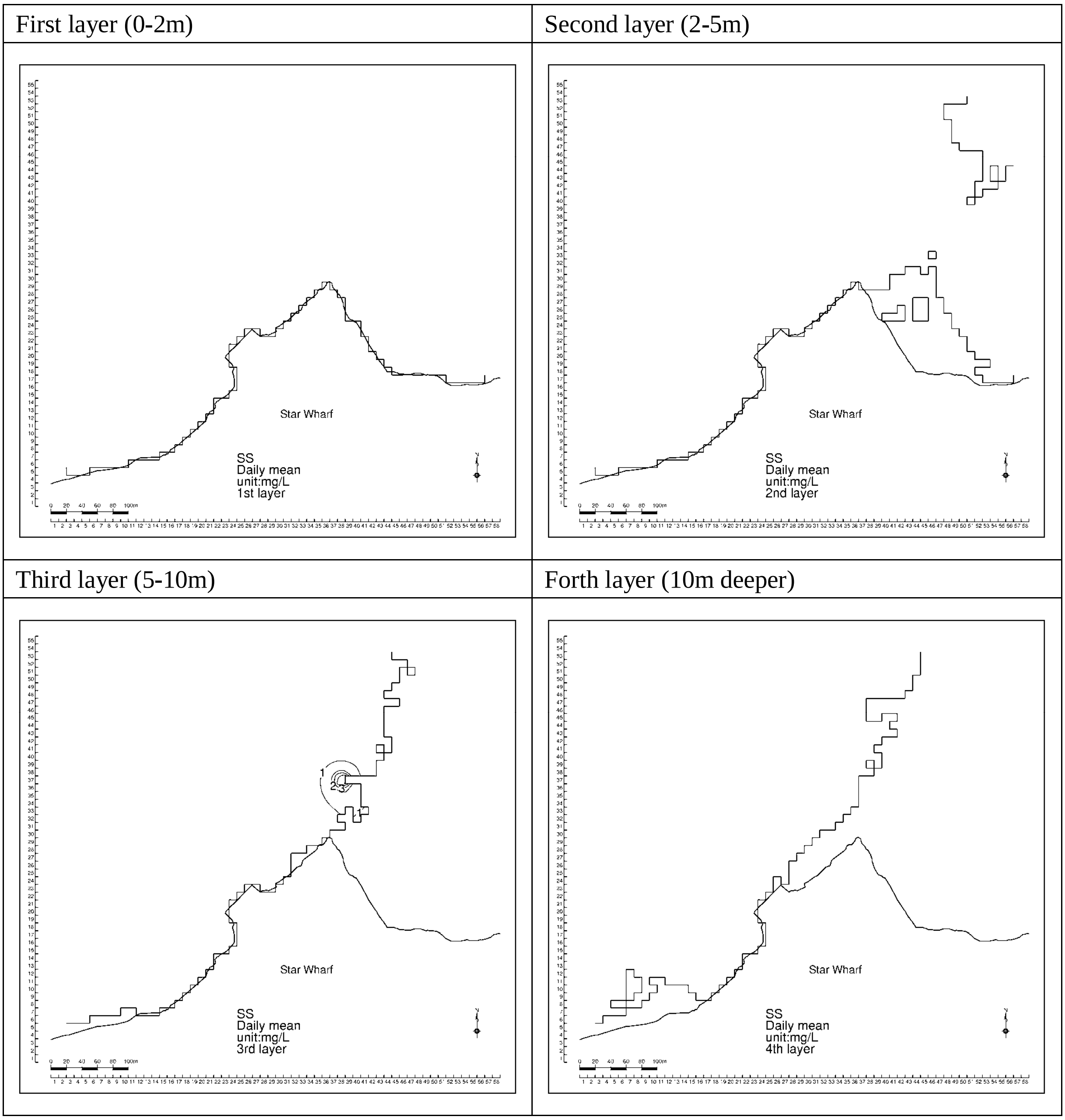
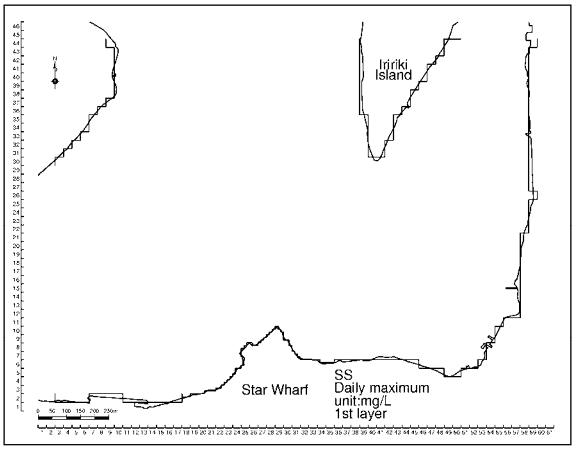
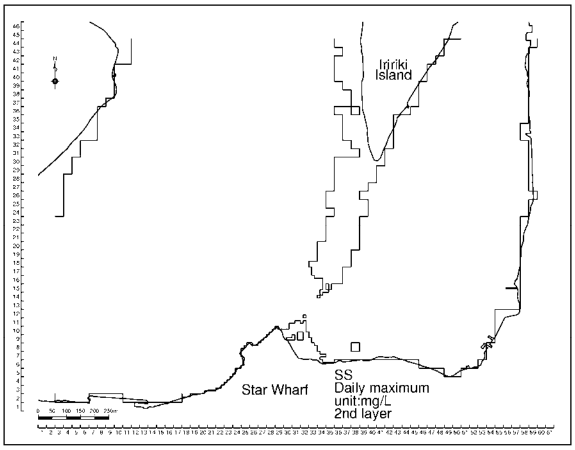


Figure 6.3.3-2(2) SS concentration
(Case2：Cutter-suction dredge[With silt protector], detailed domain, daily average)

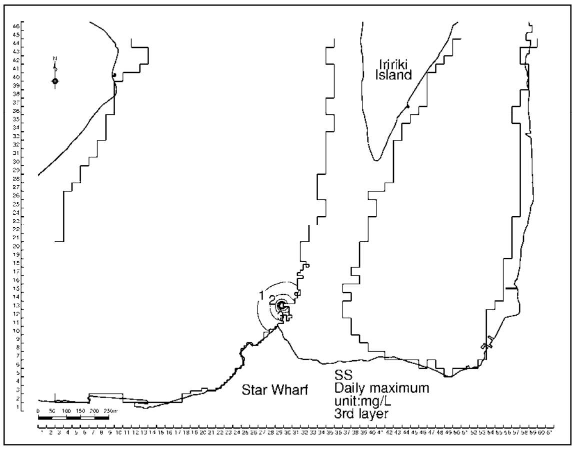
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

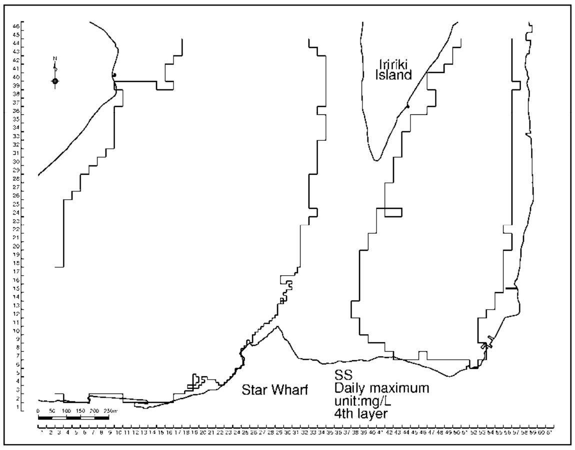


Figure 6.3.3-2(3) SS concentration

(Case2：Cutter-suction dredge[With silt protector],intermediate domain, daily maximum)

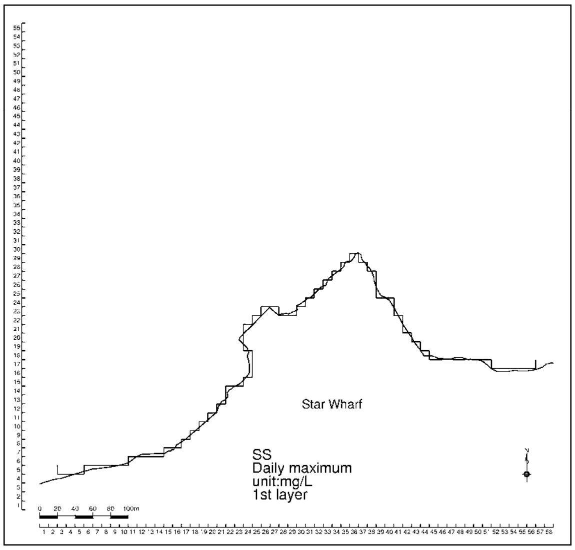
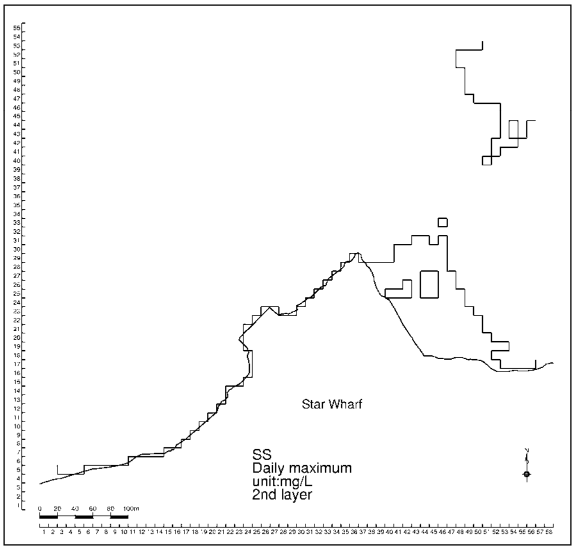
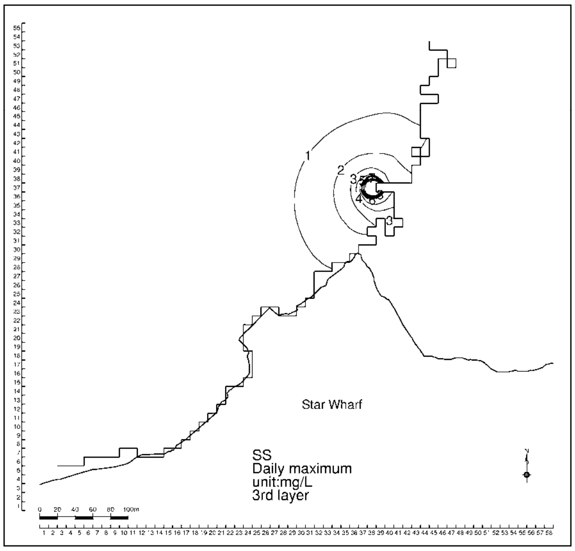
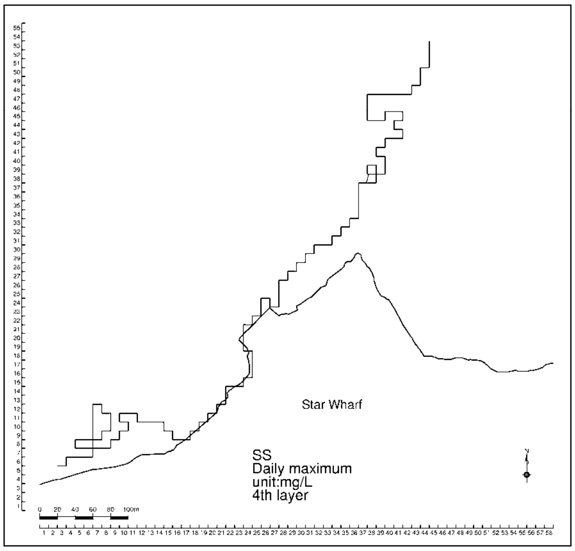
First layer (0-2m)	Second layer (2-5m)
	
Third layer (5-10m)	**Forth layer (10m deeper)**
	

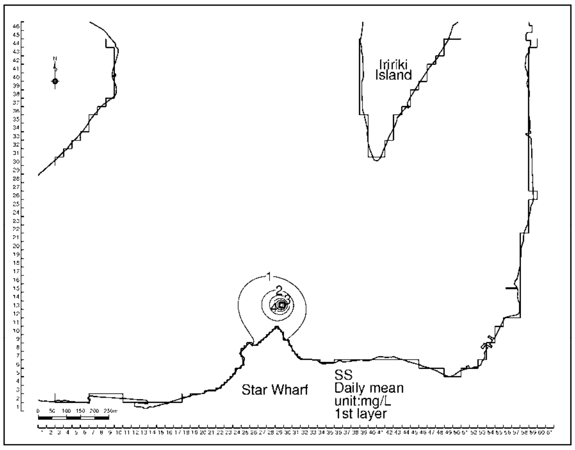
Figure 6.3.3-2(4) SS concentration
(Case2：Cutter-suction dredge[With silt protector], detailed domain, daily maximum)

(b) Case 3 and 4(Grab dredge)

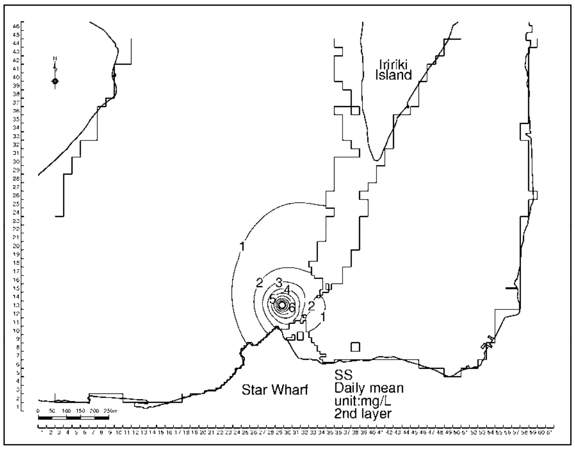
Results of case 3 and 4 are presented in Figure 6.3.3-3 and Figure 6.3.3-4 respectively. Daily average and maximum concentrations are shown for each case. In case 3, SS concentrations over 1mg/L are seen in all four layers and area of SS spread is most wide in the second layer (2-5m) among layers. In the daily maximum concentrations, a contour of 2 mg/L is within a sector with a radius of 200m centered the load point in the first layer (0-2m) , 250m in the second layer (2-5m) , 150m in the third (5-10m) and fourth layer (10m deeper), respectively .

In case 4 (with silt protector), SS spreading is suppressed compared with case3, and daily maximum concentration contours of 2 mg/L in layers are within sectors with radiuses of 100-200m centered the load point.

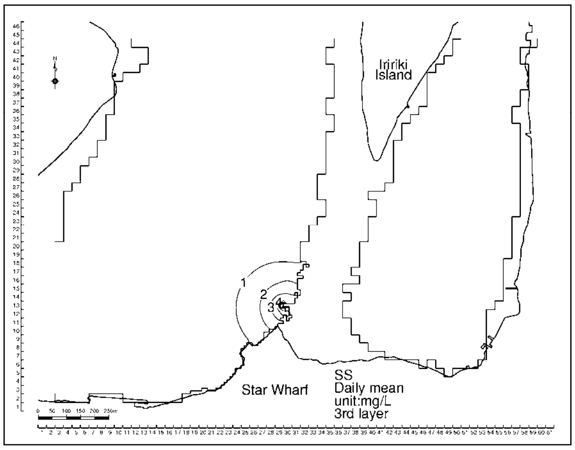
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

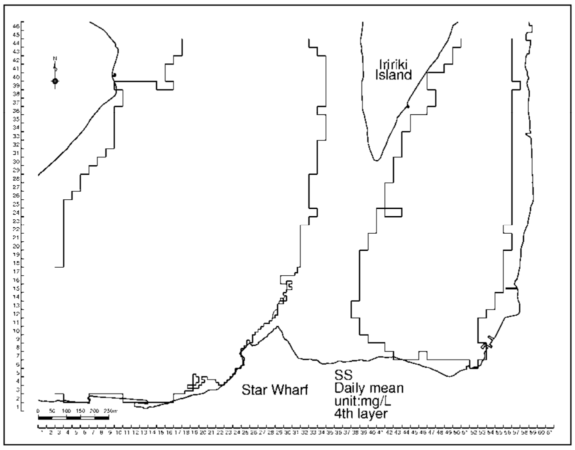
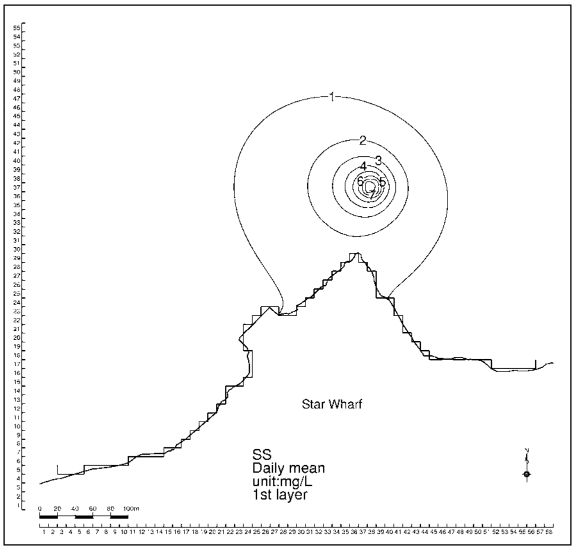


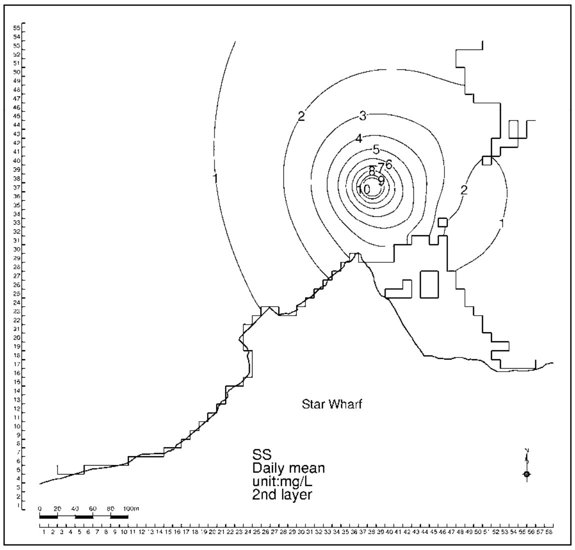
Figure 6.3.3-3(1) SS concentration

(Case3：Grab dredge[Without silt protector], intermediate domain, daily average)

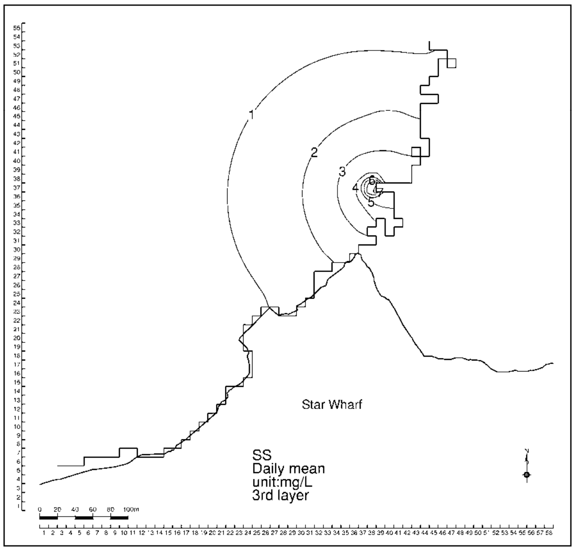
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

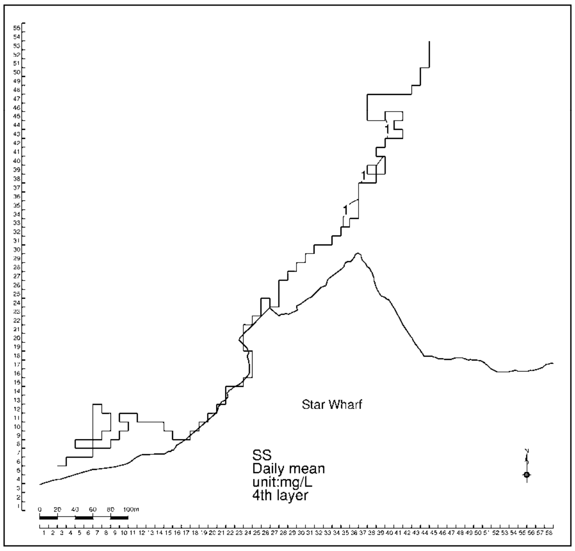


Figure 6.3.3-3(2) SS concentration

(Case3：Grab dredge[Without silt protector], detailed domain, daily average)

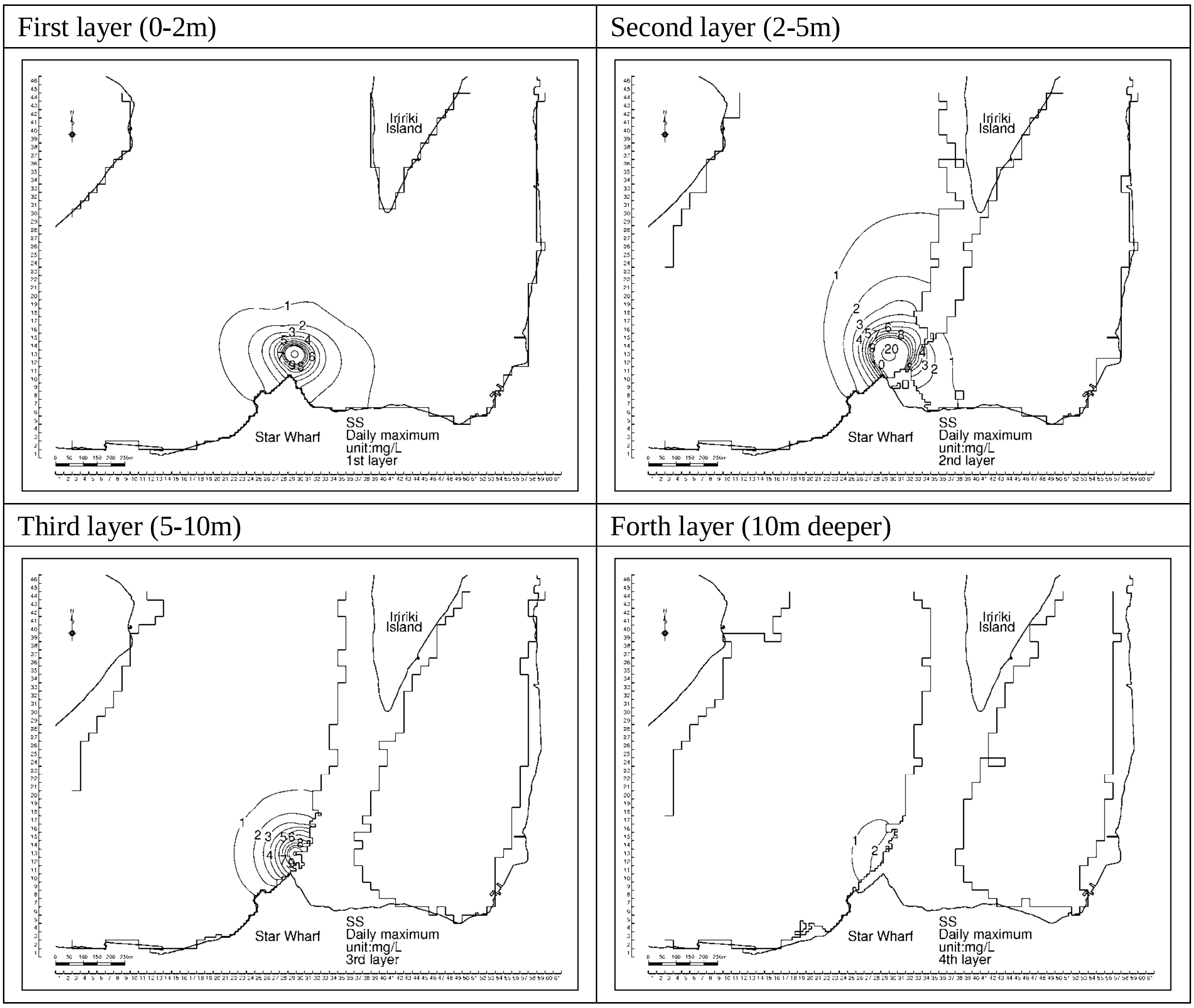
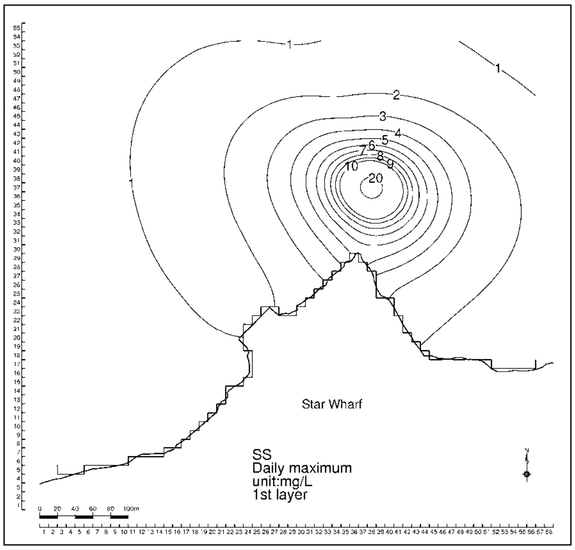
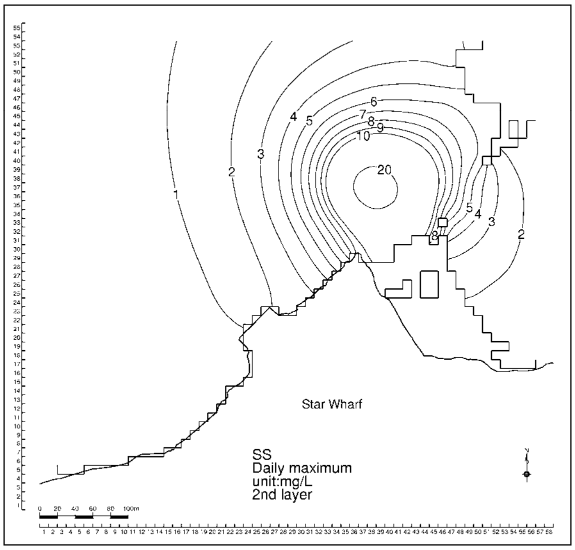


Figure 6.3.3-3(3) SS concentration
(Case3：Grab dredge[Without silt protector], intermediate domain, daily maximum)

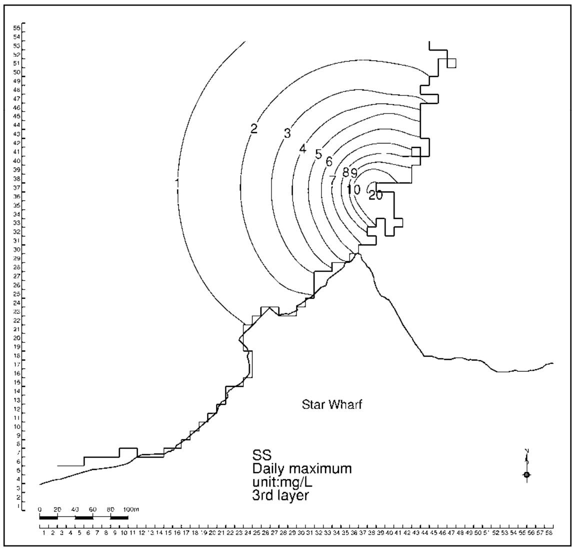
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

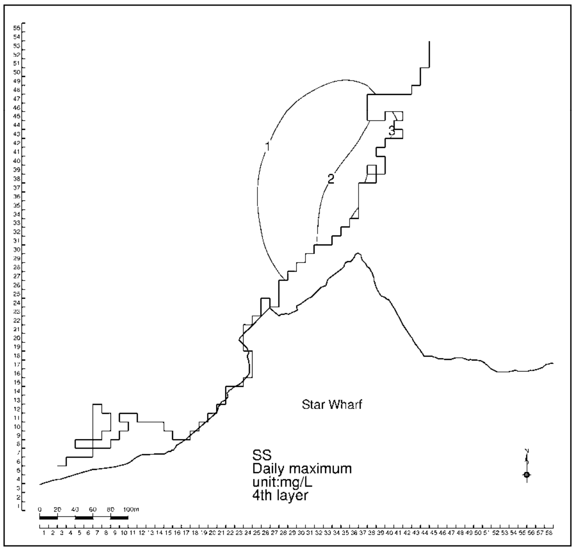


Figure 6.3.3-3(4) SS concentration
(Case3：Grab dredge[Without silt protector], detailed domain, daily maximum)

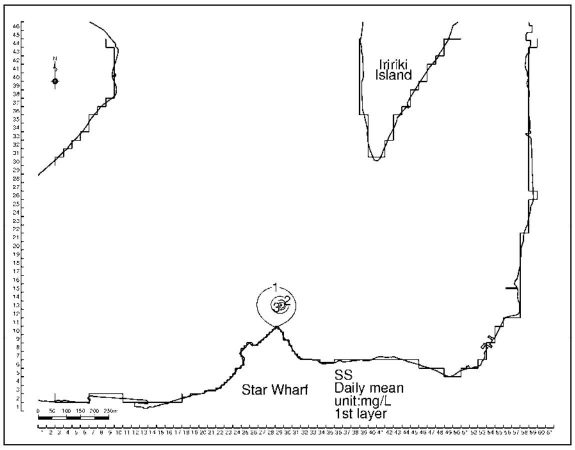
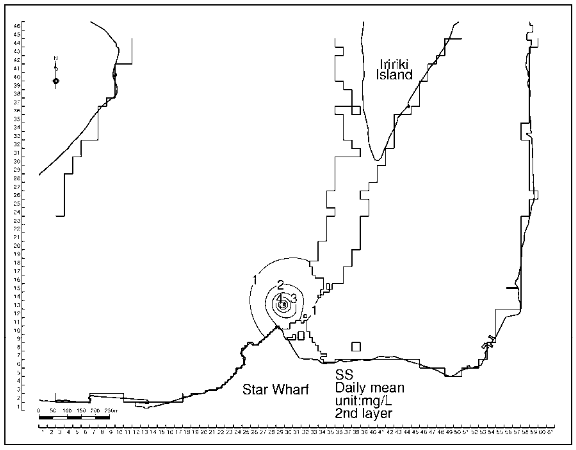
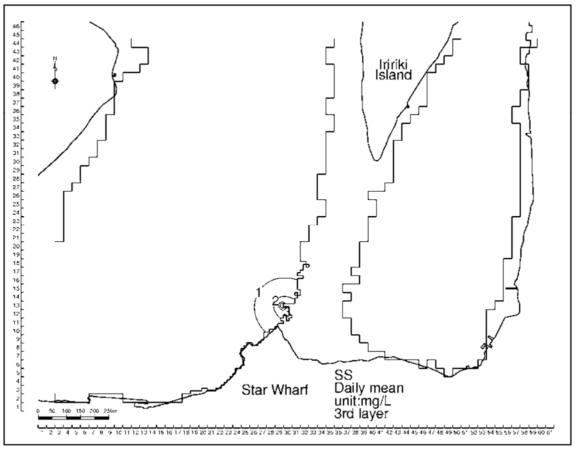
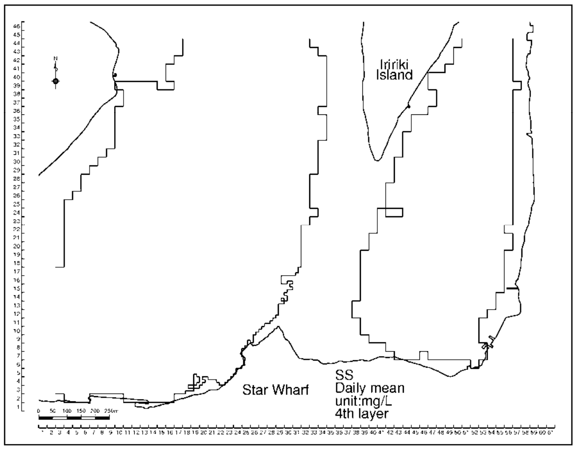
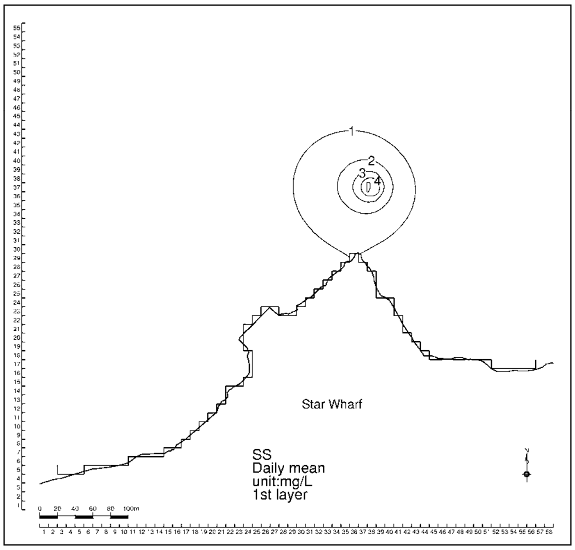
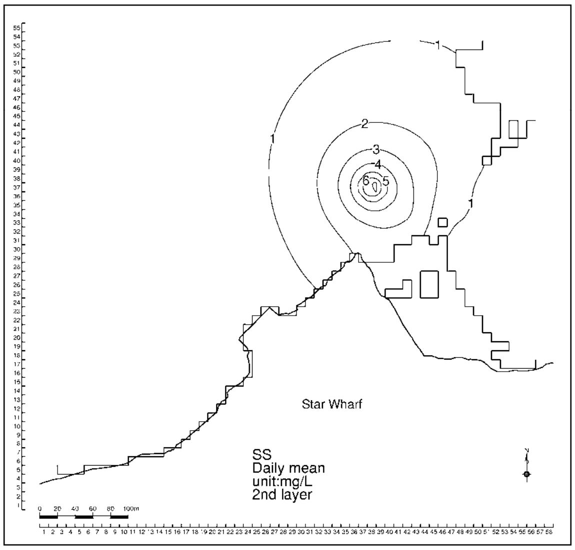
First layer (0-2m)	Second layer (2-5m)
	
Third layer (5-10m)	**Forth layer (10m deeper)**
	

Figure 6.3.3-4(1) SS concentration
(Case4：Grab dredge[With silt protector], intermediate domain, daily average)

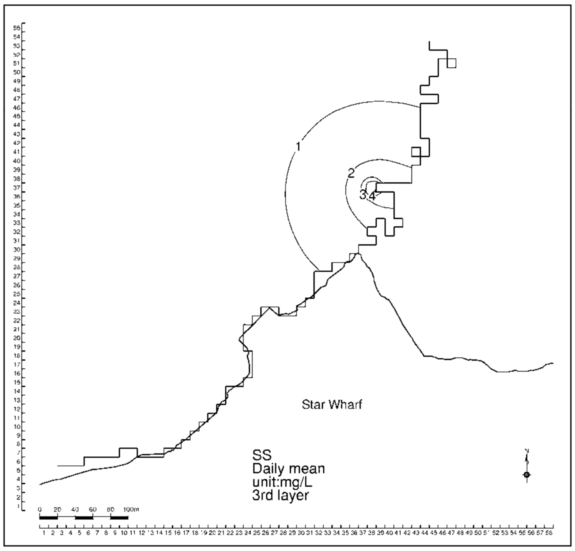
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

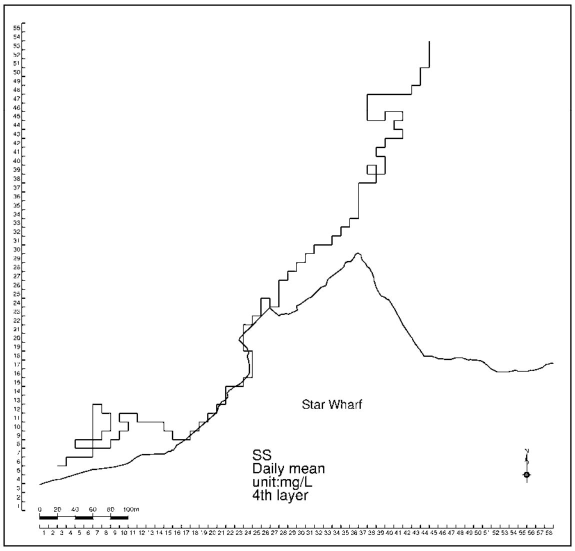
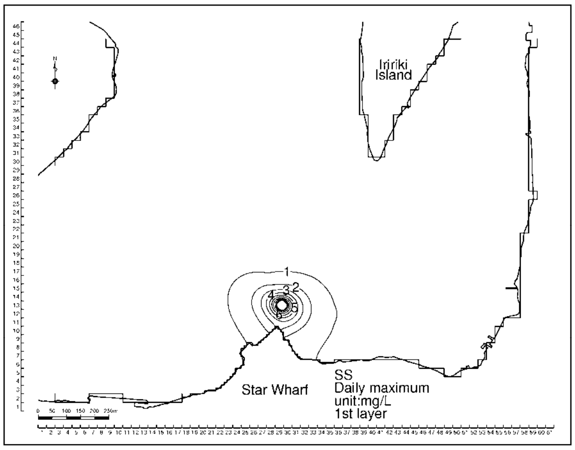
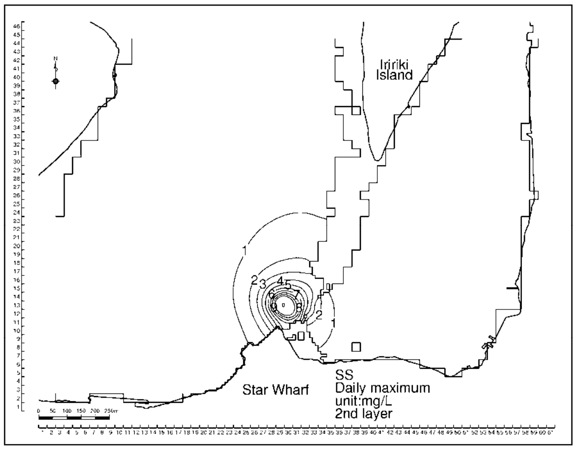


Figure 6.3.3-4(2) SS concentration
(Case4：Grab dredge[With silt protector], detailed domain, daily average)

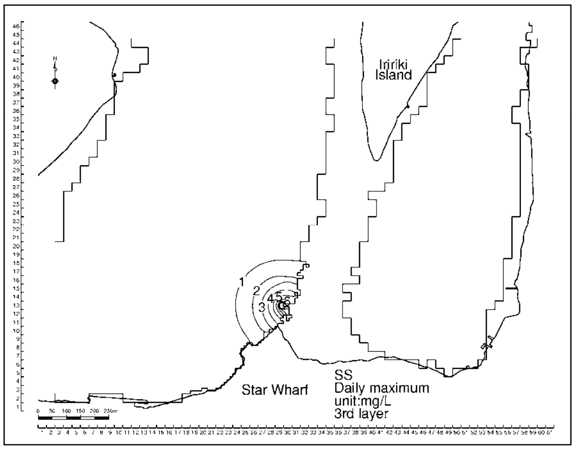
First layer (0-2m)



Second layer (2-5m)



Third layer (5-10m)



Forth layer (10m deeper)

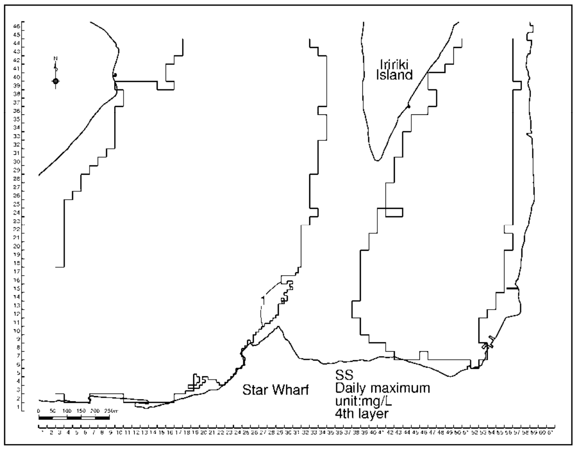


Figure 6.3.3-4(3) SS concentration

(Case4：Grab dredge[With silt protector], intermediate domain, daily maximum)

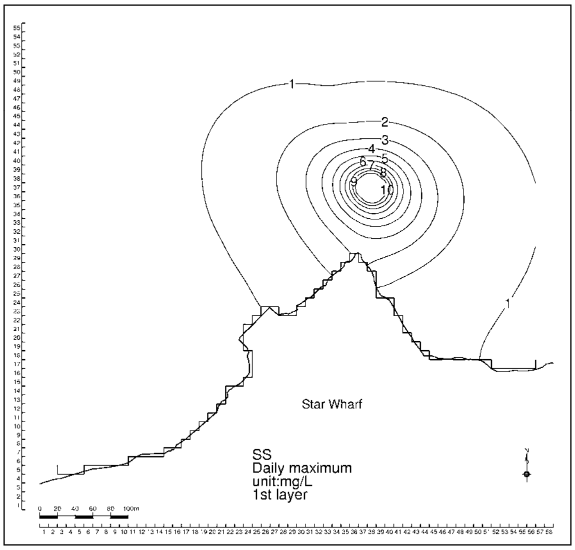
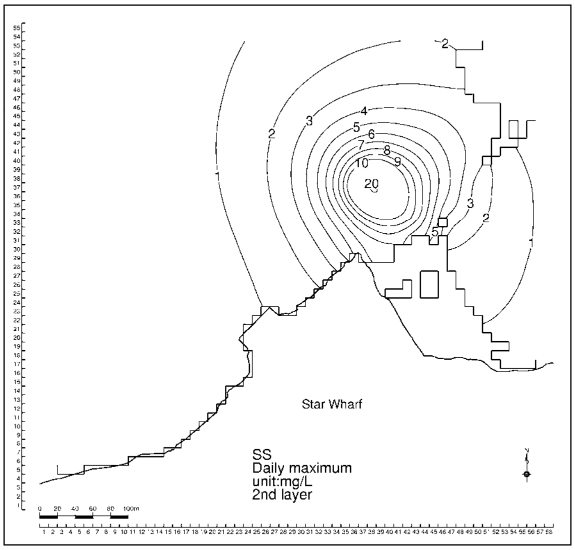
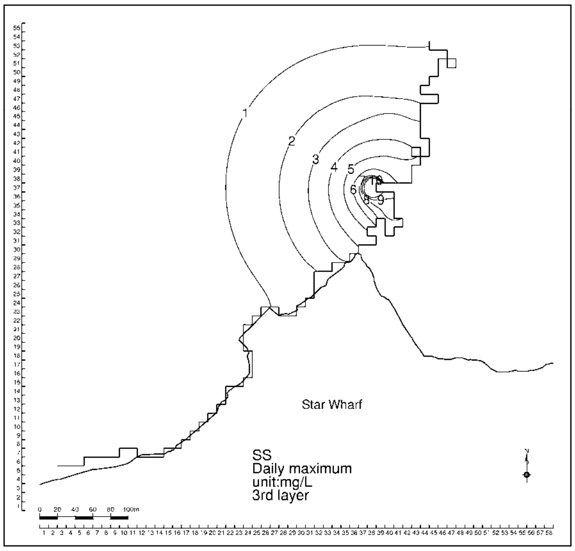
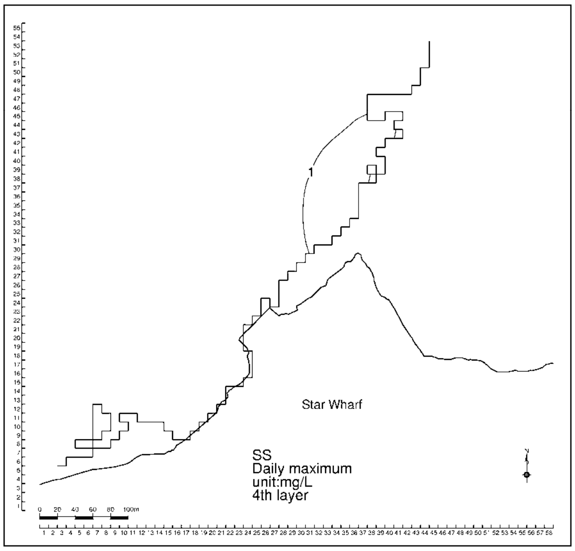
First layer (0-2m)	Second layer (2-5m)
	
Third layer (5-10m)	**Forth layer (10m deeper)**
	

Figure 6.3.3-4(4) SS concentration
(Case4：Grab dredge[With silt protector], detailed domain, daily Maximum)

(2) Silt deposition

Silt deposition is calculated as accumulated deposit amount of suspended sediment onto the sea bed from the prescribed SS simulation. This quantity has a unit of grams/m^2 and this is converted to the thickness using a formula previously mentioned. Although deposition amount obtained from the SS simulation is that per a day, this is multiplied by 30 days to form deposition amount per 30 days, because of planned dredging period of 30 days.

Table 6.3.3-2 Computation cases of silt deposition

Case name	Dredge method	Silt protector
Case1	Cutter-suction	Without
Case 3	Grab	Without

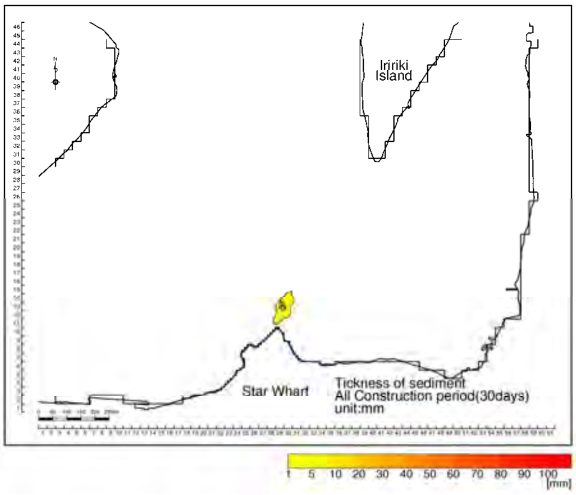
(a) Case1(Cutter-suction dredge)

Results of silt deposition computation onto the sea bed are shown in Figure 6.3.3-5. Area where deposit thickness is thicker than 1mm is within a circle of 60m radius centered the load point. A tendency can be seen that westward spread of deposit area is larger than eastward. The maximum thickness of deposit is predicted to be 10 mm, however this value becomes lower in reality because dredging point moves in a area to be dredged really, although dredging point is fixed in the simulation.

(b) Case3(Grab dredge)

Results of silt deposition computation of case3 are shown in Figure 6.3.3-6. Area where deposit thickness is thicker than 1mm is within a circle of 150m radius centered the load point. A tendency can be seen that westward spread of deposit area is larger than eastward. The maximum thickness of deposit is predicted to be 10 mm, however this value becomes lower in reality because of the same reason stated for case1.

Intermediate domain



Detailed domain

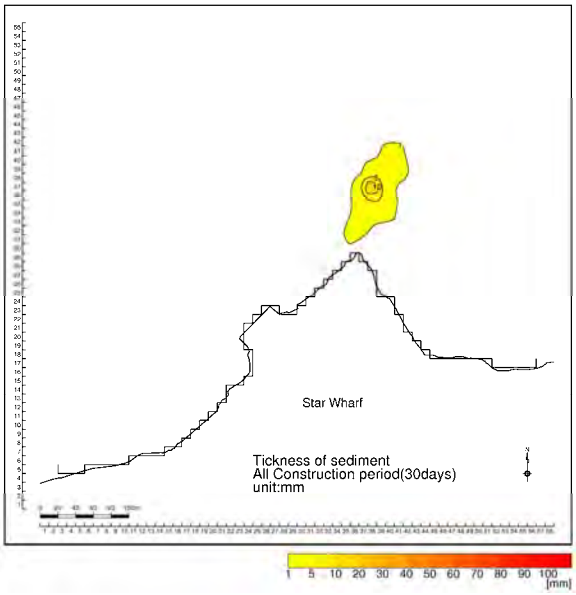
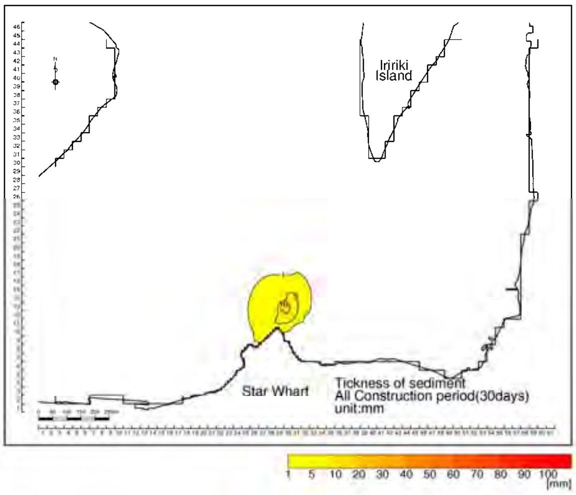


Figure 6.3.3-5　Silt depsition(Case1 ： cutter-suction dredge)

Intermediate domain



Detailed domain

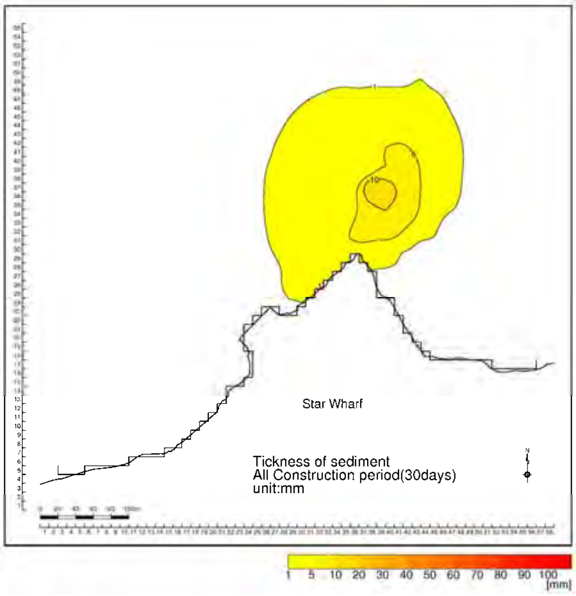


Figure 6.3.3-6　Silt depsition(Case3 ： grab dredge)

CHAPTER 7 Effects to Corals and Current due to implementation of the project and its mitigation

7.1 Impact assessment to implementation of the project

7.1.1 Extinction of corals by reclamation

Overlay figure of coral distribution and construction area is shown as Fig. 7.1.1-1.

Twenty five coral species belonged to Pocilloporidae, Acroporidae, Poritidae and Faviidae were confirmed in implementation and the vicinity area. *Porites, P. cylindrical and Psammocora contigua* in those species are confirmed as large colonies larger than 50 cm diameter.

Therefore, it is supposed that part of high coral coverage and large colonies corals are lost by reclamation.

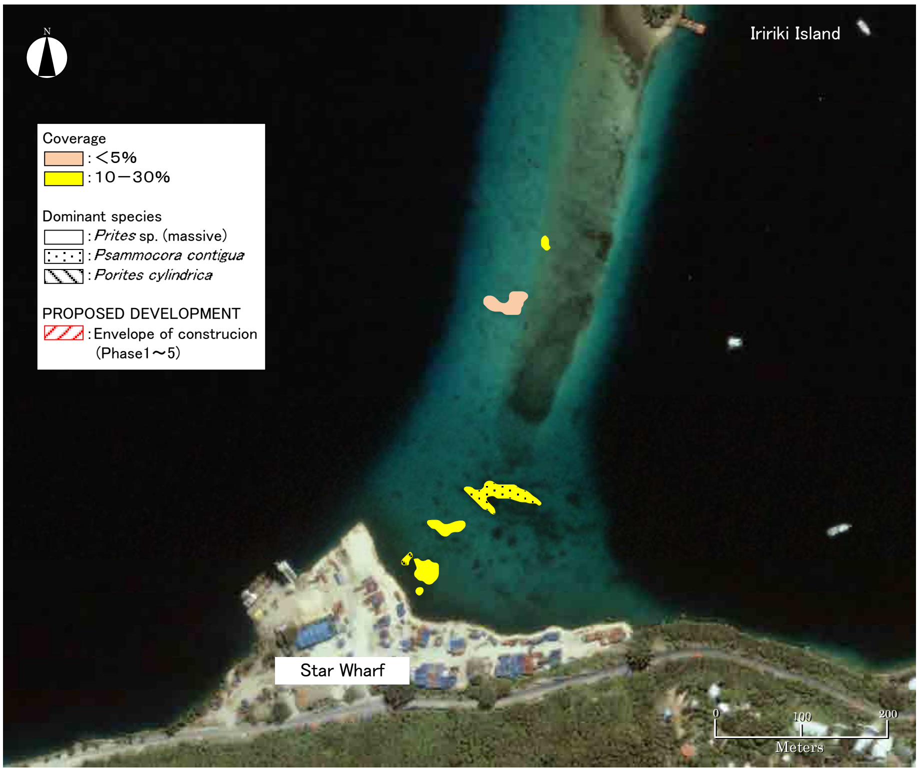


Fig. 7.1.1-1 Overlay of construction area to coral communities

7.1.2 Effect from flow change and silt deposition

(1) Effect from flow change

As shown in Fig. 7.1.2-1, the area of changes of current velocity is found at surface layer near the Star Warf, and the change of the current velocity is 1 ㎝/s lower. The area of velocity change tends to expand at ebb and low tides and be limited at flood tide. There is no area where velocity changes more than ±0.5 cm/s at high tide. Limited area where mean current velocity decreases 0.5 cm/s is seen near the predicted reclamation area.

Current direction does not change much from original situation although a little change occurs due to existence of predicted reclamation area.

Results from examination on change of water exchange in Port Vila Bay by the prediction indicated that apparent change on horizontal circulation in the Bay was not seen.

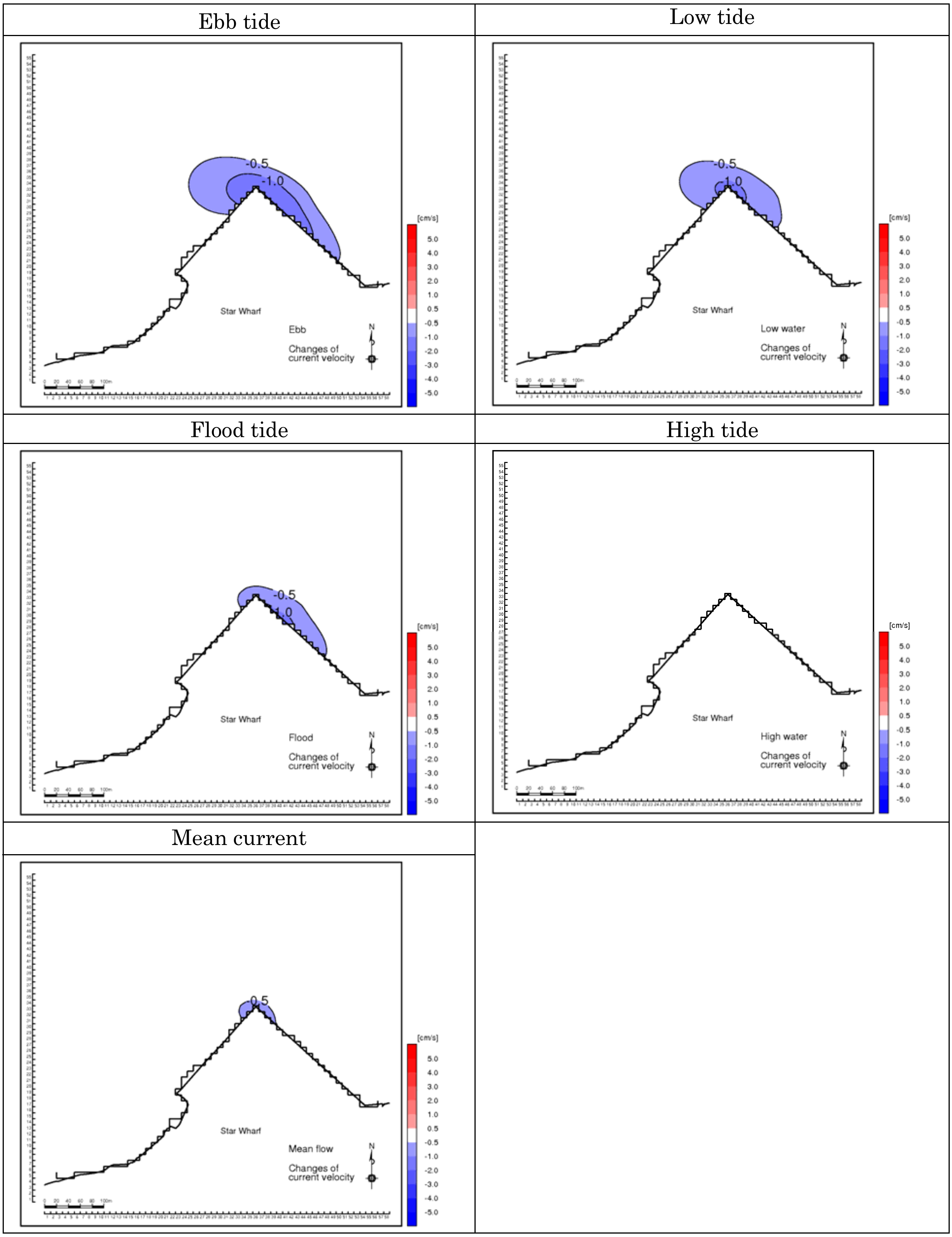


Fig. 7.1.2-1 Change of current velocity (Small region, First layer)

(b) Effect on flow change to coral

Corals are differed adaptation range of current velocity according to species and size. In general speaking, place affected by current and wave is suitable for coral growth. Decreasing of flow velocity may induce possibility of growth decline. However, change of velocity is approximately 1 cm/s so that effect on it to coral is predicted negligible although current velocity is predicted to be smaller than original situation. Area where current velocity changes is seen near the predicted reclamation area as shown in Figs. 7.1.2-2 to 7.1.2-4.

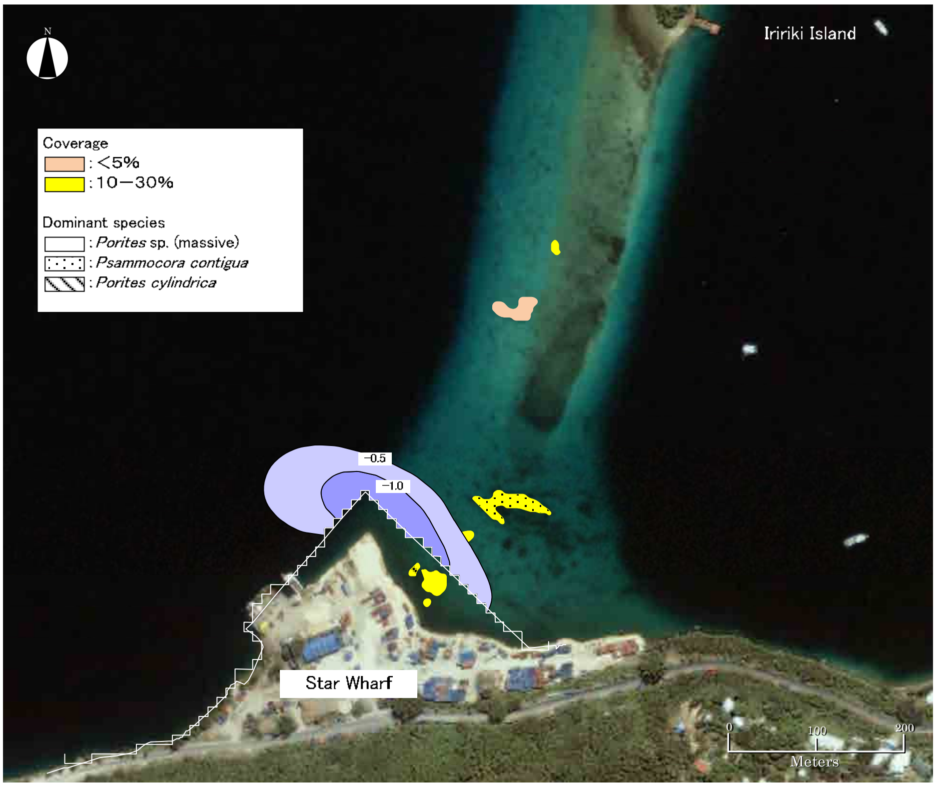


Fig. 7.1.2-2 Overlay of value of current velocity change to coral communities (ebb tide)

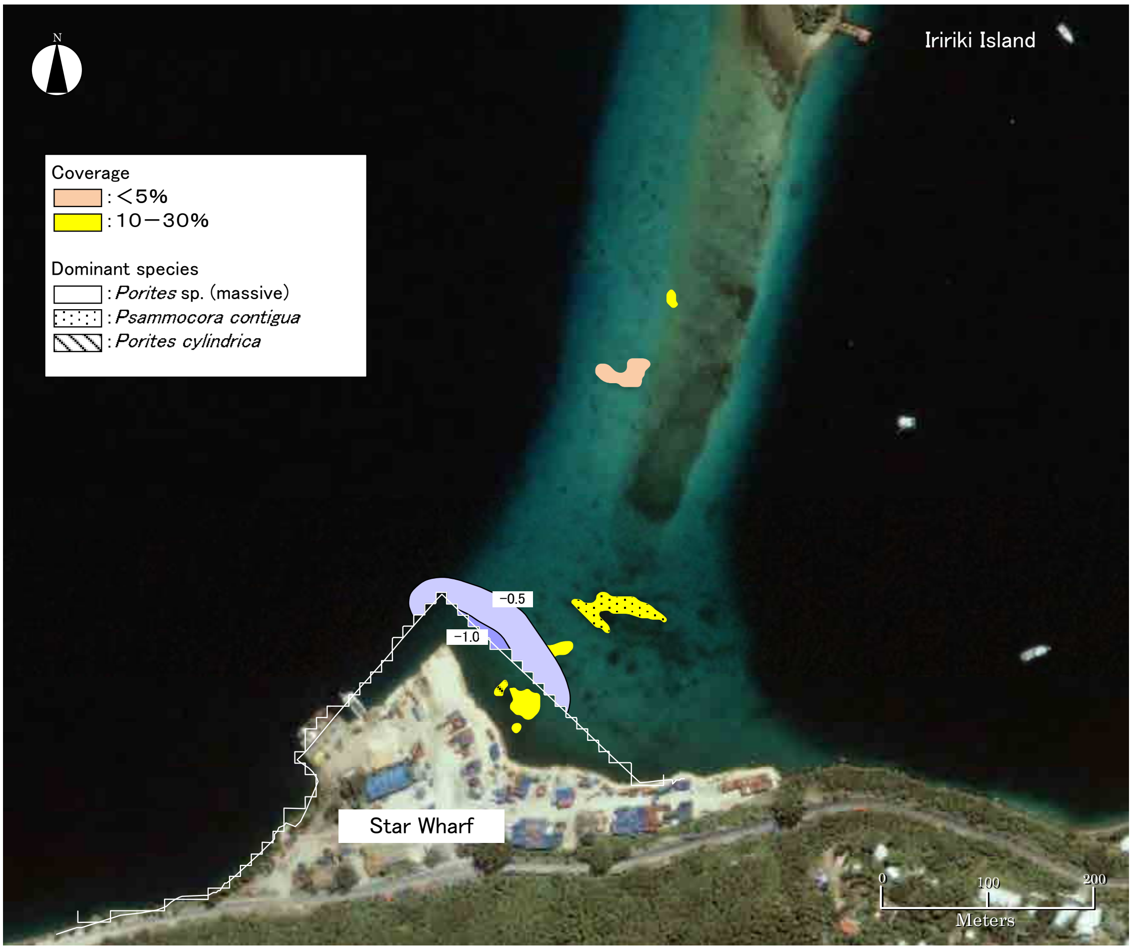


Fig. 7.1.2-3 Overlay of value of current velocity change to coral communities (flood tide)

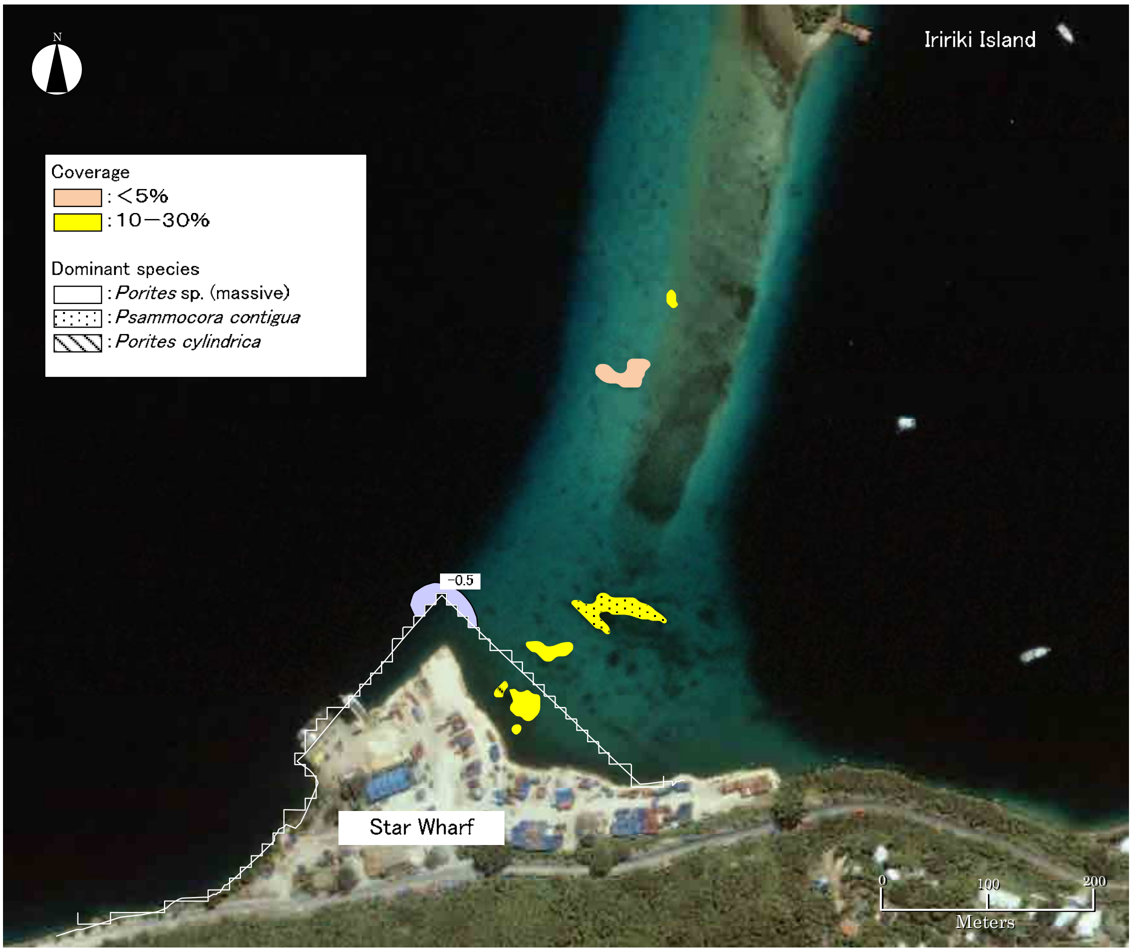


Fig. 7.1.2-4 Overlay of value of current velocity change to coral communities (mean current)

(2) Effect from diffusion and deposition of silt

(a) Prediction of silt diffusion

Silt diffusion in construction phase of implementation of Star Wharf project indicates SS dispersion near the dredging area as shown in Figs. 7.1.2-5 to 7.1.2-6. In case of pump dredging, diffusion of turbid material is not seen in surface layer. SS occurs around sea bottom and expand horizontally. On the other hand, in case of grab dredging, diffusion of turbid material is seen all layers. Diffusion range of SS is predicted that in case of pump dredging, it limits smaller area than in case of grab one. Installment of silt protection curtain can make dispersion range decrease.

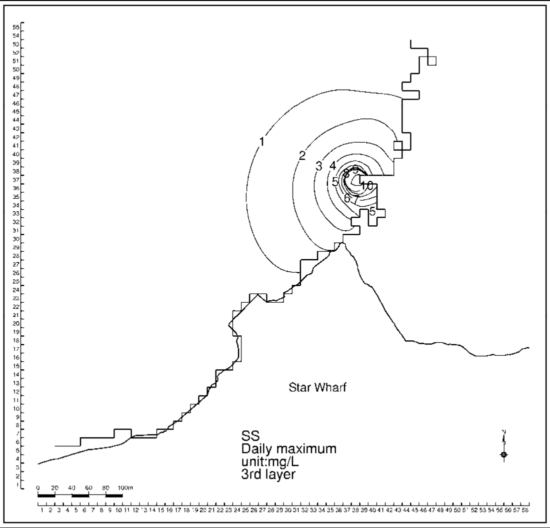
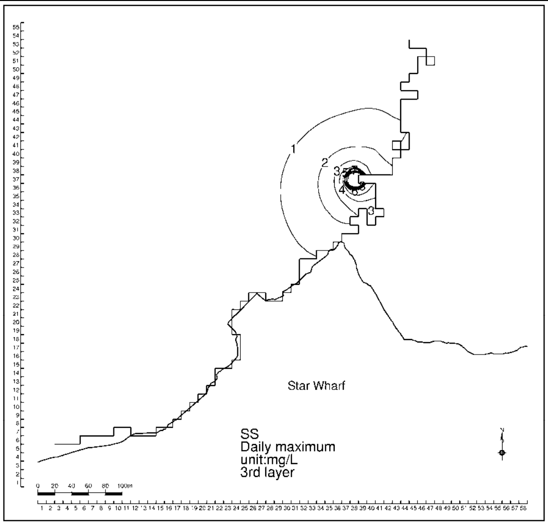
Without silt protection curtain	With silt protection curtain
	

Fig. 7.1.2-5 SS distribution of daily maximum concentration (small region, pump dredging, 3rd layer: 5 to 10m)

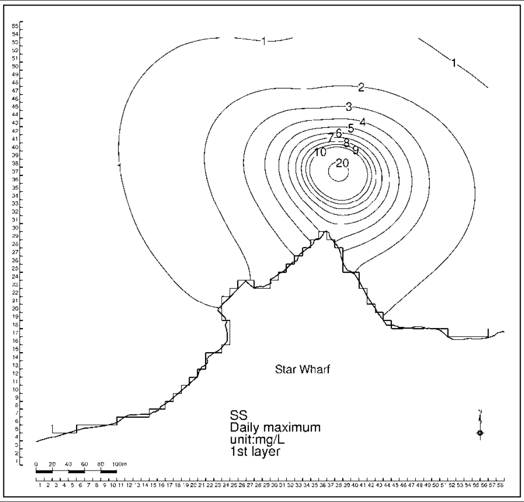
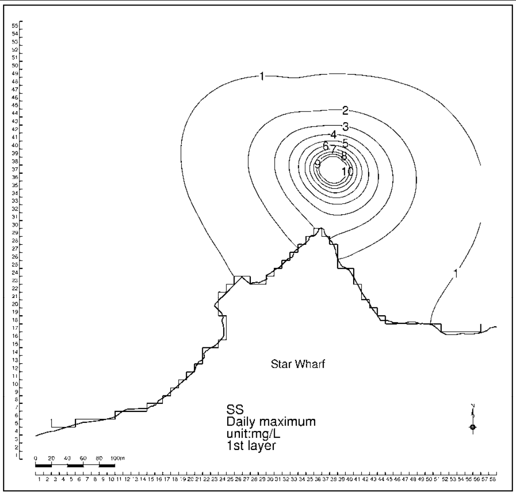
Without silt protection curtain	With silt protection curtain
	

Fig. 7.1.2-6 SS distribution of daily maximum concentration (small region, grab dredging, 1st layer: 0 to 2m)

(b) Prediction of silt deposition

Range of deposition thicker than 1mm is predicted to include area within 60m radius from construction place in case of pump dredging and 150m radius in case of grab dredging. Both cases indicated that deposition range tended to expand westward from construction place.

In this prediction, it is hypothesized that construction is carried out at same place during construction phase. In real case, because construction place usually moves slightly, deposition thickness is estimated to be thinner and wider.

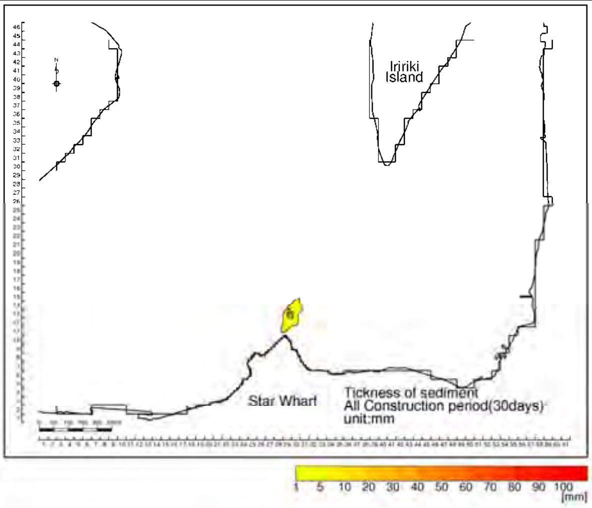
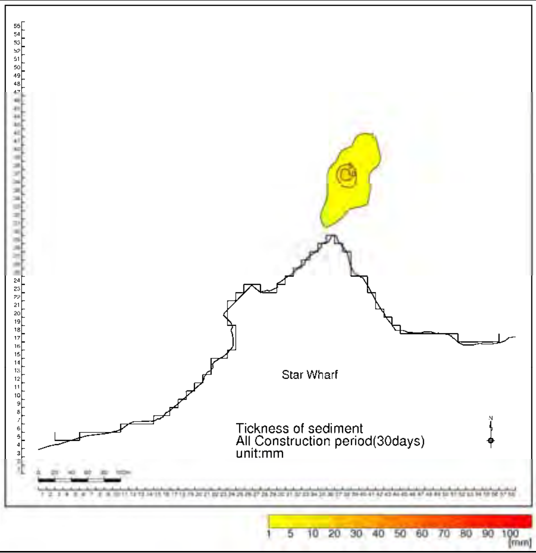
Middle region	Small region
	

Fig. 7.1.2-7 Distribution of SS deposition (Pump dredging)

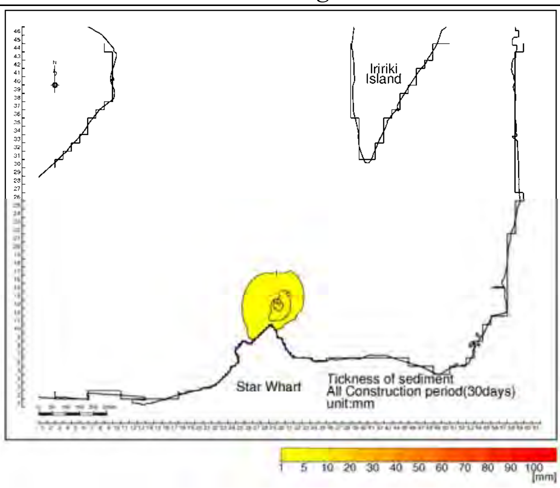
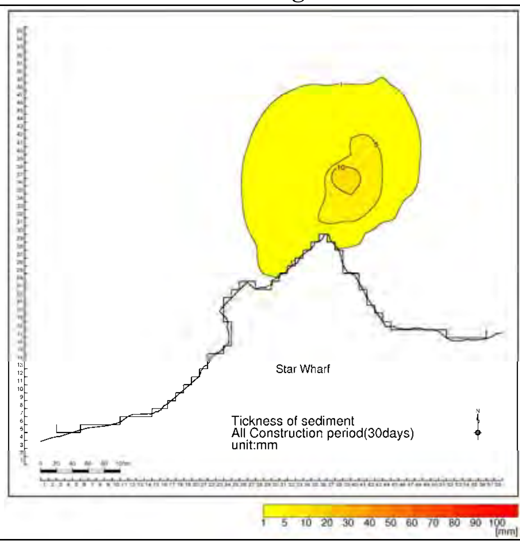
Middle region	Small region
	

Fig. 7.1.2-8 Distribution of SS deposition (Grab dredging)

(c) Effect from diffusion and deposition of silt

In case of pump dredging, distribution of daily maximum concentration of SS does not reach to coral distribution area, but the one produced by grab dredging reaches the coral habitat. Distribution of deposition of SS produced by both pump dredging and grab dredging do not reach the coral habitat. Therefore, when grab dredging is used, diffusion of silt can give adverse effect on the corals, and thus, it is recommended to select pump dredging. However, even when pump dredging is used, the turbid material occurs and deposits near the coral habitat, and thus, the coral may be affected depending on the flow regime. In case soil, sand or silt that flows out deposits on the corals, photonic synthesis activity of zooxanthella that cohabit with the corals is deteriorated, gives adverse effect on their growth. And at the same time, the corals secrete much mucus for removing the deposits from their surface, possibly debilitating themselves. Moreover, during vulnerable period such as high water temperature period during which bleaching occurs easily, the deposits may give more adverse effect on the corals.

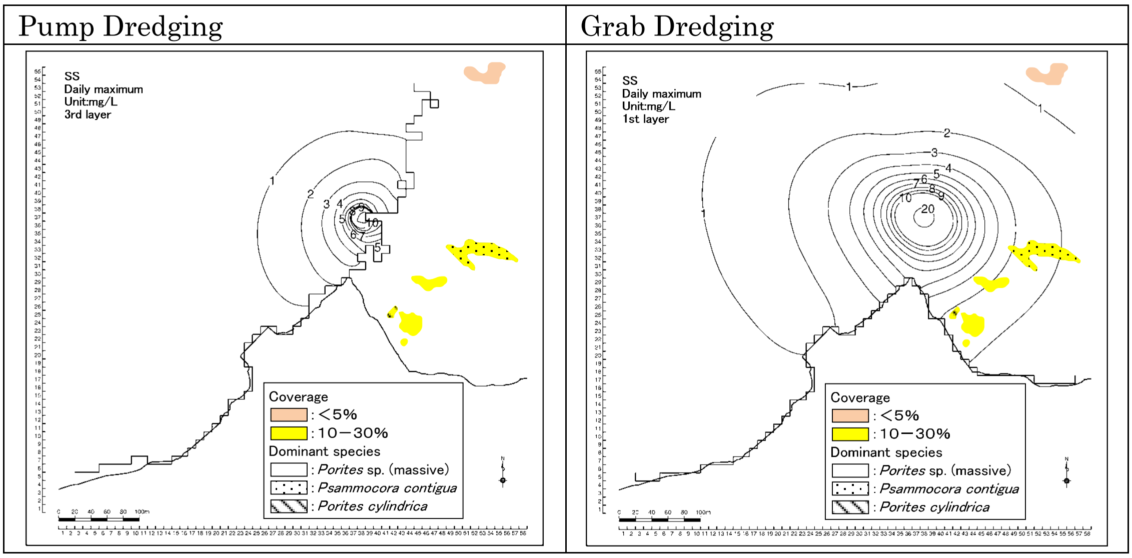


Fig. 7.1.2-9 Overlay of SS distribution of daily maximum concentration to coral communities

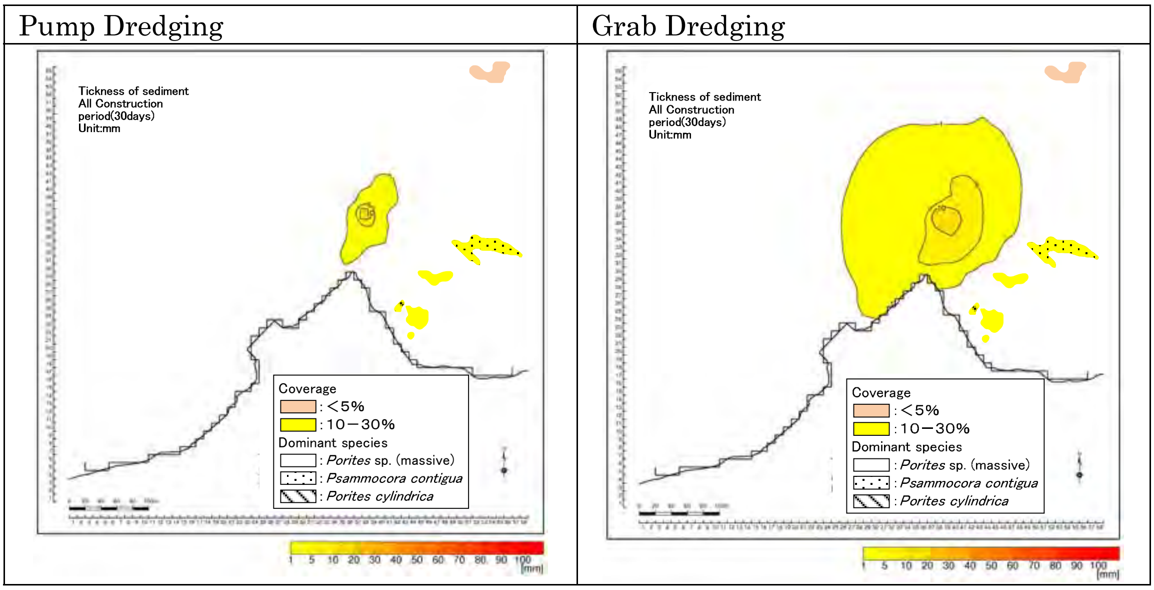


Fig. 7.1.2-10 Overlay of distribution of SS deposition to coral communities

7.1.3 Effects on construction to others

According to the Ecostrategic Consultants, three individuals of dugongs inhabit in Mele Bay and sometimes enter to Port Vila Bay but they only come to around Marapoa Reef where sea grass beds support, not to pontoon and Paray Bays. Turtles occur all around the sea of Vanuatu but scarcely come to Port Vila Bay except for accidental visit because of lack of suitable beech to nest. Therefore,

Effects on conservation to those animals are considered to be negligible.

7.1.4 Effects from human activities activated

This project influences water quality of Port Vila Bay scarcely and does not occur water quality deterioration directly. Because population concentration to Port Vila City and Efate Island has already occurred so far, it does not link with harbor development directly. Harbor development is planned on background that international cargo of container volume has increased due to economic development so that harbor development itself does not induce increasing of cargo volume and rapid economic development of Port Vila City.

However, there is a fact that harbor development can contribute to economic development of Vanuatu and consequently it is considered that harbor development has possibility to influence to water quality more than before indirectly in Port Vila Bay.

7.1.5 Effects from sea water temperature to coral bleaching

Sea water temperature data collected by the study in the project area are shown in 5.2.3. No bleaching was found in the field survey (see 5.1.1). Coral bleaching normally occurs when sea water temperature is more than 30 degree C. Coral bleaching is not considered to be occurring because the sea water temperature during the survey ranged 27 to 28 degree C.

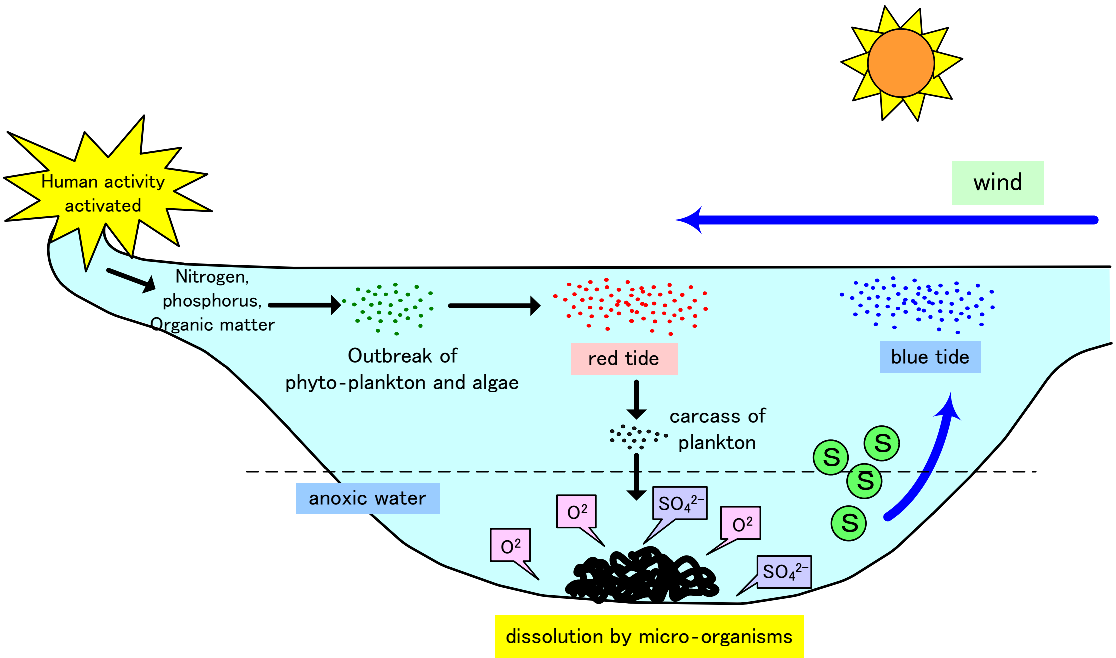


Fig. 7.1.4-1 Example of effects from human activities activated

(Modified from Website of Graduate School of Frontier Sciences, University of Tokyo)

7.1.6 Scoping results for the whole project

After reflecting impacts to the environment described in this chapter based on the study results to the scoping in 4.2, items evaluated as C- (Additional verification is necessary as impact level is not clear) are determined as shown below.

Item	Construction phase	Operation phase	Evaluation Basis
Natural Environment			
Hydrology	D	B-	Although there was a possibility to change currents due to landfills etc., the change was predicted to be minimal by the study.
Pollution measure			
Sediment	B-	D	A prediction was conducted in the study because silt diffusion was envisaged during dredging. As a result, possibility of silt diffusion was recognized.

For the item which was described to need detailed survey but not need evaluation change, the evaluation basis was determined as shown below.

Item	Construction phase	Operation phase	Evaluation Basis
Natural Environment			
Fauna, flora and ecosystem	B-	B-	About 60 planted-species trees will be transplanted, which does not cause major impact. Although fruits of the trees are being used as food or medical purpose by local community, the number of transplanted tree is limited and impact to livelihood of the people is minor. Fauna originally living in the project area does not exist. Although wild birds and bats are using the project area as habitat, impact is considered minor because the habitat is not limited to the project area. Two (2) species of bat, *Pteropus anetianus* (Vanuatu flying fox) and *Notopteris macdonaldi* (Fijian blossom bat) which are categorized as VU (Vulnerable) by IUCN red list, are living in Efate Island. As their feeding area is forest or orchard, impact by this project is not considered. As for bird species, *Charmosyna palmarum* (Palm Lorikeet), *Erythrura regia* (Royal Parrotfinch), *Megapodius layardi* (Vanuatu Megapode) categorized as VU and *Esacus giganteus* (Beach Thick-knee) categorized as NT (Near threatened), are

Item	Construction phase	Operation phase	Evaluation Basis
			living in Efate Island. *M. layardi and E. giganteus* are endemic species. As their habitat is mainly mountain area or mangrove and estuary, impact by this project is not considered. In the coastal area, marine benthic organisms living in coral habitat will be affected by 1.6ha of reclamation.

7.2 Mitigation measures

7.2.1 Mitigation against extinction by reclamation

Massive *Porites* and *P. cylindrica* support in large scale rather than moderate in the predicted reclamation area. Because high coverage community of *P. cylindrica* especially indicates rare presence in Port Vila Bay where shallow area is limited and thus growing conditions are limited, it should be relocated to adequate area as well as massive *Porites*. Adequate relocation makes volume of outcrop, reproduction and habitat keep and then contributes coral reef conservation of Port Vila Bay.

(1) Distribution of main corals in the predicted reclamation area

As mentioned in the 5.1.4, dominant corals in the predicted reclamation area are massive *Porites* and *P. cylindrica*. Both species usually occurs calm waters. The former is also seen commonly in the mouth of Vatumaru Bay other than the predicted reclamation area but *P. cylindrica* is limited to distribute in north of Ifira Island. Although *P. cylindrica* in the predicted reclamation area is small scale but it is valuable in Port Vila Bay because of relatively high coral coverage community. Both Pontoon and Paray Bays have steep bottoms and only shallow area near Star Wharf allows distribute both species. Therefore, it is required that those corals in the bay head area are relocated to similar environmental place and survived as much as possible.

Corals in the predicted reclamation area are 127 colonies on massive *Porites* and approximately 20 square meters on *P. cylindrica*. Because those corals support in shallow area of 1.5 to 2.1 m in deep, it is difficult to transport them by large boat. Therefore, massive corals are limited to scale that can be transported by small boat. According to scale of boats which can be hired in Port Vila Bay, corals less than approximately 2m diameter are adequate for relocation. Those are 121 colonies on massive *Porites* and some 20 square meters on *P. cylindrica* as shown on Table 7.2.1-1.

Table 7.2.1-1 Corals to be relocated (Yellow hatch)

Range		A		B		C
Dominant species		Massive *Porites*		Massive *Porites*		*Porites cylindrica*
Item		No. of colonies	Area (㎡)	No. of colonies	Area (㎡)	Size of community (㎡)
Longer diameter of colonies	<1m	97	19			ca20
	1 to 2m	19	34	5	9	
	2 to 3m	5	25			
	>3m	1	10			
Total		122	122	88	5	9
Total no. of colonies to be transplanted		116	53	5	9	ca20

(2) Discussing relocation method

There are many methods on transplantation and relocation of existing corals in the world. Those are compiled as the Reef Rehabilitation manual[1] by the fund of World Bank as follows (Table 7.2.1-2).

Table 7.2.1-2 Classification of transplantation and relocation methods

No	Contents of transplantation and relocation	Country	Region
1	Substrate stabilization to promote recovery of reefs damaged by blast fishing	Indonesia	Komodo National Park
2	Transplantation of coral colonies to create new patch reefs	Tuvalu	Funafuti atoll
3	Transplantation of coral fragments and colonies at tourist resort using coated metal frames as a substrate	Maldives	
4	Use of artificial substrate to enhance coral and	Thailand	Phuket

[1] Edwards AJ (ed) (2010) Reef Rehabilitation Manual, Coral Reef Targeted Research & Capacity Building for Management Program

	fish recruitment		
5	Transplantation of nursery reared corals to a degraded reef	Israel	Eilat
6	Re-attachment and monitoring of broken fragments following a ship grounding	Puerto Rico	Mona Island
7	Coral transplantation, using ceramic coral settlement devices	Japan	Sekisei Lagoon
8	Transplantation of corals to a traditional no-fishing area affected by coral bleaching	Fiji	Moturiki Island
9	Transplantation of coral fragments onto artificial reefs at a hurricane-damaged site	Mexico	Cozumel
10	Rehabilitation of a reef damaged by blast-fishing by stabilizing rubble using plastic mesh	Philippines	Negros Island

In those methods, ones on existing coral transplantation are examples of Tuvalu, Maldives, Israel, Puerto Rico, Fiji and Mexico. Those examples are the method of fixing coral fragments by adhesive.

In case of this project, *P. cylindrica* exists as called floating coral which does not settle on the bottom so that they should be relocated as same situation to the similar environmental place. However, it needs that relocated colonies are surrounded by plastic net for reinforcing until colonies become stable. Massive *Porites* can not be fixed by adhesive due to large and should be stable using steel stake. This method is introduced in the transplantation method manual issued by Ministry of the Environment, Japan[2].

(3) Minute transplanting method

Boats in Port Vila Bay are not suitable for handling large corals more than 2m diameter using large scale equipment because they do not have wide working space on the deck or strong power engine. Therefore, following method is recommended in case of large scale transplantation by divers and using boat in Port Vila Bay.

In general speaking, massive *Porites* is considered as relatively tolerant species to high temperature severely. That place emerges at law tide in spring tide. Therefore, massive *Porites* can be relocated by that they are pulled up on a boat, put into sea water tank, covered by a wet cloth and transported without damage.

For *P. cylindrica*, 4 sea water tanks of 1 square meter are provided to transport colonies without

[2] Nature Environment Bureau, Ministry of the Environment (2003) Manual on Coral Reef Remediation

emerging from tank.
It is predicted that some 25 massive *Porites* colonies can be relocated for a day and 121 colonies in 62 square meters can be relocated for 5 days. *P. cylindrica* can be relocated on 8 square meters colonies for a day and done on 20 square meters for 3 days.
It is commented by Prof. Mineo Okamoto, Tokyo University of Marine Science and Technology, who is a specialist on coral transplantation that those methods are adequate for coral relocation.

(4) Monitoring after relocation

Relocated corals are required to be monitored and managed adequately if ones are smothered by algae or eaten by predators. Monitoring is carried out one, six and twelve months and one to two years interval after relocation and continued for 5 years. Sampled volume for monitoring is usually 10 % of relocated colonies.
Sampled volume is 2 square meters for *P. cylindrica* and some 6 square meters for massive *Porites*. Quadrat of 0.5m x 0.5m is used. Monitoring items include dead tissue part, growth volume, bleaching, predation, sedimentation, algal smothering and inhabiting animals.

(5) Relocation and monitoring system

(a) Charged organization

The relocation is charged with the project operator and should be supervised by the Department of Fisheries that is a specialist on marine biology. Department of Fisheries discussed with us and agreed on it. It is supposed that a researcher supervise on the work during relocation. Equipments other than diving gears are not needed. Relocation work is adequate to ask a marine consultant that has much experience on one.
Monitoring is required to be carried out by Department of Fisheries that agrees operation from one year later with long-term monitoring in Port Vila Bay. Monitoring needs to buy a underwater camera.

(b) Budget

Operational fee is as shown on Table 7.2.1-3. Monitoring needs no budget without personnel cost.

Table 7.2.1-3 Budget for relocation (yen)

Items	Total cost	Personnel cost	Equipments cost	Remarks
Planning	1,319,604	461,400 (6 Chief engineers, 6 Engineers)	858,204	
Pre-survey	213,031	82,600 (1 Engineer, 2 divers)	130,431	

Relocation work	7,368,714	1,454,400 (1 Engineer, 1 Assistant engineer, 1 Assistant, 4 divers per day respectively)	5,913,314	Work for 8 days
Monitoring	277,380	111,000 (1 Engineer, 3 divers)	166,380	Per one monitoring
Compiling	1,375,946	481,100 (3 Chief engineers, 4 Senior engineers, 6 Engineers)	894,846	
Report work	515,431	384,650 (1.5 Chief engineers, 2.5 Engineers, 3 Assistant engineers, 10 Assistants	130,781	
Total	11,070,105	2,975,150	8,094,955	

7.2.2 Mitigation against effect of silt deposition

(1) Enforcement of turbid material deposition measure in dredging and reclamation phase

In case of pump dredging with or without silt protection curtain, distribution of daily maximum concentration of SS does not reach to coral distribution area, but the one produced by grab dredging indicated possibility to reach the coral habitat. Therefore, when grab dredging is used, diffusion of silt can give adverse effect on the corals, and thus, it is recommended to select pump dredging.

Removal of existing wharf and reclamation construction are also considered to be occurred turbid materials. Because silt protection curtain is also available for those construction according to prediction on effectiveness of silt curtain on dredging, silt protection curtain should be installed as measure to silt diffusion and deposition.

Different dredging method occurs different turbid situation as shown in Fig. 7.2.2-1. In case of pump dredging, turbid materials occur around sea bottom and from sea bottom to surface in case of grab dredging. We would like to suggest a mitigation measure as enforcement of prevention for turbid dispersion based on above-mentioned difference on turbid situation, as follows.

According to “Manual for prediction on turbid effect in harbor construction (Ports and Harbors Bureau, Ministry of Land, Infrastructure, Transportation and Tourism, April 2004)”, the mitigation measure is usually employed as prevention method for turbid dispersion in maritime construction. Silt protection rate by silt protection curtain is known as 40 to 80% calculated from example of constructions using silt protection curtain.

- In case of pump dredging;

  Since Occurrence and deposition of turbid material locates near coral habitat, it may influence adverse effect to coral depending on current. Therefore, double installment of silt protection curtain (Stood type inside and hang type outside of the construction area) as shown in Fig. 7.2.2-2 in east side of construction area is recommended to protect silt diffusion to coral habitat.

- In case of grab dredging;

Occurrence and deposition of turbid material may influence adverse effect to partial coral community. In order to prevent reaching turbid water to coral habitat, it is recommended to install hung type silt protection curtain around, the double curtains in east side and silt protection frame at immediate site in dredging area as shown in Fig. 7.2.2-2.

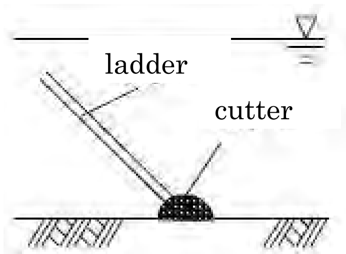
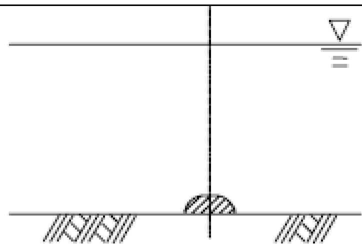
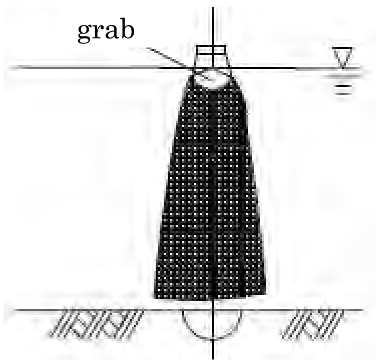
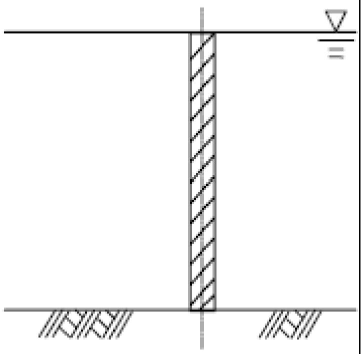
Methods	Turbidity spreading	Model of turbidity generation	Explanation
Cutter-suction dredge			Turbidity is generated at the sea bed when cutter swings. Therefore location of turbidity generation is the sea bed.
Grab dredge			Turbidity is generated due to various causes such as rolling up of sediment when grabbing, release of attached sediment into water when pull-up and seepage of water/sediment mixture above the sea surface. Therefore location of turbidity generation is through all water columns from sea bed to surface.

Fig. 7.2.2-1 Turbidity spreading and model of turbidity generation

(Manual for prediction on turbid effect in harbor construction (Ports and Harbors Bureau, Ministry of Land, Infrastructure, Transportation and Tourism, April 2004)

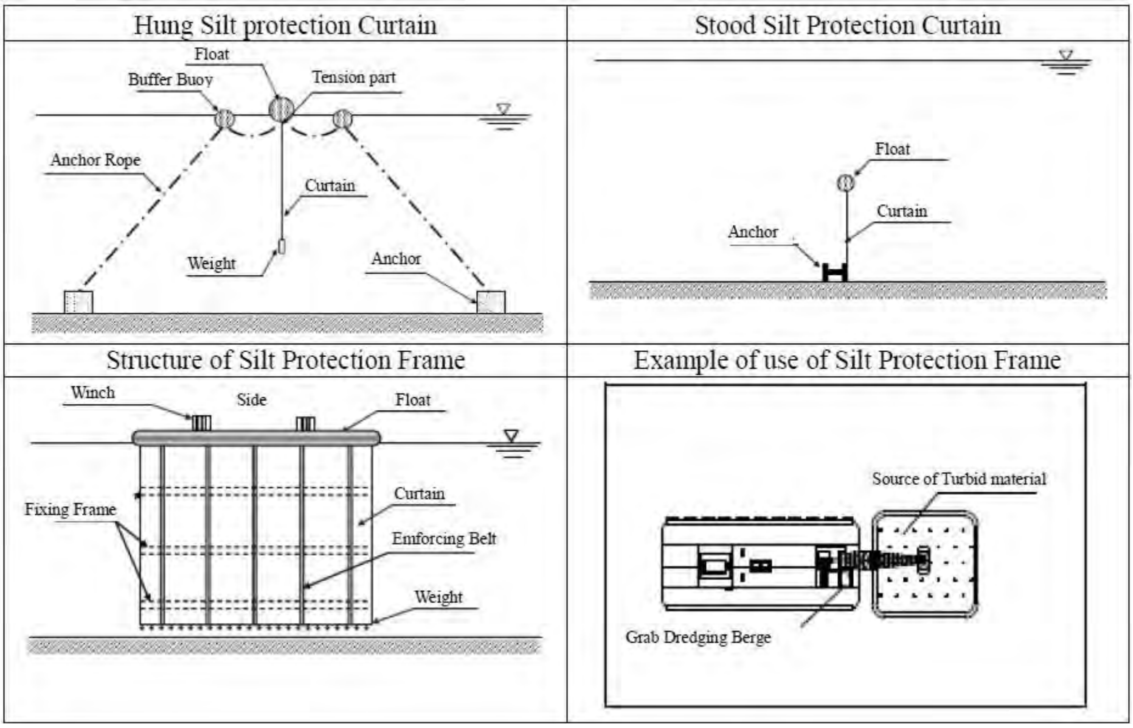


Fig. 7.2.2-2 Installment example of silt protection curtain and frame

(Draft of technical material on silt protection curtain, Service Center of Port Engineering, April 2008)

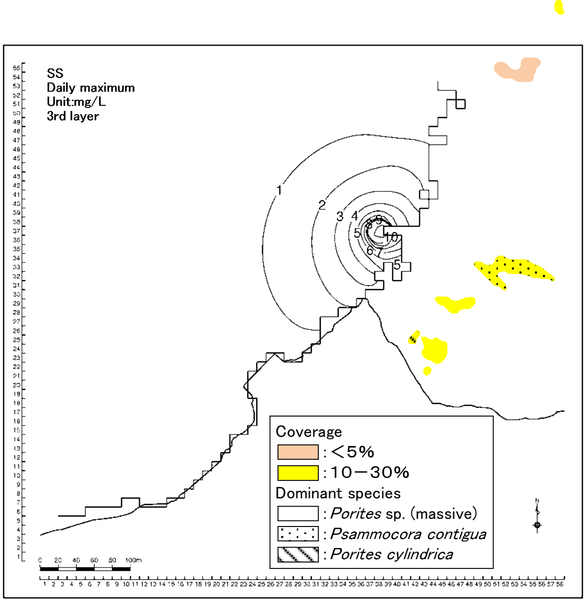
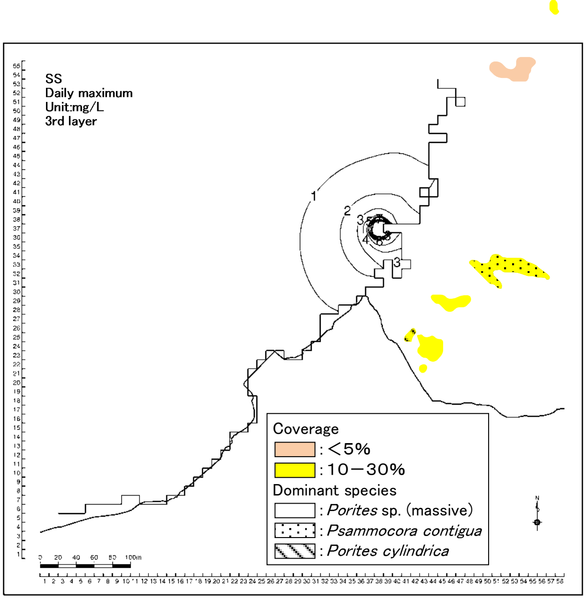
Without silt protection curtain	With silt protection curtain (single)
	

Fig. 7.2.2-3 Overlay of SS distribution of daily maximum concentration to coral communities (Pump dredging)

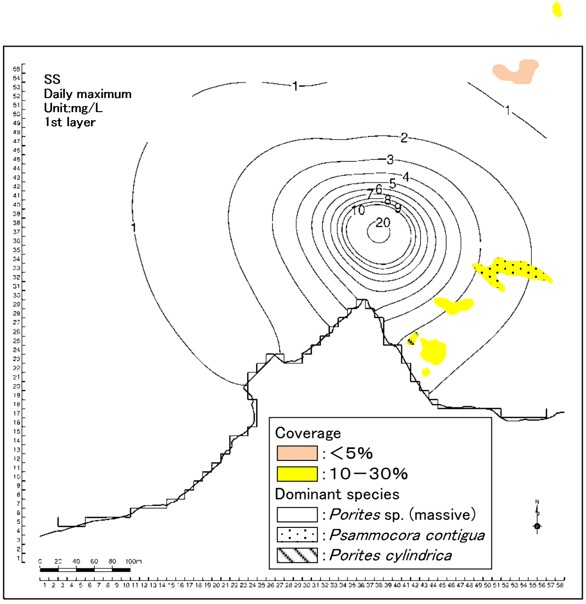
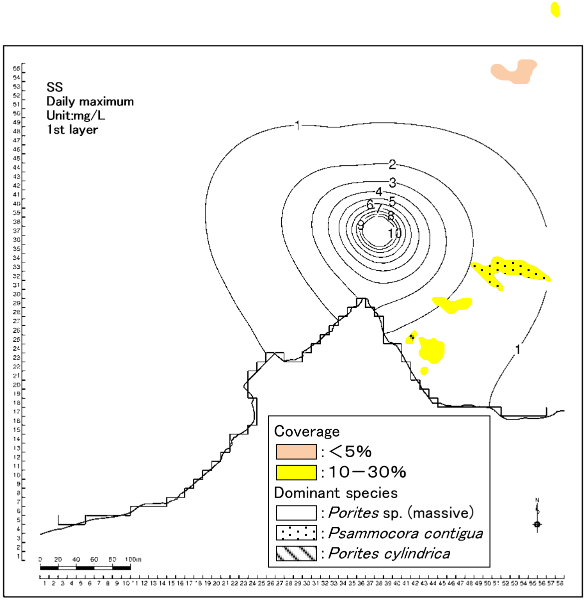
Without silt protection curtain	With silt protection curtain (single)
	

Fig. 7.2.2-4 Overlay of SS distribution of daily maximum concentration to coral communities (Grab dredging)

(b) Adequate selection and maintenance of silt protection curtain

Example of maintenance of silt protection curtain is shown in Table 7.2.2-1.

Table 7.2.2-1 Example of maintenance

Management No (span No) Examined by ___________

Part examined	Check item	On boat	By diving	Result (in case of unusual, situation is described)
Float	Line and layout	○		
	Free board	○		
	Fouling	○		
	Injury	○	○	
Curtain	Drop out	○	○	
	Injury		○	
	Fouling		○	
	Weight chains		○	
joint	Failing joint of curtains		○	
	Slack and drop out of metal fitting		○	
	Failing and slack of shackle		○	
Mooring	Anchor movement		○	
	Anchor rope	○	○	
	Failing and slack of shackle		○	
	Injury and slack of metal fitting connecting with anchor		○	

(2) Control of turbidity in spillway

Because spill water occurred in the reclamation area is flowed out to the sea through spillway, turbidity control is needed by portable turbidity meter (Fig. 7.2.2-5) for measure of turbid water diffusion.

Fig. 7.2.2-5 Portable Turbidity Meter

(from HP of DKK-TOA Corporation)

(3) Establishing standard of construction watch and management

(a) Standard of construction watch in the sea

Items	Standard	Basis
Turbidity	Control+2 NTU	-Standard of fisheries water in Japan
pH	7.8 to 8.3	-Environmental standard in Japan (on the Basic Environment Act)

(b)Standard of spillway management

Items	Standard	Basis
Turbidity	200 NTU	-Drainage Standard in Japan (based on the Water Pollution Prevention Act)
pH	5.8 to 8.6	Same as the above

(4) Details of basis on standard of construction watch and management

(a) Standard of construction watch in the sea

- Turbidity

It is established by based on the standard of fisheries water in Japan.

If it is hypothesized that value of turbidity and SS is approximately same, standard value becomes "Control +2 NTU" based on following point.

- SS added by anthropogenic activity in the sea must be not exceeding 2 mg/l (Standard of fisheries water in Japan)

Turbidity is different from SS in term of strict sense so that the standard should be re-established by acquiring correlation between turbidity and SS before construction in the field.

"The standard of fisheries water in Japan was established by Japan Fisheries Resources Conservation association as water quality standard on environment for conservation of aquatic organisms. This standard is founded from basis obtained information on field research and examination".

-pH

It is established by based on the environmental standard in Japan on the Basic Environment Act. It provides between 7.8 and 8.3 in the water applied for the most strict standard that requires to protect human health and conserve life environment.

(b) Management standard of spillway

-Turbidity

It is established by based on Drainage Standard in Japan (based on the Water Pollution Prevention Act). It provides 200 mg/l of SS as standard controlling drainage from factory and business body to public water and to underground. Turbidity in this project is established as 200 NTU based on the standard.

-pH

It is established by based on Drainage Standard in Japan (based on the Water Pollution Prevention Act). It provides between 5.8 and 8.6 of ph as standard controlling drainage from factory and business body to public water and to underground. The pH in this project is applied this standard.

7.2.3 Mitigation against effect due to current change

Mitigation against effect due to current change is not provided because current velocity change occurs only limited area near Star wharf and is small.

7.2.4 Mitigation against water quality deterioration in Port Vila Bay due to economic development

Water quality deterioration is caused by mainly flow in of land drainage, therefore, implementation of sewage treatment system in Port Vila City is required in the near future. ADB is now proceeding Port Vila Urban Development Project from 2011 to 2016 (refer Chapter 3 Present Situation on Environmental Conservation in Vanuatu, 3.4.3 Plan for Water Quality Improvement). It is expected that drainage flow in to Port Vila Bay is improved by above-mentioned project.

CHAPTER 8 Environmental Management and Monitoring Plan

8.1 Construction Phase

8.1.1 Overall Implementation Framework

Figure 8.1.1-1 shows schematic of environmental responsibilities and reporting during construction phase. Environmental Management and Monitoring Plan (EMMP) will be implemented under responsibility of Ministry of Infrastructure and Public Utilities (MIPU) and Ministry of Finance and Economic Management (MFEM), which have overall responsibility on the project. Most of the monitoring activities will be implemented by delegated contractor, while IPDS Project Management Group will support it practically. Coral transplanting and monitoring, which need certain skill and experience on marine organisms, will be undertaken with cooperation of Department of Fisheries. Department of Fisheries is deemed to have enough capacity for the works, since the human resources and the budget are assured as described in Chapter 3 (3.1.2) and technical assistance of JICA has been implemented.

Roles of relevant agencies on EMMP implementation are listed below.

- **Department of Environmental Protection and Conservation (DEPC)**, in the Ministry of Lands and Natural Resources, will inspect the implementation of EMMP in accordance with Environmental Conservation Act.
- **Department of Geology, Mines and Water Resources (DGMWR)**, in the Ministry of Lands and Natural Resources, will monitor and supervise the EMMP activities as the responsible agency for water quality in Vanuatu.
- **Department of Fisheries** in the Ministry of Agriculture, Forestry, Fisheries and Livestock, will monitor and supervise the EMMP activities in terms of biological marine resource protection. Upon requests of MIPU or IPDS Project Management Group, work cooperation will be made on the activities related to biological resources such as coral transplantation.
- **Ministry of Infrastructure and Public Utilities (MIPU)** and **Ministry of Finance and Economic Management (MFEM)** have overall responsibility on the project, including reporting the monitoring results to JICA.
- **Project Management Unit (PMU)**, which is organized under MIPU, MFEM with Prime Minister Office, Department of Fisheries, Ministry of Home Affairs and the other relevant ministries, has responsibility on implementation of EMMP.
- **IPDS Project Management Group** participates to PMU to take charge of EMMP practically.
- **Contractor** will implement the EMMP activities in accordance with the delegated responsibility.
- **Environmental Supervisor** appointed by Contractor will induct and train all workers involved in the construction phase to ensure that they are fully aware of their obligations under the EMMP and relevant legislation.

Project Management Unit (PMU) was established in September 2011 as a standing organization which consists of the Prime Minister Office developing policies and strategy of the government, Ministry of Home Affairs being responsible for municipalities such as Port Vila City, and the other relevant ministries such as the Ministry of Agriculture, Forestry, Fisheries and Livestock. It is responsible for all of the large scale projects which may cause significant impacts on the use of Port Vila Harbor, not limited to this project but include domestic wharf project and urban development project (drainage and sewage improvement) being funded by ADB. Therefore, it is expected that cooperation between ministries will be assured through PMU for sustainable use of the harbor.

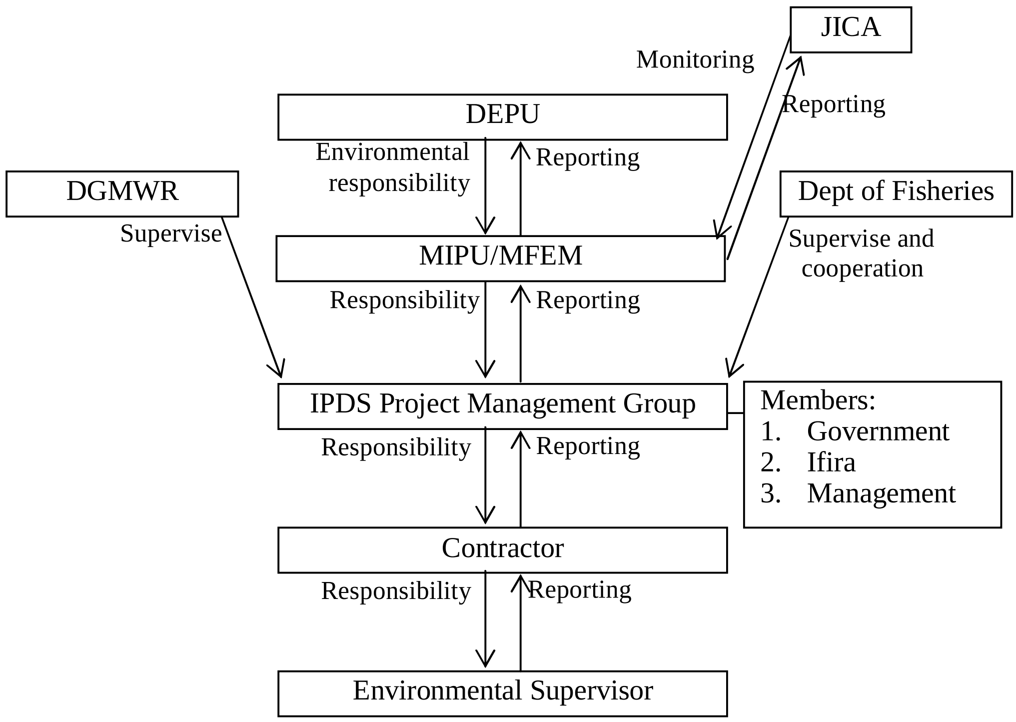


Figure 8.1.1-1 Schematic of Environmental Responsibilities and Reporting during Construction Phase

8.1.2 Water Quality

Environmental Management and Monitoring Plan to turbidity in construction phase is as follows.

(1) Survey Items

-Turbidity, pH, Water temperature and Salinity

(2) Survey Items

Above-mentioned items are measured by multiple water quality meter (Fig.8.1.2-1).

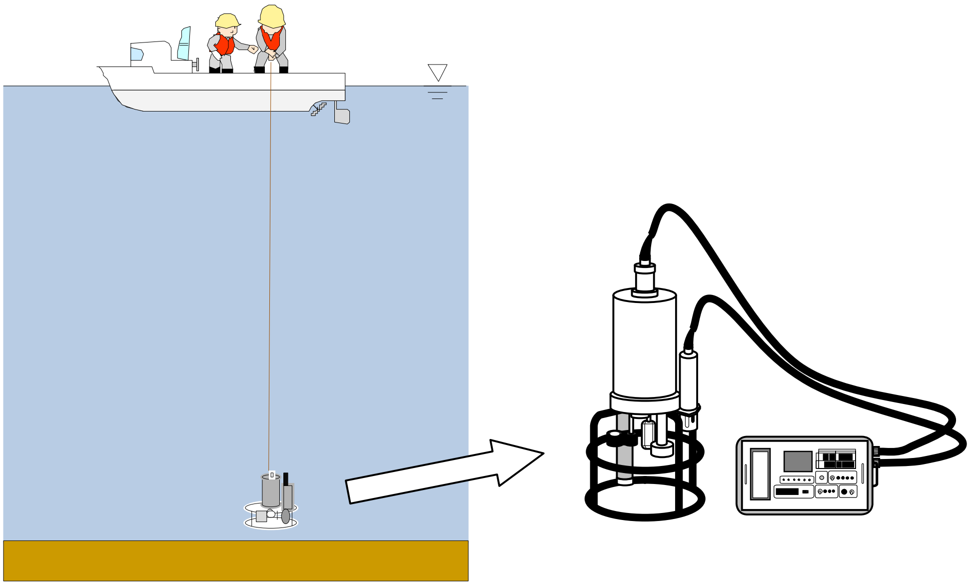


Fig. 8.1.2-1 Water quality survey using multiple meter

(3) Survey Period

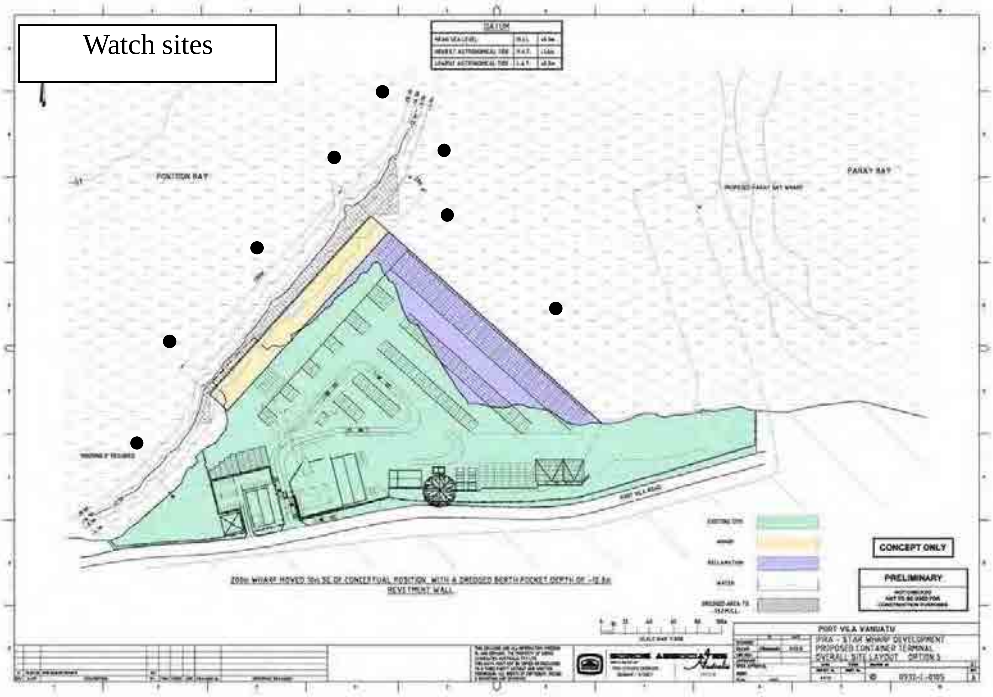
-Immediately before construction: Once a day, 3 times

-During dredging: Once a day during dredging period

*It is possible to discuss deeper on water quality change during dredging period if water quality data just before construction is acquired.

(4) Survey Sites

Survey sites are as Fig. 8.1.2-2.



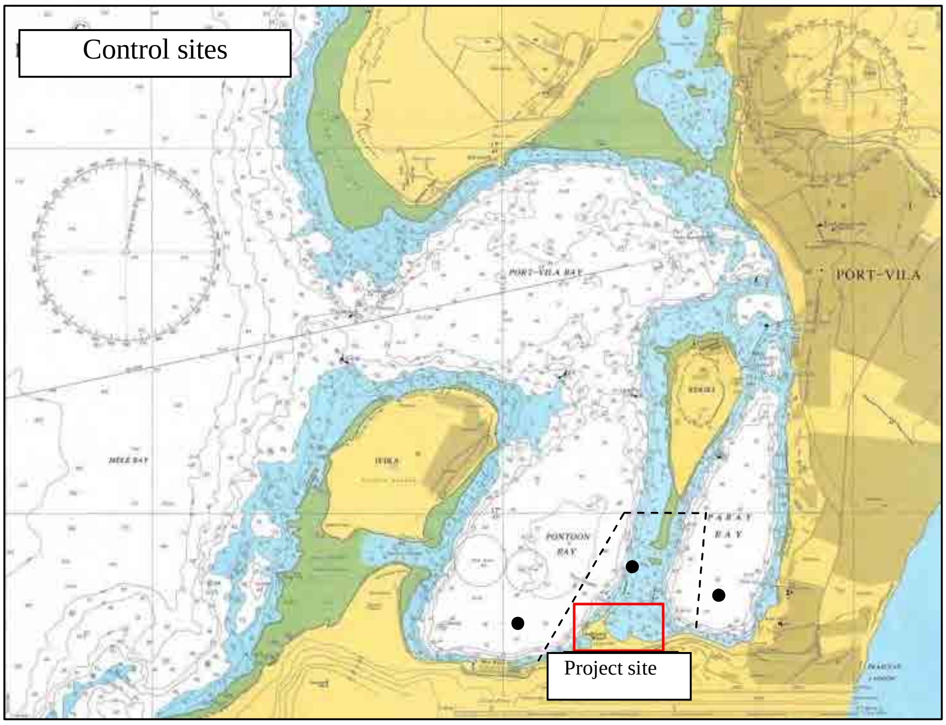


Fig. 8.1.2-2 monitoring sites of water quality

(5) Watch method for construction

Water quality data will be compared with the standard (Table 8.1.2-1) and dredging will be stopped until water quality recovers the standard if the data exceeds the standard. In this case, although control data is produced by averaging ones of 3 sites, abnormal data will be omitted.

It would be judged by salinity and field observation whether turbidity occurred from construction or storm water because terrestrial runoff sometimes occurred turbid water.

Table 8.1.2-1 Water quality standard for the construction

Items	Standard	Basis
Turbidity	Control+2 NTU	-Results of water quality survey in Port Vila Harbor -Standard of fisheries water in Japan
pH	7.8 to 8.3	-Environmental standard in Japan (on the Basic Environment Act)

(6) Construction management method

Because spillage occurred from the reclamation area is streamed to the sea through spill way, turbidity in the spill way is required to be managed for countermeasure of dispersion of turbid water. The pH is also managed if flocculants are used for turbid water measure.

Table 8.1.2-2 Water quality standard for the spill way

Items	Standard	Basis
Turbidity	200 NTU	-Drainage Standard in Japan (based on the Water Pollution Prevention Act)
pH	5.8 to 8.6	Same as the above

8.1.3 Corals

(1) Survey items

-Spot check: Survey of massive *Porites* that distributes near the Star Wharf

-Relocated coral survey: Monitoring of relocated coral

Table 8.1.3-1 Survey Items

Items	Contents	Aim
Spot check	Survival, mortality and disappearance of massive corals Bleaching and secretion of mucus	Watch of effect to coral on turbid water
Relocated coral survey	Survival, mortality and disappearance of massive corals Bleaching and secretion of mucus	Monitoring of relocated coral
Dugong and sea turtle survey	Survival and mortality of dugong and sea turtle migrating in the bay	Watch of effect to dugong and sea turtle migrating in the bay due to the increase of marine traffic etc.

(2) Survey method

-Spot check

Survival of coral community distributed near the Star Wharf is observed by divers

-Relocated coral survey

Relocated corals are observed.

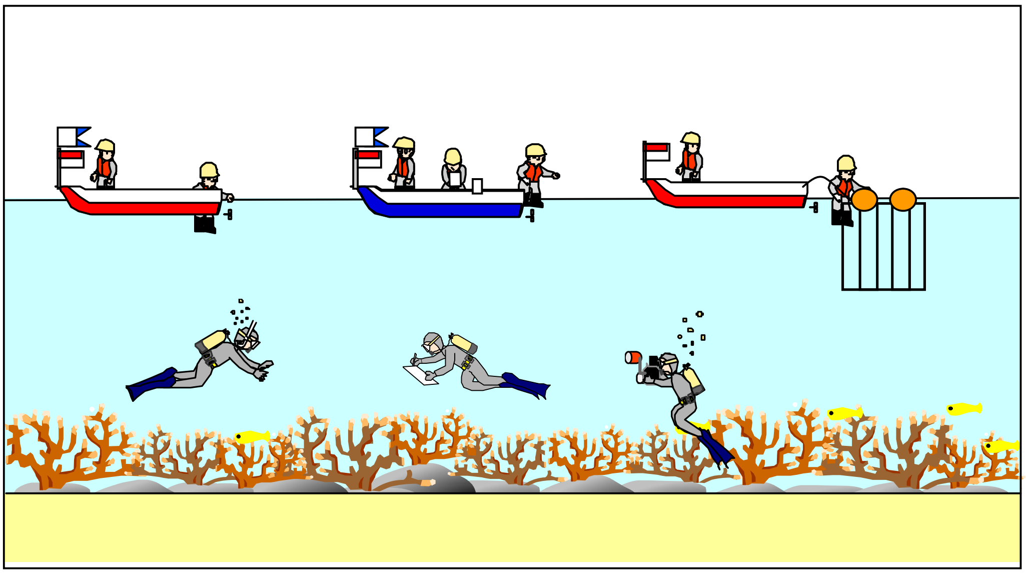


Fig. 8.1.3-1 Survey method on corals

-Dugong and sea turtle survey

Reports of sightings are collected from fishermen etc. operating in the bay

(3) Survey period

-Spot Check

Immediately before dredging: once, During dredging period: once

-Relocated coral survey

After relocation: just after relocation, 1, 3 and 6 months later

-Dugong and sea turtle survey

As needed

(4) Survey site

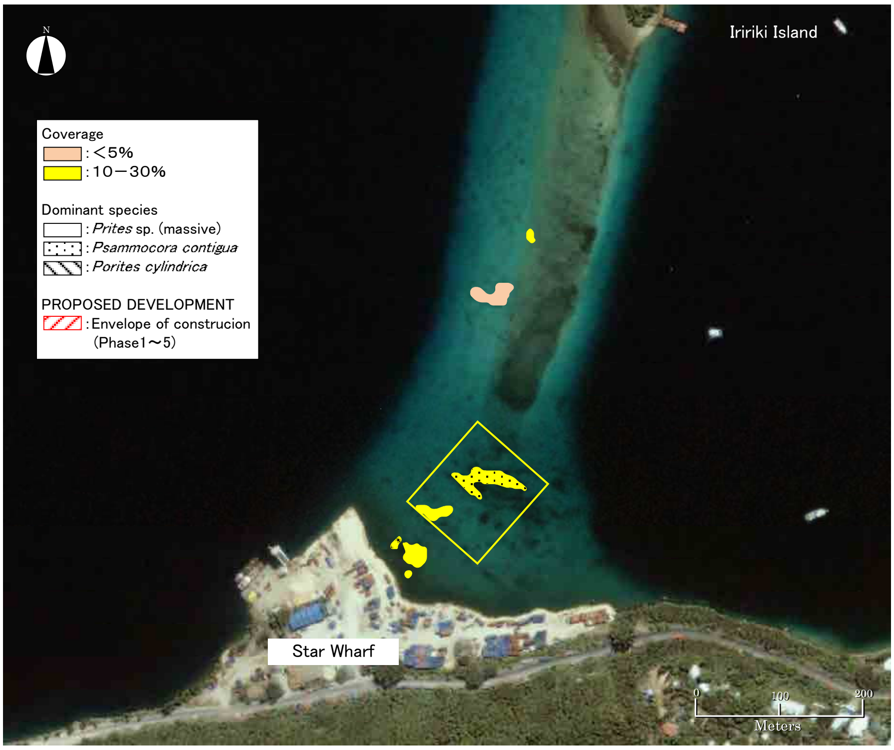


Fig. 8.1.3-2 Spot check survey area (yellow square)

Fig. 8.1.3-3 Survey area on relocated corals (red dotted circle)

(5) Watch method for the construction

Survey results on spot check will be compared with the standard (Table 8.1.3-2) and countermeasure such as transplantation will be carried out if the construction lacks to the standard.

Table 8.1.3-2 Standard for construction

Item	Standard
Spot check	Survival of massive coral almost equals with situation before construction. In this case, it should be confirmed that corals at control site are not influenced by causes other factors than construction such as bleaching.

8.1.4 Updating EMMP in the EIA Report

Besides above described subjects such as water quality and corrals, the existing EIA report, which was conducted in the Feasibility Study and approved by the Government of Vanuatu, has proposed another Environmental Management and Monitoring Plan (EMMP) in accordance with the following categories.

1) Construction phase (Land-based activities): C-L
2) Construction phase (Marine activities): C-M
3) Operation phase (Land-based activities): O-L
4) Operation phase (Marine activities): O-M

Out of those categories, the plans categorized into 2) and 4), which may affect coral reef ecosystem and water current, were discussed with the relevant agencies in Vanuatu to confirm the feasibility and update the plan if necessary. The updated plan for '2) Construction phase (Marine activities)' is described in the following sections. For '4) Operation phase (Marine activities)' is shown in chapter 8.2.

(1) EMMP Proposed in the EIA Report and the Outline of Confirmation and Updating in This Study

Table 8.1.4-1 shows what was confirmed and updated in this study for each subjects proposed in the EMMP of the EIA report for construction phase (marine activities). The results of each confirmation and updating is described in the section (2) or the other chapter shown in the table.

Table 8.1.4-1 EMMP Proposed in the EIA Report and the Outline of Confirmation and Updating in This Study

EMMP Proposed in the EIA Report (Cited from the EIA Report)			Outline of Confirmation and Updating in This Study
Activity / Issue	Environmental management and monitoring measures	Responsibility	
C-M 1. Demolition of existing wharf and piles:	C-M1.1.Existing Piles to Landfill: To prevent the potential spread of marine pests on piles, ensure that demolished piles are not be disposed of in the marine environment, but removed and disposed of to land-fill.	Contractors.	It was confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
	C-M 1.2. Silt Curtains: Deploy marine silt curtains around the work site during all marine demolition, reclamation and construction activities (curtains do not need to drop full depth to sea-bed in deeper areas – just 1st 3 metres to stop surface plumes spreading)	"	Effectiveness and necessity of the silt curtains were identified in this study. **(see chapter 6 and 7.2.2)** Deploying silt curtains were confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
	C-M 1.3.Marine Biota Clearance: Just prior to	Owner/operator	Corals to be

	marine works commencing, invite the Vanuatu Dept of Fisheries to move any easily movable marine organisms out of the impact zone to other suitable habitat in the Harbor (apply also to reclaim area, see C-M 2).		transplanted were identified through field survey around the project site.
	C-M 1.4. Harvest Food Species: Just prior to marine works commencing, site workers be invited to collect all marine species of food value from the impact zone (apply also to reclaim area, see C-M 2).	“	As the results of the field survey around the project site, species to be collected were not observed.
	C-M 1.5. Aquarium Species Collection: Just prior to marine works commencing, invite the local marine aquarium collector to collect all species of aquarium trade value from the impact zone (apply also to reclaim area, see C-M 2).	“	As the results of the field survey around the project site, species to be collected were not observed. Fish is not to be collected as it is capable for escaping.
C-M 2. Land reclamation:	C-M 2.1: As per C-M 1.2 to 1.5 (silt curtains at reclaim area should be full-depth to sea bed).	“	Effectiveness and necessity of the silt curtains were identified in this study. **(see chapter 6 and 7.2.2)** Deploying silt curtains were confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
	C-M 2.2: Environmental Offset: Possible declaration of tabu over Vatumaru Bay to compensate from destruction of corals.	Ifira and GoV	Possibility of the declaration of tabu was discussed with the Dept of Fisheries. **(see section (2) in this chapter)**
C-M 3. Dredging:	C-M 3.1. Detailed Hydrographic Survey: Prior to dredging commencing, conduct detailed hydrographic survey using multi-beam side scan sonar to determine precise area to be dredged and optimize/reduce dredging required.	Contractors Owner/operator	It was confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
	C-M 3.2. Silt Curtains: Deploy marine silt curtains around the work site during all dredging activities (curtains do not need to drop full depth to sea-bed in deeper areas – just 1st 3 metres to stop surface plumes spreading)	Dredging contactor	Effectiveness and necessity of the silt curtains were identified in this study. **(see chapter 6 and 7.2.2)** Deploying silt curtains were confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**

	C-M 3.3: Productive Use of Dredge Material: Place all dredge material to reclaim area (which should be encircled by full-depth, fixed silt curtains)	"	It was confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
	C-M 3.4: Visual Plume Monitoring: Environmental Supervisor to observe and video dredge plumes daily from top of hill behind Star Wharf site. If plumes moves towards sensitive coral areas, management action to be taken. Observations to be made over daily tidal cycle.	Environmental Supervisor Dredging contactor	Turbidity monitoring plan was described in **chapter 8.1.2**.
	C-M 3.5: Turbidity Monitoring: Department of Geology, Mines and Water Resources (DGMWR) to be engaged to monitor daily marine turbidity levels over sensitive coral areas adjacent to the site, throughout the dredging period. If turbidity levels exceed pre-set trigger levels, management action to be taken. Observations to be made over daily tidal cycle.	DGMWR Dredging contactor	Monitoring plan was specified. **(see chapter 8.1.2)** Contractor will implement the monitoring while DGMWR will supervise.
C-M 4. Introduction of new marine pests:	C-M 4.1: Marine Pest Prevention: Prior to construction commencing, develop and implement proper arrangements for managing the risk of new marine pest introductions via the arrival of work barges, work boats, dredge etc - including:	Terminal owner/operator. Contractors.	It was confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
	• a contractual requirement that such vessels must be totally free of bio-fouling *prior to leaving* their source ports (with inspections at the source port);		
	• inspections of the hulls of these vessels for bio-fouling on arrival at Port Vila, by Dept Fisheries divers; and	Dept. Fisheries	The feasibility was discussed with Dept of Fisheries. **(see section (2) in this chapter)**
	• If such arriving work vessels are found to have fouling, they should be directed out to the open ocean beyond Mele Bay for in-water hull cleaning, prior to being allowed to commence work on the construction.	Contractors	It was confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**
C-M 5. Marine spills	C-M 5.1: Marine Spill Prevention & Response Plan: Prior to construction commencing, develop and implement proper arrangements for the prevention, containment and clean-up of any spills of pollutants into the marine environment from construction activities. Such arrangements might include entering into an agreement with one or both of the two local oil terminals, to provide response and clean-up services in the event of a spill, and running an oil spill exercise with construction staff prior	Terminal owner/operator. Contractors.	It was confirmed to be included in TOR for contractor of the construction work. **(see section (2) in this chapter)**

	to work commencing.		
C-M 6. Impacts on other marine users and uses	C-M 6.1: Marine Exclusion Zone: For safety reasons, declare and enforce a marine exclusion zone around the construction site, to prevent potential conflict between work boats and barges and other marine users and for safety and security.	Harbor Master	The procedure to implement the management plan was discussed with the terminal owner/operator. **(see section (2) in this chapter)**

(2) Results of Confirmation and Updating

Environmental management plans confirmed and updated in this study were described below.

(a) Environmental Management to be Included in TOR for Contractor of the Construction Work

Following environmental management shall be included in the TOR for contractor of the construction work by IPDS Project Management Group under the responsibility of MIPU and MFEM.

(a)-1. Measures for Marine Pests

(i) Prevention of Spread of Marine Pests (Existing Piles to Landfill) [C-M 1.1]

As a part of EIA study, fouling assemblages of Star Wharf were investigated to find out the existence of marine pests listed in a 'target list' developed by reference to the previous study in Australia. Consequently, five species (one barnacle and four bryozoans) out of 30 species listed in the target list were found in the Star Wharf. Although those species has not seemed to affect the existing ecosystem so far, there is a possibility that they may spread if the demolished piles are disposed in the marine environment. Hence, the demolished piles shall not be disposed in marine environment and need to be ensured to dispose at land.

(ii) Marine Pest Prevention (Removal of Bio-fouling on Hulls of Vessels) [C-M 4.1]

Construction vessels which come from other regions may newly bring marine pests in the case they have bio-fouling on their hulls. Hence, the construction vessels shall remove the bio-fouling on the hull completely and be inspected prior to leaving the source port. If the vessels are found to have fouling after arriving at Port Vila, they shall be out to the open ocean beyond Mele Bay for in-water hull cleaning.

In the case that the water temperature of the source port is totally different from Port Vila with little possibility that the brought organisms can survive in Port Vila, above treatment process is not necessarily required based on the risk assessment.

The measures above have been implemented in Australia and other countries based on guidelines.

(a)-2. Proper Implementation of Dredging

(iii) Detailed Hydrographic Survey [C-M 3.1]

Prior to dredging commencing, detailed hydrographic survey using multi-beam side scan sonar shall be conducted to determine precise area to be dredged and optimize/reduce dredging required.

(iv) Productive Use of Dredged Materials [C-M 3.3]

Quarry Permit (No.VAQP211002) for this project based on the Mines and Minerals Act requires the dredged materials to be used only for reclamation of Star Wharf as one of the conditions of the permission. Hence, it shall be ensured to follow the requirement, not disposed in marine environment.

(a)-3. Measures for Preventing Turbidity and Oil Spill

(v) Deploying Silt Curtains [C-M 1.2, C-M 2.1, C-M 3.2]

During the work of demolishing the existing piles, dredging and reclamation, silt curtains shall be deployed to prevent turbidity dispersion.

Effect of the silt curtains was described in chapter 6.3.

(vi) Turbidity Monitoring [C-M 3.5]

Plan of turbidity monitoring is described in chapter 8.1.2.

(vii) Marine Spill Prevention and Response Plan [C-M 5.1]

In case of construction accidents, there is a possibility of oil spill caused by fuel oil leaking. Quality assurance for oil spill prevention shall be requested to contractor as a condition for contracting.

(b) EMMP with Cooperation of Department of Fisheries

Following activities related to biological marine resources shall be implemented with cooperation of the Department of Fisheries if necessary, under the responsibility of MIPU and MFEM.

(i) Transplanting of Corals in the Construction Area [C-M 1.3]

Transplanting methodology was described in chapter 7.2.1.

(ii) Monitoring of Corals

Monitoring plan for corals during construction is described in chapter 8.1.3.

(iii) Inspection of Marine Pests [C-M 4.1]

Bio-fouling on the hulls of the vessels which has to be removed prior to leaving the source port shall be inspected and recorded by divers after arriving at Port Vila. An example of the inspection items are shown below.

a. Date and location of the dive survey
b. Area or side of the vessel surveyed
c. General observation with regard to bio-fouling (i.e. extent of bio-fouling and predominant bio-fouling types (e.g. mussels, barnacles, tubeworms, algae and slime))
d. Whether any suspected marine pest/s were found, and action taken
e. Name and signature of the person in charge of the activity.

Source: National Bio-fouling Management Guideline, An Australian Government Initiative, 2009

It is feasible for Department of Fisheries to implement the inspection, since it has experience of marine pest survey around the Star Wharf as a part of the EIA study.

(c) Others

(i) Designation of Vatumaru Bay as a Fisheries Restricted Area

In the EIA report, it is proposed that Vatumaru bay to be designated as a fisheries restricted area (tabu) to compensate from destruction of corals by the construction works. The possibility of designation was discussed with Department of Fisheries as well as Department of Environmental Protection and Conservation in this study. Consequently, designating as tabu and the other legal protected area was seemed not to be feasible for Vatumaru bay, since local people have used the area as fishing ground and development plans have already been on the process. On the other hand, the survey results of corals in this study shows that the corals at the mouth of Vatumaru bay is in good condition to be conserved in the future. Therefore, it is proposed that the corals at the mouth of Vatumaru bay shall be monitored as a part of the long-term monitoring after the construction to conserve them by monitoring. In addition, corals around the project site is also proposed to be monitored during construction phase to monitor some possible impacts such as water quality change although EIA report has not proposed it (Detail of the monitoring plan is shown in chapter 8.1.3 and 8.2.4).

In addition, corals in the affected area are proposed to be transplanted. Environmental offset is proposed by combing the coral transplanting with the coral monitoring.

(ii) Arrangement for Marine Exclusion Zone [C-M 6.1]

Construction vessels are able to access to the construction site through the existing navigation route; therefore, there is little possibility to disturb the other use of water area such as fishing activities on the process of arriving and leaving. On the other hand, it is observed that small boats such as fishing boats and reissue boats are frequently passing nearby the Star Wharf, the construction site. Hence, MIPU and IPDS Project Management Group shall arrange with the harbor master to declare an exclusion zone along with the construction area and inform to the water area users.

(3) Summary of EMMP during Construction Phase

EMMP during construction phase (marine activities) are summarized and proposed in Table 8.1.4-2.

Table 8.1.4-2 Summary of EMMP during Construction Phase (Marine Activities)

Purpose	Activities	Implementation	Cost (Japanese Yen)	Remarks on the Cost
Measures for Marine Pests	Prevention of Spread of Marine Pests (Existing Piles to Landfill)	Included in the TOR for contractor by IPDS Project Management Group under the responsibility of MIPU and MFEM.	*	Included in the bidding price for construction.
	Marine Pest Prevention (Removal of			

	Bio-fouling on Hulls of Vessels)			
	Inspection of Marine Pests	Implemented with cooperation of the Department of Fisheries under the responsibility of MIPU and MFEM.	30,000	SCUBA tank, boat and others Three times
Proper Implementation of Dredging	Detailed Hydrographic Survey	Included in the TOR for contractor by IPDS Project Management Group under the responsibility of MIPU and MFEM.	*	Included in the bidding price for construction.
	Productive Use of Dredged Materials			
Measures for Preventing Turbidity and Oil Spill	Deploying Silt Curtains			
	Turbidity Monitoring		1,200,000	Multi-parameter water quality meter
	Marine Spill Prevention and Response Plan		—	
Conservation of Corals	Transplanting of Corals in the Construction Area	Implemented with cooperation of the Department of Fisheries under the responsibility of MIPU and MFEM.	11,070,000	LS for the transplanting works (see chapter 7.2.1).
	Monitoring of Corals		30,000	SCUBA tank, boat and others Three times
Safety Measures	Arrangement for Marine Exclusion Zone	Arranged by MIPU and IPDS Project Management Group with the harbor master	—	
Total			12,330,000	

8.2 Operation Phase

8.2.1 Overall Implementation Framework

Figure 8.2.1-1 shows schematic of environmental responsibilities and reporting during operation phase. Environmental Management and Monitoring Plan (EMMP) will be implemented under responsibility of Ministry of Infrastructure and Public Utilities (MIPU) and Ministry of Finance and Economic Management (MFEM), which have overall responsibility on the project as same as during construction phase. With regards to the monitoring of corals and water quality, results of long-term monitoring by Department of Fisheries and Department of Geology, Mines and Water Resources (DGMWR) will be utilized.

Roles of relevant agencies on EMMP implementation are listed below.

- **Department of Environmental Protection and Conservation (DEPC)**, in the Ministry of Lands and Natural Resources, will inspect the implementation of EMMP in accordance with Environmental Conservation Act. (same as the construction phase)
- **Department of Geology, Mines and Water Resources (DGMWR)**, in the Ministry of Lands and Natural Resources, will provide their long-term monitoring data on water quality to MIPU to utilize the data for the monitoring during operation phase.
- **Department of Fisheries** in the Ministry of Agriculture, Forestry, Fisheries and Livestock, will provide their long-term monitoring data on corals to MIPU to utilize the data for the monitoring during operation phase.
- **Ministry of Infrastructure and Public Utilities (MIPU)** and **Ministry of Finance and Economic Management (MFEM)** have overall responsibility on the project, including reporting the monitoring results to JICA.
- **IPDS Management** has overall responsibility on implementation of EMMP under MIPU and MFEM.
- **Environmental Officer**, qualified staff member in IPDS Management, will be in charge of summarizing and reporting the EMMP activities.

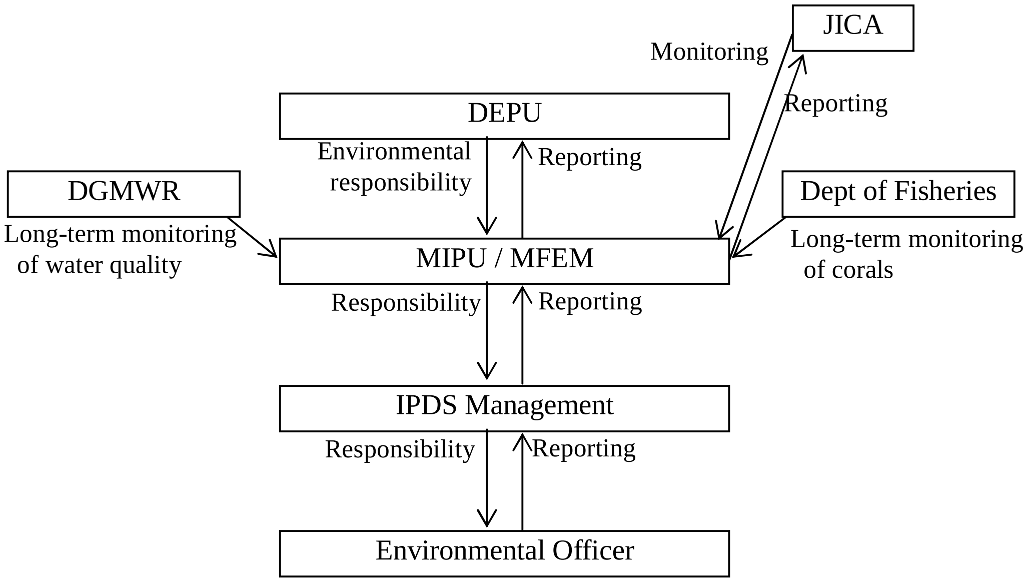


Figure 8.2.1-1 Schematic of Environmental Responsibilities and Reporting during Operation Phase

8.2.2 Water Current

According to the prediction on current change in Port Vila Bay in the operation phase, effect on implementation of the Star Wharf project to water change in the Bay is only small change on current velocity and considered to be negligible. Therefore, it is evaluated that monitoring on the effect from this project is scarcely needed.

However, the more data is the more accuracy and other development is planned in Port Vila Bay so that long-term monitoring is available for other development evaluation. For long-term monitoring, observation buoy is examined as mentioned next item.

8.2.3 Water Quality

Water quality control in the operational phase is required to hold a control policy that comprehends whole Port Vila Harbor because economical development is anticipated by Star wharf improvement. For this purpose, Paray Bay should be chosen as monitoring site of water quality because it shapes the most independent topography and concentrates environmental load from urban area. Because improvement project on urban drainage control is now planned, effect of the control should be traced and monitoring data should be fed back to the control.

(1) Monitoring Method

Acquiring meaningful water quality data needs much effort because it changes time to time due to fluctuate meteorological and oceanographic conditions. It needs to set measuring frequency and time for reflect actual condition exactly. Therefore, automatic measuring that can acquire lots data frequently is required. It needs much initiative cost but can avoid to be interrupted by budget lack because it needs only maintenance cost after installment. However, there are limited automatic measuring sensors and items that can be analyzed at laboratory only, so that it is required to examine efficiency on environmental trace of Paray Bay for selecting sensors.

The bottom layer in Paray Bay is known as anoxic situation because of poor vertical circulation due to deep bottom over 40m and mortar topography. Because turbidity in the bottom layer tends high due to terrestrial runoff, dissolved oxygen and turbidity should be measured regularly in the surface and bottom (30 to 40m) layers. Water temperature and Salinity should be added to measure as basic oceanographic data.

In order to obtain those data regularly, observation buoy is very available. There is a example for the buoy installed in Sekisei Lagoon, Iriomote-Ishigaki National Park, South Ryukyus. The buoy installed in 2008 continues to get data with out accident although it locates in pathway of Tayhoon. Data is sampled every hour, sent to server by mobile telephone circuit and shown through internet at real time.

We received comment from Prof. Mineo Okamoto, Tokyo University of Marine Science and Technology that the buoy is effective for water quality monitoring in coral reef and expected to be available in this project.

Followings are contents of the buoy in Sekisei Lagoon[1];

Aim: In order to monitor coral reef environment in the national park and take measure adequately if disturbance such as bleaching occurs.

Outline of the buoy: The buoy is installed instruments observing water quality, current and wave height automatically able to send data every hour by mobile phone circuit. The site of buoy locates in semi-closed environment in the lagoon and at 7.9m in deep.

Specifications of the buoy are as follows (Fig. 8.2.3);

-Total length: Approximately 3.9m

-Light position: Approximately 2.4m

-Weight: Approximately 340 kg except for instruments

-Total Buoyancy: Approximately 720 kg

-Margin Buoyancy: 380 kg

-Diameter of Body: Approximately 1.5m

-Height of buoyancy body: Approximately 0.6m

Fig. 8.2.3-1 Observation Buoy in Sekisei Lagoon

[1] Naha Nature Conservation Office, Ministry of the Environment & IDEA Consultants, Inc. (2010) Report of general survey on coral reef conservation in Sekisei Lagoon (from HP)

Specification of instruments is shown in Table 8.2.3-1

Table 8.2.3-1 Specification of instruments

Items	Instruments	Range	Remarks
Water temperature, Salinity	WTS Sensor with wiper ACTW-Di（JFE Advantech Co）	WT: 0 to 45℃、Conductivity: 0 to 70 mS/cm	
Chlorophyll, Turbidity	Chlorophyll, Turbidity Sensor with wiper ACLW-Di（JFE Advantech Co）	Chrolophyll: 0 to 400μg/ℓ、Turbidity: 0 to 1000FTU	
Current Direction and Velocity	Wave and Current Maeter DL3 (Sonic Corporation)	Direction（0 to 360 degree） Velocity（0 to ±500cm/s）	
Wave height	Wave and Current Maeter DL3 (Sonic Corporation)	0 to 20m	
Radio control	Aqua mail（JFE Advantech Co）	Sampling:30seconds average	Data sending: every 1 hour

Maintenance: Maintenance work such as cleaning of sensors and check is carried out every 2 weeks. Details of the work include checking wiper of sensors and corrosion-proof zinc.

(2) Monitoring System

(a) Operating organization

Department of Geology, Mines and Water resources is adequate as operating organization because it has carried out water quality survey so far and can provide equipments and staffs. The Department proposes to install the buoy.

(b) Budget

Table 8.2.3-2 Cost of installment and operation of the buoy (x 1,000 yen)

Items	Cost	Contents	Remarks
Production	20,000	Buoy and sensors	
Transportation	1,000	4m length and 340 kg	Japan to Vanuatu
Construction	3,150		Including training and initiative maintenance cost
Maintenance	120	Examination of sensors	Twice a month (Boat fee)
Total	24,270		

8.2.4 Corals and Marine Lives

(1) Monitoring method

The AusAID has set 16 Transect sites in the Port Vila Bay including near the Star Wharf area and carried out the survey as a part of the EIA and baseline of long-term monitoring.

According to Mr. Sompert, Department of Fisheries will be able to operate the monitoring for around 3 sites. Three monitoring sites are selected after dividing the bay to 3 areas for the between Star Wharf and Iririki Island, Ifira Island coast and mouth of Vatumaru Bay. Selected sites are S2T3 between Star Wharf and Iririki Island, S2T1 in north of Ifira Island and S4T2 in mouth of Vatumaru Bay (Fig. 8.2.4-1).

Dugong and sea turtle survey during construction will be continued even after operation begins.

It is adequate that survey frequency is once a year and method follows the AusAID one that this study also employed. However, coral observation should be carried out in species level. According to Mr. Sompert, it is possible.

(2) Monitoring system

It is adequate that coral reef monitoring in operation phase including long-term monitoring is operated by Department of Fisheries that charged with marine biology. Ability of the Department is already described and we obtained the opinion from Mr. Moses Amos, Director of the Department after discussing with him that the department can operate the monitoring if necessary equipments are supplied.

(a) Operating organization
Department of Fisheries

(b) Budget

Table 8.2.3-2 Cost of coral reef monitoring

Item	Cost	Contents	Remarks
Boat fuel	2,000 VT	Mixed fuel	Per day
Bombe hiring fee	6,000 VT	For 2 divers	2 bombes/day/diver
Equipments purchasing	203,000 yen	Underwater video camera (Canon iVISHF)130,000 yen Underwater camera (Olympus XZ-1) 73,000 yen	

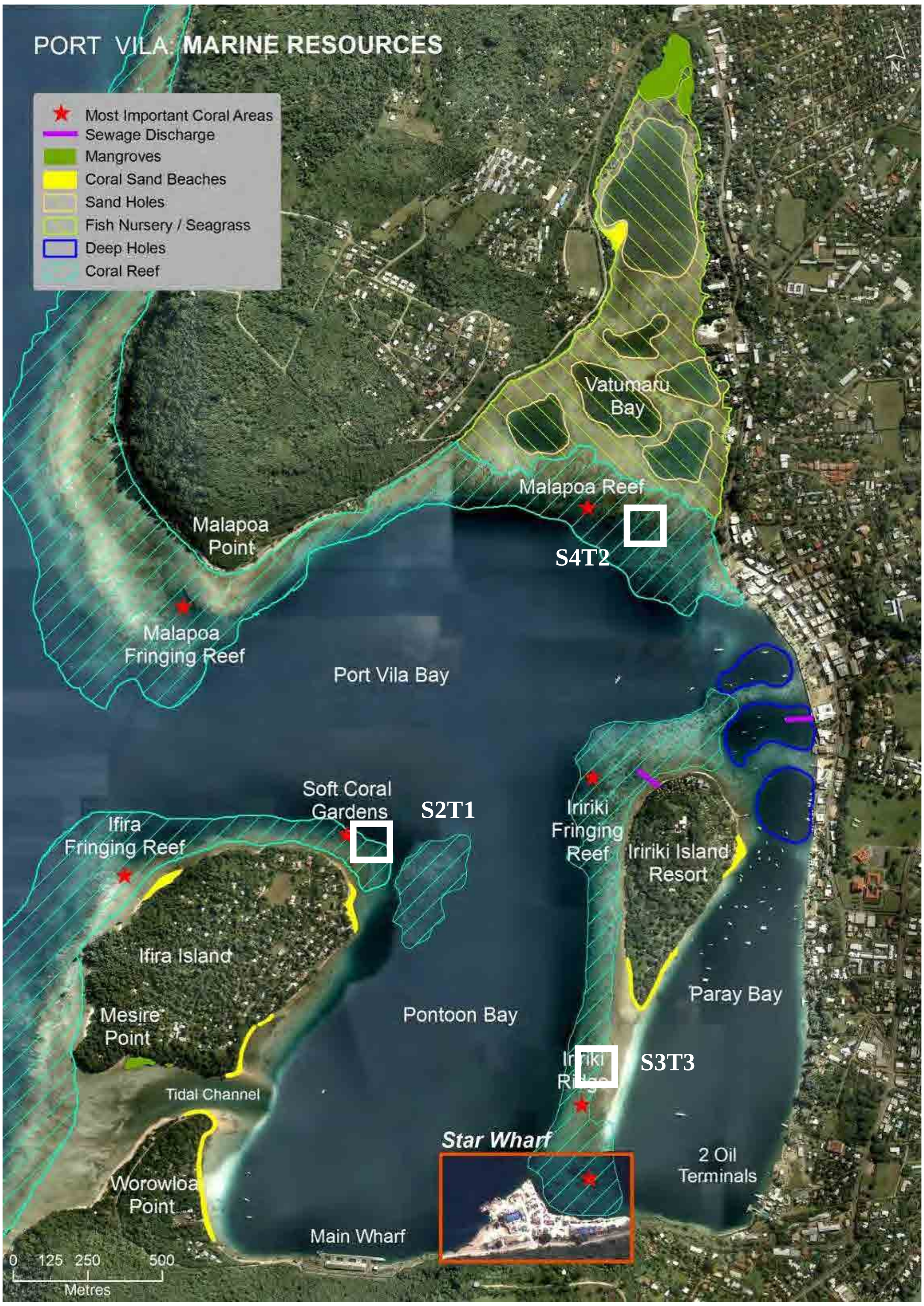


Fig. 8.2.4-1 Monitoring Sites (White square)

8.2.5 Updating EMMP in the EIA Report

(1) EMMP Proposed in the EIA Report and the Outline of Confirmation and Updating in This Study

Table 8.2.5-1 shows what was confirmed and updated in this study for each subjects proposed in the EMMP of the EIA report for operation phase (marine activities). The results of each confirmation and updating is described in the section (2) or the other chapter shown in the table.

Table 8.2.5-1 EMMP Proposed in the EIA Report and the Outline of Confirmation and Updating in This Study

EMMP Proposed in the EIA Report			Outline of Confirmation and Updating in This Study
Issue	Environmental management and monitoring measures	Responsibility	
O-M 1. Impacts on marine biodiversity	O.M 1.1 Marine Biological Monitoring: Undertake ongoing, long-term monitoring of the potential impacts of the terminal on the marine environment, by re-surveying the baseline survey sites at least annually into the future (building on the Marine Biodiversity Baseline Survey undertaken as part of the Supplementary EIA).	Terminal owner/operator to fund. Department of Fisheries to undertake.	Baseline survey for corals in Port Vila Harbor was undertaken. **(see chapter 5.1)** Long-term monitoring plan was proposed. **(see chapter 8.2.4)**
O-M 2. Impacts on marine water quality	O-M 2.1 Marine Pollution Monitoring: Enter into an arrangement with the Department of Geology, Mines and Water Resources (DGMWR) to undertake marine pollution monitoring near the Harbor discharge points, and include suspended solids, pesticide chemicals and hydrocarbons in water, sediments and biota in the suite of parameters analysed. Site to be sampled quarterly or immediately following significant rainfall.	Terminal owner/operator to fund. DGMWR to undertake	The feasibility of water quality monitoring was confirmed with DGMWR and the monitoring plan was proposed. **(see chapter 8.2.3)**
O-M 3. Impacts on hydrodynamics and coastal processes	O-M 3.1 Hydrodynamic Model: Implement a comprehensive program to collect oceanographic data and develop a 4D hydrodynamic model for Port Vila, to support proper assessment, planning and management of all proposed developments and activities in the Harbor.	GoV with donor support.	3D hydrodynamic model was developed based on the observation results of water current; and then possible water current change caused by the project was estimated. **(see chapter 6)**
O-M 4. Marine spill prevention and response	O-M 4.1 Oil Spill Contingency Plans: Develop and maintain oil spill contingency plans both for Port Vila and for Vanuatu as a whole, including training, exercises and	"	It was proposed to be addressed by the Gov of Vanuatu as it is not a project specific issue and needs more comprehensive

	equipment.		discussions. **(see section (2) in this chapter)**
	O-M 4.2. IMO Conventions: Undertake a thorough review and update of the IMO conventions that Vanuatu is a party to.	“	“
	O-M 4.3. Maritime Legislation: Undertake a thorough review and update of the national legislation that implements the IMO conventions in Vanuatu – recent maritime legislative work in PNG may be used as a model.	”	“
	O-M 4.4: Terminal Nav-Aids: Include any new navigation aids relating to Star Terminal as may be determined by the Harbor Master.	Terminal designer Owner/operator	The procedure to implement the management plan was discussed with the terminal owner/operator. **(see section (2) in this chapter)**
	O-M 4.5: Nav-Aids Update: Undertake a review of the adequacy of navigation aids for the whole of Port Vila, and make improvements to these as necessary.	GoV with donor support.	It was proposed to be addressed by the Gov of Vanuatu as it is not a project specific issue and needs more comprehensive discussions. **(see section (2) in this chapter)**
	O-M 4.6 Port State Control Enhancement: Implement a program to build the PSC capacity of DPM, as well as the capacity of GoV in general to implement and enforce its maritime legislation.	“	“
O-M 5. Marine pests	O-M 5.1: Marine Pest Risk Assessment: Once likely trading patterns are clarified, conduct a marine pest risk assessment for the terminal.	“	“
	O-M 5.2 Marine Pest Survey: Undertake a full-scale Marine Pest Survey for the whole of Port Vila Harbor.	“	“
	O-M 5.3: Ballast Water Convention & Legislation: Vanuatu to sign and ratify the BWM Convention and develop, pass and enforce national legislation which implements this Convention for international ships visiting Vanuatu.	“	“

O-M 6. Ships' anti-fouling	O-M 6.1: AFS Convention & Legislation: Vanuatu to sign and ratify the AFS Convention and develop, pass and enforce national legislation which implements this Convention for international ships visiting Vanuatu.	"	"
O-M 7. Ships' waste management:	O-M 7.1. Ships' Waste Management: Develop and implement proper ships' waste reception arrangements for Port Vila, including for Star Terminal and other port developments. As a minimum, these arrangements might include: • repairing, recommissioning and maintaining one of the high temperature quarantine incinerators for burning quarantine waste (all garbage received from internationals ships); and • opening discussions with the oil terminals to explore options for them to receive, reuse and recycle waste oil taken from ships using Star Terminal and other port facilities in Port Vila.	"	The procedure to implement the management plan was discussed with the terminal owner/operator. **(see section (2) in this chapter)**
O-M 8. Ships' sewage:	O-M 8.1: MARPOL Annex IV & Legislation: Vanuatu to sign and ratify the Annex IV of MARPOL and develop, pass and enforce national legislation which implements this Convention for international ships visiting Vanuatu.	"	It was proposed to be addressed by the Gov of Vanuatu as it is not a project specific issue and needs more comprehensive discussions. **(see section (2) in this chapter)**
O-M 9. Impacts on other marine users and uses:	O-M 9.1: Marine Exclusion Zone: Declare and enforce a marine exclusion zone around the new terminal, to prevent potential conflict between ships using the terminal and other marine users and for safety and security.	Harbor Master	The procedure to implement the management plan was discussed with the terminal owner/operator. **(see section (2) in this chapter)**

(2) Results of Confirmation and Updating

Environmental management plans confirmed and updated in this study were described below.

(a) Environmental Management to be Implemented by Terminal Owner/Operator

Following environmental management shall be implemented by terminal owner/operator (IPDS Co. Ltd.) coordinating with relevant agencies under the responsibility of MIPU and MFEM.

(i) Ship's Waste Management [O-M 7.1]

Since vessels which use the new pier are not passenger vessels but cargo vessels, amount of garbage from the vessels will be limited. If garbage needs to be disposed, it shall be disposed by Quarantine Service. The high temperature incinerator to receive the garbage from Quarantine Service is currently working although it had not been operated at the time of EIA study.

Waste oil is currently received by the oil company adjacent to Star Wharf; it shall be ensured continuously.

(ii) Arrangement for Terminal Nav-Aids [O-M 4.4]

Once the new pier is start to be operated, international cargo vessels which are currently using Main Wharf will move to Star Wharf. Since Main Wharf is adjacent to Star Wharf, moving from Main Wharf to Star Wharf does not require new nav-aids such as lead marks and lights. However, in order to secure the safety and prevent oil spill incidents caused by accidents, terminal owner/operator shall arrange with the harbor master to install any additional nav-aids if the risk of accidents gets increasing due to increase of the number of vessels in the future.

(iii) Arrangement for Marine Exclusion Zone [O-M 9.1]

Once the new pier is started to be operated, large international vessels will access to the wharf. Since it is observed that small boats such as fishing boats and reissue boats are frequently passing nearby the Star Wharf, the terminal owner/operator shall arrange with the harbor master to declare an exclusion zone around the wharf if necessary.

(b) EMMP with Cooperation of DGMWR and Department of Fisheries

Following activities shall be implemented with cooperation of DGMWR and the Department of Fisheries if necessary, under the responsibility of MIPU and MFEM.

(i) Long-term Monitoring of Water Quality in Port Vila Harbor [O-M 2.1]

Port development will promote urbanization and industrial growth and may increase pollutant load to Port Vila Harbor, although the new wharf will not discharge polluted water to the harbor as the drainage facilities will be improved. Therefore, long-term monitoring of water quality was proposed in this study to contribute to conserving water quality in Port Vila Harbor (see chapter 8.2.3).

Department of Geology, Mines and Water Resources (DGMWR), which takes charge of coastal water quality monitoring in Vanuatu, has a laboratory for water quality analysis and has been conducted the monitoring survey of Port Vila Harbor since 1999. However, the survey was suspended after damage of the equipments due to fire accident in 2004, and it is still difficult to be implemented periodically due to shortage of the budget although it has been restarted in 2010. In addition, frequent sampling analysis seems to be difficult as the limitation of human resource although it was conducted for the parameters such as nitrogen and phosphorus in 2010. Considering the capacity on budget and human resources, automatic observation buoy was proposed as it assures continuous data with smaller human power.

(ii) Long-term Monitoring of Corals in Port Vila Harbor [O-M 1.1]

Corals with good condition are remained in Port Vila Harbour especially around the coastal area near the harbor entrance. Although it is said that the water quality tends to be deteriorating, the water transparency is still in good condition and it is available for people to enjoy underwater observation by snorkeling and glass boat. Therefore, long-term monitoring of marine biological resources represented by corals is important not only for ecological conservation but also for preserving tourism resources.

Methodology of coral transect survey taken in EIA study followed by this study is suitable for long-term monitoring and is feasible for Department of Fisheries to undertake technically. It was proposed to be implemented by the Department of Fisheries as it would not be a burden on their budget and personnel as long as it will be a small-scale survey such as yearly survey at three sites (see chapter 8.2.4).

(c) Environmental Management to be addressed by the Government of Vanuatu

Following environmental management is proposed to be addressed by the Gov of Vanuatu or entire Port Vila Harbor as it is not a project specific issue and needs more comprehensive discussions in the future.

(i) Oil Spill Contingency Plans and Securing Navigation Safety [O-M 4.4, O-M 4.5]

It is not likely that large scale oil spill will occur at Star Wharf, since neither oil tankers' use nor oil supply at the wharf has been planned. However, the risk of the spill caused by collision accident in the harbor may increase in accordance with growing number of vessels in the future. It is proposed for the government of Vanuatu or Port Vila to develop oil spill contingency plans including training in case of the accidents as well as to update Nav-Aids for securing navigation safety.

(ii) Legislation to Prevent Oil Spill and Capacity Enhancement of Relevant Agencies [O-M 4.2, O-M 4.3, O-M 4.6]

Vanuatu has already ratified Appendix I of MARPOL Convention which regulates oil pollution. However, national legislation has not established to cope with the issue according to the EIA report. It is proposed to be addressed in the future as well as the capacity enhancement of the Department of Port and Harbor for implementing the Port State Control.

(iii) Comprehensive Measures for Marine Pests [O-M 5.1, O-M 5-2]

It is hardly to say that operation of the new wharf will immediately bring a risk of new marine pests, since the vessels which will use the wharf is currently using Main Wharf adjacent to the Star Wharf. However, the future risk is implied if vessels from various regions will come to the wharf in the future. Comprehensive discussion on the measures is deemed to be desirable, since the risk is not limited for the Star Wharf but the measures need to be applied to all vessels which use Port Vila Harbor. The examples of the study for comprehensive discussion are listed below.

- Marine Pest Survey in Port Vila Harbor to understand the current condition,
- Risk analysis considering the examples of neighboring countries and
- Discussion on the possibility to make the measures obligatory for the vessels which come to Port Vila (e.g. removal of the bio-fouling before leaving source port and measures for ballast water).

(iv) Ballast Water Management [O-M 5.3]

For the same reason mentioned above, it is hardly to say that operation of the new wharf will immediately bring a risk of ballast water issue. However, restriction of ballast water discharge is needed to reduce the impacts on ecosystems, since the future risk is implied if vessels from various regions will come to the wharf in the future.

Vanuatu has not ratified the "International Convention for the Control of Ship's Ballast Water and Sediments" (BWM Convention). Although EIA report is proposing to ratify the convention, it is proposed in this study to establish national legislation for more effective management such as compulsory of water exchange at offshore (more than 200 nautical miles and deeper than 200m) because of following reasons: BWM Convention has not come into force, obligation of loading treatment system will not be started until 2016, and popularization of the treatment system is unsure due to technical issues. According to the EIA report, Vanuatu has a draft legislation which includes restriction of ballast water discharge; however, the report points that it is not realistic. Effective and economically feasible legislation needs to be discussed.

(v) Restriction of Harmful Anti Fouling System [O-M 6.1]

Since the vessels which will use the new wharf is currently using the Main Wharf adjacent to the Star Wharf, it is hardly to say that operation of the new wharf will immediately bring a new risk of harmful anti-fouling system. However, proper restriction and management of the anti-fouling are needed, since the future risk is implied if the number of vessels will increase in the future.

Although the EIA report is proposing to ratify "International Convention on the Control of Harmful Anti-Fouling Systems on Ships" adopted by IMO, it is proposed in this study for Vanuatu to address the issue comprehensively; for example, to collect information on current use of harmful anti-fouling substances such as TBT.

(vi) Management of Ship's Sewage [O-M 8.1]

Only seven vessels is planned to use the Star Wharf immediately after it starts to be operated: one from Singapore, two from Japan and Korea, two from Australia and two from New Zealand. They have shipboard treatment systems in accordance with their own countries' regulation; therefore, additional waste water pollution will not be caused immediately. However, it is desirable to strengthen the restriction on waste water management from ships which covers entire harbor to conserve water quality of Port Vila Harbor, since most of the pleasure boats and small cargo ships which use the harbor seem not to have treatment systems in addition to the possibility that vessels from various countries may come to use the Star Wharf in the future.

Vanuatu has already ratified Appendix IV of MARPOL Convention, which requires management of waste water discharge from ships. It is expected to address the issue practically in order to observe the convention.

(3) Summary of EMMP during Operation Phase

EMMP during operation phase (marine activities) are summarized and proposed in Table 8.2.5-2. The issues to be addressed by the Government of Vanuatu are also listed in

Table 8.2.5-3.

Table 8.2.5-2 Summary of EMMP during Operation Phase (Marine Activities)

Activities	Implementation	Cost (Japanese Yen)	Remarks on the Cost
Arrangement for Terminal Nav-Aids	Terminal owner/ operator (IPDS Co. Ltd.) will arrange with the relevant agencies.	—	
Ship's Waste Management		—	
Arrangement for Marine Exclusion Zone		—	
Long-term Monitoring of Water Quality	DGMWR will implement and provide data to MIPU.	24,390,000	Producing the buoy, transportation, deploying and maintenance for two years (120,000 yen/year).
Long-term Monitoring of Corals	Department of Fisheries will implement and provide data to MIPU.	219,000	Equipments such as camera, fuel of boat and SCUBA tank for two years (8,000 yen/year).
Total		24,609,000	

*DGMWR: Department of Geology, Mines and Water Resources

Table 8.2.5-3 Proposal to the Government of Vanuatu to be Addressed

Items	Proposal
Oil Spill Contingency Plans and Securing Navigation Safety	・ Establishing oil spill contingency plans and training. ・ Reviewing and updating Nav-aids for securing navigation safety.
Legislation to Prevent Oil Spill and Capacity Enhancement of Relevant Agencies	・ Establishing national legislation in accordance with MARPOL Convention. ・ Enhancement of Port State Control.
Comprehensive Measures for Marine Pests	・ Marine Pest Survey in Port Vila Harbor to understand the current condition ・ Risk analysis considering the examples of neighboring countries ・ Discussion on the possibility to make the measures obligatory for the vessels which come to Port Vila (e.g. removal of the bio-fouling before leaving source port and measures for ballast water).
Ballast Water Management	・ Establishing national legislation including compulsory of offshore exchange of ballast water.
Restriction of Harmful Anti Fouling System	・ Collecting information on current use of harmful anti-fouling substances and establishing national legislation for the restriction.
Management of Ship's Sewag	・ Strengthening restriction to observe MARPOL Convention.

CHAPTER 9 Proposal

Related to or apart from this project, the subjects to be addressed by the Government of Vanuatu, besides the study plan such as the implementation of mitigation measures, environmental management, monitoring plan, etc., were proposed as follows by the JICA Study Team based on the information obtained through this study.

9.1 Establishing coral reef conservation plan

Most of water environmental load influencing the coral reef in Port Vila Bay is considered to occur in urban area of Port Vila. Sewage treatment project in the urban area is now proceeding. In near future when the project is completed, water quality in the bay will be stable and contribute for coral reef conservation.

In that opportunity, establishment of coral reef conservation plan is required to sustain coral community for long term for showing good grade tourism place. In order to realize it, keeping target such as number of species and coverage of coral community should be established and monitored for environmental management.

Coral creation on the bulkhead of the reclamation

Corals distributing in the predicted reclamation area in Star Wharf are relocated to conserve to west of Iririki Island as moderating measure. As mitigation measure, coral creation is required by coral transplantation and recruitment introduction on the bulkhead. Coral creation can contribute to coral reef conservation in Port Vila Bay through larvae supply by reproduction, habitat supply to other animals such as fish and creation of underwater seascape.

In Hirara Port, Miyako Island, Ryukyus, transplantation of coral which will distinguish due to breakwater construction to bulkhead and recruitment introduction on breakwater were implemented. In this project, since corals in extinct area will be relocated to similar environmental place, those are not transplanted on the bulkhead. Therefore, it is recommended to employ coral creation by seed production by larvae settlement and recruitment introduction.

The method of seed production is that coral settlement devices deployed on the sea bottom in spawning time collect coral larvae and grow them on the bottom. After scheduled time, devices are transplanted to the sea bottom as seeds. Because past transplanting methods used to take fragments of existing donor corals, they usually perceive damage due to breaking. On the other hand, seed production method does not give any damage to existing coral and can produce diversified lots of seeds.

Recruitment introduction method includes rough processing and formulating bulkhead by natural stones. In those cases, it needs to research recruitment possibility before implementation.

Because those methods must be able to be applied to Port Vila Bay, evaluation of possibility should be done through examination.

9.2 Establishing plans for environmental conservation and development in national level

The population of the urban area in and around Port Vila, estimated as 58,000 as of 2009, has been projected it may reach to 109,000 in 2025 (Proposed Loan and Administration of Grant, Port Vila Urban Development Project, ADB, 2011). In accordance with the population growth, development demand on ports and the connected roads is expected to increase in near future. Additionally, improving traffic infrastructure is indispensable for growth of tourism, which is major industry of Vanuatu.

In Efate Island, untouched nature is widely remained outside of Port Vila and no other large-scale urban area has been developed. However, it is foreseen that comprehensive discussion will be required from various viewpoints not only for intensive utilization of the limited water area in Port Vila Harbor but also for considering possibility of alternative development in other region to cope with the increased demand of port and the other infrastructure development. Since development in the area with untouched nature may cause significant environmental impacts, it is proposed to implement strategic environmental assessment in order to consider environmental appropriateness on expanding industrial, economical, and daily human activities as well as to discuss future plan of traffic infrastructure development considering tourism as soon as possible.

For implementing the strategic environmental assessment, it is indispensable to conduct basic study on natural resources such as identifying resources to be protected, comprehending their distribution and evaluating, since those study results in national level are quite limited at this moment. Based on the wide-scale study results on natural resources and the evaluation results, comprehensive development plan such as conservation plan, land utilization plan, tourism development plan with decentralization needs to be developed. Furthermore, infrastructure development plan in national and island level needs to be discussed upon all of the plans.

Therefore, infrastructure development plan, tourism development plan and conservation plan on natural environment should be established by “step by step” from national level essentially. Then, giving position to Port Vila Bay area in respective plans is examined and infrastructure development plan of the area should be established based on a general upper level plan graded up through above-mentioned plans.

Coral reef conservation plan mentioned in the item 9.1 should be also established about national level plan firstly. Then, necessary conservation plan in the project area should be discussed based on national level plan. Through those processes, fruit and technical accumulation of monitoring that will be carried by this project can be activated effectively.

9.3 Formation of Framework for Sustainable Utilization of Port Vila Harbor

In Port Vila Harbor, several projects have been planned beside this project for Star Wharf, such as domestic wharf and resort development. At this moment, EIA study has been carried out by each project; however, cumulative and combined impacts may be caused as the results of all of the projects. Therefore, firstly it is recommended for the Government of Vanuatu to coordinate the EIA studies not to duplicate or contradict each other. Secondary, it is proposed to facilitate each project to consider environmental conservation and utilization systematically based on a comprehensive development plan for sustainable utilization of the harbor, which includes consideration of potential cumulative and combined impact.

In Vanuatu, public consultation has become obligatory as a part of EIA process. The Government of Vanuatu needs to facilitate the information to be shared among interested people of different projects in order to the potential cumulative and combined impacts will be considered in the consultation.

Various types of utilization and development plan have been observed in Port Vila Harbour. Practically, Ifira people have strong discretion on the development project around Port Vila Harbour and every project needs to be understood or decided by the Ifira people, since large part of the area is categorized as their custom land. Hence, it is necessary for the government to discuss with the representatives of Ifira to obtain their understandings on the concept of sustainable utilization of the harbor, in order to realize the concept.

On the other hand, public consultation has become obligatory for developing development plans as a part of EIA process by the EIA regulation, which was newly issued this year. This change is expected to move a step forward for establishing a framework for consensus-building on sustainable utilization of the harbor as it provides opportunities to people from all standpoints to raise their voice officially on the project.

Department of Environmental Protection and Conservation (DEPC) has a role of receiving the public opinion and approve the project implementation in terms of environmental consideration. The department is expected to increase their capacity for coordinating relevant agencies as well as to establish a practical policy for conservation of the harbor. According to the director, DEPC is proposing to develop a master plan for environmental conservation of Port Vila Harbor. It is recommended to complete the plan or comprehensive strategy earlier to respond to the social requirement on environmental conservation.

In order to make decision on the project implementation, scientific knowledge has not been accumulated sufficiently among relevant agencies as well as Ifira people at this moment. For environmental monitoring survey in the harbor, Department of Geology, Mines and Water Resources (DGMWR) is in charge of water quality while Department of Fisheries has experience of coral survey. However, DGMWR has not been able to conduct sufficiently due to budgetary issue and Department of Fisheries has not allocated long-term monitoring points in the harbor. Considering this situation, the study team proposed implementation of long-term monitoring by both two departments as a part of the monitoring plan during operation phase. In addition to the expectation that the continuous monitoring will be ensured, it is desirable that an organizational and technical framework will be formed for effective disclosure and utilization of the monitoring results for further step. The study team would like to propose to establish a 'Committee for Environmental Conservation and Sustainable Utilization of Port Vila Harbor' described below as one of the approaches to form the framework. While the Committee is expected to work for decision making on environmental conservation and sustainable utilization of the harbor in the future, it is proposed to start the initial work with sharing scientific data among interested people.

It is expected that DEPC will be able to facilitate the Committee. However, annual budget of the department (15,000,000 VT in 2011, 18,000,000 in 2010) and the number of the staffs are limited (18 permanent staffs, 7 project based staff and one volunteer advisor). Organizational strengthening on both budgetary aspects and human resources is expected as well as cooperation from the other relevant agencies tentatively.

"Committee for Environmental Conservation and Sustainable Utilization of Port Vila Harbor" (Draft)

Objectives: Evaluation of the monitoring data, discussion on environmental conservation and sustainable utilization of Port Vila based on the data, information sharing and forming consensus.

Members: DEPC, DGMWR, Department of Fisheries, academicians and experts,

Ministry of Infrastructure and Public Utilities (Department of Port and Harbour and Department of Public Works) and the other government agencies,

Ifira people, Shefa province, Port Vila municipality, truism business and others.

9.4 Capacity building and enforcement of organizations concerning environmental management and monitoring

It is needed that forming sufficient system such as capacity building and budget obtaining for operating environmental management and monitoring that are planned in this project. Enforcement of organizations and capacity building for administrations that control environmental conservation and monitoring are required. Department of Environmental Protection and Conservation charged of environmental administration and EIA examination is especially needed for performing the matters. Department of Fisheries and Department of Geology, Mine and Water Resources are also required to form the system.