CHAPTER 13 PRELIMINARY DESIGN OF PROJECT

13.1 Hydraulic Design

13.1.1 Site for Diversion Channel and Short Cut Channel

(1) Site for Diversion Channel

4 possible alignments which are located upstream Nadi river from the Nadi town (9.5 km ~ 12.0 km upstream from river mouth) were examined for the Nadi diversion channel in terms of topographical features, land acquisition and length (Chapter 6). As a result, an alignment which passes along the Enamanu road and whose total length is the shortest among 4 alignments was selected.

Based on results of topographical survey, geological survey and social-environmental survey conducted during the 3rd work period in Fiji from November 1997 to March 1998, the alignment of the diversion channel was finally determined. Items considered for the determination of alignment are topographical features, geological features, land acquisition and compensation, and preservation areas, such as cemetery, archaeological site etc., in the project site. As a result, the diverting point is the right bank of Nadi river located at 14.6 km from river mouth and the total length is approximately 3.3 km. These figures are slightly different from the Master Plan (diverting point: 14.0 km from river mouth, total length: 3.0 km).

(2) Site for Short Cut Channel

Based on results of topographical survey and social-environmental survey conducted during the 3rd work period in Fiji, the site for the short cut channel was finally determined. In fact, the site is not different from that proposed in the Master Plan because there is no land use practiced in the site.

The short cut channel will connect between 7.5 km and 9.0 km points of Nadi river from river mouth. Its total length is approximately 250 m.

(3) Location

Location of the Nadi diversion channel and short cut channel are shown in Figure-13.1

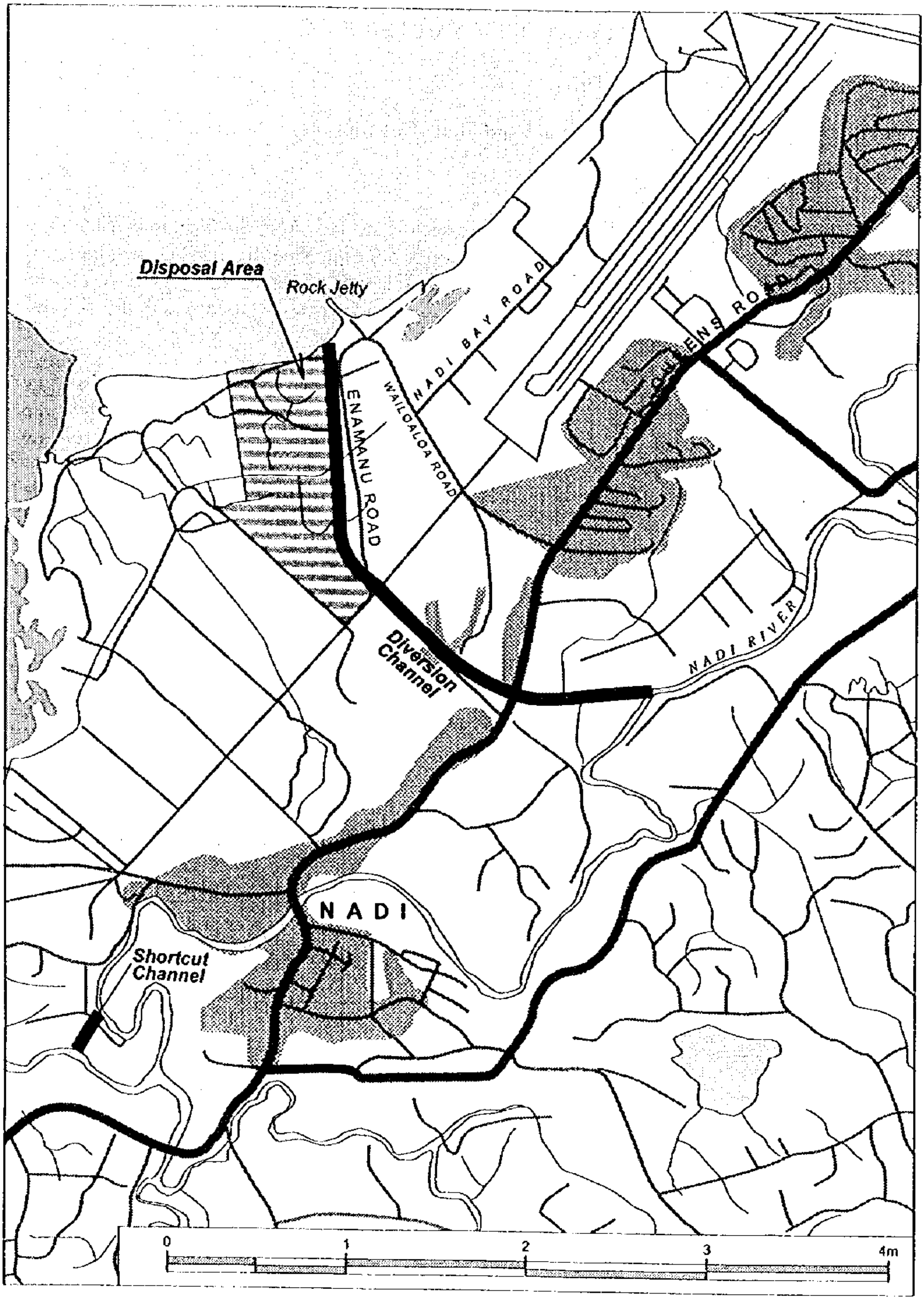


Figure-13.1 Location of Nadi Diversion Channel and Short Cut Channel

13.1.2 Diverting Ratio

Diverting ratio was determined as drainage through the diversion channel starts when discharge of Nadi river increases by rainfall. According to daily rainfall data at Nadi airport in the last 53 years (1942 ~ 1995, data gaps in 1946), rainfall contributes discharge for 23 % ~ 49 % of year. Considering the rainfall distribution in year and flow regime, the diversion channel was designed to start drainage when discharge of Nadi river is approximately 15 m^3/sec which is discharge at 25 % of year from the maximum, allowing Nadi river to drain water for 75 % of year without the diversion channel. For the rest of year, 25 % of year, water is drained by both Nadi river and diversion channel varying the diverting ratio. Diverting ratios with different discharge were determined by non-uniform flow calculation and the result is shown in Figure-13.2.

Based on the flow regime at Votualevu station (catchment area = 164 km^2), the flow regime at the diverting point (catchment area = 327 km^2) was estimated by ratio of catchment area. The result is shown in Figure-13.3.

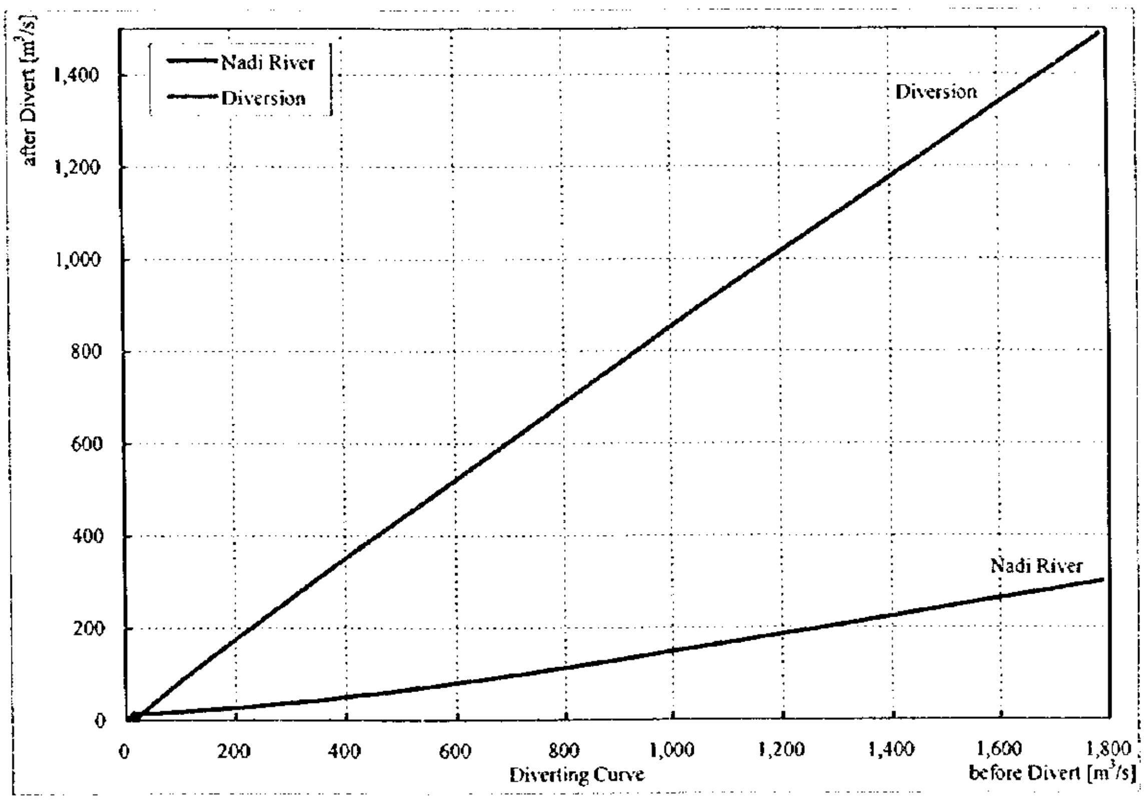


Figure-13.2 Diverting Ratio of Nadi River and Diversion Channel

Votualevu (HA020) : Nadi River

Catchment Area : 164 km²

Year	Max	Q1.4%	Q 2.7%	Q 4.1%	Q 5.5%	Q 8.2%	Q 11.0%	Q 13.7%	Q 16.4%	Q 19.2%	Q 26.0%	Q 50.7%	Q 75.3%	Q 97.3%
1980	127.0	43.2	25.2	19.0	15.8	12.3	10.1	8.4	7.8	6.6	4.5	1.1	0.5	0.5
1981	127.3	69.5	36.4	32.0	25.1	14.3	9.4	7.6	6.5	5.6	4.3	1.3	0.7	0.6
1982	415.0	63.0	31.2	28.7	24.1	18.0	15.3	12.9	10.8	9.6	5.9	0.7	0.2	0.1
1984	87.6	30.7	22.3	17.5	16.1	14.5	12.7	11.8	11.2	10.6	9.5	5.7	2.6	2.3
1986	378.0	70.9	36.1	33.8	26.4	19.0	14.8	12.2	10.4	9.5	6.6	4.5	4.2	4.2
1988	84.0	19.5	16.5	11.3	10.9	8.9	8.9	8.5	8.2	8.0	7.7	3.2	2.3	2.2
Ave.	203.2	49.5	28.0	23.7	19.7	14.5	11.9	10.2	9.2	8.3	6.4	2.8	1.8	1.7

Diverting Point of Nadi River

Catchment Area : 327 km2

Year	Max	Q1.4%	Q 2.7%	Q 4.1%	Q 5.5%	Q 8.2%	Q 11.0%	Q 13.7%	Q 16.4%	Q 19.2%	Q 26.0%	Q 50.7%	Q 75.3%	Q 97.3%
1980	253.2	86.1	50.2	37.9	31.5	24.5	20.1	16.7	15.6	13.2	9.0	2.2	1.0	1.0
1981	253.8	138.6	72.6	63.8	50.0	28.5	18.7	15.2	13.0	11.2	8.6	2.6	1.4	1.2
1982	827.5	125.6	62.2	57.2	48.1	35.9	30.5	25.7	21.5	19.1	11.8	1.4	0.4	0.2
1984	174.7	61.2	44.5	34.9	32.1	28.9	25.3	23.5	22.3	21.1	18.9	11.4	5.2	4.6
1986	753.7	141.4	72.0	67.4	52.6	37.9	29.5	24.3	20.7	18.9	13.2	9.0	8.4	8.4
1988	167.5	38.9	32.9	22.5	21.7	17.7	17.7	16.9	16.4	16.0	15.4	6.4	4.6	4.4
Ave	405.1	98.6	55.7	47.3	39.3	28.9	23.7	20.4	18.2	16.6	12.8	5.5	3.5	3.3

Diverting Point = Votualevu x 327/164

Q 1.4% : daily discharge exceeding this volume for 1.4 % of a year (5 days) or 5th daily discharge from the maximum

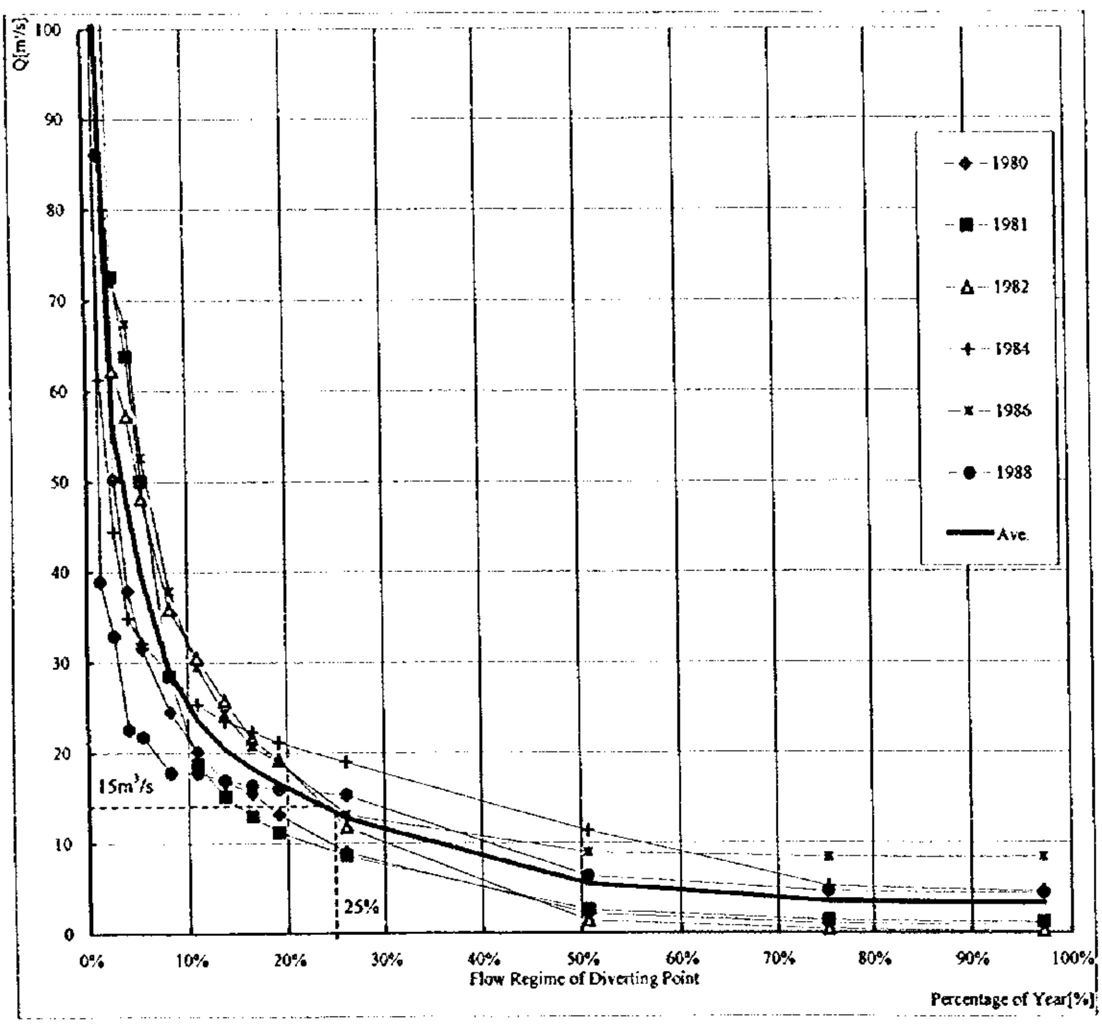


Figure-13.3 Flow Regime at Diverting Point in Nadi River

13.1.3 Hydraulic Design of Diversion Channel and Short Cut Channel

Hydraulic analysis of the diversion channel and short cut channel was conducted to determine the hydraulic specifications, such as bed slope, cross section and so on. Target flood for the analysis is only 20 year return period flood. Since diversion channels for other smaller floods have same bed slope as the diversion channel for 20 year return period flood but smaller bed width depending on flood discharge and the hydraulic phenomena for the smaller floods are almost similar to that for 20 year return period flood, it is not necessary at present to conduct the hydraulic analysis for other smaller floods (1/15, 1/10 and 1/5 probability floods). Therefore, in the following sections, hydraulic design of the diversion channel and short cut channel is discussed for 20 year return period flood.

(1) Design Method

The Nadi diversion channel has the following functions.

- 20 year return period flood at diverting point (1,800 m^3/sec) is drained through the diversion channel (1,500 m^3/sec) and Nadi river (300 m^3/sec).
- Drainage through the diversion channel starts, when discharge of Nadi river is increased by rainfall and is 15 m^3/sec.

For the design, following 2 items were considered.

- to minimize width of the diversion channel in order to reduce work quantity and cost
- to design bed elevation of the diversion channel as high as possible in order to reduce work quantity in the sea resulting cheaper cost

Method to examine the hydraulic design of the Nadi diversion channel is as follows.

1) to determine widths of the diversion channel inlet and Nadi river at diverting point so as to allocate floods in accordance with the design

Table-13.1 Widths of Inlet and Nadi River at Diverting Point

Width	Case 1 (m)	Case 2 (m)	Case 3 (m)	Case 4 (m)
Nadi River	9	10	11	12
Diversion Channel	54	60	65	71

Width of the diversion channel is required at least 50 ~ 70 m based on topographic condition and discharge.
Width of Nadi river was determined based on width of the diversion channel.

2) to calculate water level and energy head of Nadi river form river mouth to diverting point by non-uniform flow computation with the above conditions (Table-13.1)
3) to calculate water level and energy head of the diversion channel from downstream end to diverting point by non-uniform flow computation
4) to conduct 3) calculation varying hydraulic specifications (cross section and longitudinal profile) of the diversion channel until water levels and energy heads of the diversion channel and Nadi river are equal to each other at diverting point
5) to select the hydraulic specification whose width is equal to inlet width of the diversion channel among several specifications determined in 4)

(2) Design Conditions

The followings are design conditions of the diversion channel.

1) Sea water level: Since the mean high water of tide is approximately EL. 0.6 m (above mean sea level), EL. 1.0 m was adopted as a boundary condition of non-uniform flow computation considering the safety factor.

2) Calculation in the sea around the downstream end: Assuming that flow from the diversion channel spreads with an angle of 5°, a staring point of non-uniform flow computation where velocity of the flow is dissipated is 1.5 km away from the downstream end. The angle of 5° is the popular empirical figure.

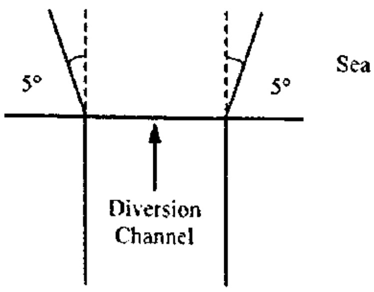


Figure-13.4 Spreading Angle of Flow into Sea

3) Slope gradient of diversion channel: Considering slope stability of the diversion channel and vegetation cover on slope, slope gradient is assumed to be 1:2.

4) Manning roughness coefficient: Manning roughness coefficient in Nadi river and the diversion channel is assumed to be 0.03.

5) Bed elevation at diverting point: Bed elevation of Nadi river is equal to the present bed elevation (EL. -1.0 m), while bed elevation of the diversion channel is EL. 0.0 m which water starts to flow into the diversion channel when discharge of Nadi river is 15 m^3/sec.

(3) Results of Hydraulic Design

Based on the conditions above, non-uniform flow computation was employed to determine the hydraulic design of the diversion channel varying widths of inlet and Nadi river at diverting point. Results of 4 cases are summarized below.

1) Case 1

The hydraulic design to satisfy diversion conditions is that bed elevation of the diversion channel at downstream end is EL. -3.0 m and section from downstream end to 2,300 m is flat. Bed width of the diversion channel is 55.5 m.

2) Case 2

There are two designs to satisfy diversion conditions. One is that bed elevation of the diversion channel at downstream end is EL. -2.5 m and section from downstream end to 2,500 m is flat, and another is that bed elevation at downstream end is EL. -3.0 m and section from downstream end to 1,800 m is flat. For both designs, bed width of the diversion channel is 60.0 m.

3) Case 3

There are two designs to satisfy diversion conditions. One is that bed elevation of the diversion channel at downstream end is EL. -2.5 m and section from downstream end to 1,800 m is flat, and another is that bed elevation at downstream end is EL. -3.0 m and section from downstream end to 1,300 m is flat. Bed width of the diversion channel for the former design is 67.1 m and that for the latter design is 66.2 m.

4) Case 4

The hydraulic design to satisfy diversion conditions is that bed elevation of the diversion channel at downstream end is EL. -2.5 m and section from downstream end to 1,800 ~ 2,300 m is flat. Bed width of the diversion channel varies form 96.5 m to 66.4 m, depending on length of the flat section.

Bed elevation of the diversion channel should be as high as possible in terms of construction of outlet in the sea, while bed width should be narrow in terms of work quantity or construction cost. The case 1 has the smallest bed width; however, bed elevation at downstream end (EL. -3.0 m) has a disadvantage. If bed elevation is EL. -2.5 m, the smallest bed width is 60 m (case 2). Therefore, considering the construction of outlet and cost of the diversion channel, the case 2 (the following specifications) was adopted as the hydraulic design of the diversion channel.

- bed width of diversion channel: 60 m
- bed elevation at downstream end: EL. -2.5 m
- flat section of bed: from downstream end to 2,500 m

The hydraulic design of the diversion channel is summarized in Table-13.2 for not only the design flood (1/20 probability flood) but also 1/15, 1/10 and 1/5 probability floods. The diversion channel for a smaller flood than 1/20 probability flood was designed to have the same longitudinal profile as the diversion channel for 1/20 probability flood but smaller channel width depending on flood discharge in order to enable stepwise construction.

The short cut channel has 250 m length connecting 7.5 km point and 9.0 km point of Nadi river from river mouth. Longitudinal profile was designed to be equivalent to the current one of Nadi river (1/2,000) and bed elevation was also designed to be same as bed elevation of Nadi river (7.5 km point: EL. -1.0 m and 9.0 km point: EL. -0.9 m). Bed width of the short cut channel was determined as 30 m which is same as bed width of Nadi river at 9.0 km point, while bed width of Nadi river at 7.5 km was designed to be enlarged to 40 m considering confluence with Nawaka river.

The hydraulic design of the short cut channel is shown in Table-13.2.

Table-13.2 Summary of Hydraulic Design (Diversion Channel and Short Cut Channel)

Item			Probability of Design Flood			
			1/20	1/15	1/10	1/5
Discharge	NR upstream DC		1,800 m^3/sec	1,500 m^3/sec	1,200 m^3/sec	810 m^3/sec
	NR downstream DC		300 m^3/sec	300 m^3/sec	300 m^3/sec	300 m^3/sec
	Diversion		1,500 m^3/sec	1,200 m^3/sec	900 m^3/sec	510 m^3/sec
	Start of diverting		15 m^3/sec	15 m^3/sec	15 m^3/sec	15 m^3/sec
Diverting Point	Location of diverting		Nadi river 14.6 km upstrem from river mouth			
	Bed slope		1/5,000			
	Bed elevation		EL. -1.00 m			
	Width of NR (bed)		10.0 m	10.0 m	10.0 m	10.0 m
	Width of inlet (DC)		60.0 m	48.0 m	36.0 m	21.0 m
	WL at inlet		EL. 5.145 m	EL. 5.019 m	EL. 4.899 m	EL. 4.787 m
	WL at inlet without DC		(EL. 13.041 m)	(EL. 11.971 m)	(EL. 10.799 m)	(EL. 10.313 m)
	Total head		EL. 6.361 m	EL. 6.286 m	EL. 6.219 m	EL. 6.158 m
	Velocity		4.88 m/sec	4.98 m/sec	5.09 m/sec	5.18 m/sec
	Froude number		0.63	0.65	0.67	0.69
Diversion Channel	Total length		approximately 3,300 m			
	Bed slope		downstrem from 2.5 km point : Level			
			upstream from 2.5 km point : 1/320			
	Elevation at downstream end		EL. -2.500 m			
	Elevation of inlet		EL. 0.000 m			
	Bed width		60.0 m	48.0 m	36.0 m	21.0 m
Short Cut Channel	Location		between 7.5 km and 9.0 km of Nadi river from river mouth (length : 250 m)			
	Bed slope		1/2,500			
	Bed elevation	7.5 km	EL. -1.000 m			
		9.0 km	EL. -0.900 m			
	Bed width	7.5 km	40.0 m			
		Short cut	30.0 m			
	WL at 9.0 km point		EL. 4.810 m	EL. 4.607 m	EL. 4.395 m	EL. 4.174 m
	WL at 9.0 km poit with DC without short cut		(EL. 5.147 m)	(EL. 4.957 m)	(EL. 4.764 m)	(EL. 4.547 m)
	Velocity		1.27 m/sec	1.33 m/sec	1.40 m/sec	1.47 m/sec
	Froude number		0.19	0.20	0.22	0.23

NR: Nadi River

DC: Diversion Channel

WL: Water Level

(4) Water Level

Non-uniform flow computation was applied to estimate water level of Nadi river for 20 year return period flood with implementation of the diversion and short cut channels. Expected water level is shown in Figure-13.5. Water level of the diversion channel for the design discharge (1,500 m^3/sec) was also estimated by non-uniform flow computation and its result is shown in Figure-13.6.

Since width of Nadi river is narrowed to 10 m at diverting point, velocity of flow increases resulting in lower water level (velocity head + water level = energy head: approximately constant). However, the flow does not become turbulent because it is not supercritical flow.

Nadi river upstream from diverting point is improved to flow 2,100 m^3/sec; however, Nadi river is very narrow in further upstream. Therefore, as shown in Figure-13.5, water level around 15 km point is much higher than downstream due to backwater resulting from the narrow areas.

Bed slope of the diversion channel is flat from downstream end to 2,500 m point as shown in Figure-13.6; however, there is no stagnation during drainage even if discharge is small because flow is governed by not bed slope but energy gradient.

(5) Recommendation

Hydraulic design of the diversion channel and short cut channel in this study was conducted by one dimensional analysis. Since Nadi river is a natural channel which does not have uniform cross section and objective of hydraulic calculation is flood whose velocity is very fast, it is not possible to get expected accuracy of hydraulic examination by two or three dimensional analysis. Therefore, hydraulic model experiment would be strongly recommended to reexamine the design of the diversion and short cut channels, to understand flow conditions (area of water collision etc.) and to study sediment transportation if the diversion and short cut channel project were determined to be implemented.

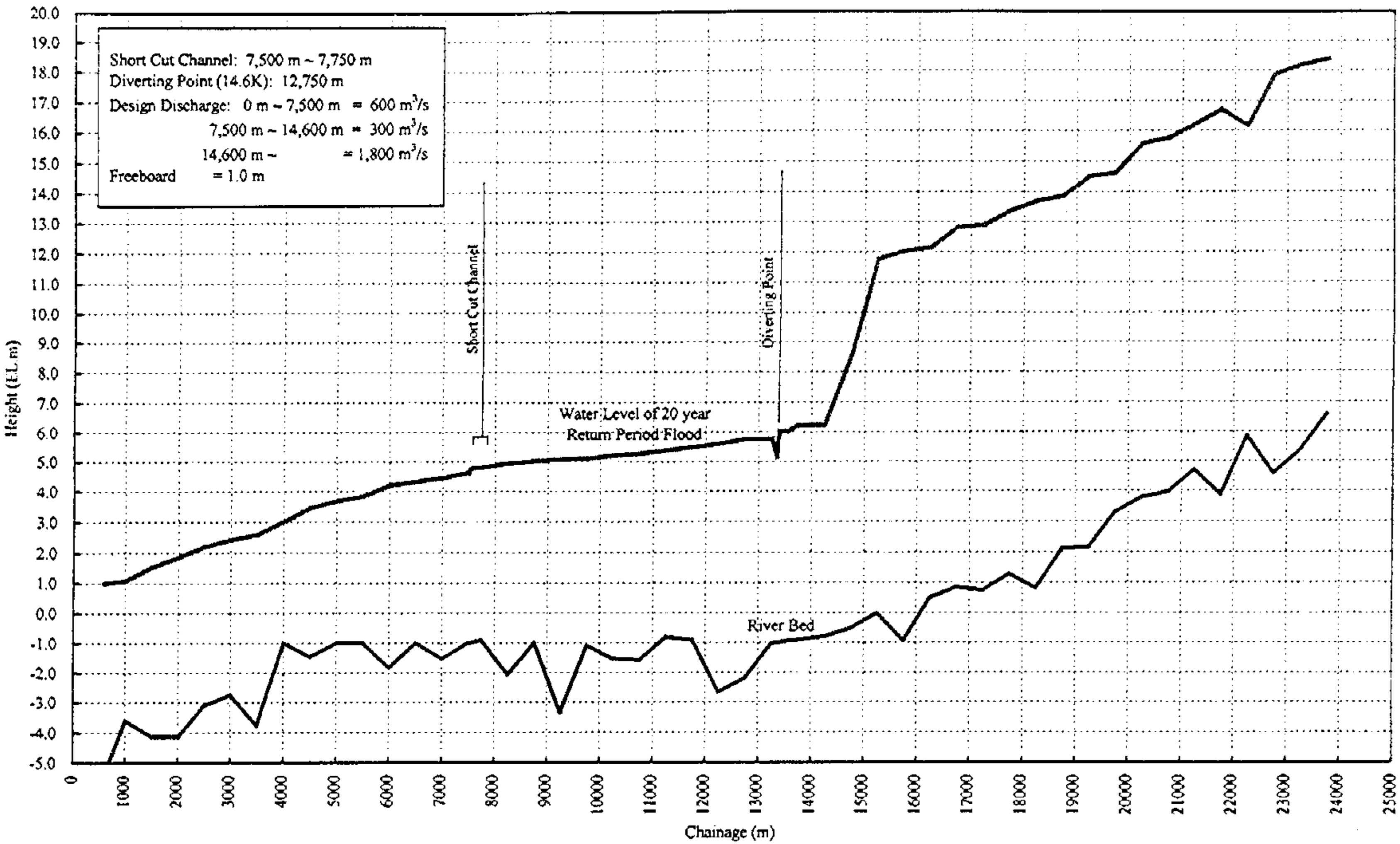


Figure-13.5 Longitudinal Profile of Nadi River with Expected Water Level

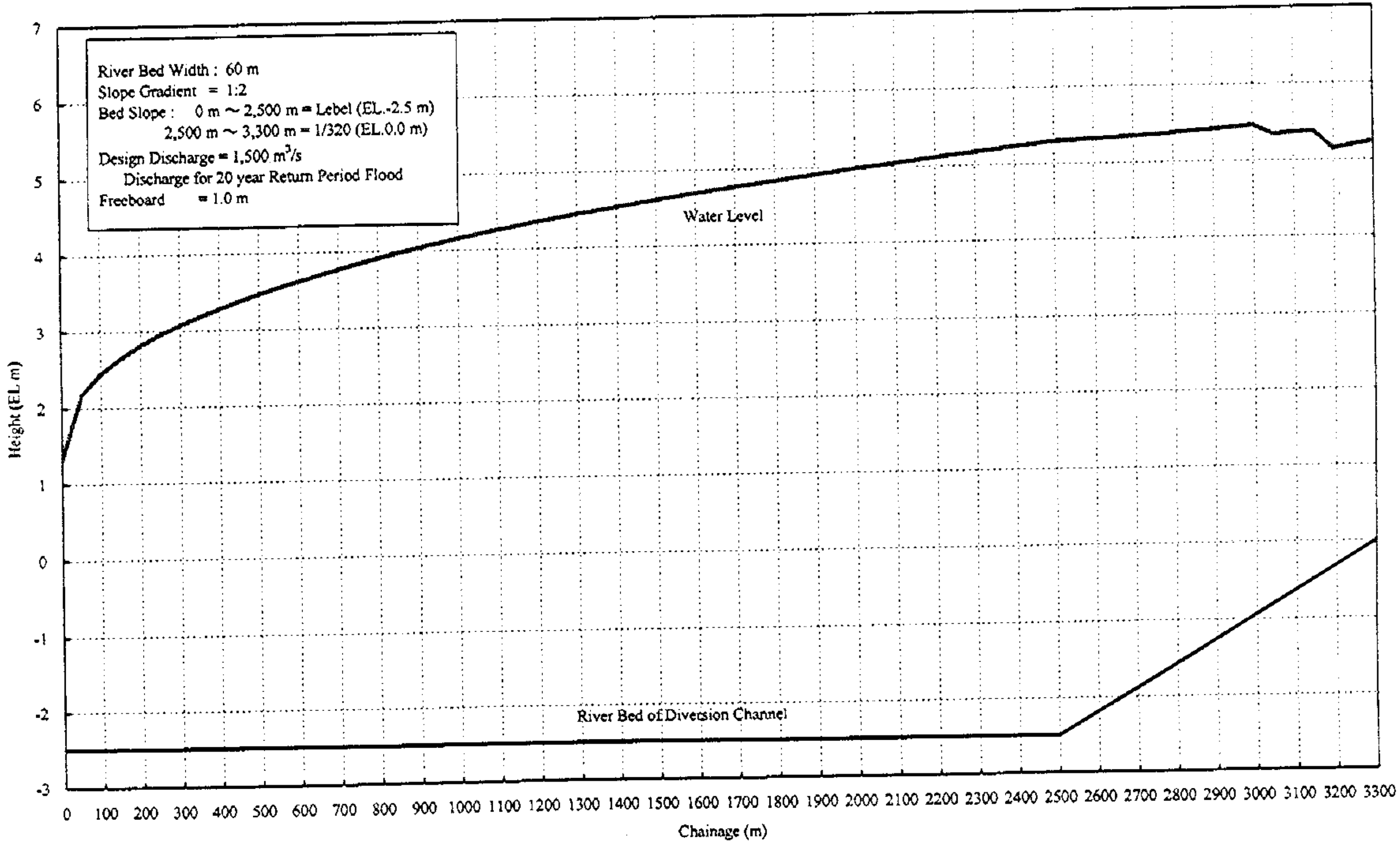


Figure-13.6 Longitudinal Profile of Nadi Diversion Channel with Expected Water Level

13.1.4 Other Factors Considered

(1) Bank Erosion

When the design flood or 3 smaller floods (1/20, 1/15, 1/10 and 1/5 probability floods) flows in the diversion channel, the maximum velocity of flow would be approximately 5 m/sec, regardless of flood size. Therefore, bank protection works, such as vegetation, are required.

According to the analysis conducted in this study, there is no critical areas of water collision, except diverting point. Therefore, revetment works are considered not necessary at this stage of study. However, results of hydraulic model experiment recommended for the next stage (detail design stage) may require revetment works and bed protection works. In the structural design (section 13.2), water collision prone area which is left bank of the diversion channel at a bend is designed to have more strength than other areas of bank by widening bank width. Therefore, if bank protection for critical areas of water collision was required in the further study, it would be recommended to consider not only revetment works but also increase in bank stability by widening bank width and applying more gentle bank slope.

(2) Sedimentation in Diversion Channel and Nadi River

Since bed elevation of the diversion channel is 1.0 m higher than that of Nadi river at diverting point, bed load flows only in Nadi river but not in the diversion channel. Therefore, only suspended load flows and some may be deposited in the diversion channel. Since the suspended load mostly consists of particles smaller than 0.03 cm, its deposit is easily drained by a flush of flood (see Chapter 17).

Bed load deposit in a particular place of Nadi river is not expected, because weir structures are not planned. Even if there is some change in river profile, dynamic equilibrium gradient will be achieved soon, and scouring and sediment deposit in a particular place is not expected.

(3) Sedimentation at Outlet

Since there is no flow, except periodical tidal flow, in the diversion channel for 75 % of year, sea sand is expected to be deposited at the outlet of the diversion channel. However, particle size of sand in the Nadi bay is fine enough to be flushed by drainage of floods. Therefore, the cross section of the diversion channel is maintained.

In Chapter 17, sediment transportation through the diversion channel was studied based on the hydrograph of flood and particle size distribution in the upper reach of Nadi river. The study results show that sediment load through the diversion channel mostly consists of particles smaller than fine sand ($\leq$ 0.03 cm), such as suspended load and wash load. Those particles are easily drained into the sea and diffused by ordinal tide. Therefore, serious problems of sedimentation at outlet are not expected to occur.

Present conditions at outlet of the Sabeto drainage canal located near the diversion channel site prove the above. Although there are flood gates at outlet resulting in rapid decline of flow velocity, sedimentation at outlet is hardly observed.

Sediment load through the diversion channel is considered not to cause serious problems at outlet. However, it is recommended to conduct sediment transportation experiment to review the sediment transportation and study sedimentation in the Nadi bay in details if the project proceeds the next stage, detailed design stage.

(4) Storm Surge

The study on extension of the Nadi airport assumed that storm surge of 20 year return period is EL. 3.0 m. Since the historical records has not confirmed that figure, it may be overestimate; however, it is considered as a safety factor for the airport extension.

Assuming that sea level is EL. 3.0 m and discharge of the diversion channel is 1,500 m^3/sec (drainage for 20 year return period flood), water level of the diversion channel was calculated and results are shown in Figure-13.7. As shown in Figure-13.7, water level when sea level is EL. 3.0 m is within freeboard at any section of the diversion channel. Therefore, even if storm surge was EL. 3.0 m, the diversion channel would drain the deign discharge safely.

(5) Flood Gate

Sugarcane is currently cultivated along the proposed alignment of the diversion channel; however, its area is expected to be reduced considerably due to the future land use, such as the extension project of Nadi airport, tourism development and earth works of the diversion channel. Since the diversion channel project proposes land development of soil disposal area, it would stipulate the development in the vicinity of the diversion channel resulting in the further reduction of sugarcane field if the proposal was implemented. Therefore, flood gates at outlet of the diversion channel are considered not necessary because there will be no crops to be protected from saline problems.

Flood gates at outlet induce water stagnation resulting in water pollution. The direct results may be mosquito breeding, emitting of unpleasant smell or odor, and unwanted growth of vegetation in the channel. This problem has been pointed out by many specialists and thought to be hazardous to public health in the surrounding area. Therefore, flood gates are not recommendable from an environmental point of view.

Sea water intrusion through the diversion channel is discussed in the next section. Conclusion is that the sea water hardly reach to Nadi river through the channel. Since sea water intrusion improves water quality in the channel by periodical flow of tide and hardly affect water quality of Nadi river through the channel, flood gates should not be installed.

Flood gates are considered not necessary at this stage of the study. Necessity of flood gates to mitigate saline problems should be examined by groundwater monitoring along the site of the diversion channel after completion of the diversion channel construction.

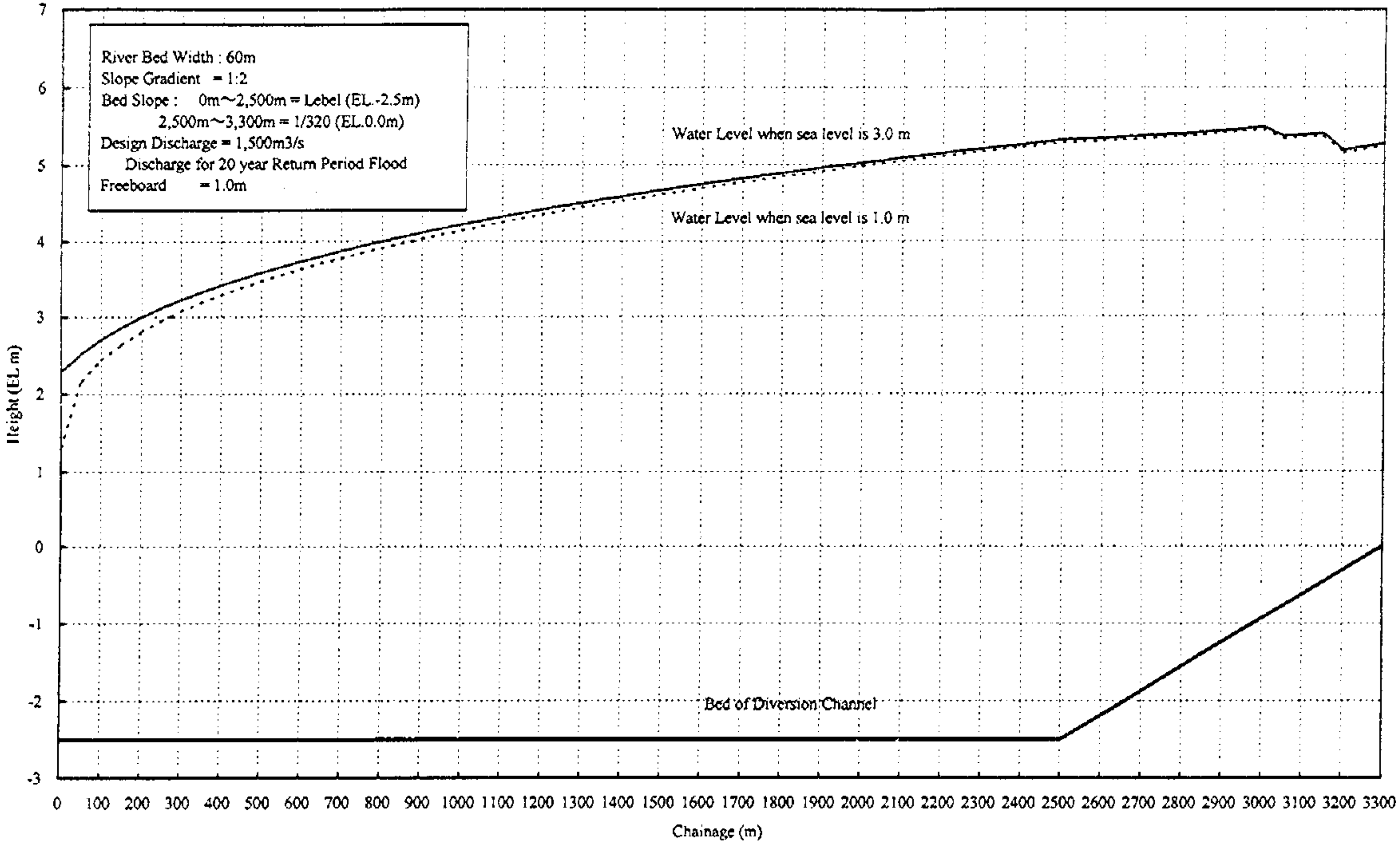


Figure-13.7 Expected Water Level by Storm Surge

(6) Sea Water Intrusion

When the brine intrudes into river, saltwater wedge is formed due to the difference of specific gravity between the fresh water and brine. Since the diversion channel bed is designed to be flat from downstream end to 2,500 m point and is raised from 2,500 m point to inlet, saltwater wedge is difficult to move on further upstream as shown in Figure-13.8.

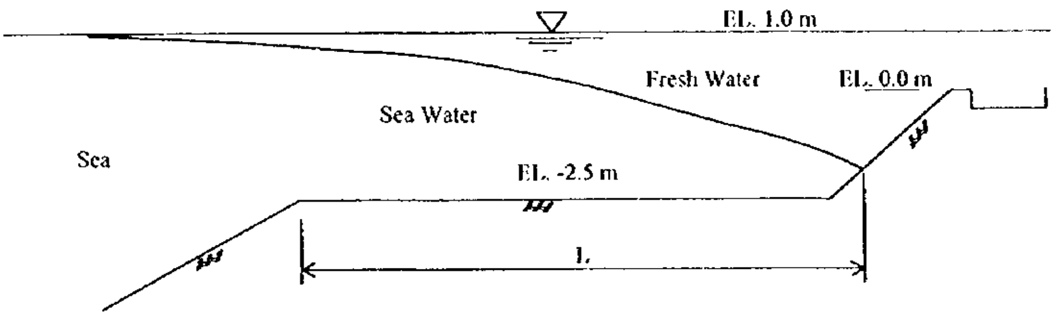


Figure-13.8 Saltwater Wedge (Diversion Channel)

Based on the saltwater wedge equation (Schijf et al., 1953, and Harleman, 1961), effective length of saltwater wedge was estimated. As a result, the effective length of saltwater wedge (L) is approximately 2,000 m ~ 3,100 m. Since total length of the diversion channel is 3,300 m, sea water intrusion is not expected to reach Nadi river through the channel.

13.2 Structural Design

12.2.1 Objective Structures for Feasibility Study

Feasibility Study of the Nadi diversion channel and short cut channel includes the following structures based on the hydraulic design and current landuse in the vicinity of site. Structural design was examined for the design flood (20 year return period flood). Based on the results of examination, structural designs for smaller floods (1/15, 1/10 and 1/5 probability floods) were determined by changing bed width.

1) Diversion channel
2) Short cut channel
3) Bridges for vehicles, sugarcane tramline and pedestrians
4) Road
5) Others (shift works)
   sugarcane tramline, water and sewage pipe lines, electric cable and telephone line

13.2.2 Design of Diversion Channel

(1) Alignment

As a result of the Master Plan Study, the alignment No.2 has been selected as the most feasible route of the Nadi diversion channel among the 4 alignments. Based on the alignment No.2, the specific route of the channel was determined considering the following conditions and the result is shown in Figure-13.9.

1) Since there are residential and tourism development plans in the area on the north of site for the airport extension and on the east of Enamanu road, this area should be avoided for the diversion channel.

2) A cemetery and transmitter station of the Nadi airport are located along the western side of Enamanu road between Queens road and site for the airport extension. Therefore, those area should be avoided for the diversion channel.

3) To locate the diversion channel in the airport extension site has been agreed by the Civil Aviation Authority of Fiji, as long as the diversion channel does not cross the area within 300 m from the end of planned runway.

4) There is a private cemetery in Waqadra garden on the east of Queens road and there is a traditional sacred site in the north of McDonald's and on the west of Queens road. Those areas should be avoided for the diversion channel.

5) Since compensation for McDonald's is expected very high, it should be avoided for the diversion channel.

(2) Longitudinal Profile

No. 0 point of the topographical survey is located on a road along the seashore, while the starting point of hydraulic design is located 150 m offshore from the road where sea bed is almost same elevation as the diversion channel bed (EL. -2.5 m). Therefore, the total length of the diversion channel in the hydraulic design is counted from a point of 150 m offshore and is 3,300 m. In the structural design, distances are always referred to No. 0 point, where outlet is to be located. As a result, the distance from outlet to inlet is 3,150 m.

Based on the hydraulic design, bed slope of the diversion channel was determined as flat from outlet to 2,350 m (EL. -2.5 m) and 1/320 from 2,350 m to inlet. As shown in Figure-13.10, the longitudinal profile of the diversion channel has two sections, embankment and cutting sections. The former is located from outlet to 1,500 m and the latter is located from 1,500 m to inlet (3,150 m from outlet).

In the section of embankment, freeboard was designed to have at least 1.0 m from water level of the design discharge (1,500 m^3/sec, drainage for 1/20 probability flood), as shown in Figure-13.10. Longitudinal slope of bank crest is 1/800.

(3) Cross Section

Standard cross sections of the diversion channel based on the following conditions are shown in Figure-13.11.

1) Cutting Section

Slope gradient in the cutting section was determined as 1:2 based on the results of soil test conducted by the Study Team and design of existing structures. Since the deepest depth of cutting is 13 m, berm with 3 m width was designed at 5.0 m high from channel bed for maintenance of the channel. Vegetation is applied on the bank slope to prevent bank erosion.

2) Embankment Section

Slope gradient in the embankment section was determined as 1:3 based on the bank stability analysis. Berm with 3 m width was also designed for maintenance and increase in bank stability (see Supporting Report Part E for the details).

The cross sections adopted in the structural design are slightly different from that assumed in the hydraulic design. As the area of the former cross section is almost same to or slightly larger than that of the latter, the difference does not cause any significant change in the hydraulic analysis.

Vegetation is applied on the bank slope to prevent bank erosion.

Since crest of bank is used for road whose size is same as Nasoso road, the crest width of bank was designed 8.0 m; however, it can be reduced to 4.0 m as long as only the bank stability is considered (Japanese Standards).

The left bank at a bend is considered as water collision prone area but not critical based on the hydraulic examination. There are two bends; however, one in the upper reach does not require any measure because it is located in the cutting section whose slope is stable. Another in the lower reach is located in the embankment section. Therefore, some measures should be considered in case of bank collapse. Since the disposal area for surplus soil is planned next to the bend, bank width inclusive of soil disposal area at the bend is much bigger than the other sections. As a result, bank stability is maintained by widening bank width and any revetment works are not required.

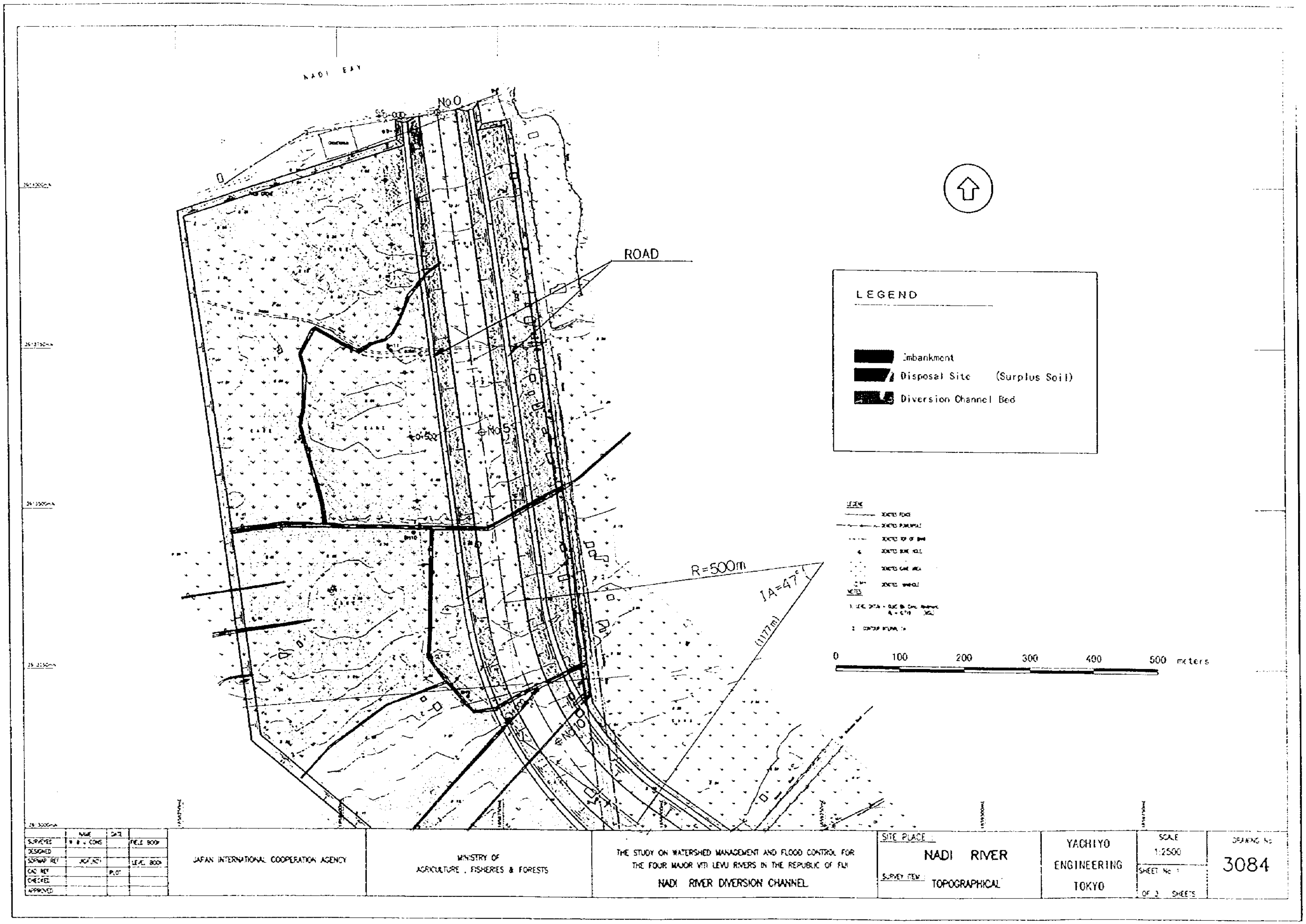


Figure-13.9 (1/3) Plan of Diversion Channel for 20 Year Return Period Flood

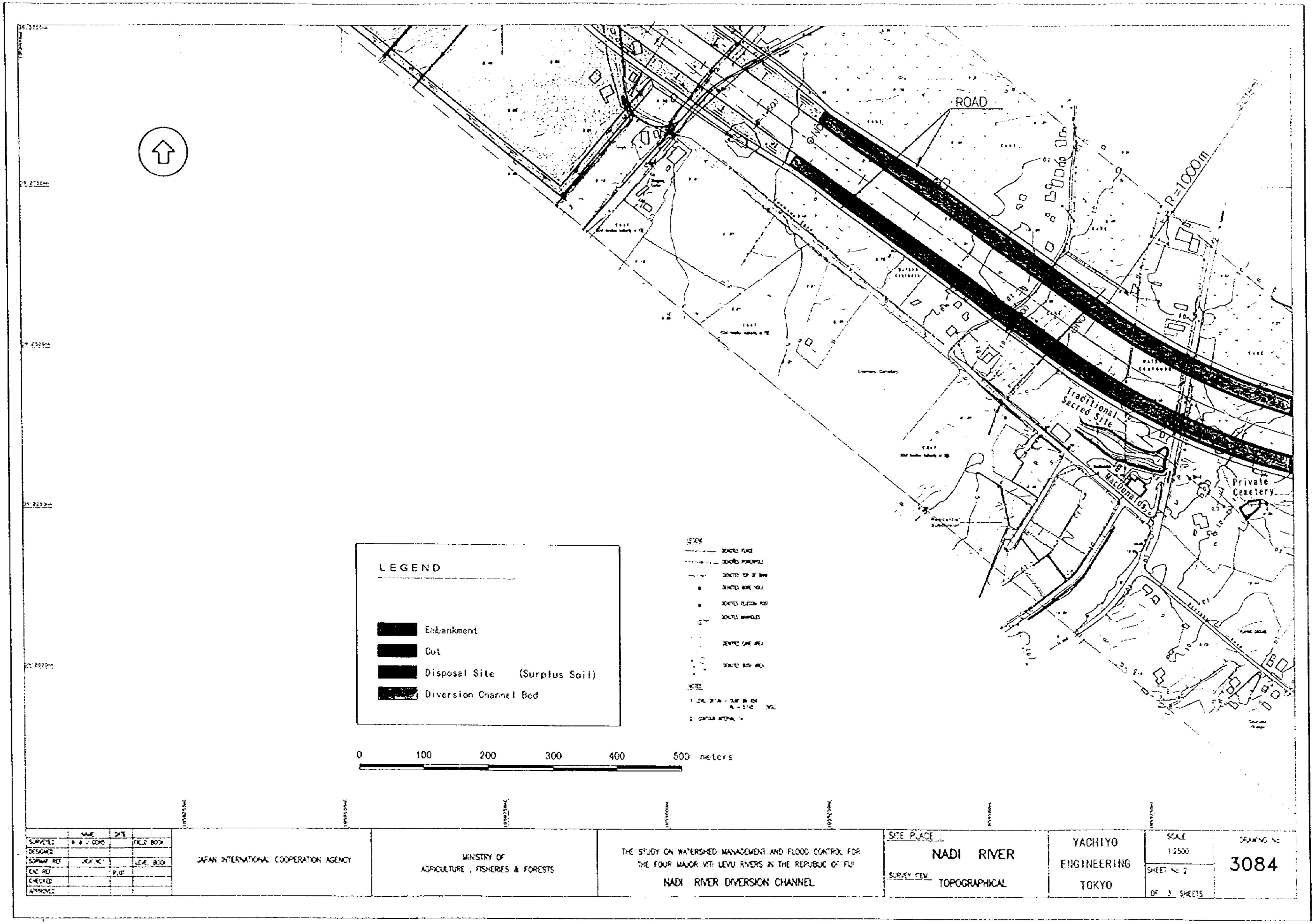


Figure-13.9 (2/3) Plan of Diversion Channel for 20 Year Return Period Flood

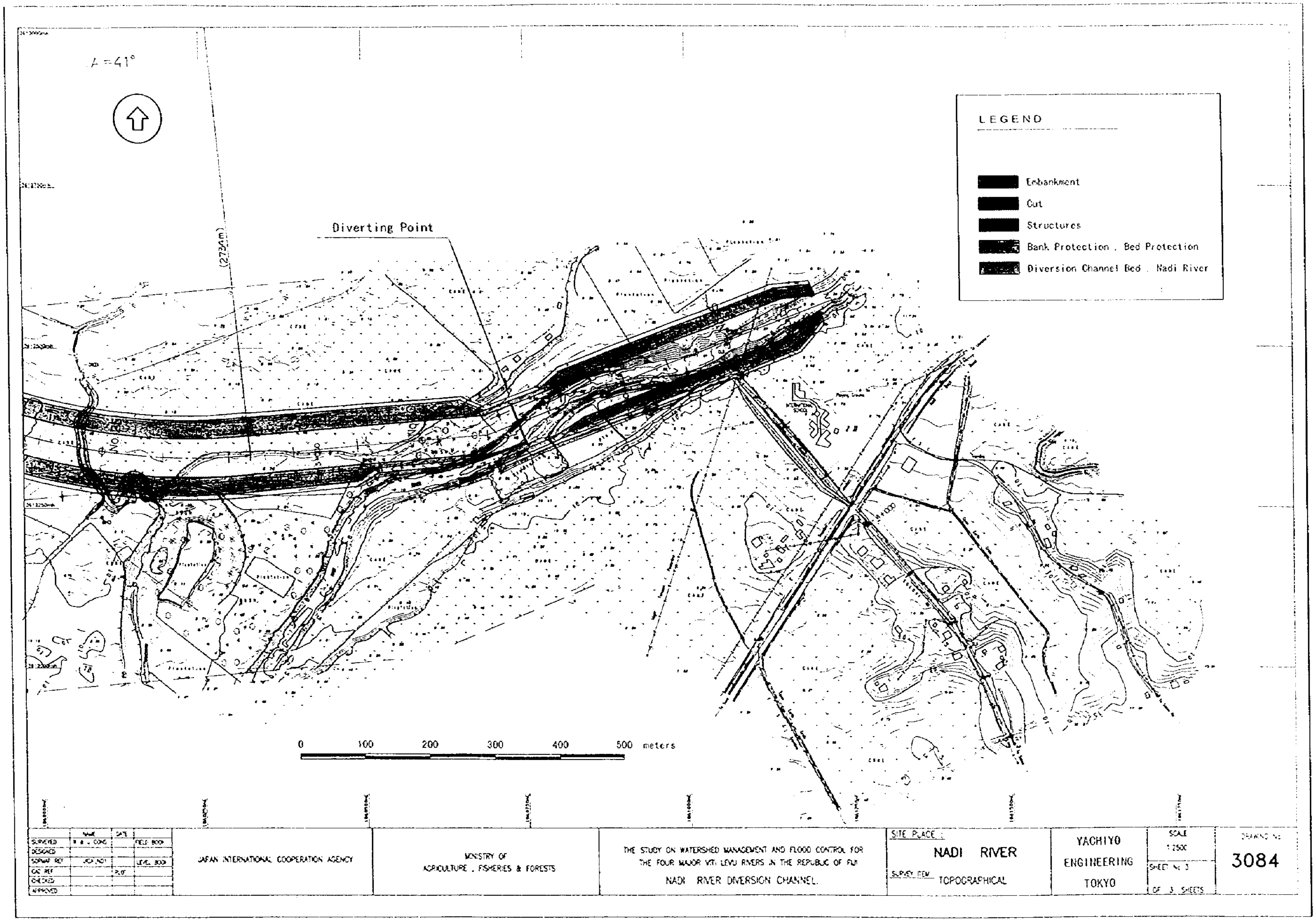
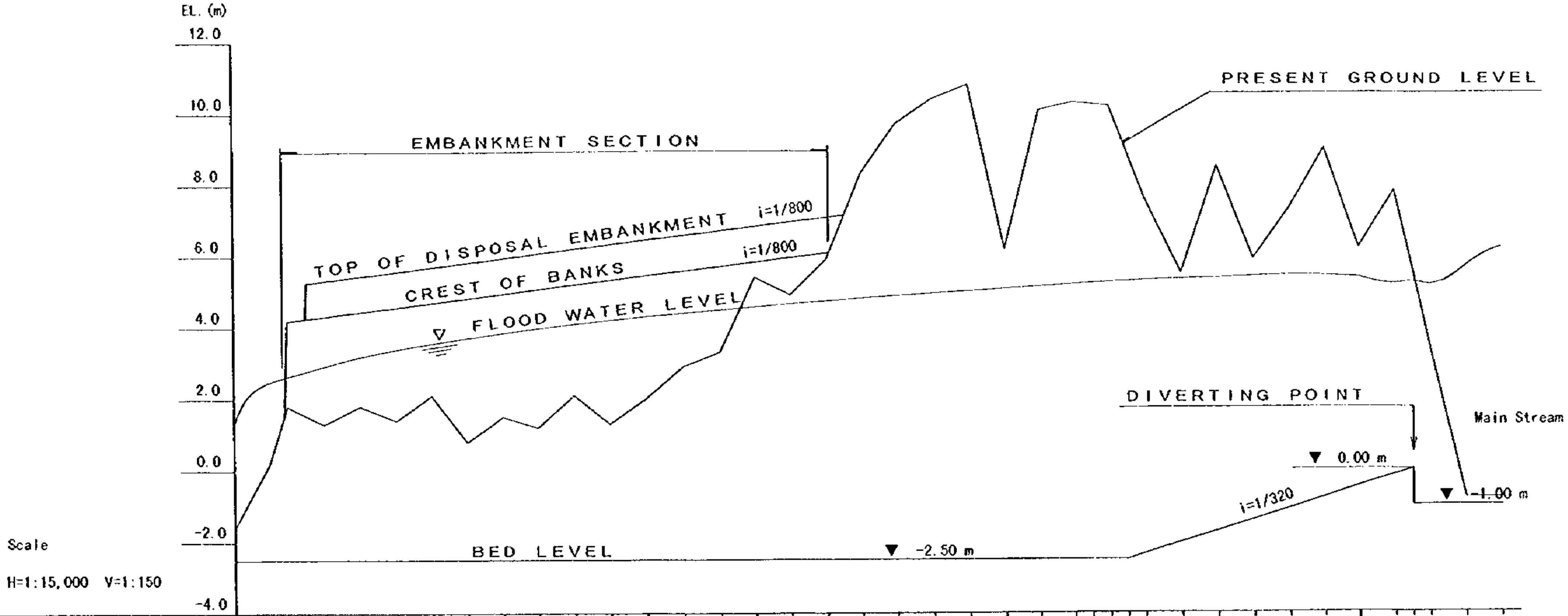


Figure-13.9 (3/3) Plan of Diversion Channel for 20 Year Return Period Flood



PRESENT GROUND LEVEL (EL. m)	FLOOD LEVEL (EL. m)	BED LEVEL (EL. m)	CREST OF BANKS (EL. m)	DISTANCE (m)	STATION
-1.6	1.32	-2.50	0.00	0.00	No. 0 -150
0.2			0.00		
1.8	2.64		4.20	150	NO. 0
1.3					
1.8	3.19		4.45	350	NO. 2
1.4					
2.1	3.56		4.70	550	NO. 4
0.9					
1.5	3.85		4.95	750	NO. 6
1.2					
2.1	4.09		5.20	950	NO. 8
1.3					
2.0	4.30		5.45	1150	NO. 10
2.9					
3.3	4.48		5.70	1350	NO. 12
5.4					
4.9	4.65		5.95	1550	NO. 14
5.9					
8.3	4.81			1750	NO. 16
9.7					
10.4	4.95			1950	NO. 18
10.8					
6.2	5.08			2150	NO. 20
10.1					
10.3	5.20			2350	NO. 22
				2400	
10.2					
		-2.50		2500	
7.6	5.30	-2.34		2550	NO. 24
5.5				2650	
8.5	5.36	-1.72		2750	NO. 26
5.9					
7.3	5.43	-1.09		2950	NO. 28
9.0					
6.2	5.37	-0.47		3150	NO. 30
7.8					
		0.00		3300	
3.4	5.163	-1.00		3350	NO. 32
-0.8					
-0.8	6.202	-1.00		3550	NO. 34

Figure-13.10 Longitudinal Profile of Diversion Channel for 20 Year Return Period Flood

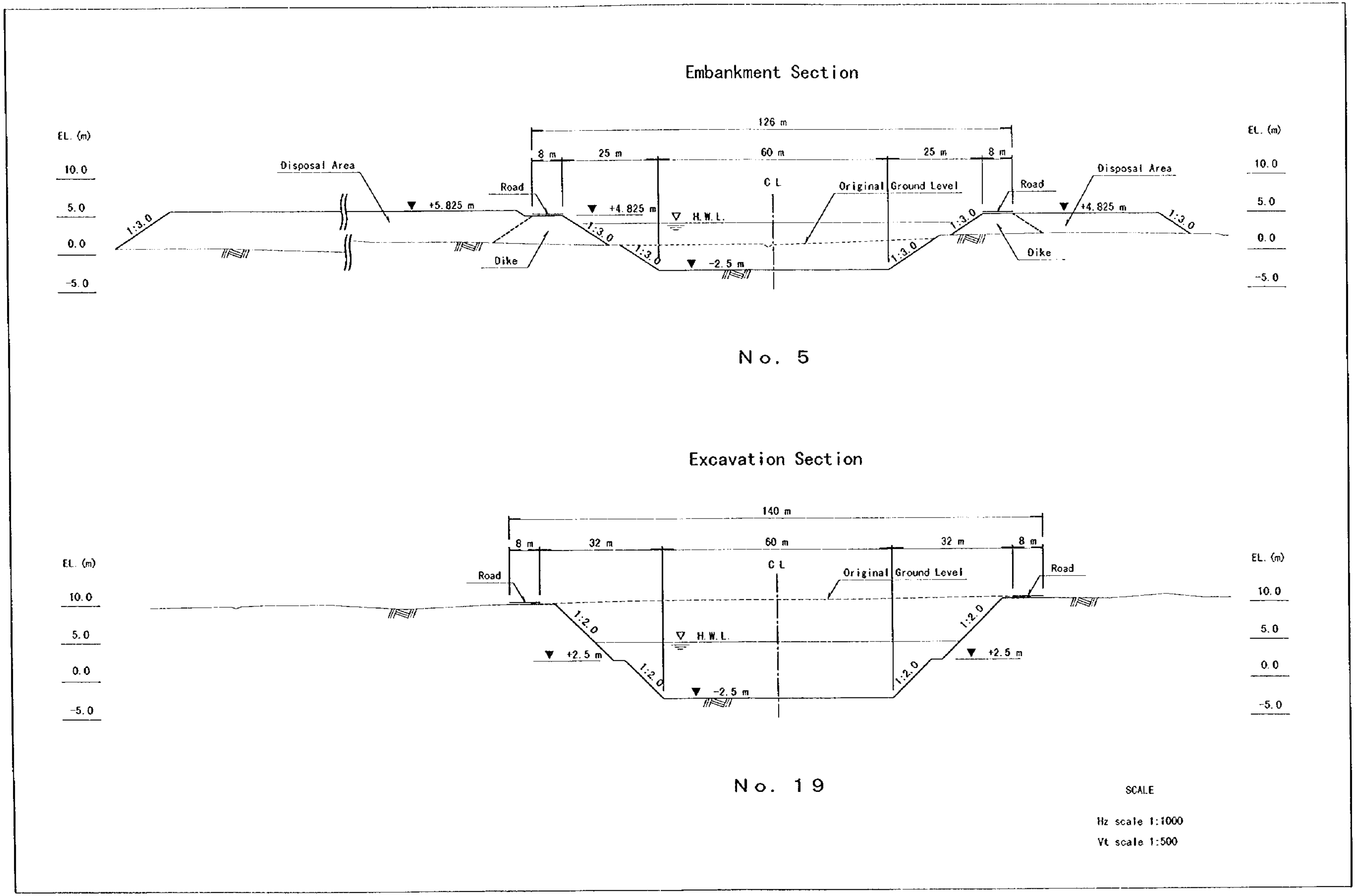


Figure-13.11 Standard Cross Section of Diversion Channel for 20 Year Return Period Flood

(4) Stability Analysis of Embankment

According to the geological survey and soil test conducted by the Study Team (Chapter 11), loose and weak sand and clay deposits, especially Cwc (weak clay layer) and Cws (weak silt layer), are underlain around the designed bottom of the diversion channel in the lower reach, from outlet to 1,200 m. Effect of the loose and weak deposits on bank stability was analyzed by the circular arc method and the most suitable design of bank was determined.

As a result of the bank stability analysis, countermeasures to increase the strength of loose layers are necessary to stabilize the bank. Considering the followings, pre-loading method was adopted to improve the loose layers. The pre-loading method is to make embankment on the present land surface before actual construction starts, to accelerate consolidation in loose layers by load of the embankment. After the strength of loose layers is improved by consolidation, cutting and actual embankment for the diversion channel is conducted.

- Critical layer of bank stability is Cwc, which is the weak clay layer and its depth in the site is not thick, approximately 3 m at maximum.
- Since Cls (loose sand layer) overlays on Cwc, drainage distance by consolidation is short, approximately 3 m at maximum. Therefore, the strength of Cwc is expected to increase by consolidation.
- Cost of pre-loading is relatively cheap compared to other measures and it does not require any special construction machinery or plant.

The strength of Cwc layer can be improved to the necessary strength, 2.5 tf/m^2, by pre-loading of 2.5 m bank. Period required for pre-loading is 3 months. Surplus soil in the cutting section, the upper reach of the channel, is used for pre-loading.

Figure-13.12 shows to cross section of pre-loading with the cross section of the diversion channel in the embankment section. The bank of pre-loading consists of two parts. One is to be used as a bank of the diversion channel and another is to be removed after pre-loading. Volume of soil required for the part to be removed is approximately 120,000 m^3.

Safety Factor = 1.295

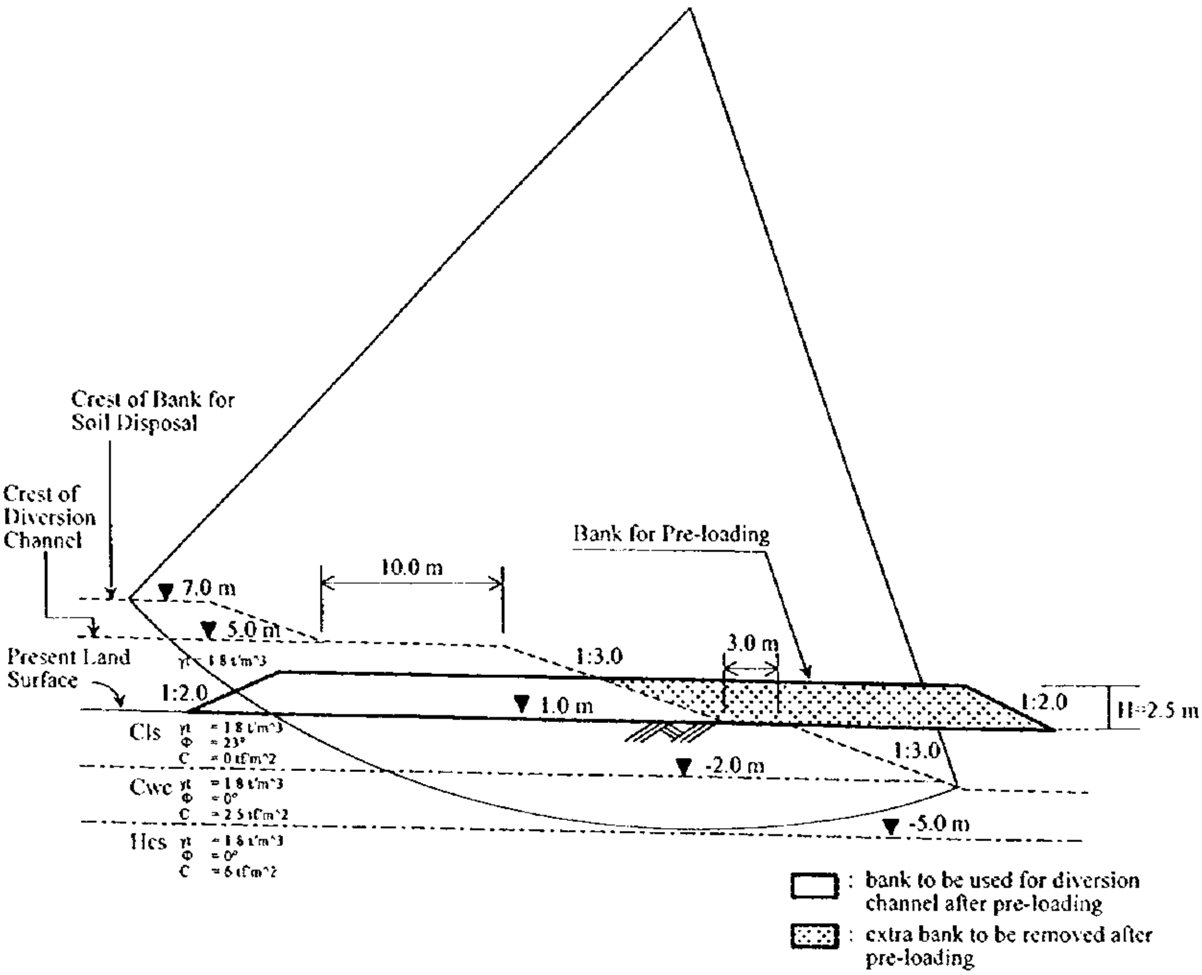


Figure-13.12 Cross Section of Pre-loading

(5) Disposal Site of Surplus Soil

Some of surplus soil (excavated soils) is used for embankment of the diversion channel, while the rest of soil is dumped in the disposal area located on the left bank side in the lower reach of the channel. The maximum height of the disposal area is 6 m based on the bank stability analysis, and the disposal area is 10 m away from top of slope of the diversion channel (Figure-13.12). Necessary area of the disposal site is 49 ha.

(6) Material for Embankment

Material for embankment is necessary to satisfy the following conditions.

- Fine particles (less than 0.075 mm) are contained more than 15 % in soils whose particle sizes are less than 75 mm to have impermeable property.
- The maximum particle size is less than 10 ~ 15 cm to enable compaction effectively.

- Soil material has enough strength for trafficability of construction machinery and its moisture content is not too high.

According to the soil test conducted by the Study Team as a part of the geological survey, most of soils to be excavated satisfy the above conditions, except Rgs (gravelly sand layer), Cws (weak silt layer) and Cwc (weak clay layer). Rgs, Cws and Cwc are distributed partially in the geological profit along the diversion channel. Therefore, surplus soils (excavated soils) can be used for embankment of the diversion channel in terms of quality and quantity.

(7) Structures of Diverting Point

According to the hydraulic design, 20 year return period flood is drained through the diversion channel with discharge of 1,500 m^3/sec and Nadi river with discharge of 300 m^3/sec. Diverting point is 14.6 km point of Nadi river from river mouth.

The following structures are required for the diverting point.

- separation structure
- bank and bed protection
- dike on the left bank of Nadi river in the upstream from diverting point

They were designed considering the following items and the results are shown in Figure-13.13 and Figure-13.14.

1) Bed widths of Nadi river and the diversion channel are 10 m and 60 m, respectively, based on the hydraulic design.
2) Bed elevations of Nadi river and the diversion channel at inlet are EL. -1.0 m and EL. 0.0 m respectively.
3) Cross section at diverting point needs to be fixed to allocate discharge to Nadi river and the diversion channel in accordance with the hydraulic design. Therefore, bank and bed protection works are required for prevention of erosion and stability of bank.
4) Partition wall between Nadi river and the diversion channel is required. Partition wall whose length is 90 m was designed by cast-in-place concrete.
5) The diversion channel is close to Nadi river in the downstream from diverting point, which is the left bank of the channel between 2,900 m and 3,100 m from outlet. This section requires bank protection work.
6) Blocks of concrete secondary products are applied to the bank and bed protection works.
7) Flow capacity of Nadi river is not sufficient for the design flood in the upstream from diverting point. Therefore, dike which starts near the survey point of No. 35 and runs perpendicularly to Nadi river until Nadi backroad is necessary to prevent overflow on the left bank of the river from flowing into the river in the downstream.

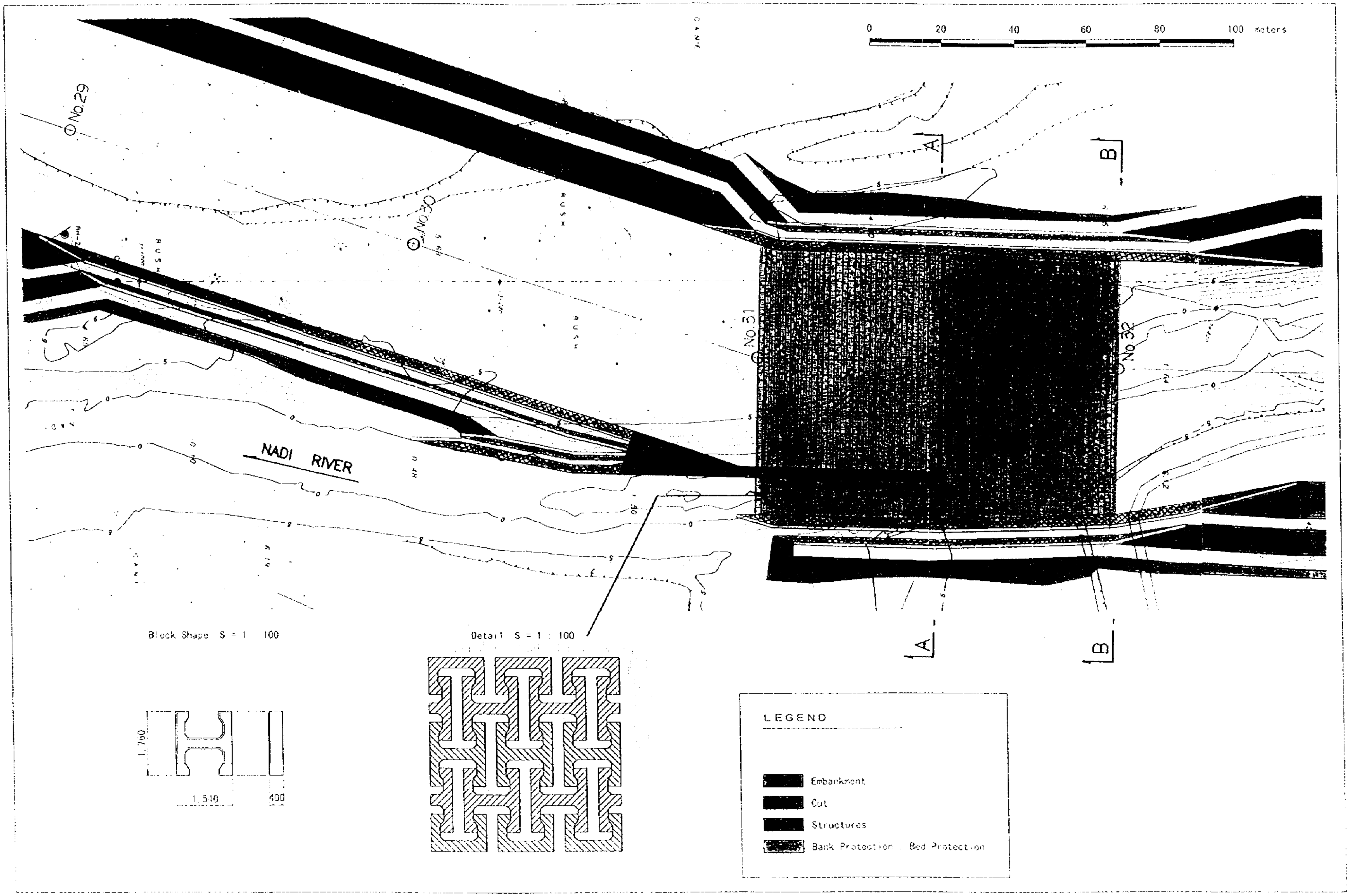
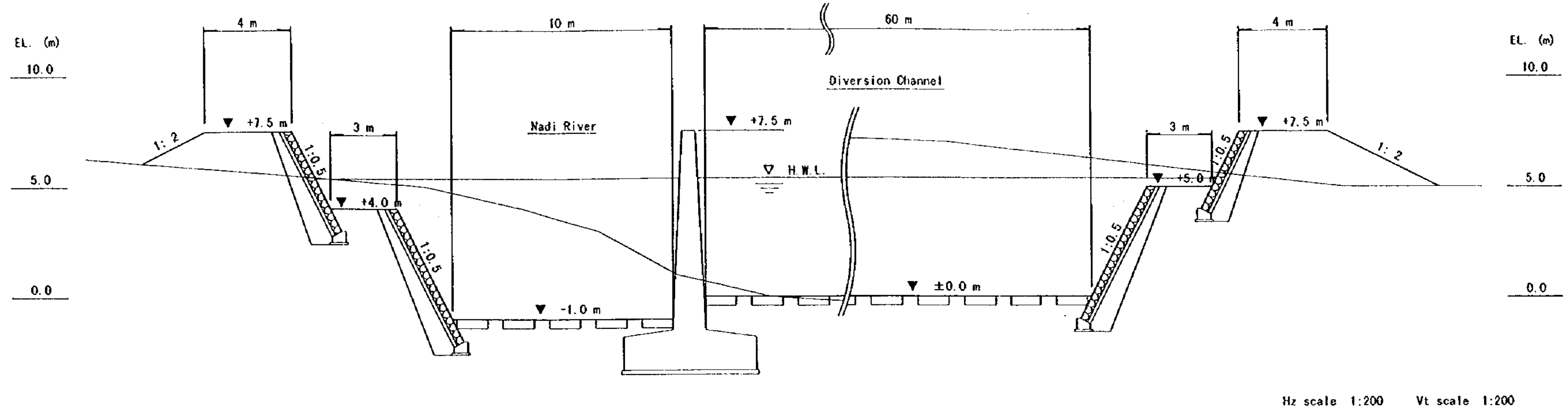
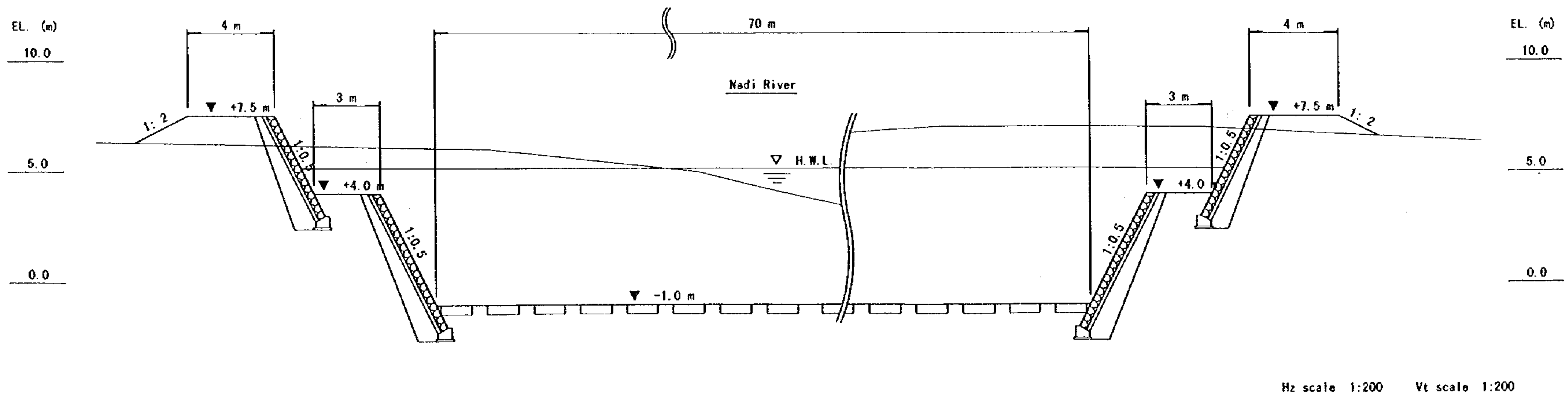


Figure-13.13 Plan of Diverting Point (20 Year Return Period Flood)



A - A (No. 31+50)



B - B (No. 32)

Figure-13.14 Cross Section of Diverting Point (20 Year Return Period Flood)

12.2.3 Design of Bridge

The following three bridges are planned to provide the access crossing the diversion channel.

1) Queens Road Bridge

A bridge whose scale is same as Sigatoka and Ba bridges constructed recently was planned at the crossing of Queens road and the diversion channel. Roadway consists of 2 lanes and foot way is located at both sides.

2) Sugarcane Tramline Bridge

As shown in Figure-13.11, sugarcane tramlines currently expand east and west direction crossing the proposed site of the diversion channel. Considering the Nadi airport extension plan, a sugarcane tramline bridge was planned to cross the diversion channel at 200 m in the east-south of the current position. The tramline bridge is for the use of sugarcane tram and pedestrians but not for vehicles. In addition, sewage pipe line, electric cable and telephone line are attached to the bridge.

3) Bridge for Pedestrians

Seashore around outlet of the diversion channel is recreation area for the public. Therefore, a pedestrian bridge at the outlet was planned to provide the access along the seashore. The bridge is just for pedestrians.

Since there are no design standards in Fiji, Japanese standards were applied for the design of the above three bridges, such as superstructure, foundation, bridge structure and so on. The details are discussed in Supporting Report Part E and only the results are shown in Table-13.13.

Table-13.3 Selection of Bridge Type

Name of Bridge	Length (m)	Span (m)	Type of Superstructure	Type of Foundation		Grade of Bridge	Bridge Width
				Abutment	Pier		
Queens Road	120	3 x 40 m	PC T-Girder	PC Pile	Deep Caisson Foundation	National Road	Roadway: 7.3 m Footway: 1.4 m x 2 Total width: 10.9 m
Sugarcane Tramline	111	3 x 37 m	PC T-Girder	PC Pile	Deep Caisson Foundation	Tram with Footway	Tramline: 1.2 m Footway: 2.3 m Total width: 4.5 m
Pedestrian	93	3 x 31 m	PC Hollow Slab	PC Pile	Deep Caisson Foundation	Footway	Total width: 2.8 m

PC: pre-stressed concrete
Length, Span: Figures in the table are for 20 year return period flood.
Type of superstructure and foundation does not vary with scale of target flood.

13.2.4 Design of Road

At present, Enamanu road runs along the site of the diversion channel. Therefore, crests of both banks were designed for roads from crossing with Queens Road to outlet. Specifications of roads (paved roads) were determined in accordance with those of Enamanu road upgrading project (Third Road Upgrading Project). Cross section of roads is shown in Figure-13.15.

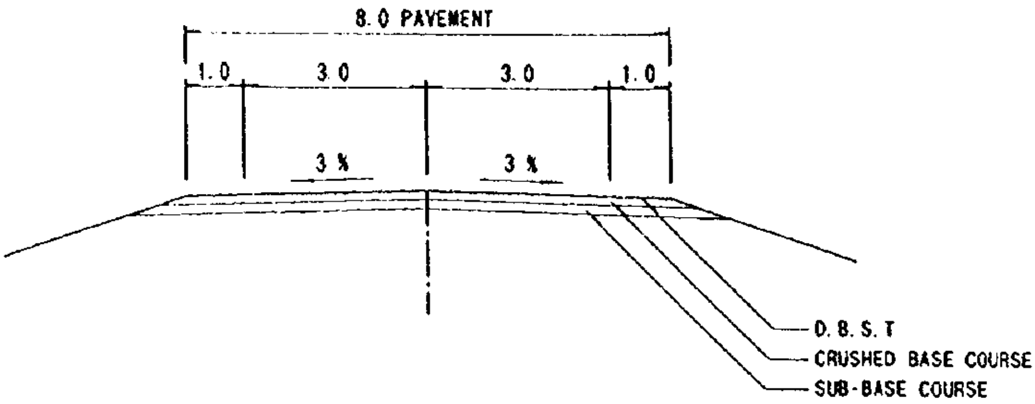


Figure-13.15 Proposed Cross Section of Road

13.2.5 Others (Shift Works)

The following works are required as shift works with implementation of the diversion channel. Proposed layout of facilities in the vicinity of the channel is shown in Figure-13.16.

(1) Pipe Lines for Water Supply

There are currently two main pipe lines with diameters of 250 mm and 150 mm along Queens road. In addition, there is a branch line with a diameter of 80 mm along Enamanu road.

Main pipe lines along Queens road were designed to be attached to the proposed Queens road bridge and two branch lines on both banks of the diversion channel were designed to replace the existing branch line.

(2) Sewage Pipe Line

A sewage pipe line with a diameter of 675 mm is located along the sugarcane tramline and the Enamanu pomp station is located in the south-west of the crossing of Enamanu and Tramline roads.

The sewage pipe line was designed to be attached to the sugarcane tramline bridge. Since the present line is under the ground, head of flow may not be sufficient when the pipe line is uplifted to the bridge. In this case, a new pump station is necessary on the right bank of the diversion channel.

(3) Electric Cable

A main electric line (11 kV) runs under the ground along the sugarcane tramline, while a branch line runs above the ground along Enamanu road.

The main electric cable was designed to be attached to the sugarcane tramline bridge and some part of the branch line alignment needs to be changed.

(4) Telephone Line

A main telephone line is located under the ground along Queens road and there is a branch line along Enamanu road.

The main telephone line was designed to be attached to the Queens road bridge and some part of the branch line alignment needs to be changed.

(5) Extension of Nadi Airport

According to Civil Aviation Authority of Fiji (CAAF), the extension of runway is 800 m from the end of the present runway. Guide lights are required at approximately 150 m interval from the end of extended runway and its alignment crosses the diversion channel. Since each location of guide lights can be shifted longitudinally to 6 m ~ 22.5 m depending on position, the diversion channel can be located between two positions of guide lights.

There is a cable under the ground along the runway connecting the airport and the transmitter station located in the south of Enamanu road. This cable is designed to be attached to the sugarcane tramline bridge.

(6) Sugarcane Tramline

Alignment of sugarcane tramline has to be changed partially due to the location of the sugarcane tramline bridge. New alignment was determined based on the landuse and design standards of sugarcane tramline, and has been agreed by Fiji Sugar Corporation.

13.2.6 Short Cut Channel

Short cut channel connecting 7.5 km and 9.0 km points of Nadi river with the total length of approximately 250 m was designed with the following conditions. Results are shown in Figure-13.17 and Figure-13.18.

1) Bed width of the short cut channel is 30 m based on the hydraulic examination and slope gradient is 1:2 because all section is cutting but not embankment.
2) Crest width is 4 m and its elevation is EL. 6 m considering 1 m freeboard.
3) Bed elevations of upstream and downstream ends are EL -0.9 m and EL. -1.0 m, respectively, taking same elevation as Nadi river.
4) The present section of Nadi river from the confluence with Nawaka river to around 9.0 km point from river mouth is filled by surplus soil of approximately 13,000 m^3 from construction of the short cut channel (refer to Figure-13.17).
5) Design of the short cut channel does not vary with the scale of floods concerned (1/20, 1/15, 1/10, and 1/5 probability floods).

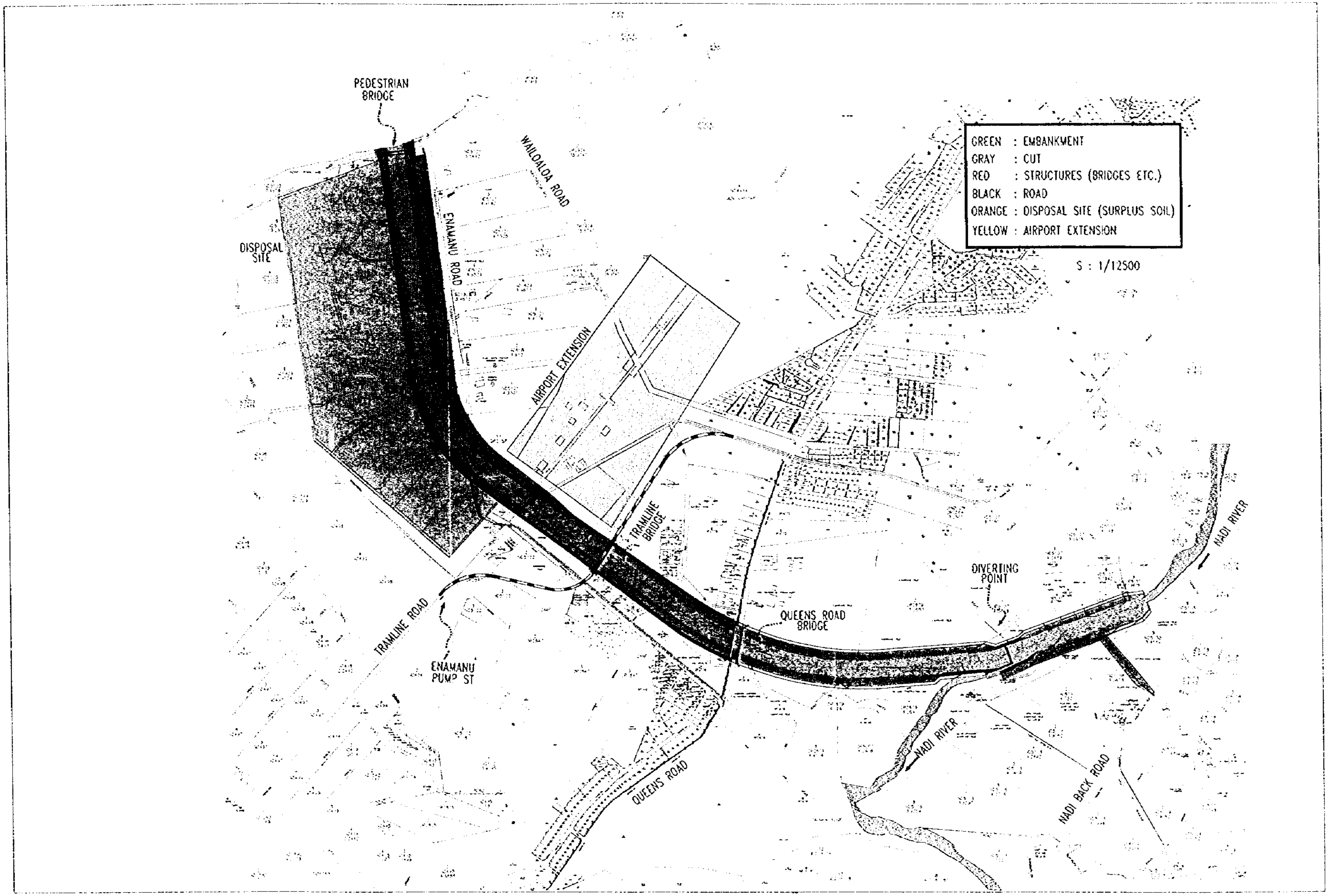


Figure-13.16 Proposed Layout of Facilities

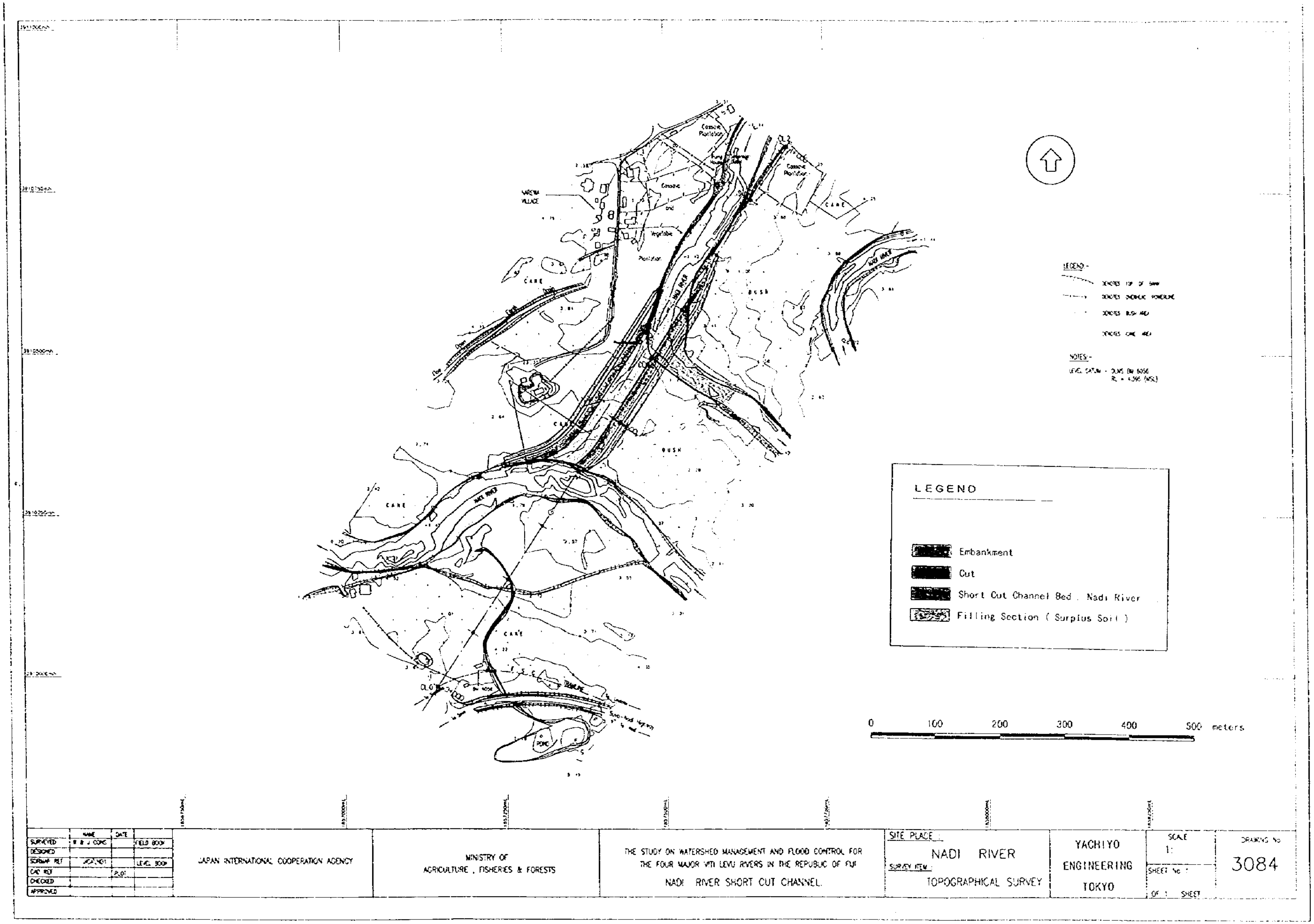
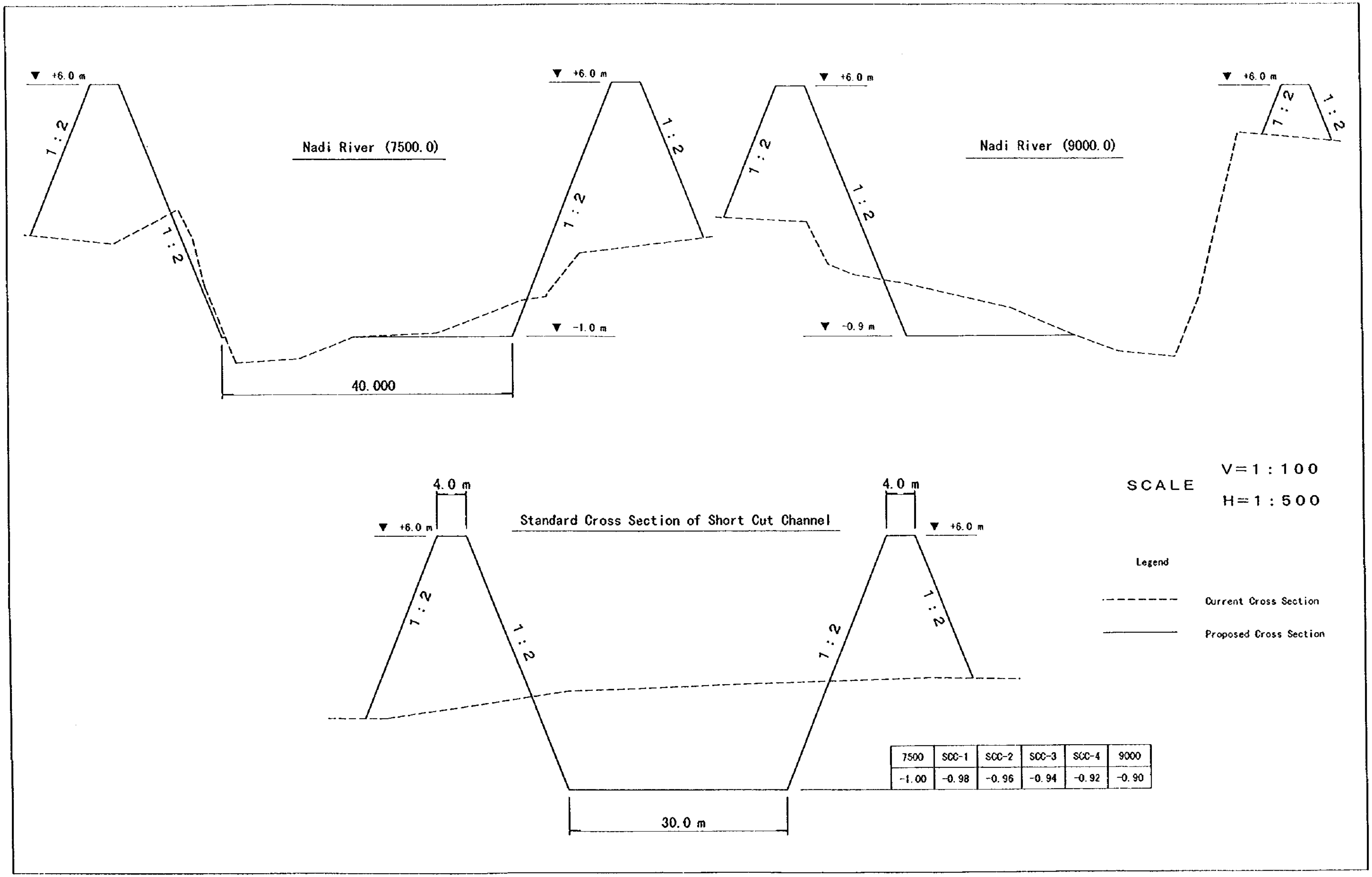


Figure-13.17 Plan of Short Cut Channel



7500	SCC-1	SCC-2	SCC-3	SCC-4	9000
-1.00	-0.98	-0.96	-0.94	-0.92	-0.90

Figure-13.18 Cross Section of Short Cut Channel

13.3 Work Quantity and Construction Plan

13.3.1 Work Quantities

Work quantities of the Nadi diversion channel and short cut channel was estimated varying return period of flood from 1/5 to 1/20. Although the design flood is 1/20, work quantities for smaller floods were estimated considering the stepwise implementation (refer to Chapter 12).

Quantities of earth works were estimated based on the results of cross section survey conducted by the Study Team. In the Master Plan Study, transportation distance of excavated soil was assumed to be 1,500 m; however, in the Feasibility Study, the distance for embankment and that for surplus soil were separated. The former was assumed to be 200 m because excavated soil can be consumed for embankment near the excavation site. The latter was assumed to be 2,000 m because excavated soil needs to be carried to the soil disposal area.

Results of work quantity estimate are shown in Table-13.4.

Table-13.4 Work Quantities of Diversion Channel and Short Cut Channel

Description			Unit	Return Period of Flood			
				1/20	1/15	1/10	1/5
Main Work	Excavation*1	Sand and Soil	m^3	2,290,000	2,030,000	1,780,000	1,470,000
	Loading*1		m^3	2,290,000	2,030,000	1,780,000	1,470,000
	Embankment	Transportation (L=2,000 m)	m^3	130,000	130,000	130,000	130,000
		Grading	m^3	130,000	130,000	130,000	130,000
		Compaction	m^3	130,000	130,000	130,000	130,000
	Banking (Surplus Soil)	Transportation (L=200 m)	m^3	570,000	510,000	440,000	360,000
		Transportation (L=2,000 m)	m^3	1,590,000	1,390,000	1,210,000	980,000
		Grading, Compaction	m^3	2,160,000	1,900,000	1,650,000	1,340,000
Compensation Work	Queens Road Bridge		m	120	108	96	81
	Sugarcane Tramline Bridge		m	111	99	87	72
	Pedestrian Bridge		m	93	81	69	54
	Road		m	4,000	4,000	4,000	4,000

*1: including 50,000 m^3 for short cut channel and 120,000 m^3 for pre-loading

13.3.2 Construction Plan

(1) Basic Idea of Construction

Basic idea of the diversion channel construction is that excavated soil at hilly place (EL. 10 m) in the upper reach of the channel (1,500 ~ 3,150 m from outlet) is used for embankment of the channel in the lower reach where elevation is approximately 2 m. In addition, surplus soil is dumped in the soil disposal area on the left bank side of the channel.

(2) Material Supply

Main construction material, such as cement, gravel, sand, timber, concrete, fuel, steel, asphalt, are obtainable in Fiji. In addition, concrete blocks for bed and bank protection are available in Fiji. There is no problem in access to carry the material to the site.

(3) Construction Schedule

Construction schedule of the diversion and short cut channels for 20 year return period flood was determined considering the followings and the result is shown in Table-13.5.

- Construction period is 2 years based on the work quantities.
- Excavation in the cutting section starts prior to pre-loading in the embankment section because excavated soil is used for pre-loading.
- In the embankment section, pre-loading is implemented first to improve the soft and weak layer before actual works start.
- Actual works (excavation and embankment) of the diversion channel in the embankment section starts where consolidation by pre-loading is completed. Required period for consolidation is 3 months.
- Pavement of roads on both banks of the diversion channel is conducted 3 months later after embankment is completed. Period of 3 months was determined considering settlement of banks.
- Excavation of the short cut channel starts regardless of pre-loading.

Table-13.5 Construction Schedule of Diversion and Short Cut Channels
(20 Year Return Period Flood)

Description	Unit	Quantity	First Year												Second Year											
			1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
(1) Preparation of Works			■	■																						
(2) Earth Works																										
- Excavation	m^3	2,290,000			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
- Embankment	m^3	130,000											■	■	■	■										
- Banking (Surplus Soil)	m^3	1,900,000							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
- Pre-loading	m^3	260,000			■	■	■	■	■	■																
(3) Bridges																										
- Queens Road Bridge	m	120				■	■	■	■	■	■															
- Sugarcane Tramline Bridge	m	111														■	■	■	■							
- Pedestrian Bridge	m	93										■	■	■	■											
(4) Shift Works																■	■	■	■	■	■	■	■	■	■	■
(5) Road (w = 8.00 m)	m	4,000																■	■	■	■	■				

(4) Plan of Construction Machinery

Based on the construction schedule above, necessary number of construction machinery was estimated and the result is shown in Table-13.6.

Table-13.6 Necessary Number of Construction Machinery for Diversion and Short Cut Channels (20 Year Return Period Flood)

Work	Machinery	Necessary Number
(1) Earth Works	Bulldozer, 21 t	16
	Back Hoe, 0.6 m^3	10
	Dump Truck , 11 t	30
	Tire Roller 8~20 t (for Dike)	2
(2) Bridges	Truck Crane, 30 t (for Erection Girders)	2
	Truck Crane, 10 t	1
	Concrete Mixer Truck, 4.5 m^3	3
	Concrete Mixer Truck, 65~85 m^3/hr	1
	Clamshell, 0.4 m^3	1
(3) Shift Works	Truck Crane, 10 t	1
	Concrete Mixer Truck, 4.5 m^3	3
	Concrete Mixer Truck, 65~85 m^3/hr	1
(4) Road (w = 8.00 m)	Motor Grader, 3.1 m	1
	Road Roller, 10~12 t	1
	Tire Roller, 8~20 t	1
	Asphalt Finisher, 2.4 m	1
	Water Tank Car, 3,800 ltr	1

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Schijf, J.B. and Schonfeld, J.C. (1953). "Theoretical consideration of the motion of salt and fresh water." Proc, Minnesota Int. Hyd. Conf., pp. 321~333.

CHAPTER 14 LAND ACQUISITION AND COMPENSATION

14.1 Land Acquisition Plan

Proposed site for the diversion channel in Nadi is located in State Lands and freehold lands and the one for the short cut channel in Nadi is situated in Native Reserve. Since the Project will benefit the public, lands for the Project can be acquired by the Land Department on behalf of the State with the provisions of the State Land Acquisition Act (Cap. 135).

1) State Land

In case some parts of the site are situated in State Lands, no purchase of the land is necessary because the State has the ownership already. Some compensation, however, is necessary for the present use. The State, in case the land is leased, will have to compensate the remaining years of the leasehold.

2) Freehold Land

The process for the acquisition from freehold lands is as follows:

- The executing agency proposing a project shall submit the plan of the project including maps of the project site to the Department of Lands and Survey.
- The Department may start to negotiate with the title holder for conditions of the dealing or compensation
- In case that the conditions are not agreed, the Supreme Court determines the conditions.

For the acquisition of a freehold land, payment for land price (unimproved capital value, UCV) of the land is necessary. In case the land is leased, some portion of the UCV should be paid to the tenants and the rest to the owner of the land, depending on the remaining years of the lease.

3) Native Reserve

For land acquisition of the short cut channel in Nadi, de-reservation of the land is necessary. Originally, the Native Reserve was assigned as the reserved area required for the subsistence of the native Fijians. The Native Reserve can be leased only to Fijians. Although acquisition by the State may be carried out under the State Land Acquisition Act, re-reservation of some State Land in exchange to the State acquisition would be preferable, considering the purpose of the original reservation.

For the re-reservation, some area of the land for the equivalent use to the current one should be prepared for the exchange. If the Government can find some vacant State Land, that land can be assigned to a Native Reserve without paying any costs and compensation to the current occupier of the State Land. Some State Land with agricultural lease would be preferable; however, for the exchange because of its relatively low compensation costs. The field reconnaissance with the officers of the Department of Lands and Surveys and the NLTB showed possibility of availability of State Lands currently leased to the farmers near the village of owners of the Reserve in the proposed short cut channel.

Although some parts of the site for the short cut channel are bushes, total area for sugarcane farming is considered for the exchange in this cost estimation.

A public cemetery, an archeological site (a traditional sacred place on the north of the McDonald's), and a temple (near the crossing point of Enamanu Road with Tramline) were avoided, taking their cultural value into account.

For all types of the land tenure, the land area to be acquired was determined in order not to remain fragmentation of land in any lots and to avoid insolated portion, unless it occurs before the acquisition, considering continuation of the current use and convenient access as much as possible.

14.2 Compensation

Matters to be considered in determining compensation are stipulated in the Section 12 of the State Land Acquisition Act. Although valuation of each of properties should made one by one before the acquisition, estimations are made with the result of "Social Environmental Survey" by a local consulting firm and cooperation by the Department of Lands and Surveys.

(1) Buildings and Additional Investments by the Occupiers or Owners

Valuation of the buildings was made by measuring building areas on the site by local consultants. Even in the case that a small portion of a building or a garden is on the site, the whole building was counted for estimation of the compensation. The unit price of compensation for each type of the building, given by the Department of Lands and Surveys for concrete and timber buildings and by the Housing Authority for corrugated iron structures and Fijian traditional houses, was applied for the estimation. The amount of additional investment for electricity distribution, telecommunication, water supply and sewerage service, and other improvements on the lots were estimated with interview survey with each household by the local consultant.

(2) Crops

Although standing crops or trees at the time of the State acquisition can not be known at present, annual harvests were counted in the estimation. Since sugarcane farming is predominant in the farming lots of the site area, the maximum yield of sugarcane (30 ton/acre=74 ton/ha) in the interview survey was applied for all farming areas. Cultivated area on the farming lots was assumed as 90 % because some portions of the farming lots are used for residential or other purposes.

(3) Compensation Works

Construction of the diversion channel will cut some parts of road networks, telephone lines, electricity distribution lines, water pipes, sewers and tramlines. Compensation works were planed to secure the availability of those services after the construction as much as possible. Some compensation works may enhance those networks.

(4) Other Compensation to be Considered Later

The construction and operation of the diversion channel may cause sedimentation or other impact on fishing. Affected area even at the time of the flood once in 20 years is estimated less than two kilometers from the outlet at most with narrow angle of the sector. In the affected area, there are fishery rights held by a Fijian community (mataqali). They fish for their own consumption and professional fishermen fish far from the affected area, according to the information by Fishery Department. Although further investigation is necessary to be carried out at the detail design stage to evaluate the damage in fishery activities, the damage was not included in this estimation because of the small scale of probable damage by the channel construction.

There seems to be a small shop on the site (ND5121 Lot 4) according to the Map submitted by the local consultant. The compensation was not included in this estimation since the earning from the shop was not known (the household income is F$ 100,000/year, according to the result of the interview survey). The evaluation is necessary at detail design stage.

14.3 Quantity

(1) Land

Total land area to be acquired was estimated at 108.8 ha for the diversion channel, whose breakdown is given below, and 2.4 ha for the short cut channel. The river area to be filled after the construction of the short cut channel was not counted for this estimation, despite a possibility for exchange or selling. The land area of the original alignment for the diversion channel was 102.0 ha. Additional land of 6.8 ha is planned to be acquired to avoid fragmented remaining areas. The unit cost suggested by the Department of Lands and Surveys is as follows. The land cost for the short cut channel was estimated at F$ 89 thousand.

Table-14.1 Lands for the Diversion Channel

Type of Lands		Area (ha)	Unit (F$/acre)	Cost (F$/ha)	Cost (F$ 1,000)
State Land (Leasehold)	Agriculture	72.7	7,500	18,532	1,347
Freehold	Residential	13.3	10,000	247,097	3,277
	Agriculture	15.6	15,000	37,064	578
	Airport Extension (alternative use agriculture)	7.2	15,000	37,064	266
Total		108.8			5,468

Note: by Classification of the Department of Lands and Surveys

(2) Buildings and Additional Investments by Occupiers or Owners

Building areas on the site for the diversion channel is shown below, while no building or no significant additional investments was found in the site for the short cut channel. The unit costs given by the Department and the Housing Authority are also listed below. There are three sets of buildings found in the Maps from the local consultant whose owners or residents could not attend the interview. The value of these buildings were assumed as F$ 50,000/set.

Table-14.2 Buildings and Additional Improvements/Investments

Type of Structure	Area (m^2)	Unit Cost (F$/ m^2)	Cost (F$ 1,000)
Concrete	2,419	450	1,089
Timber	2,095	350	733
Corrugated Iron	1,786	300	536
Fijian Traditional Houses	0	250	0
Additional Improvements to Buildings			53
Subtotal	6,300		2,411
Additional Investment to the Property			335
3 Properties (not interviewed)			150
Total			2,896

Note: Unit Costs were given by the Department of Lands and Surveys and the Housing Authority

(3) Crops

Quantities for estimation of the compensations are calculated below.

Table-14.3 Crop Value to be Compensated

	Diversion Channel	Re-reserved Area for Short Cut	Unit
- Farming Area	95.5	2.4	ha
- Cultivated Area	86.0	2.4	ha
- Yields (Sugarcane)	74.1	74.1	ton/ha
- Harvest (Sugarcane)	6,373	178	ton
- Unit Price (Sugarcane)	65	65	F$/ton
- Crop Value	414	12	F$ 1,000

14.4 Land Acquisition and Compensation Costs

Costs for land acquisition and compensation are summarized below.

Table-14.4 Costs for Land Acquisition and Compensation

(Unit: F$ 1,000)

	Diversion Channel	Short Cut
(1) Land	5,468	89
(2) Buildings/Investment	2,896	---
(3) Crops	414	12
Total	8,778	101

Comparing to cost estimates in the Master Plan Study, the land acquisition and compensation costs for the diversion channel reach to more than the doubled. The major reasons are as follows:

- The land area estimated in the Master Plan Study was 72.1 ha, including that for land for surplus soil disposal while that for the Feasibility Study was 108.8 ha after examining available land for the filling, the boring tests in the site, as well as rough formulation of the land acquisition plan as described above.

- In the Master Plan Study, all site areas, except a large commercial lot, were assumed as farming areas whose unit cost in freehold lands was F$ 13,500/ha, while in the Feasibility Study, 12 % of the total area is assumed as residential areas in freehold lands, whose cost suggested by the Department of Land and Surveys after the site survey by the staff amount to almost F$ 250,000 ha. The portion the residential areas in the land cost shares almost 60 % of the total land cost in the Feasibility Study. Other unit prices of the land suggested by the Department also increased to near the doubled.
- Compensation costs for buildings were also doubled due to the detail investigation of the floor areas and costs suggested by the Department and the Housing Authority.

CHAPTER 15 COST ESTIMATE

15.1 Composition of Project Cost

The composition of project cost is shown below. Ratios of the administration cost, engineering cost and contingency were estimated based on comparison of similar projects in the world.

1) Construction cost
2) Land acquisition
3) Administration: 5 % of 1)
4) Engineering: 15 % of 1)
5) Physical contingency of construction quantities: 5 % of the sum of 1) ~ 4)
6) Price contingency: based on annual inflation rate of 5 % for local cost and 3 % for foreign cost, and construction period of 2 years
7) Taxes and duties: 10 % of the sum of 1) ~ 6)

In the Master Plan Study, physical contingency was assumed to be 10 % of the sum of 1) ~ 4). Since the accuracy of proposed plan has been improved by the geological survey, topographical survey and so on, 5 % is considered appropriate.

15.2 Estimate of Construction Cost

1) Condition of Unit Cost

a) In Fiji, the standard price per unit work is not available for the cost estimate. Therefore, the unit price of each work item was estimated based on the costs of previous works similar to the project. The unit price for the earth work in Fiji is approximately 80 % of that in Japan.

b) The unit price of the construction work for the bridges and roads in compensation work was estimated with data collection and interview study to the contractors in Fiji.

2) Estimate of Construction Cost

The construction cost for the 4 floods was estimated as shown in Table-15.1 to Table-15.4, based on the above conditions.

Table-15.1 Construction Cost of Diversion and Short Cut Channels for 1/20 Probability Flood

Description			Unit Price	Quantity	Amount (F$)	Remarks
Main Work	Excavation*1	Sand and Soil	2.7 F$/$m^3$	2,290,000 m^3	6,183,000	Distance to Bulldoze = 60 m
	Loading*1		2.1 F$/$m^3$	2,290,000 m^3	4,809,000	
	Embankment	Transportation	4.0 F$/$m^3$	130,000 m^3	520,000	Distance = 2,000 m
		Grading	1.6 F$/$m^3$	130,000 m^3	208,000	
		Compaction	0.4 F$/$m^3$	130,000 m^3	52,000	
	Banking (Surplus Soil)	Transportation	2.7 F$/$m^3$	570,000 m^3	1,539,000	Distance = 200 m
		Transportation	4.0 F$/$m^3$	1,590,000 m^3	6,360,000	Distance = 2,000 m
		Grading & Compaction	2.1 F$/$m^3$	2,160,000 m^3	4,536,000	
	Bed & Bank Protection			Lump Sum	4,841,400	Main Work x 20 %
	Sub-Total				29,048,400	
Compensation Work	Bridge (Vehicles)		32,500.0 F$/m	120 m	3,900,000	
	Bridge (Sugarcane Tramline)		12,000.0 F$/m	111 m	1,332,000	
	Bridge (Pedestrians)		6,500.0 F$/m	93 m	604,500	
	Road		350.0 F$/m	4,000 m	1,400,000	
	Shift Works			Lump Sum	723,650	Total of Above Compensation Works x 10 %
	Sub-Total				7,960,150	
Construction Cost = Main Work + Compensation Work					37,008,550	

*1: including 50,000 m^3 for short cut channel and 120,000 m^3 for pre-loading
Shift Works: pipe lines for water supply, sewage pile line, electric cable, telephone line, cable between transmitter station & airport, sugarcane tramline

Table-15.2 Construction Cost of Diversion and Short Cut Channels for 1/15 Probability Flood

Description			Unit Price	Quantity	Amount (F$)	Remarks
Main Work	Excavation*1	Sand and Soil	2.7 F$/$m^3$	2,030,000 m^3	5,481,000	Distance to Bulldoze = 60 m
	Loading*1		2.1 F$/$m^3$	2,030,000 m^3	4,263,000	
	Embankment	Transportation	4.0 F$/$m^3$	130,000 m^3	520,000	Distance = 2,000 m
		Grading	1.6 F$/$m^3$	130,000 m^3	208,000	
		Compaction	0.4 F$/$m^3$	130,000 m^3	52,000	
	Banking (Surplus Soil)	Transportation	2.7 F$/$m^3$	510,000 m^3	1,377,000	Distance = 200 m
		Transportation	4.0 F$/$m^3$	1,390,000 m^3	5,560,000	Distance = 2,000 m
		Grading & Compaction	2.1 F$/$m^3$	1,900,000 m^3	3,990,000	
	Bed & Bank Protection			Lump Sum	4,290,200	Main Work x 20 %
	Sub-Total				25,741,200	
Compensation Work	Bridge (vehicles)		32,500.0 F$/m	108 m	3,510,000	
	Bridge (Sugarcane Tramline)		12,000.0 F$/m	99 m	1,188,000	
	Bridge (Pedestrians)		6,500.0 F$/m	81 m	526,500	
	Road		350.0 F$/m	4,000 m	1,400,000	
	Shift Works			Lump Sum	662,450	Total of Above Compensation Works x 10 %
	Sub-Total				7,286,950	
Construction Cost = Main Work + Compensation Work					33,028,150	

*1: including 50,000 m^3 for short cut channel and 120,000 m^3 for pre-loading
Shift Works: pipe lines for water supply, sewage pile line, electric cable, telephone line, cable between transmitter station & airport, sugarcane tramline

Table-15.3 Construction Cost of Diversion and Short Cut Channels for 1/10 Probability Flood

Description			Unit Price	Quantity	Amount (F$)	Remarks
Main Work	Excavation[*1]	Sand and Soil	2.7 F$/$m^3$	1,780,000 m^3	4,806,000	Distance to Bulldoze = 60 m
	Loading[*1]		2.1 F$/$m^3$	1,780,000 m^3	3,738,000	
	Embankment	Transportation	4.0 F$/$m^3$	130,000 m^3	520,000	Distance = 2,000 m
		Grading	1.6 F$/$m^3$	130,000 m^3	208,000	
		Compaction	0.4 F$/$m^3$	130,000 m^3	52,000	
	Banking (Surplus Soil)	Transportation	2.7 F$/$m^3$	440,000 m^3	1,188,000	Distance = 200 m
		Transportation	4.0 F$/$m^3$	1,210,000 m^3	4,840,000	Distance = 2,000 m
		Grading & Compaction	2.1 F$/$m^3$	1,650,000 m^3	3,465,000	
	Bed & Bank Protection			Lump Sum	3,763,400	Main Work x 20 %
	Sub-Total				22,580,400	
Compensation Work	Bridge (Vehicles)		32,500.0 F$/m	96 m	3,120,000	
	Bridge (Sugarcane Tramline)		12,000.0 F$/m	87 m	1,044,000	
	Bridge (Pedestrians)		6,500.0 F$/m	69 m	448,500	
	Road		350.0 F$/m	4,000 m	1,400,000	
	Shift Works			Lump Sum	601,250	Total of Above Compensation Works x 10 %
	Sub-Total				6,613,750	
Construction Cost = Main Work + Compensation Work					29,194,150	

*1: including 50,000 m^3 for short cut channel and 120,000 m^3 for pre-loading

Shift Works: pipe lines for water supply, sewage pile line, electric cable, telephone line, cable between transmitter station & airport, sugarcane tramline

Table-15.4 Construction Cost of Diversion and Short Cut Channels for 1/5 Probability Flood

Description			Unit Price	Quantity	Amount (F$)	Remarks
Main Work	Excavation[*1]	Sand and Soil	2.7 F$/$m^3$	1,470,000 m^3	3,969,000	Distance to Bulldoze = 60 m
	Loading[*1]		2.1 F$/$m^3$	1,470,000 m^3	3,087,000	
	Embankment	Transportation	4.0 F$/$m^3$	130,000 m^3	520,000	Distance = 2,000 m
		Grading	1.6 F$/$m^3$	130,000 m^3	208,000	
		Compaction	0.4 F$/$m^3$	130,000 m^3	52,000	
	Banking (Surplus Soil)	Transportation	2.7 F$/$m^3$	360,000 m^3	972,000	Distance = 200 m
		Transportation	4.0 F$/$m^3$	980,000 m^3	3,920,000	Distance = 2,000 m
		Grading & Compaction	2.1 F$/$m^3$	1,340,000 m^3	2,814,000	
	Bed & Bank Protection			Lump Sum	3,108,400	Main Work x 20 %
	Sub-Total				18,650,400	
Compensation Work	Bridge (Vehicles)		32,500.0 F$/m	81 m	2,632,500	
	Bridge (Sugarcane Tramline)		12,000.0 F$/m	72 m	864,000	
	Bridge (Pedestrians)		6,500.0 F$/m	54 m	351,000	
	Road		350.0 F$/m	4,000 m	1,400,000	
	Shift Works			Lump Sum	524,750	Total of Above Compensation Works x 10 %
	Sub-Total				5,772,250	
Construction Cost = Main Work + Compensation Work					24,422,650	

*1: including 50,000 m^3 for short cut channel and 120,000 m^3 for pre-loading

Shift Works: pipe lines for water supply, sewage pile line, electric cable, telephone line, cable between transmitter station & airport, sugarcane tramline

15.3 Estimate of Project Cost

The project cost (1996 prices) was estimated based on the conditions below.

- The ratio between local currency portion and foreign currency portion was set as shown in Table-15.5 based on the construction works in Fiji.
- The price contingency was taken into consideration with annual inflation rate of 5 % for the local currency portion and 3 % for the foreign currency portion.

Table-15.5 Ratio of Local Currency and Foreign Currency

Item	Local Currency	Foreign Currency
1. Construction Cost		
1) Material & Equipment	20 %	80 %
2) Labor	80 %	20 %
2. Land Acquisition	100 %	0 %
3. Administration	100 %	0 %
4. Engineering	20 %	80 %
5. Physical Contingency	40 %	60 %

The result of project cost estimate is shown in Table-15.6.

Table-15.6 Project Cost of Diversion and Short Cut Channels

Unit: F$ 1,000

Flood Scale	Item	Project Cost	Local Currency	Foreign Currency
1/20	1. Construction Cost	37,000	14,060	22,940
	1) Material & Equipment	25,900	5,180	20,720
	2) Labor	11,100	8,880	2,220
	2. Land Acquisition	8,900	8,900	–
	3. Administration	1,900	1,900	–
	4. Engineering	5,600	1,120	4,480
	5. Physical Contingency	2,700	1,080	1,620
	Sub Total	56,100	27,060	29,040
	6. Price Contingency	1,120	680	440
	7. Tax	5,720	5,720	0
	Grand Total	62,940	33,460	29,480
1/15	1. Construction Cost	33,000	12,540	20,460
	1) Material & Equipment	23,100	4,620	18,480
	2) Labor	9,900	7,920	1,980
	2. Land Acquisition	8,000	8,000	–
	3. Administration	1,700	1,700	–
	4. Engineering	5,000	1,000	4,000
	5. Physical Contingency	2,400	960	1,440
	Sub Total	50,100	24,200	25,900
	6. Price Contingency	1,000	610	390
	7. Tax	5,110	5,110	0
	Grand Total	56,210	29,920	26,290
1/10	1. Construction Cost	29,200	11,120	18,080
	1) Material & Equipment	20,400	4,080	16,320
	2) Labor	8,800	7,040	1,760
	2. Land Acquisition	7,400	7,400	–
	3. Administration	1,500	1,500	–
	4. Engineering	4,400	880	3,520
	5. Physical Contingency	2,100	840	1,260
	Sub Total	44,600	21,740	22,860
	6. Price Contingency	880	540	340
	7. Tax	4,550	4,550	0
	Grand Total	50,030	26,830	23,200
1/5	1. Construction Cost	24,400	9,260	15,140
	1) Material & Equipment	17,100	3,420	13,680
	2) Labor	7,300	5,840	1,460
	2. Land Acquisition	6,700	6,700	–
	3. Administration	1,200	1,200	–
	4. Engineering	3,700	740	2,960
	5. Physical Contingency	1,800	720	1,080
	Sub Total	37,800	18,620	19,180
	6. Price Contingency	760	470	290
	7. Tax	3,860	3,860	0
	Grand Total	42,420	22,950	19,470

Note: 1) Tax: Value Added Tax (VAT), 10 %
2) Material & Equipment = Construction Cost x 70 %
3) Labor = Construction Cost x 30 %
4) Cost for land acquisition and compensation is discussed in Chapter 14.

CHAPTER 16 ECONOMIC EVALUATION AND FINANCIAL EXAMINATION

16.1 Objectives

As a result of preliminary economic evaluation on scale of diversion channel in Section 12.2 of Chapter 12, it has been recognized that the Nadi diversion channel and short cut channel for the design flood of 1/20 probability has the highest economic viability.

The objective of economic evaluation is to examine the project in detail for the design flood of 1/20 in terms of economy. Sensitivity analysis were employed to examine the economic viability in unexpected risky conditions.

Financial considerations were made assuming overseas loan. Scale of repayment for the project were examined by comparing with the mid-term schedule of repayment by the Government. The portion of funds not to be covered by overseas loan were examined by comparison with the current capital expenditure of the Government.

16.2 Sensitivity Analysis

Sensitivity analysis is to be conducted to assess whether the projects can maintain their viability, when supposed to be placed under unfavorable circumstances during and after implementation. A test is therefore carried out about the sensitivity of EIRR affected by variations in the economic costs, benefits and maintenance cost.

EIRR sensitivity analysis was examined under the conditions of the increase in 5 % and 10 % of economic cost and the decrease in 5 % and 10 % in the economic benefits for the 1/20 probability flood. Conditions, such as project life, construction period and so on, are assumed to be same as in the economic evaluation of the priority project. The results are summarized in Table-16.1.

Table-16.1 EIRR Sensitivity Analysis of the Project

		Increase in Cost		
		0 %	5 %	10 %
Decrease in Benefit	0 %	14.45	13.79	13.19
	5 %	13.76	13.13	12.56
	10 %	13.07	12.47	11.92

Note: Unit of EIRR : %

EIRR sensitivity analysis for the Operation and Maintenance Cost (OM Cost) was also examined under the conditions of the increase in 0.5 %, 1.0 % and 1.5 % of construction cost. The results are summarized below:

OM Cost (%)	0.1	0.5	1.0	1.5
EIRR (%)	14.45	14.21	13.91	13.61

As shown above, EIRR for the project of 1/20 probability flood maintains the figures of 11.92 % in the worst case of cost and benefit, and 13.61 % in the worst case of OM cost which indicate the economic feasibility of the project in comparison with the opportunity cost of capital of 10 %.

16.3 Financial Aspects

Assumptions were given on raising of the construction fund in order to examine a financial viability of the project.

The financial project cost for 1/20 design flood project is estimated at F$ 62.94 million. Most of these amount is scheduled to be disbursed over the construction period of 2 years. Considering that the project will require such a substantial amount of fund for the short period, as an example, the project cost is assumed to be financed with a loan through the overseas financial agency. Henceforth, two scenario of conditions shall be discussed ;

Scenario 1: under the terms of 1) interest rate of 1.7 % per annum, 2) a repayment of 25 years including a grace period of 7 years, and 3) paying only the interest of debt every year for the grace period, and the principal with interest in years after the grace period. And the loan amount is to be 85 % of Financial Cost.

Scenario 2: under the terms of 1) interest rate of 7.0 % per annum, 2) a repayment of 17 years including a grace period of 5 years, and 3) paying only the interest of debt every year for the grace period, and the capital amount with interest in years after the grace period. And the loan amount is to be 85 % of financial cost.

In case of Scenario 1, the total refund with interest will amount to F$ 67,141 thousand . The maximum of annual payment will amount to F$ 3,831 thousand at the eighth year from the commencement of the project.

While in case of Scenario 2, the total refund with interest will amount to F$ 90,948 thousand . The maximum of annual payment will amount to F$ 7,891 thousand at the sixth year from the commencement of the project.

Table-16.2 shows the repayment schedule for overseas borrowing of the Government of Fiji. Such a repayment schedule might be manageable in the more favorable conditions for the Scenario 1, judging from the following figures;

(a) The peak annual repayment will be 11.7 % of the total amount of the average total annual repayment to overseas loan by the Government for Scenario 1 and 24.0 % for Scenario 2.

(b) Debt coverage ratio at the peak repayment year by the figure of the average government expenditure will be 3.51 % for Scenario 1, and 3.90 % for Scenario 2.

Table-16.2 Government Repayment to Overseas Loans

Unit: F$ 1,000

		Actual	Estimate		Projection		
		1996	1997	1998	1999	2000	Average (1996/2000)
Overseas Loan Interest Payments		11,171	12,917	13,653	12,475	11,223	12,288
Overseas Loan Principal Payments		19,670	16,954	21,241	21,868	22,924	20,531
(1) Total Repayment (without the Project)		30,840	29,871	34,894	34,343	34,147	32,819
(2) Total Expenditure of the Government		958,436	1,093,237	1,101,507	1,046,645	1,032,356	1,046,436
(3) (1) / (2) x 100: (%)*		3.22	2.73	3.17	3.28	3.31	3.14
Comparison of Peak Repayment for the Project with the whole Government Repayment of each year							
(4) Peak Repayment (8th year) of Scenario 1 (F$3,831 thousand)	(5) (4) / (1) x 100 (%)	12.4	12.8	11.0	11.2	11.2	11.7
	(6) (4) / (2) x 100: (%)	0.4	0.4	0.3	0.4	0.4	0.4
	(7) 3) + (6) : (%)*	3.62	3.08	3.52	3.65	3.68	3.51
(8) Peak Repayment (6th year) of Scenario 2 (F$7,891 thousand)	(9) (8) / (1) x 100 (%)	25.6	26.4	22.6	23.0	23.1	24.0
	(10) (8) / (2) x 100: (%)	0.8	0.7	0.7	0.8	0.8	0.8
	(11) (3) + (10) : (%)*	4.04	3.45	3.88	4.04	4.07	3.90

Source: Fiji Budget Estimate as Presented to Parliament,1998, Ministry of Finance
Note: * Debt Coverage Ratio; the ratio of overseas loan repayment to government expenditure.

On the other hand, the balance 15 % of whole cost amounts to be F$ 9,441 thousand, and the average cost of F$ 4,721 thousand over construction period of 2 years accounts for 4.8 % of average capital expenditure (1991 ~ 1995) by the whole Government, and 11.5 % of average expenditure for infrastructure development by the Government (refer to Table-9.3). Meanwhile, the Government may raise, if necessary, this balance of whole cost by means of domestic loan on longer term than two years of construction period in order to reduce the annual amount of the expenditure.

Taking into consideration importance and urgent necessity of the priority project, such magnitude of budget allocation to the implementation of the priority project is reasonable and possible.

In conclusion, repayment for the overseas borrowing as well as payment for the balance of whole cost shall fall in manageable range of the Government finance.

CHAPTER 17 EFFECT OF PROJECT IMPLEMENTATION

17.1 Direct Effect

Economic effect of the Nadi diversion channel and short cut channel is discussed in Chapter 12 and Chapter 16. In this chapter, effect of the above flood control measures on area of inundation, flood level and flood duration was examined in two cases for the design flood (20 year return period flood) and excess flood (50 year return period flood).

(1) Flood Discharge and Flood Duration

Discharges of two floods (1/20 and 1/50 probability) was calculated with and without flood control measures (Nadi diversion channel and short cut channel). The cyclone Kina's hyetograph was enlarged to simulate flood discharge by the storage function model. Hydrograph of each case is shown in Figure-17.1 and discharges in the figure are at river mouth of Nadi river.

The maximum discharge of 20 year return period flood without the flood control measures is approximately 2,050 m^3/sec at river mouth, while that with the flood control measures is reduced to about 600 m^3/sec. Since flow capacity of Nadi river is 600 m^3/sec (converted discharge at river mouth), there is no flood in the area downstream from the diverting point.

Flood duration of 20 year return period flood without the flood control measures is 16 hours as shown in Figure-17.1. 16 hours means duration which discharge more than flow capacity flows in Nadi river. Actual duration inclusive of time required to drain the flood from inundated areas is estimated roughly to be 44 hours at minimum without the measures and it would be reduced to zero with the measures.

The maximum discharge of 50 year return period flood is reduced from 3,050 m^3/sec to 880 m^3/sec by implementation of the flood control measures. On the other hand, flood duration is estimated also to be reduced from 62 hours at minimum without the measures and it would be reduced to 10.0 hours at minimum with the measures.

(2) Maximum Water Level

The maximum water level of Nadi river at Nadi bridge for 20 year return period flood is reduced from EL. 11.4 m to EL. 5.1 m by implementation of the flood control measures. On the other hand, that for 50 year return period flood is reduced from EL. 14.1 m to EL. 6.3 m. Since elevation of bank crest at Nadi bridge is approximately 5.9 m, the maximum water level for 20 year return period flood is within the river channel and that for 50 year return period flood is slightly higher than the bank crest, causing small inundation.

(3) Inundated Area

Inundated areas with and without implementation of the flood control measures are shown in Figure-17.2 and Figure-17.3. The flood control measures are effective in the area downstream from the diverting point.

Inundated area without the implementation is 36.2 km^2 for 20 year return period flood and it is reduced to 5.2 km^2 with the implementation. There is no inundated area in the downstream from the diverting point.

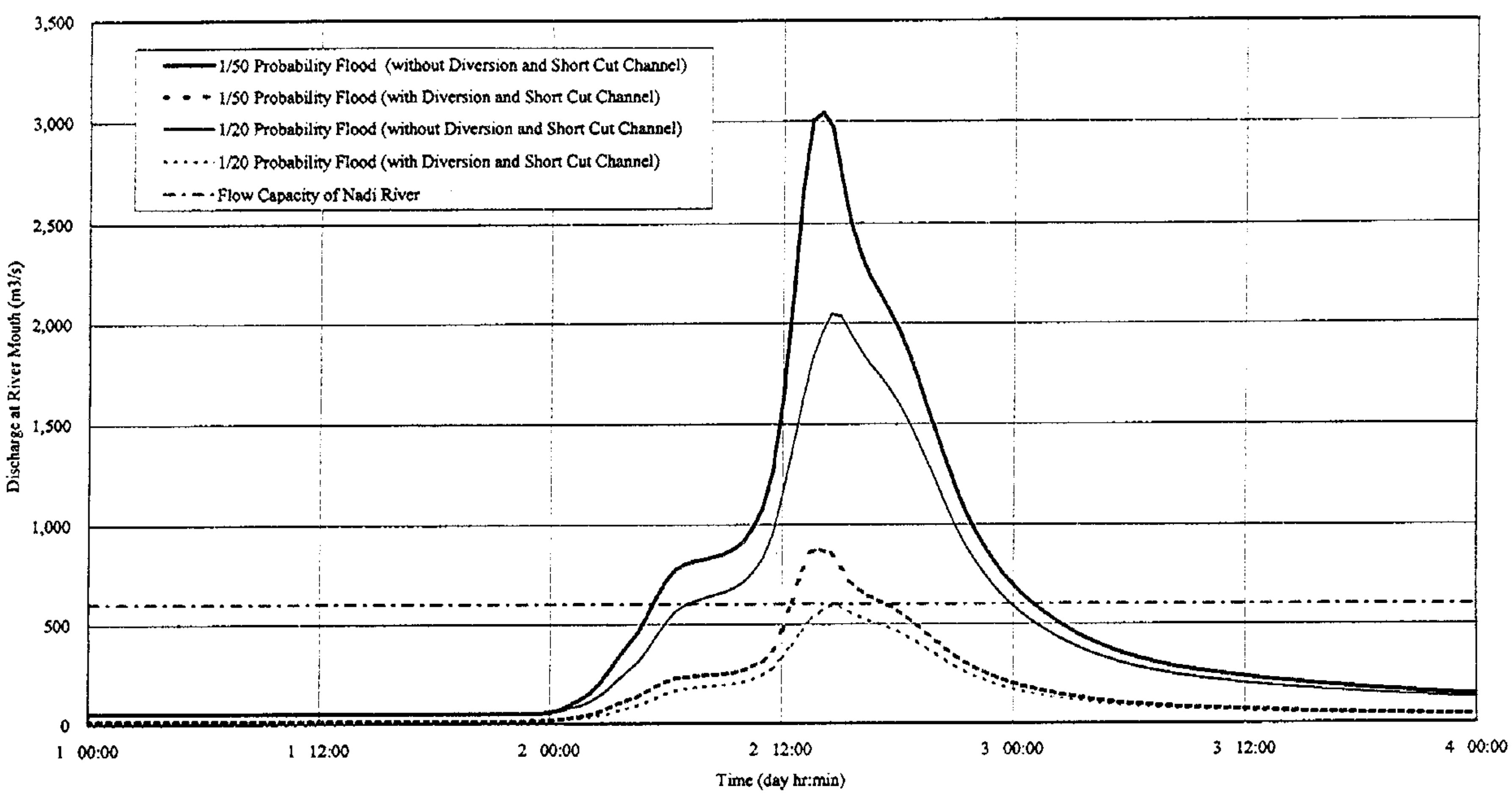


Figure-17.1 Hydrograph with and without Diversion and Short Cut Channels

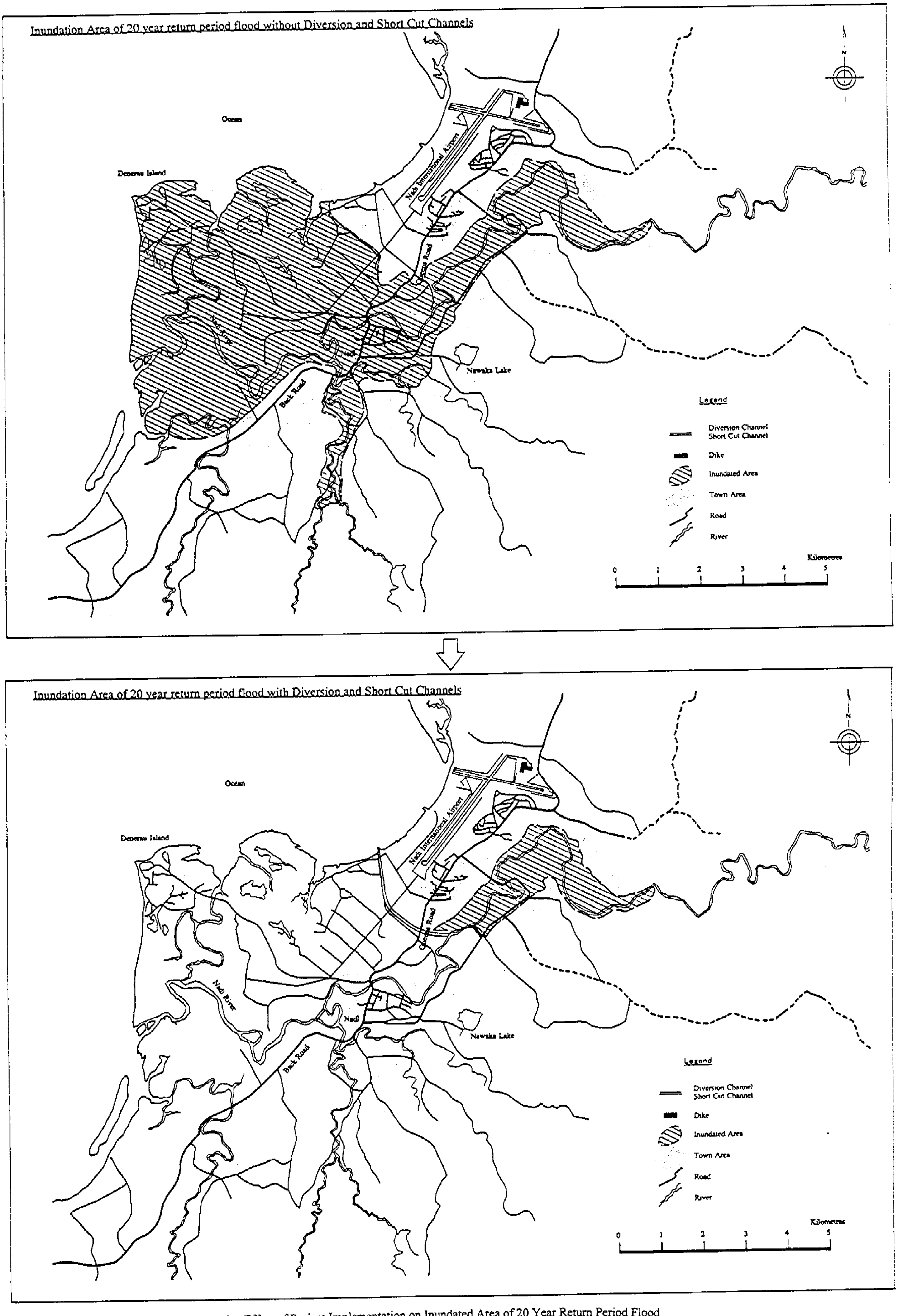


Figure-17.2 Effect of Project Implementation on Inundated Area of 20 Year Return Period Flood

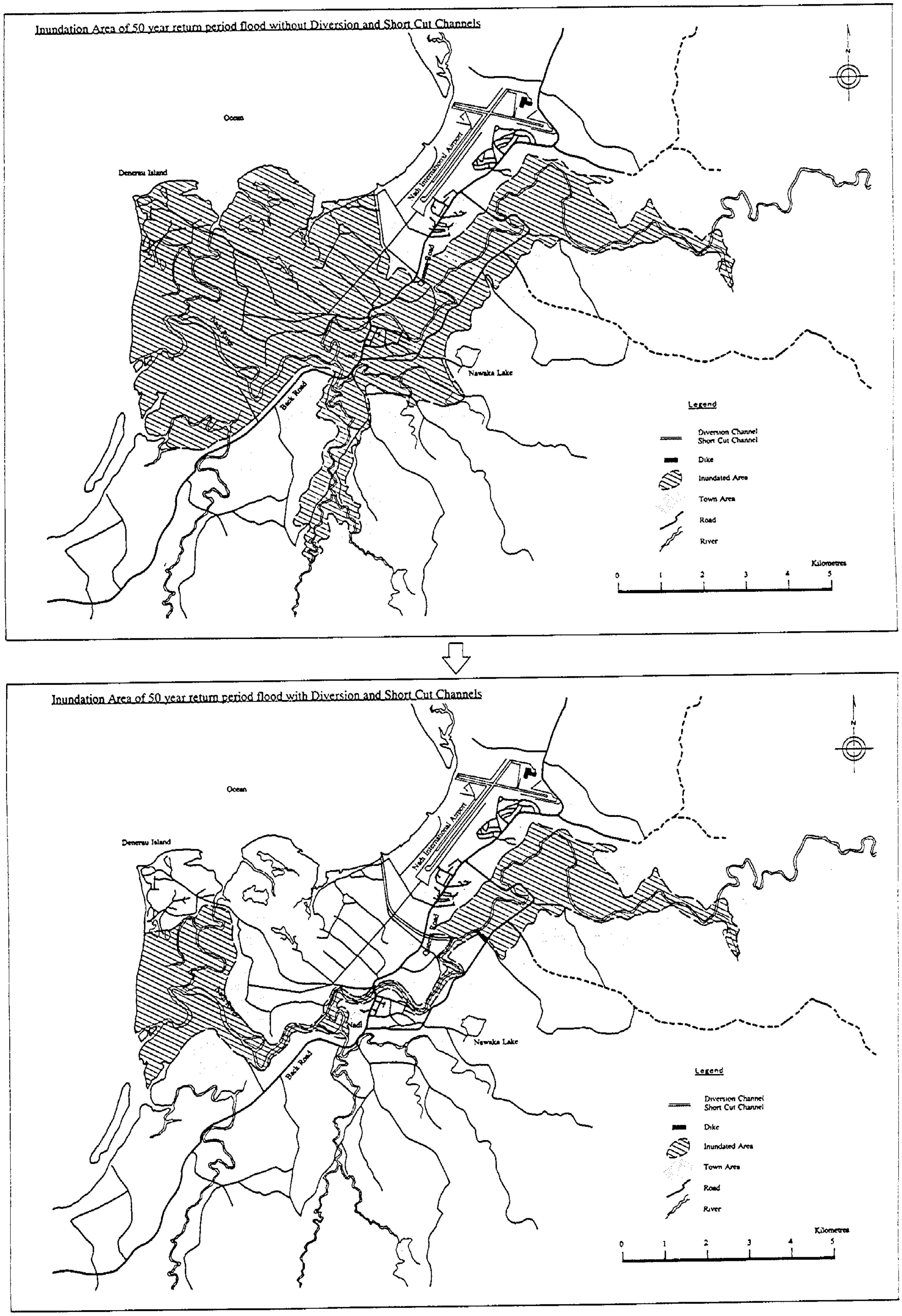


Figure-17.3 Effect of Project Implementation on Inundated Area of 50 Year Return Period Flood

For 50 year return period flood, inundated area is reduced from 45.4 km^2 to 16.0 km^2 by the implementation of the flood control measures. Inundated area downstream from the diverting point is reduced from 39.0 km^2 to 9.6 km^2. The area of 9.6 km^2 is distributed along Nadi river.

17.2 Indirect and Intangible Effect

Effects of flood control measures consist of direct and indirect ones. The former is examined quantitatively as discussed in the previous section, while the latter is difficult to be examined quantitatively. Therefore, indirect effects are examined qualitatively in the following section.

Indirect effects of flood control measures extend mainly to the following items, contributing to improvement of living conditions.

1) multiplier effects of project cost investment
2) technology transfer
3) land development
4) effective usage of maintenance roads
5) mental damage to suffers
6) distribution and communication system
7) public health
8) tourism
9) landuse

(1) Multiplier Effects of Project Cost Investment

The project cost investment brings the multiplier effects to the project area and its vicinity. The employment opportunity is one aspect. During the construction period of two years, considerable amount of investment is executed in local portion of laborers, engineering and administration which respond to the employment creation. Consequently, the consumption coming out from those wages paid to the people concerned accelerates the commercial and economic activities in the surrounding area of the Nadi project sites. The compensation cost for land acquisition also brings the multiplier effects to the economy in this area.

(2) Technology Transfer

Technology transfer, during the construction, operation and maintenance, may be categorized into the human resources development which is the formation and development of capabilities of personnel through knowledge and skills. The development of people is the most important aspect of social and economic development. On the job training during the two year construction improves the abilities of the engineers and also create the capable technicians. The technology transfer for the operation and maintenance brings not only improvement of engineers' abilities but also creates the men of talent for the administration and management system.

(3) Land Development

The Nadi diversion channel project can develop a 49 ha of land close to the seashore, as a site for the disposal of excavated soil. This size of land is large enough to establish the hotel of totaling 500 guest rooms, which eventually create the new employment opportunity of approximately 700 people. In addition to this, the citizen's green park can be located on this land. Thus, in parallel with the main project of diversion channel, this new reclaimed land brings both economic and social benefits to the inhabitants in the project area and its vicinity.

(4) Effective Usage of Maintenance Roads

The wide enough maintenance roads on both banks along the diversion channel can be the access roads to the potential residential area. Since the location of this area is favorable, close to the Nadi town and Nadi airport, the maintenance roads may stipulate the development of new residential area .

(5) Mental Damage to Suffers

Floods cause not only damage to public infrastructure and properties but also injury and death of people. Once people have flood damage, mental anguish extends to the person himself and his relatives. Even people not suffered from flood have anxiety when water level of river raise due to heavy rain. Those mental damage cannot be compensated by money and has to be removed for the sound society.

The lower reach of Nadi river is susceptible to flood damage because flow capacity of Nadi river is small and Nadi town is located along the river. With implementation of flood control measures, damage to properties and infrastructure in that area would be reduced considerably. As a result, mental damage also would be mitigated.

(6) Distribution and Communication System

Submerged road and power failure by floods suspend distribution and communication system in the inundated area. This damage influence those system in other areas not suffered from floods. Although it is difficult to estimate the damage inclusive of influence to other areas quantitatively, the suspension of distribution and communication system induces stagnation of economic activities in the whole areas.

With implementation of the Nadi diversion channel and short cut channel, stagnation of economic activities would be mitigated.

(7) Public Health

Floods contain many things distributed in inundated areas, such as garbage, sewage, waste water and so on. This contaminated water may induce infectious diseases not only during inundation but also after a flood is drained.

The Nadi diversion channel and short cut channel are effective to mitigate those problems of public health.

(8) Tourism

Major industry in Fiji is tourism and Nadi town is a main gateway to tourist resorts. Problems on the above 5) ~ 7) have negative effects on tourism resulting in decrease of tourists from overseas and depression of tourism business.

Implementation of the Nadi diversion channel and short cut channel mitigates negative effects on tourism and leaves favorable impressions of Fiji on tourists.

(9) Landuse

Frequent floods limit landuse in inundated areas. Potential of landuse in inundated areas increases considerably by implementation of flood control measures because much less frequency of floods secures land from the enormous damage. Therefore, implementation of the Nadi diversion channel and short cut channel contributes to increase in value of currently inundated areas.

17.3 Effect of Diversion Channel on Coastal Area

17.3.1 Present Conditions of Coastal Area

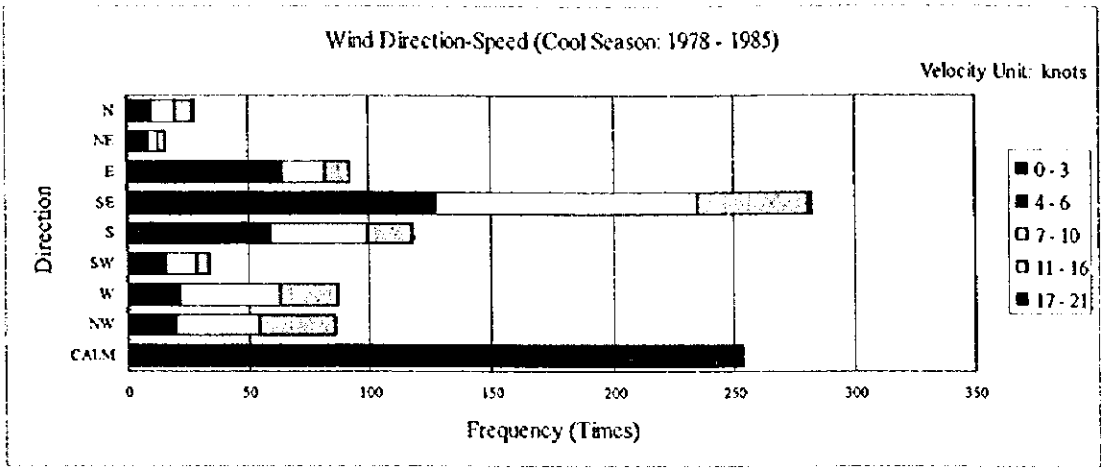
(1) Wind

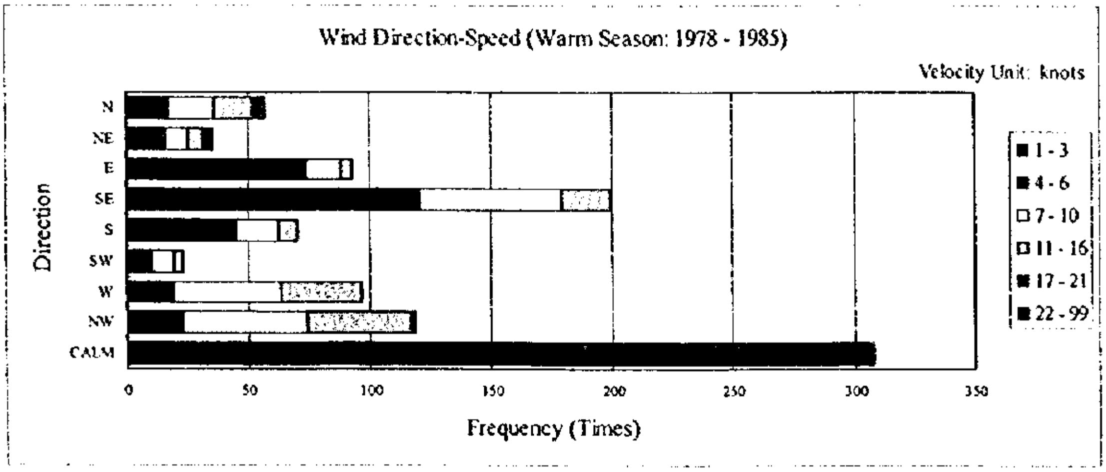
Regarding wind in the Nadi bay area, data is collected at the Nadi international airport adjacent to the bay. Based on eight year record of hourly surface wind speed over the period, 1978 ~1985 (inclusive of cyclone), the following statistics were identified.

In the cool season (from May to October), the predominant directions are East, Southeast and South (approximately 50 %) and the velocity does not exceed 21 knots.

In the warm season (from November to April) when cyclones occur frequently, the frequency of predominant winds during the cool season decreases to about 26 %, while the frequency of wind with directions of West, Northwest and North increases to about 27 %. Wind velocity during the warm season sometime exceeds 22 knots.

Calm conditions are counted approximately 25 % in the cool season, while it exceeds 30 % in the warm season (refer to Figure-17.4).





Data Source: Fiji Meteorological Service

Figure-17.4 Wind Direction - Speed (1978 -1985)

(2) Tide Levels

Based on tide data at Vuda Point, where is the nearest tidal station to Nadi and located in the northern part of Nadi bay, the relations of the tide levels between in Nadi bay and at Standard Port (Suva harbour) are shown as follows.

Table-17.1 Tide Levels

Description	Vuda Point	Standard Port (Suva Harbour)
Mean High Water Springs	1.70 m	1.60 m
Mean High Water Neaps	1.50 m	1.40 m
Mean Sea Level	0.97 m	0.96 m
Mean Low Water Neaps	0.40 m	0.50 m
Mean Low Water Springs	0.20 m	0.30 m
Chart Datum (CD) and Lowest Astronomical Tide (LAT)	0.00 m	0.00 m
Spring Tidal Range	1.50 m	1.30 m
Neap Tidal Range	1.10 m	0.90 m

Source: Marine Department, 1998

The elevations of land survey on this study are based on the mean sea level at Standard Port in Fiji (Suva Harbour).

(3) Deepwater Waves

Nadi Bay opens to the west, where sheltered by numerous off-shore islands against waves from the open sea. As waves inside the bay has not been measured, the deepwater wave heights were estimated using the SMB (Sverdrup-Munk-Bretschneider) method. The SMB relations allow the height and period of wind generated waves in deepwaters to be estimated as functions of wind speed, fetch and duration. Average wind speed over 1960 ~ 1984 is available at Nadi airport. As a result, the wind velocity in ordinary sea conditions reaches a maximum of 11.4 knots (5.9 m/sec), causing deepwater waves with a height of 40 cm and a period of roughly 2.4 seconds (wind velocity: 5.9 m/sec, fetch: 17 km).

The report on the extension of the Nadi Airport (Civil Aviation Authority of Fiji, 1994) estimated waves during storm as shown in Table-17.2. Since the method of estimate could not be obtained , figures in the table were not examined by the Study Team.

Table-17.2 Deepwater Wave Conditions

Direction	Return Period (years)	Wind Speed (m/sec)	Wave Height (m)	Wave Period (sec)
W & NW	2	35	2.7	5.7
	5	47	4.4	7.0
	10	56	5.8	8.0
	20	64	7.1	8.8

Source: Civil Aviation Authority of Fiji (1994)

(4) Storm Surge

Storm surge is defined as the temporary rise in sea level beyond the astronomical tide level during a severe storm, and is composed of pressure or atmospheric set-up, wind set-up and wave set-up.

According to the report on the extension of Nadi airport (Civil Aviation Authority of Fiji, 1994), estimated storm surge is as follows. Since the method of estimate could not be obtained, figures in Table-17.3 were not examined by the Study Team. However, the duplicated application of return period of central pressure and sustained wind speed may cause the large storm surge.

Table-17.3 Storm Surge

Return Period (years)	Central Pressure (Pa)	Sustained Wind Speed (m/sec)	Storm Surge (m)
2	999	35	0.9
5	961	47	1.8
10	946	56	2.4
20	932	64	3.0

Source: Civil Aviation Authority of Fiji (1994)

(5) Tidal Current

According to the report on the extension of Nadi airport (Civil Aviation Authority of Fiji, 1994), the mean and maximum velocities of tidal currents at the mouth of the Sabeto river and Nadi bay are 4.17 cm/sec and 15.31 cm/sec, respectively. Since those data were collected only at the proposed site for airport extension, the Study Team conducted the tidal current survey in the Nadi bay through subcontract with a local consultant. Its result is discussed in the section 17.3.2. Locations of tidal current survey by the Study Team and by Civil Aviation Authority of Fiji are shown in Figure-17.5.

(6) Materials of Shore

Properties of beach sand and seabed are available in Civil Aviation Authority of Fiji (1994). Those data were adopted to study the materials of shore.

The grain size distribution and materials of the beach sand around the proposed location for the outlet of diversion channel are shown in Table-17.4.

The materials of seabed vary from clays to gravel but the majority of samples are sandy silts with minor clay and gravel content. The gravel content in the deltaic sediments is an alluvial gravel, while in the marine sediments it is shell and coral debris. There is no indication of variation in grain size with depth.

(7) Shore Erosion

Since the western shore of the Denarau Island, located in the south of Nadi bay, has been reported to be considerably eroded, the Study Team conducted the field reconnaissance and analysis of aerial photos to assess the effect of the diversion channel and short cut channel on the seashore erosion.

As a result of comparison of aerial photos taken in 1967, 1986 and 1994 at the mouth of Nadi river, there is no significant change in the last 30 years. Besides, the study based on aerial photos and field reconnaissance disagrees with the idea that the littoral drift from the mouth of Nadi river has sent sand to form the western beach of Denarau Island.

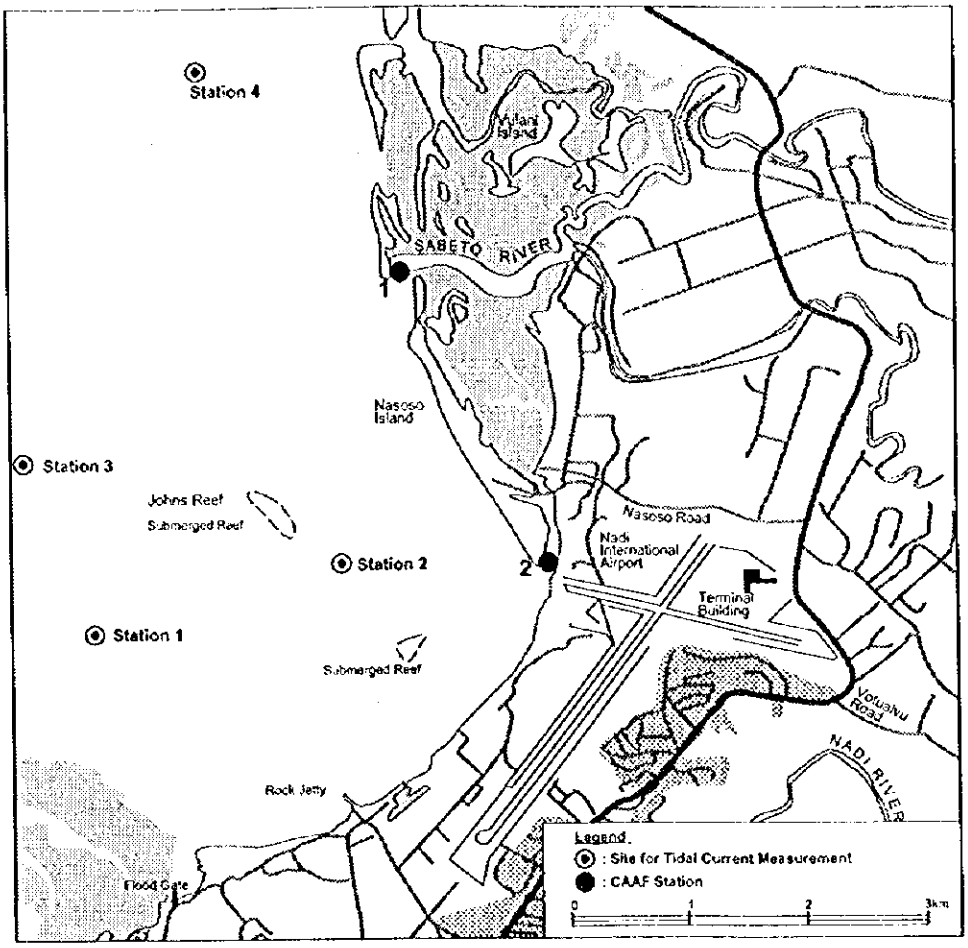


Figure-17.5 Locations of Current Observation by Civil Aviation Authority and Study Team

Table-17.4 Grain Size Distribution

unit: %

Particle Size (mm)	Below mean sea level	At mean sea level	seaward
37.500	100	100	100
26.500	100	100	100
19.000	99	100	100
13.200	99	100	100
9.500	99	100	100
6.700	99	100	100
4.750	98	99	100
2.360	98	99	99
1.180	97	99	99
0.600	95	98	99
0.425	94	95	99
0.300	87	77	97
0.150	25	14	18
0.075	2	3	1

Source: Civil Aviation Authority of Fiji (1994)

Based on the above examination, reduction in sediment transport of Nadi river by the diversion channel is considered not to have significant effect on the shore erosion in the western Denarau Island. The Land and Water Resource Management Division (LWRMD) has planned to conduct a research on the shore erosion at river mouth of Nadi river. It is recommendable to conduct the further study on effect of the diversion channel on the shore erosion based on the research result by LWRMD at the detailed design stage.

17.3.2 Tidal Current Survey

To assess the movement of sediment drained from the diversion channel under the sea, the tidal current survey was conducted through subcontract with a local consultant.

(1) Current Measurement

Four buoys each rigged with a red flag, a light bulb and a battery were anchored in positions on 29 December, as shown in Figure-17.5. Coordinates of the 4 buoys were measured by Global Positioning System (GPS).

The current measurement commenced at 6 o'clock on 30 December and ended at about 8 o'clock on 31 December 1997, when the tide is the high water springs. The total period of measurement is 25 hours. Flow velocity (once) and direction (three times) were taken at 2 m depth at every one hour interval.

(2) Tide Level Observation

Tide level observation during the tidal current measurement was also conducted in order to relate the tidal currents with the stage of the tide. Tide level readings were taken from a tide pole installed at the jetty near the airport. The tide pole was leveled to a Bench Mark close by and Lowest Astronomical Tide (LAT) was adopted as the datum.

(3) Measurement Results

1) Tide Level Data

Observed tide levels are shown in Figure-17.6. Observed high water times were 0640 hours and 1840 hours on 30 December and 0720 hours on 31 December. Heights were 1.83 m, 2.12 m and 1.89 m, respectively.

Observed low water times were 1240 hours on 30 December and 0100 hours on 31 December. The heights were 0.55 m and 0.20 m respectively.

The predicted tide levels based on the tide data at Vuda Point, are also plotted in Figure-17.6. Times predicted for high and low water can be affected by changes in the force and direction of the wind and by changes in the barometric pressure. In general, the heights are increased with on-shore and decreased with off-shore winds. Sea level rises as barometer falls, and vice versa, approximately 1 cm for each millibar.

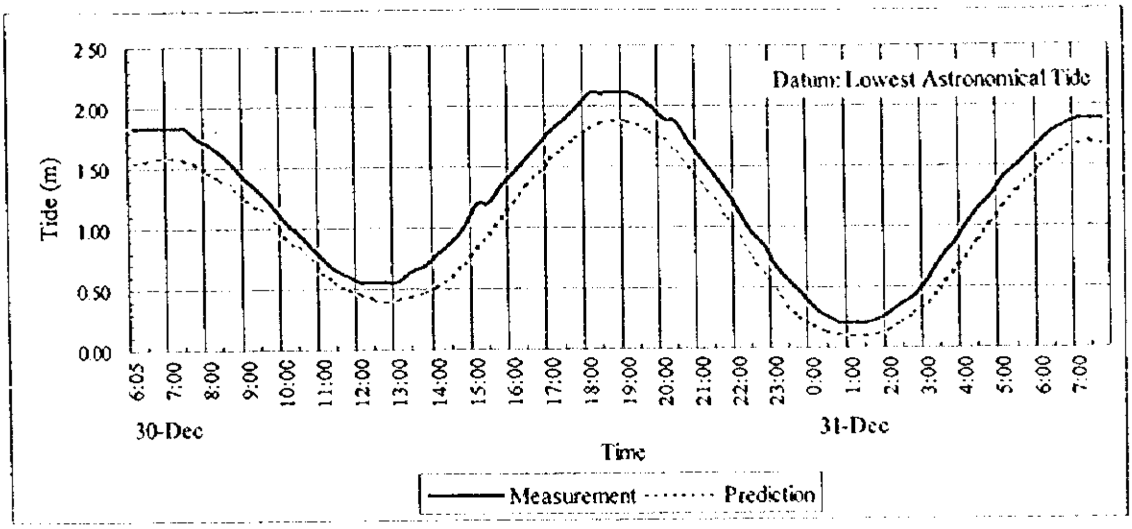


Figure-17.6 Tidal Observations in Nadi Bay

2) Current Data

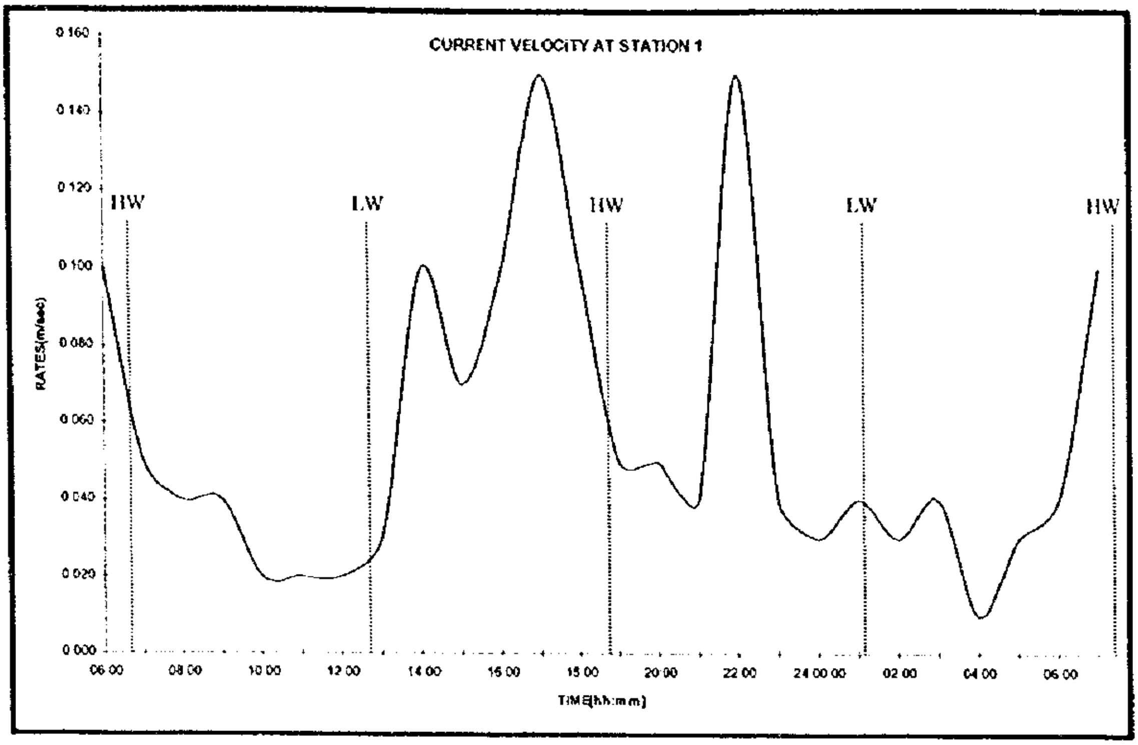
Current velocities of each location are shown in Figure-17.7. As shown in the Figure, there is no typical relation between current velocities and tide levels.

The mean current velocities over the observed period at each station are summarized in Table-17.5. The average and maximum velocities at Station 1 and 2 where the sea depth is about 5 m are 0.04 ~ 0.06 m/sec and 0.15 m/sec, respectively. The figures are close to those obtained near the Nadi International Airport (Civil Aviation Authority of Fiji, 1994). On the other hand, those at Station 3 and 4 where the sea depth is about 10 m are 0.11 m/sec and 0.25 m/sec, respectively.

The flow direction was measured together with velocity and the results are shown in Figure-17.8. The directions are random and have no typical tendency.

Table-17.5 Current Velocity in Nadi Bay

Item		Station 1	Station 2	Station 3	Station 4
Coordinates		177°23'57.70"E 17°45'24.95"S	177°25'05.66"E 17°44'59.97"S	177°23'19.83"E 17°44'34.5"S	177°24'29.17"E 17°42'54.9"S
Velocity	Average	0.06 m/sec (216 m/hr)	0.04 m/sec (144 m/hr)	0.11 m/sec (383 m/hr)	0.11 m/sec (383 m/hr)
	Maximum	0.15 m/sec (540 m/hr)	0.15 m/sec (540 m/hr)	0.25 m/sec (900 m/hr)	0.25 m/sec (900 m/hr)
	Minimum	0.01 m/sec (36 m/hr)	0.01 m/sec (36 m/hr)	0.04 m/sec (144 m/hr)	0



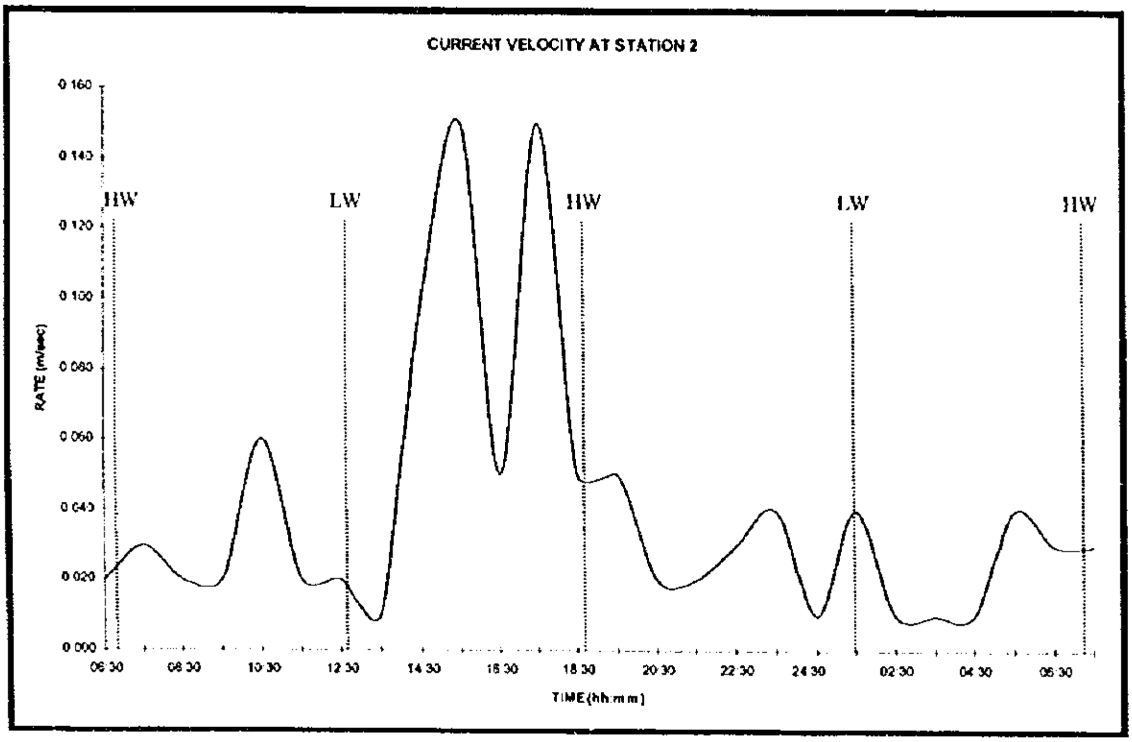
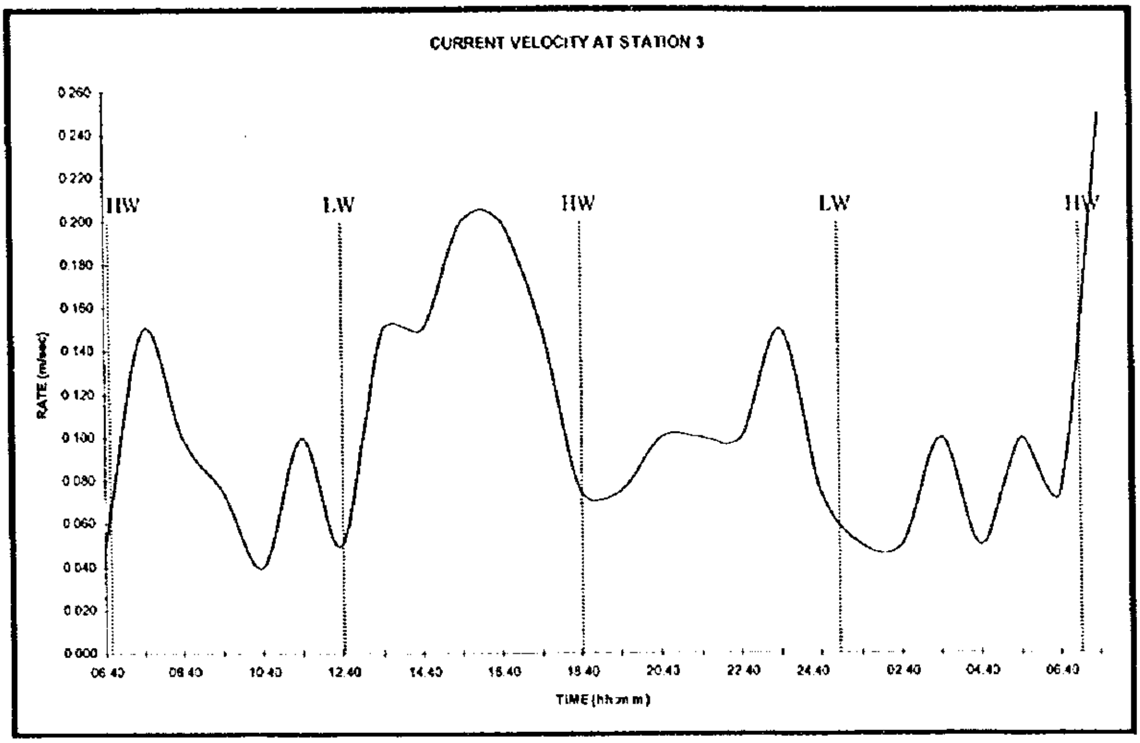


Figure-17.7 (1/2) Current Velocities at the 4 Stations (Station 1 ,Station2)



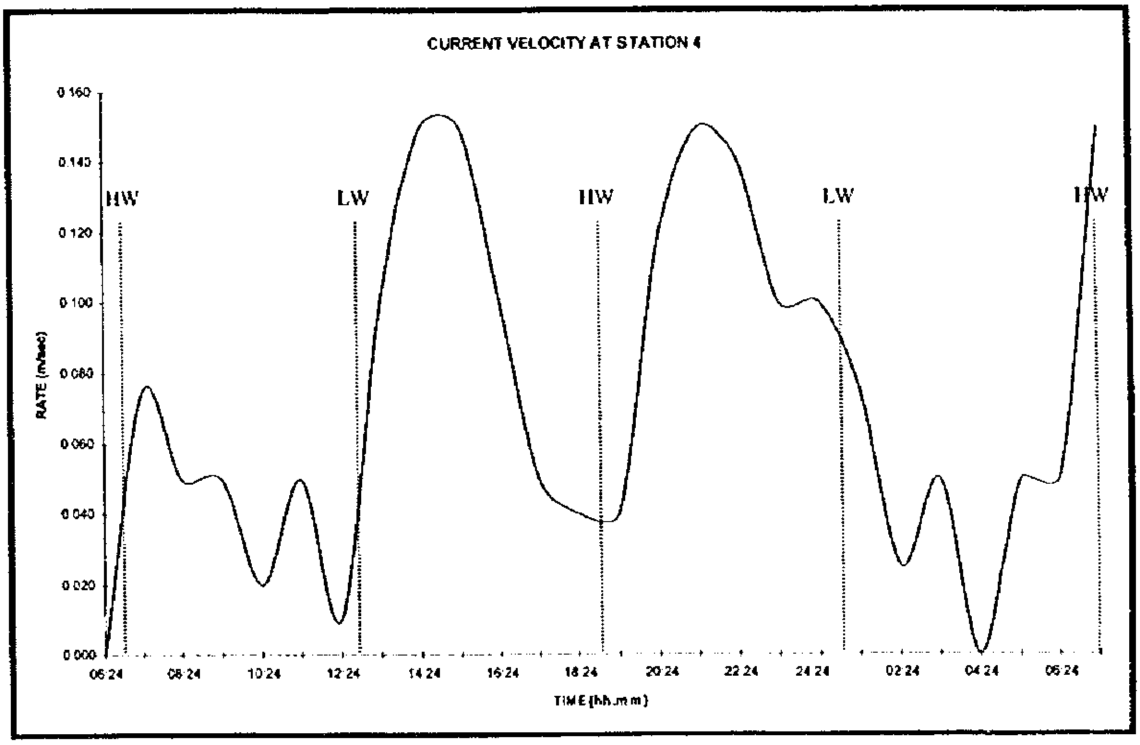
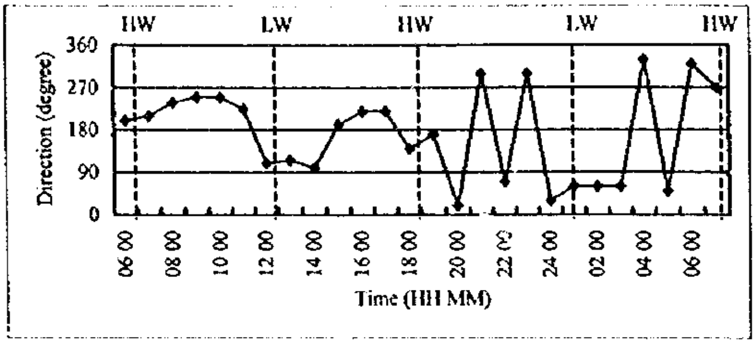
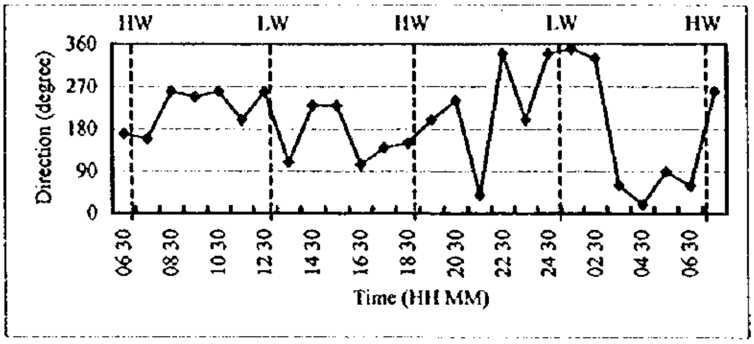


Figure-17.7 (2/2) Current Velocities at the 4 Stations (Station 3 ,Station4)

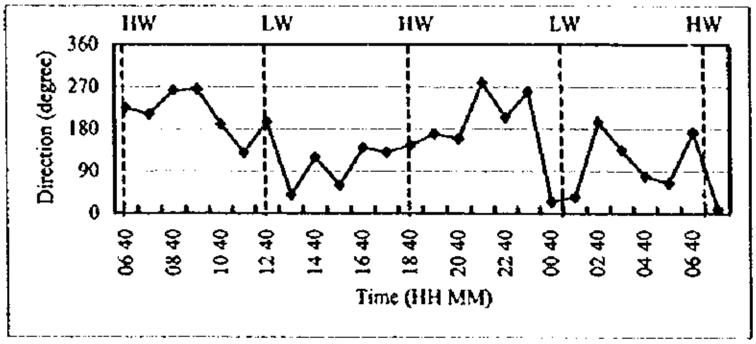
Station 1



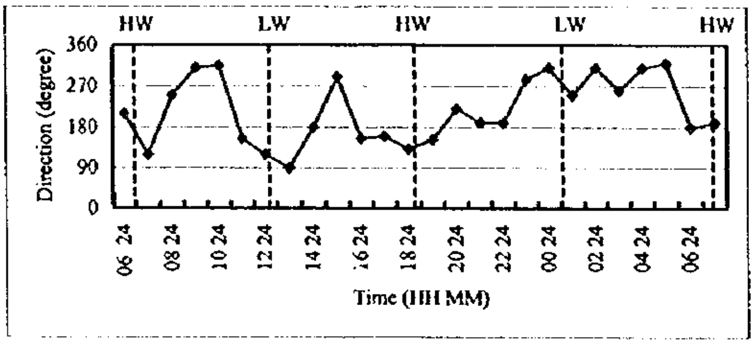
Station 2



Station 3



Station 4



Direction (degree)	0 (360)	from North to South
	90	from East to West
	180	from South to North
	270	from West to East

Figure-17.8 Tidal Directions at the 4 Stations

17.3.3 Sediment Load Analysis

During floods, sediment load is drained into the Nadi bay through the diversion channel. To examine effect of sediment on the Nadi bay, the sediment load analysis was conducted by the bed evolution simulation in order to assess sediment load into the channel, and sedimentation in the channel and the sea. And successively, effect of sediment load through the diversion channel was examined based on the tidal current survey.

(1) Analysis Method

Bed evolution simulation is generally conducted with the following three formulas solved by the finite difference equation.

Dynamic equation of flow	(I)
Equation of sediment load	(II)
Continuity equation of sediment load	(III)

Formula (I) expresses flow in the river channel. Actual flow in the river channel is unsteady flow; however, it is generally calculated as steady flow in the case that long term phenomena, such as sedimentation at river mouth, dam sedimentation and so on, are analyzed. Non-uniform and uniform flow calculations based on Manning roughness coefficient are applied to estimate water level in the river channel with conditions that discharge and cross sections of river are given.

Formula (II) computes sediment passing at a certain point of river based on average velocity of cross section and tractive force calculated by formula (I).

Formula (III) computes incomings and outgoings of sediment at each point concerned of river by continuity equation. Successively, bed elevation at each point is calculated based on the incomings and outgoings of sediment, and new elevations of river channel are determined.

In formula (II) and (III), sediment load, and incomings and outgoings of sediment are estimated by particle size.

Flow of the simulation is shown in Figure-17.9 and calculations are repeated for required time span.

(2) Model for Analysis

A section where the sediment load analysis was applied is from diverting point to 2 km offshore from outlet of the diversion channel. Longitudinal profile and cross sections of the channel for the sediment load analysis is same as the hydraulic design for 20 year return period flood.

Based on echo-sounding results, slope of sea was determined as 1/500 and dispersion of flow in the sea was assumed to be 5°.

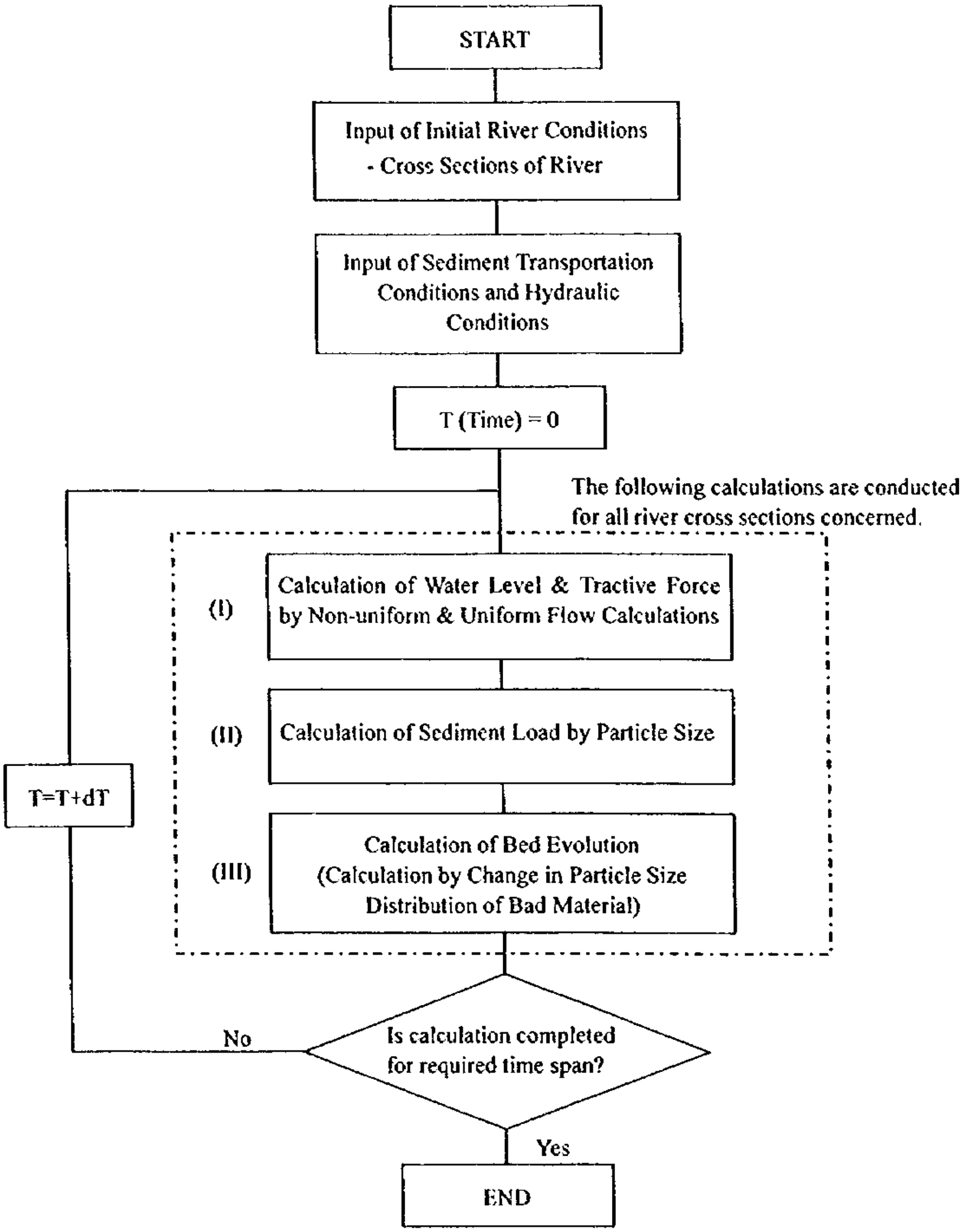


Figure-17.9 Flowchart of Bed Evolution Simulation

(3) Conditions of Sediment Transportation

Sediment load to be transported to diverting point was assumed to be bed material of Nadi river in the upstream from the diverting point, transported by increase in flow velocity due to flood. Sediment load was also assumed to be supplied without limitation and is a function of only the hydraulic force.

Bed material in the upstream was obtained from the result of the bed material analysis conducted by the Study Team (see Chapter 5). Therefore, particle size distribution of N-1 point was adopted and is shown in Table-17.6.

Table-17.6 Particle Size Distribution of Nadi River (N-1)

Sieve Size (mm)	Weight of Remained Material (g)	Remained Ratio (%)
75.0		
53.0		
37.5		
26.5	77.0	1.98
19.0	97.3	2.51
13.2	316.9	8.16
9.5	424.7	10.94
6.7	578.5	14.90
4.8	381.9	9.84
2.4	753.1	19.40
1.2	531.0	13.68
0.600	300.2	7.73
0.425	81.0	2.09
0.300	92.3	2.38
0.150	171.5	4.42
0.075	53.8	1.39
less than 0.075	23.0	0.59
Total	3882.2	100.00%

Average Particle Size (D_{50}) = 4.59 mm

Applying the cyclone Kina's hyetograph, 5 different floods (1/20, 1/10, 1/5, 1/2 and 1/1.1 probability floods) were calculated at 30 minute interval by the storage function model. The model is described in Chapter 6. Velocities at the point of sediment load supply were calculated for the discharges at 30 minute interval by non-uniform flow calculation.

Based on the velocities above, sediment load in the upstream from diverting point was estimated by comparing flow velocities and critical tractive force of each particle size.

(4) Sediment Load into Diversion Channel

Sediment load into the diversion channel was estimated by sediment transportation calculation from the upstream of Nadi river to the diverting point. Sediment load into the channel depends on velocities at the diverting point.

(5) Channel Bed Evolution

Applying sediment load into the diversion channel, sediment transportation in the channel was calculated at each cross section with change in a time series. As a result, passed and deposited sediment loads were obtained at each cross section and successively bed evolution of the channel was calculated.

Channel bed evolution is defined as sediment transportation from initial stage of flood to depression stage of flood. Therefore, it expresses conditions of sedimentation when a flood is over.

To examine the channel bed evolution, sediment transportation in 5 cases from small scale to large scale floods were calculated. Discharges in the channel were determined in accordance with the diverting ratio. Velocities were calculated by non-uniform flow computation based on discharges.

(6) Results

Sediment load into the diversion channel is summarized by particle size in Table-17.7.

Table-17.7 Sediment Loads into Diversion Channel

Particle Size (cm)	Sediment Load into Diversion Channel by Scale of Flood				
	20 year return period ($10^3 m^3$)	10 year return period ($10^3 m^3$)	5 year return period ($10^3 m^3$)	2 year return period ($10^3 m^3$)	1.1 year return period ($10^3 m^3$)
Less than 0.02	40.0	24.6	10.7	3.4	1.5
0.03	1.1	0.6	0.2	0.1	0
0.0425	0.3	0.2	0	0	0
0.06	0.4	0.1	0	0	0
0.12	0.1	0.1	0	0	0
0.24	0.1	0.1	0	0	0
0.48	0	0	0	0	0
0.67	0.1	0	0	0	0
Total	42.1	25.7	10.9	3.5	1.5

Annual average sediment load into the diversion channel was roughly estimated. As shown in Table-17.8, it is approximately 6,300 m^3/year.

Table-17.8 Annual Average Sediment Load into Diversion Channel

Turn Period	(a) Number of Occurrence in 20 years	(b) Sediment Load per Flood (10^3 m^3)	(a)×(b) (10^3 m^3)
20 years	1	42.1	42.1
10 years	1	25.7	25.7
5 years	2	10.9	21.8
2 years	6	3.5	21.0
1.1 years	10	1.5	15.0
Total	20	—	125.6*
Annual Average	—	—	6.3

* : total volume in 20 years

Occurrence of 10 year return period flood means occurrence of discharges exceeding 10 year return period flood . Therefore, the occurrence is 20 years is twice; however, since discharge more than 20 year return period flood is already counted, it is one in the table.

Result of channel bed evolution simulation for 20 year return period flood is shown in Figure-17.10.

Condition of sedimentation in the sea are summarized in Table-17.9.

Table-17.9 Sedimentation in the Sea after Floods

Item	Scale of Flood				
	1/20 Probability	1/10 Probability	1/5 Probability	1/2 Probability	1/1.1 Probability
Location of Sedimentation	-0.1 ~ -1.2 km	-0.1 ~ -0.9km	-0.1 ~ -0.6 km	-0.1 ~ -0.4 km	-0.1 ~ -0.2 km
Length of Sedimentation	1,100 m	800 m	500 m	300 m	200 m
Width of Sedimentation	270 m	220 m	150 m	130 m	100 m
Maximum Thickness of Sedimentation	0.37 m	030 m	0.23 m	0.12 m	0.07 m
Volume of Sedimentation	41,700 m^3	25,400 m^3	10,700 m^3	3,400 m^3	1,400 m^3
Particle Size	0.02 ~ 0.06 cm	0.02 ~ 0.0425 cm	less than 0.02 cm	less than 0.02 cm	less than 0.02 cm

location for the sea: distance offshore from outlet

Sedimentation in the diversion channel is less than 1 % of the total sediment load into the channel. Therefore, it is considerably small amount and easily flushed by the next flood.

Sedimentation into the channel is mostly drained to the sea, about 99 %. In the case of 20 year return period flood, sedimentation in the sea occurs between outlet and 1.2 km offshore. The maximum depth is expected at 0.7 km offshore and it is approximately 37 cm. 99 % of sedimentation in the sea consists of particles less than 0.03 cm which is almost equivalent to particle size of sea bed material.

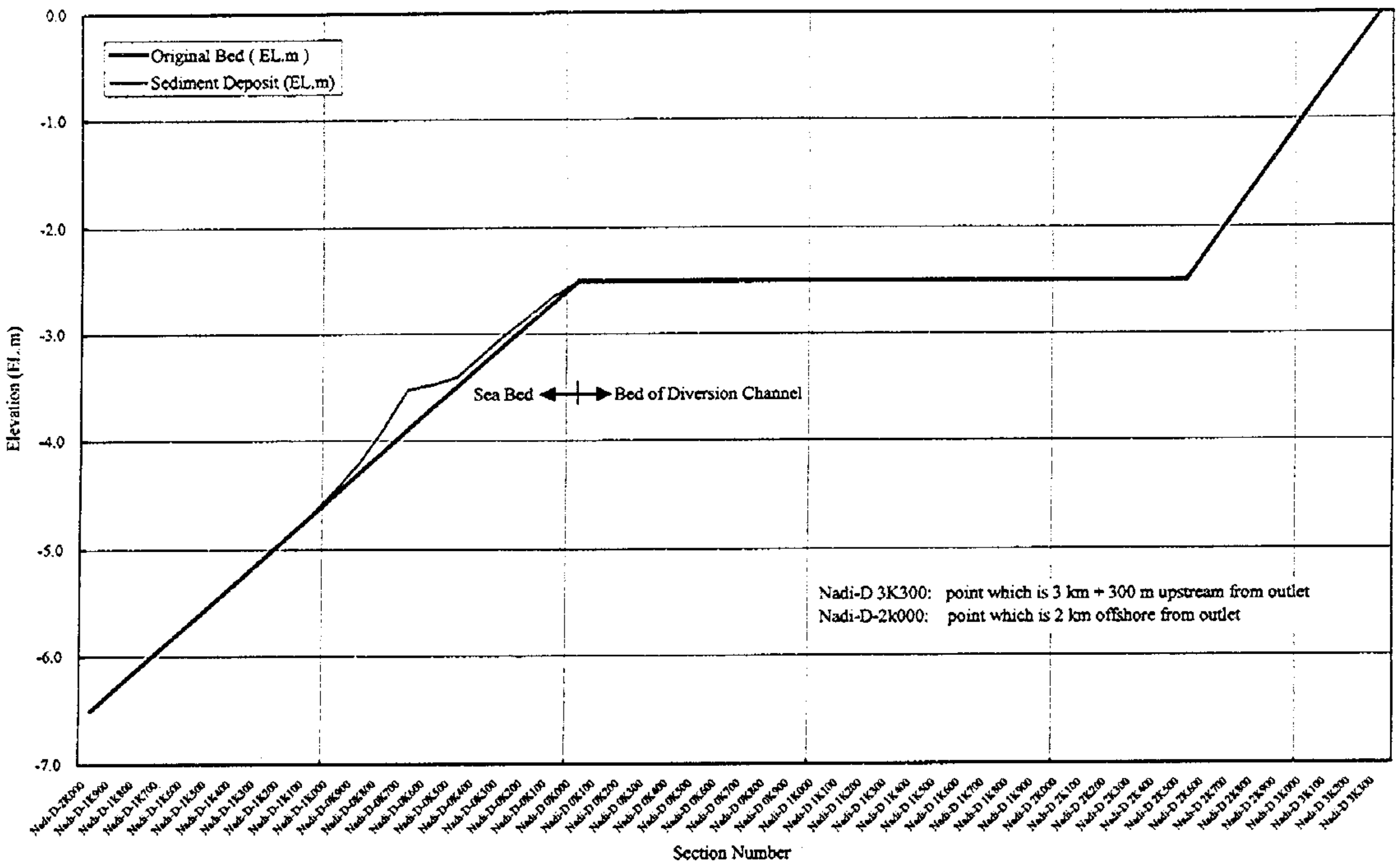


Figure-17.10 Bed Evolution of Nadi Diversion Channel (20 Year Return Period Flood)

(7) Examination of Effect

As a result of sediment load analysis, most of sediment load in the diversion channel is drained into the sea and deposited on the sea bed where the sea depth is approximately 4 m or shallower, regardless of discharge. Sediment deposited mostly consists of particles smaller than 0.2 mm. It is noted that sea depth datum is Lowest Astronomical Tide, while elevation datum is Mean Sea Level at standard port (Suva harbour).

Relation between velocity which induces suspended sediment, and its particle size is shown in Table-17.10 and Figure-17.11. According to the tidal current survey, the average velocity of tidal current where the sea depth is 5 m is approximately 200 m/hr, causing suspended sediment whose grain size is smaller than 0.06 mm. On the other hand, the maximum velocity at the same sea depth is about 540 m/hr, causing suspended sediment whose grain size is less than 0.4 mm. Therefore, most of sediment drained through the diversion channel is carried off by the maximum velocity but not by the average velocity.

Since the sea bed shallower than 4 m is disturbed and stirred by high waves due to strong wind, such as cyclones, sediment load from the diversion channel is considered to be dispersed and carried off by the high waves. Therefore, even if there were sediment deposits, the sea bed would recover to the original after certain period.

Considering the small velocity and random directions of tidal current, and high waves, neither considerable erosion nor sedimentation is expected in the Nadi bay due to the diversion channel. However, it is recommendable to conduct the further study on sedimentation in the Nadi bay by the hydraulic model experiment at the detail design stage if the proposed project is realized.

Table-17.10 Relation between Velocity and Grain Size of Suspended Sediment

Grain Size (mm)	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.4
Current Velocity (m/hr)	110	270	370	460	550	600	650	700	770	800	850	1,000

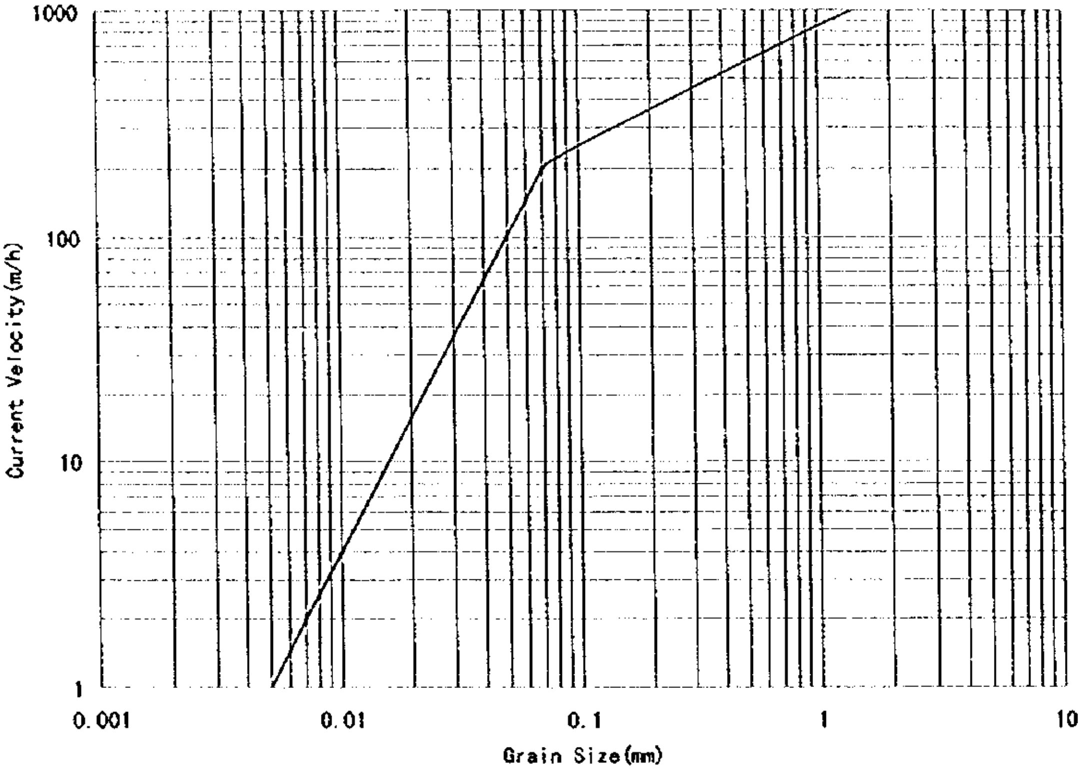


Figure-17.11 Velocity and Grain Size of Suspended Sediment

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Civil Aviation Authority of Fiji (1994). "Feasibility Study on the Proposed Extension of Runway 09-27 at Nadi International Airport", Fiji.

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