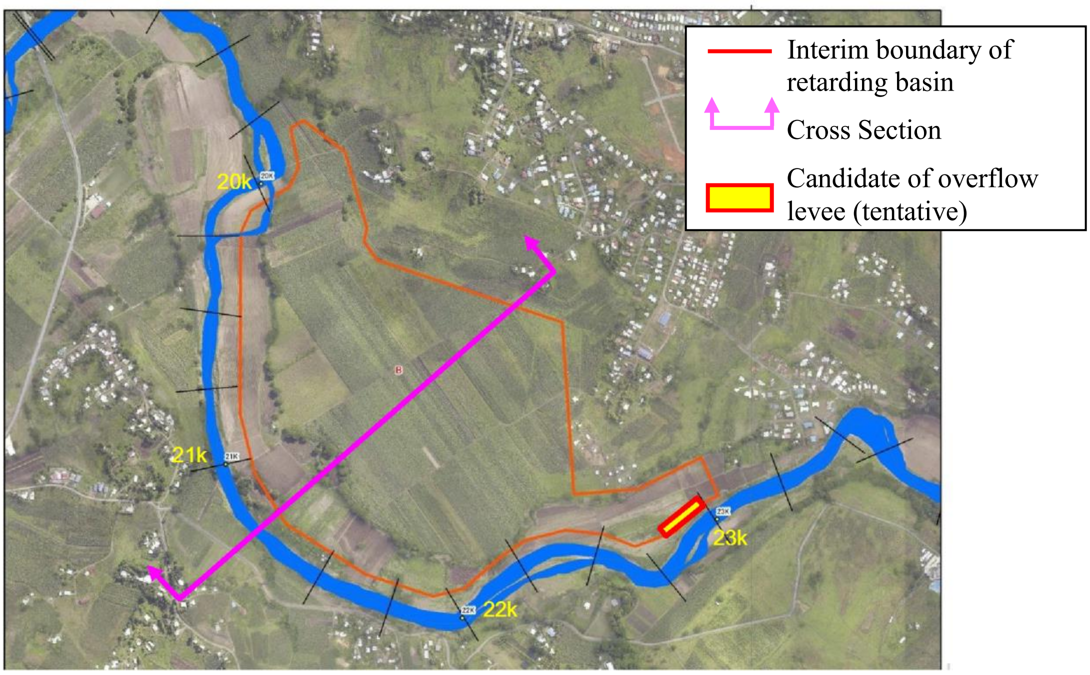
8.3 Planning and Preliminary Design of Retarding Basins in Main Stream and Tributaries

The effect of retarding basin is described in detail in 6.3. The basic outline of the retarding basins in Nadi River Basin is as shown in Table 8-9. The outline of the retarding basins are planned to regulate the design flood discharge by conduction flood and inundation analysis, however the detail examination will be required considering the topographic conditions and so on in the Feasibility Study.

8.3.1 Retarding Basins in Upstream Right Bank of Main Stream

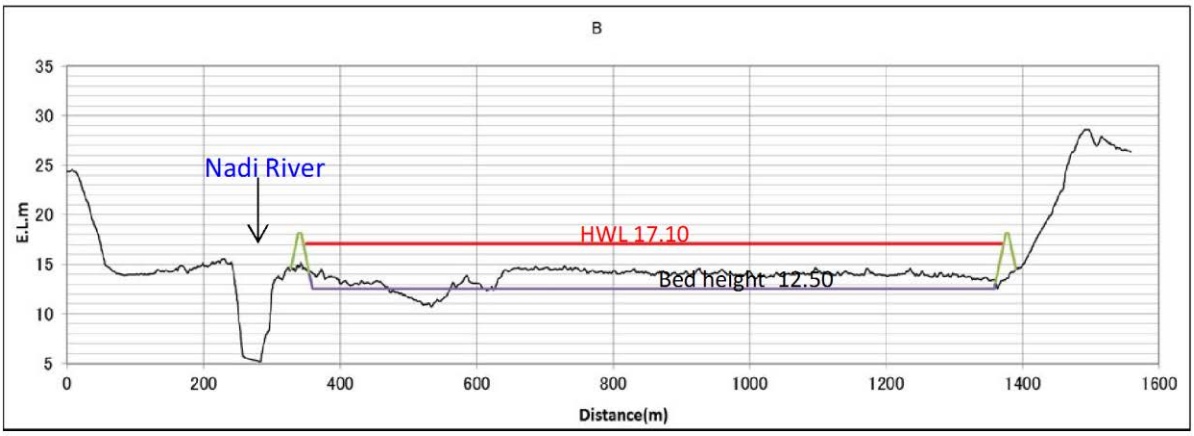
In the right bank of upstream section in the Main stream, the retarding basin is implemented to reserve flood discharge temporally. The area of retarding basin is to be the area inundated in the past floods and also do not include housing, and of which theory is applied to the other retarding basins in the Nadi River.



Source: JICA Study Team

Figure 8-35 Plan of Retarding Basin in Upstream Right Bank of Nadi River

The surrounding dike of retarding basin is arranged so as to keep the required regulating capacity and to avoid housing relocation. The necessity of dike is surveyed in detail considering the topography outside of dike, and of which theory is applied to the other retarding basins in the Nadi River.



Source: JICA Study Team

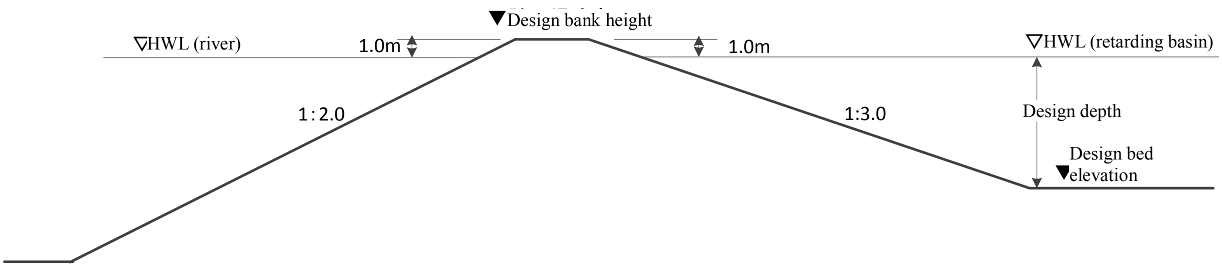
Figure 8-36 Representative Section of Retarding Basin in Upstream Right Bank of Nadi River

Table 8-9 Outline of Retarding Basins in Main Stream and Tributaries

■Specification of Retarding Basin (MP level)

	Item	Retarding Basin A	Retarding Basin B	Downstream Retarding Basin	Retarding Basin N	Retarding Basin MLK	Retarding Basin J	Retarding Basin Q	Retarding Basin NRB3	Retarding Basin Z	Retarding Basin T	Retarding Basin UXW	Retarding Basin NRB4
Retarding Basin	River	Nadi River	Nadi River	Nadi River	Nawaka River	Nawaka River	Nawaka River	Nawaka River	Nawaka River	Malakua River	Malakua River	Malakua River	Malakua River
	Right bank/Left Bank	Left Bank Side	Right Bank Side	Left Bank Side	Left Bank Side	Left Bank Side	Left Bank Side	Right Bank Side	Both sides	Right Bank Side	Left Bank Side	Left Bank Side	Both sides
	Location	18.75k-20.5k	19.5k-23.0k	0.00k-7.25k	1.50k-2.00k	2.00k-3.75k	3.75k-4.75k	5.25k-	6.25k-	0.85k-2.00k	3.00k-3.50k	3.75k-5.00k	4.50k-
	Area (ha)	42	114	725	48.5	60.8	39.4	52.3	25.0	9.5	14.5	39.2	50.0
	Volume (1000m3)	636	5,395	9,715	1,577	2,514	1,365	2,263	349	321	565	1,941	691
	HWL of Retarding Basin (EL.m)	13.53	17.10	3.86	6.97	9.03	10.20	11.09	13.15	8.50	10.17	11.56	12.11
	Bed Elevation (EL.m)	9.9～13.0	9～12.5	0.01～3.27	2.72～4.2	3.99～4.9	5.7～6.8	6.70	—	4.33～5.2	5.9～7.6	6.85	—
	Water Depth (m)	0.5～3.63	4.6～8.1	1.34(Average)	2.77～4.25	4.13～5.04	3.4～4.5	4.39	1.40	3.30～4.17	2.57～4.27	4.71	1.40
	Control Volume (m3/s)	30	250	1400	39	105	55	91	23	9	20	39	32
Overflow Dike	Length of Overflow Dike (m)	60	190	700	180	112	72	28	–	10	15	150	–
	Location	20.44k-20.5k	22.81k-23.0k	5.05-5.75k	1.59k-1.75k	3.38k-3.5k	4.43k-4.5k	5.22k-5.25k	–	1.74k-1.75k	3.242k-3.25k	4.25k-4.50k	–
	HWL	13.53	17.10	3.86	6.97	9.03	10.20	11.09	–	8.50	10.17	11.56	–
	Caluculated peak water level	13.1	15.17	3.50	6.18	8.73	9.85	10.68	12.61	7.97	10.13	10.62	11.83
	Elevation of overflow dike	12.53	14.40	2.86	5.97	8.03	9.20	9.09	–	7.50	9.17	10.56	–
	Water depth of overflow (m)	0.57	0.77	1.00	1.00	1.00	1.00	2.00	–	1.00	1.00	1.00	–
River Dike	Length (m)	1,661	3,002	6,434	2,947	2,254	1,688	–	–	1,163	486	1,092	–
	Design Dike Height (EL.m)	14.53	18.10	3.86～4.45	7.97	10.03	11.20	12.09	–	9.30	10.97	12.36	–
	H.W.L (EL.m)	13.53	17.10	3.86	6.97	9.03	10.20	11.09	–	8.50	10.17	11.56	–
	Free board (m)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	–	1.00	1.00	1.00	–
	Maximum dike height (m)	4.63	9.10	3.33					–				–
	Width of crown (m)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	–	4.00	4.00	4.00	–
	Slope gradient (river side)	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	–	1:3.0	1:3.0	1:3.0	–
	Slope gradient (land side)	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	–	1:3.0	1:3.0	1:3.0	–
Surrounding Dike	Length (m)	1,367	2,462	5,212	2,631	5,254	1,157	3,142	–	718	1,541	4,343	–
	Design Dike Height (EL.m)	14.53	18.10	2.98～4.35	7.97	10.03	11.20	12.09	–	9.30	10.97	12.36	–
	H.W.L (EL.m)	13.53	17.10	3.86	6.97	9.03	10.20	11.09	–	8.50	10.17	11.56	–
	Free board (m)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	–	1.00	1.00	1.00	–
	Deepest Elevation (EL.m)	10.00	12.50		3.70	4.90	6.80	6.70	–	5.20	5.70	6.15	–
	Maximum dike height (m)	4.53	5.60	2.60	4.27	5.13	4.40	5.39	–	4.10	5.27	6.21	–
	Width of crown (m)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	–	4.00	4.00	4.00	–
	Slope gradient (river side)	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	–	1:3.0	1:3.0	1:3.0	–
	Slope gradient (land side)	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	1:3.0	–	1:3.0	1:3.0	1:3.0	–
Sluice Gate	Width × Height × Number of Gates	B1.5m×H1.5m×1	B2.5m×H2.5m×2	–	B2.0m×H2.0m×1	B2.5m×H2.5m×1	B2.0m×H2.0m×1	B2.5m×H2.5m×1	–	B1.0m×H1.0m×1	B1.5m×H1.5m×1	B2.5m×H2.5m×1	–
	Elevation of gates (EL. m)	9.59			2.72	3.99	5.7	6.7		4.33	5.7	6.15	
	Location of drainage	19.0k	20.0k	–	1.5k	2.0k	3.75k	4.25k	–	1.0kk	3.0k	3.75k	–
Connecting Pile	Width × Height × Number of Gates	–	–	–	–	M-L:B1.3m×H1.3m×1 M-K:B1.1m×H1.1m×1	–	–	–	–	–	B2.1m×H2.1m×1	–
		–	–	–	–		–	–	–	–	–	–	–

The surrounding dike is arranged along the present river channel to obtain the maximum reservoir capacity. In the cross section of dike, the slope of dike is 1:2.0 in riverside and 1:3.0 in basin side conforming to the main stream dike, and of which theory is applied to the other retarding basins in the Nadi River.



*Design water depth of retarding basin is as shown in Table 8-9.

Figure 8-37 Typical Section of Surrounding Dike of Retarding Basin in Upstream Right Bank of Nadi River

The diverting weir is to be located in upstream of basin as much as possible to keep the regulating capacity. The diverting weir is designed with height and length to keep the required regulating capacity in the priority project and the master plan. Although the outline of diverting weir at present is as shown in Table8-9, it will be scrutinized in the Feasibility Study.

The structure of diverting dike is to be safe in the design flood discharge. Although in general structural type of diverting weir gabion work type, asphalt facing type are considered besides concrete facing type, the concrete facing type is selected at present. This type was applied to many of large scale diverting weir in Japan and is able to accommodate relatively severe hydraulic conditions, and of which theory is applied to the other retarding basins in the Nadi River.

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The typical section of diverting weir is as shown in Figure 8-38.

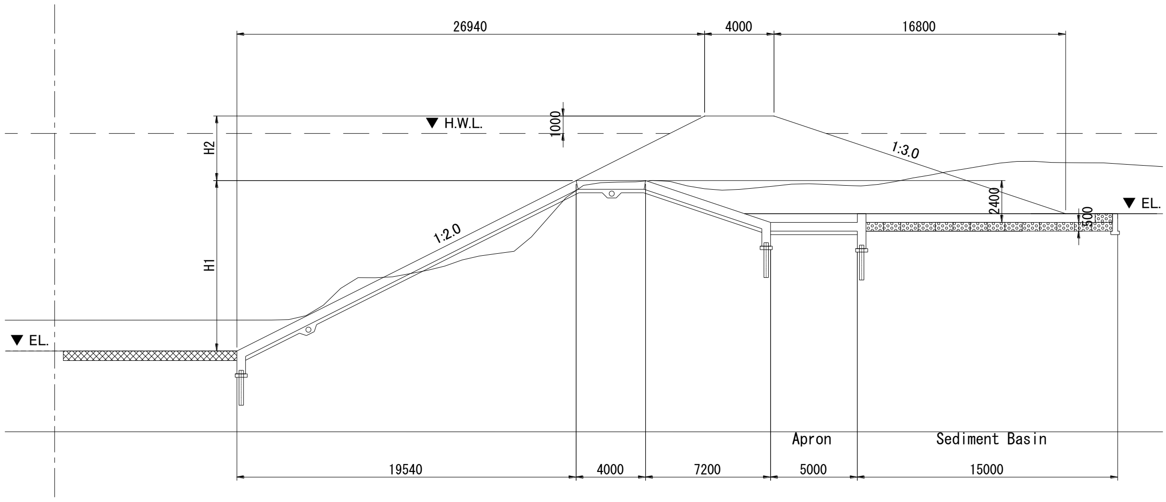
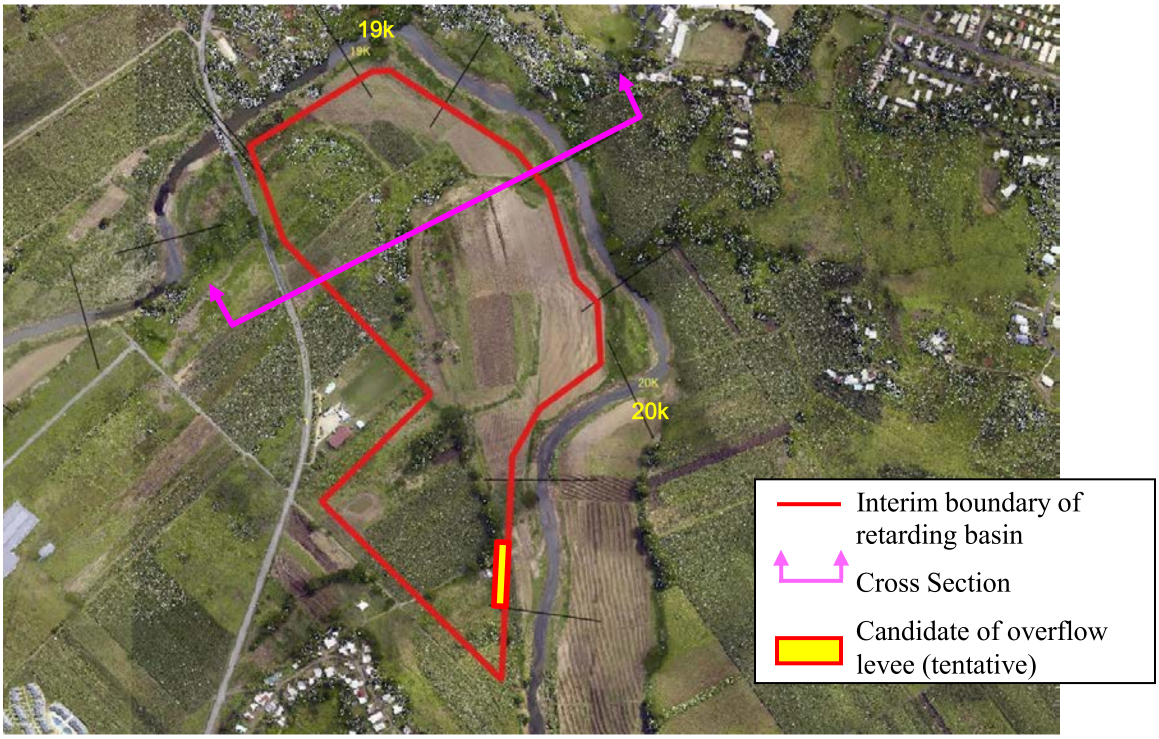


Figure 8-38 Typical Section of Diverting Weir in Upstream Right Bank of Nadi River

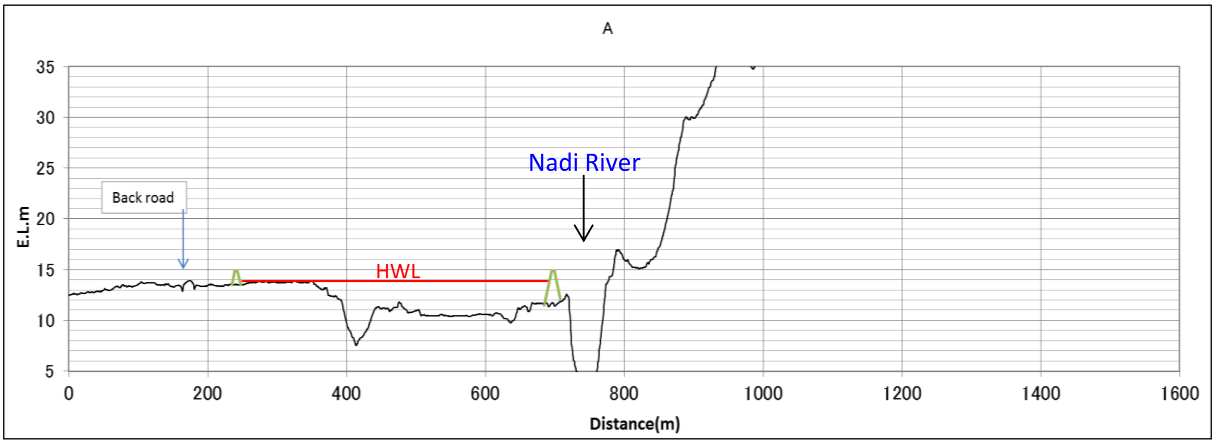
8.3.2 Retarding Basins in Upstream Right Bank of Main Stream

In the left bank of upstream section of main stream the retarding basin is implemented to reserve flood discharge temporally.



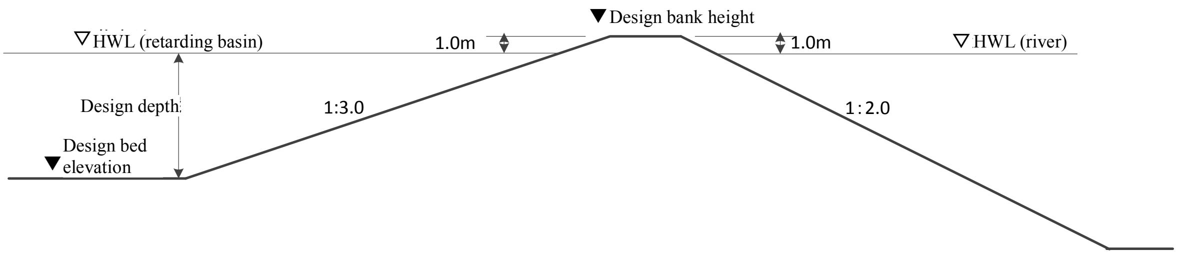
Source: JICA Study Team

Figure 8-39 Plan of Retarding Basin in Upstream Left Bank of Nadi River



Source: JICA Study Team

Figure 8-40 Representative Section of Retarding Basin in Upstream Left Bank of Nadi River



*Design water depth of retarding basin is as shown in Table 8-9.

Figure 8-41 Typical Section of Surrounding Dike of Retarding Basin in Upstream Left Bank of Nadi River

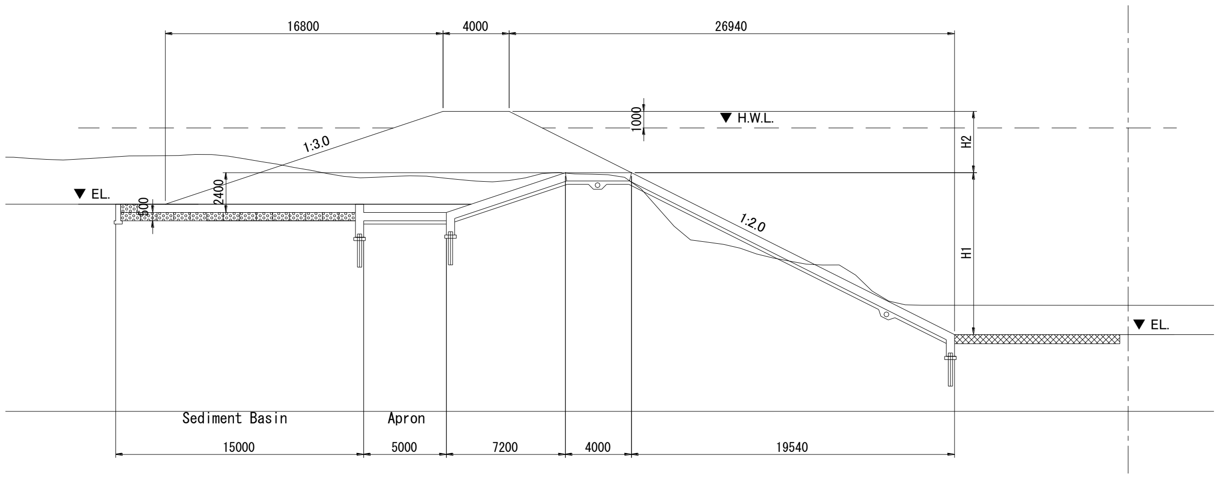
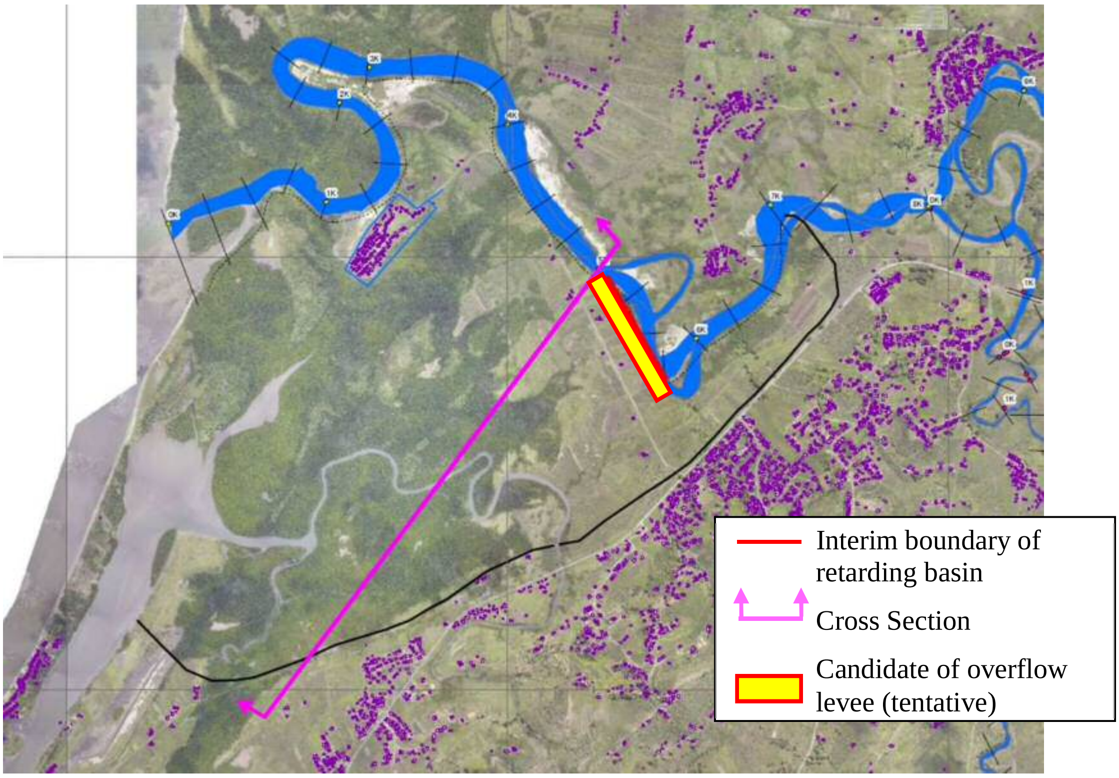


Figure 8-42 Typical Section of Diverting Weir in Upstream Left Bank of Nadi River

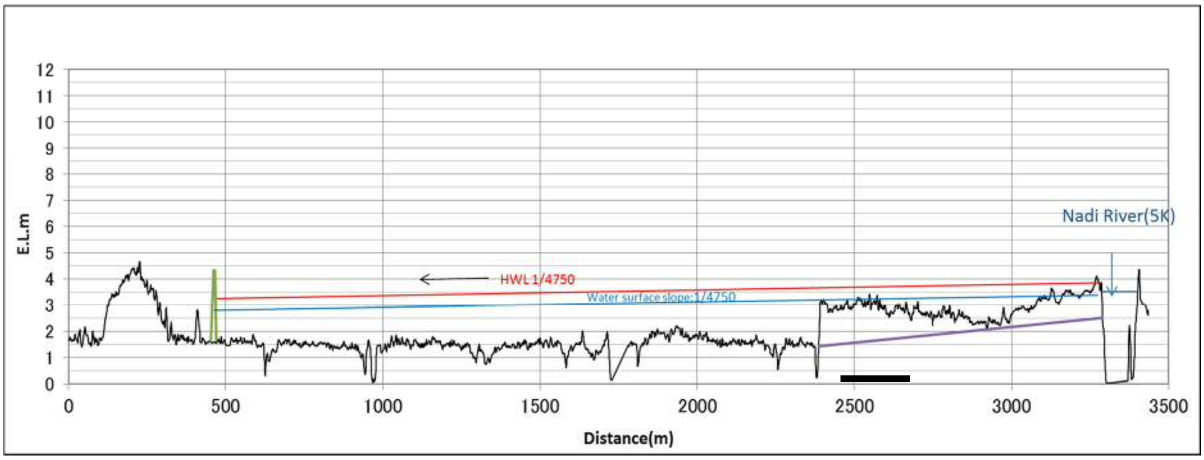
8.3.3 Retarding Basins in Downstream of Main Stream

In the downstream section of main stream the retarding basin is implemented to reserve flood discharge temporally.



Source: JICA Study Team

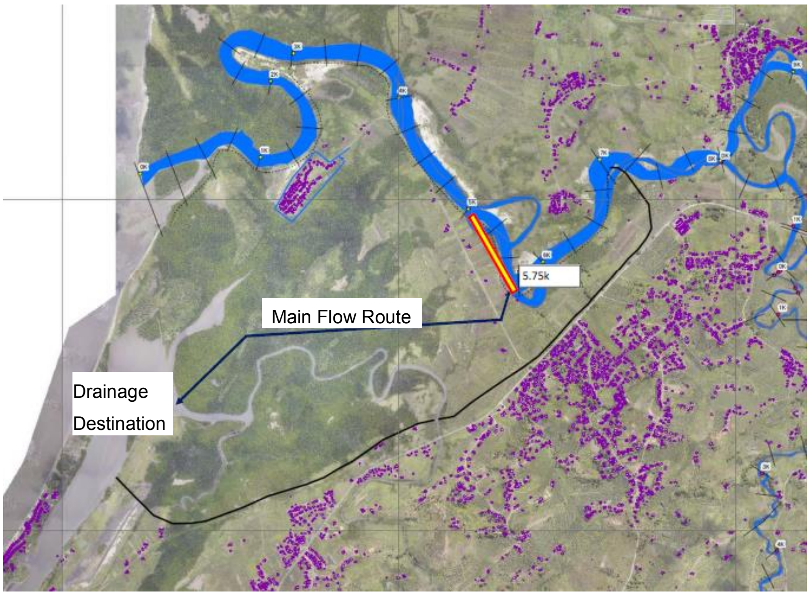
Figure 8-43 Plan of Retarding Basin in Downstream of Nadi River



Source: JICA Study Team

Figure 8-44 Representative Section of Retarding Basin in Downstream of Nadi River

This retarding basin is not reservoir type but spreading type with flowing down to seashore at the downstream end so that the gradient of water level occurs in the reservoir water level. The HWL in the retarding basin is determined by enveloping the maximum water level of reservoir by hydraulic calculation. HWL in the retarding basin is determined extending HWL of 5.75 km in Nadi River at the diverting weir to the drainage point as the gradient of HWL is assumed to the gradient of the maximum water level in the retarding basin.



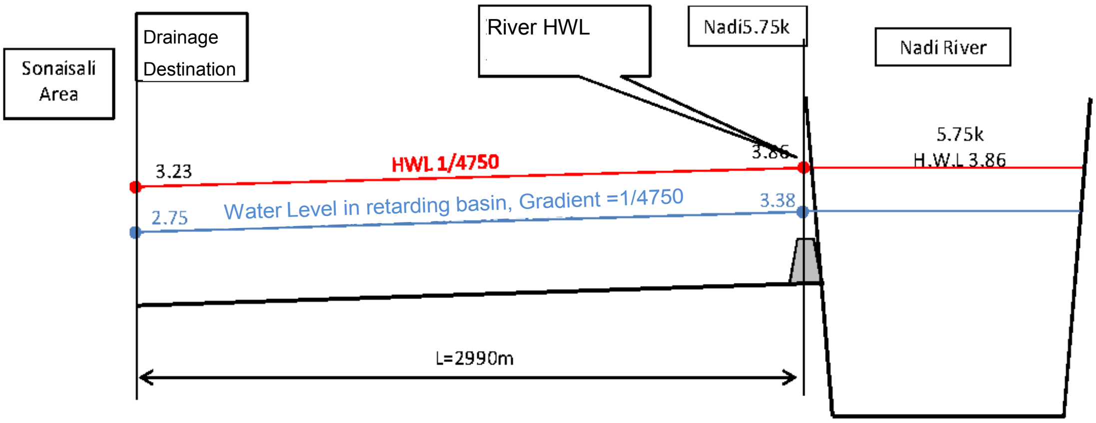
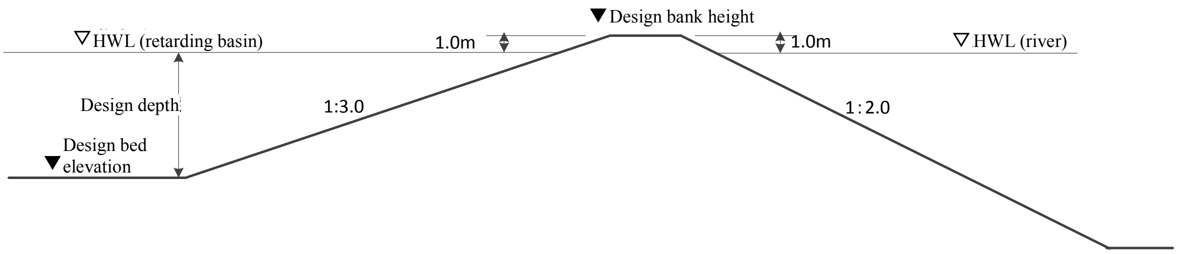


Figure 8-45 Schematic Model of Determination of HWL in Retarding Basin in Downstream of Nadi River



*Design water depth of retarding basin is as shown in Table 8-9.

Figure 8-46 Typical Section of Surrounding Dike of Retarding Basin in Downstream of Nadi River

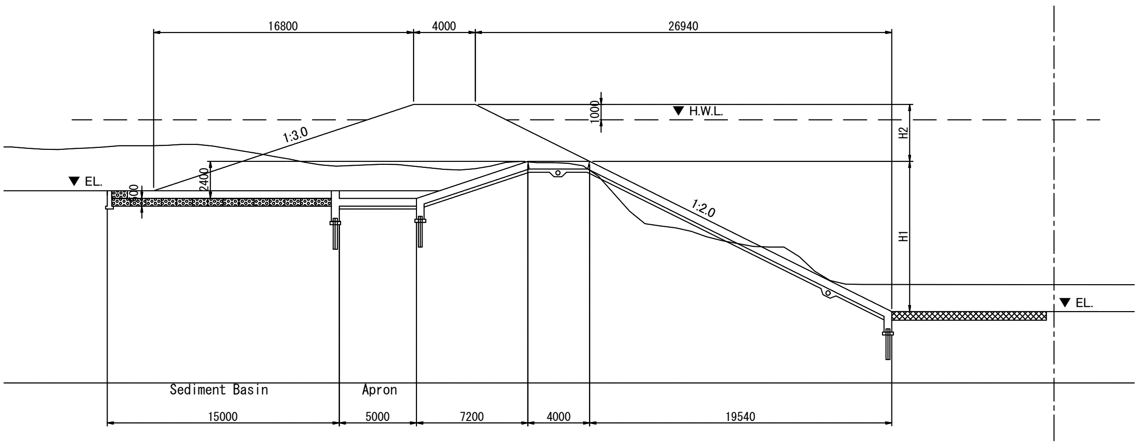
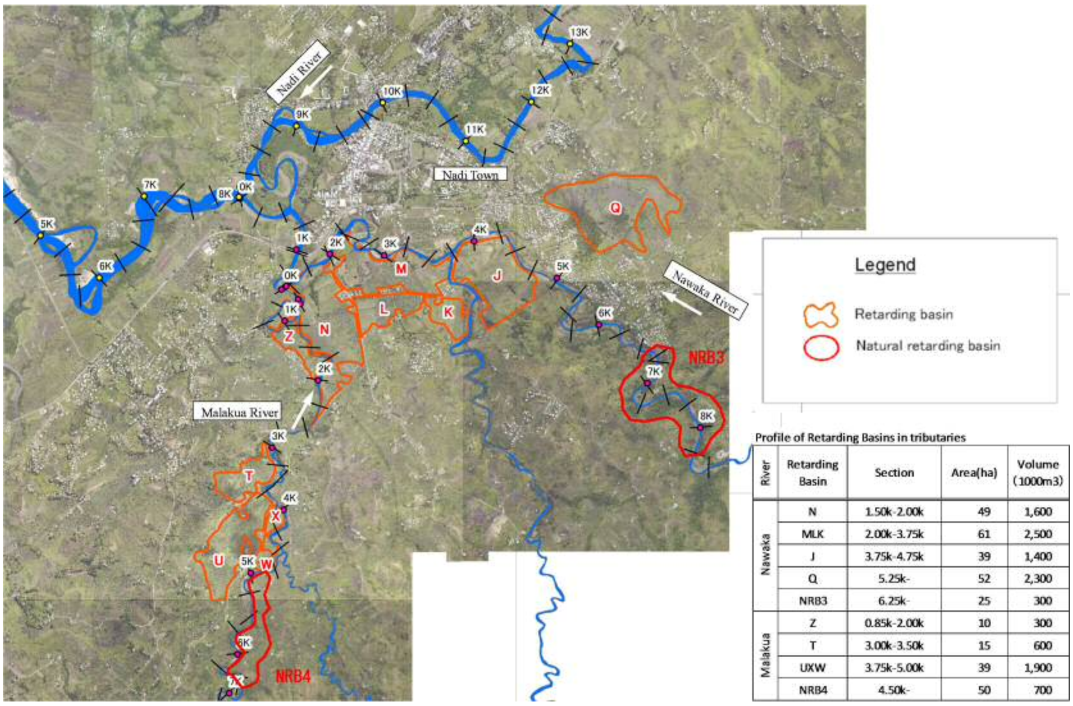


Figure 8-47 Typical Section of Diverting Weir in Downstream of Nadi River

8.3.4 Retarding Basin in Tributaries

In the tributaries of Nawaka River and Malakua River the retarding basin group is implemented to reserve flood discharge temporally.



Profile of Retarding Basins in tributaries

River	Retarding Basin	Section	Area(ha)	Volume (1000m3)
Nawaka	N	1.50k-2.00k	49	1,600
	MLK	2.00k-3.75k	61	2,500
	J	3.75k-4.75k	39	1,400
	Q	5.25k-	52	2,300
	NRB3	6.25k-	25	300
Malakua	Z	0.85k-2.00k	10	300
	T	3.00k-3.50k	15	600
	UXW	3.75k-5.00k	39	1,900
	NRB4	4.50k-	50	700

Source: JICA Study Team

Figure 8-48 Plan of Retarding Basin in Tributaries

As to the relatively large scale of retarding basins of J in Nawaka tributary and T in Malakua tributary among the retarding basins, the plan, representative section of surrounding dike, the typical Section of surrounding dike and the typical Section of diverting Weir are shown in Figure 8-49～Figure 8-56.

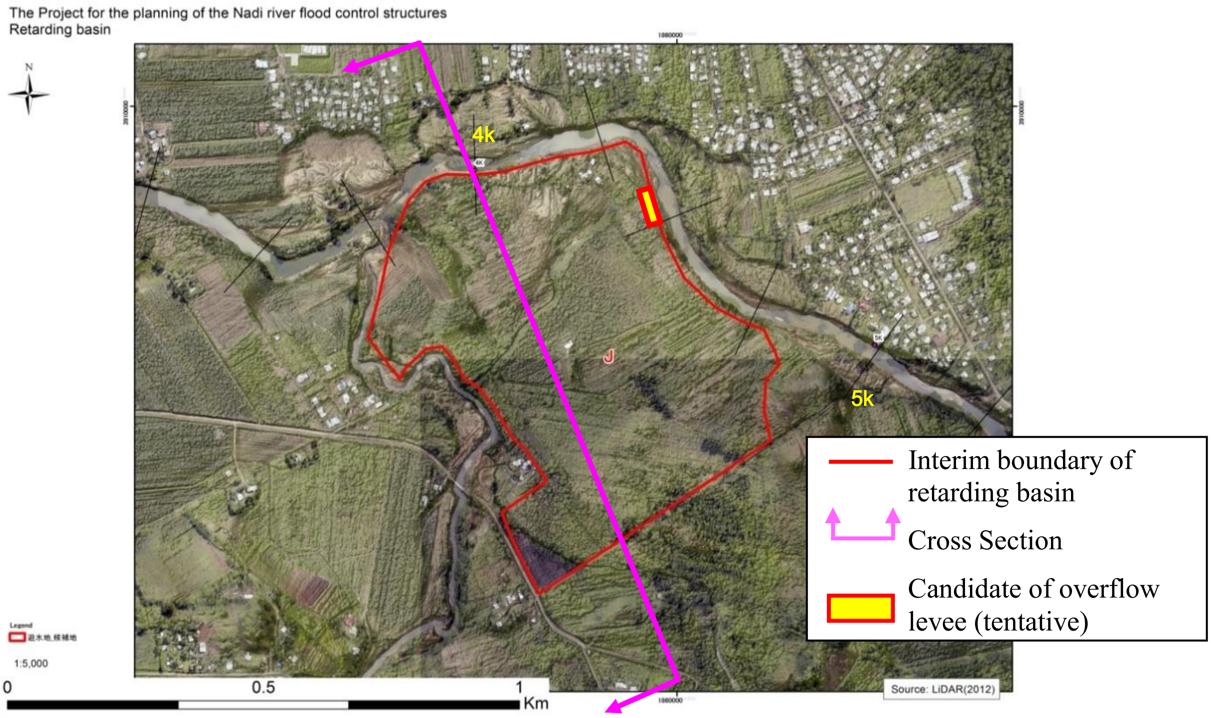


Figure 8-49 Plan of Retarding Basin J in Nawaka River

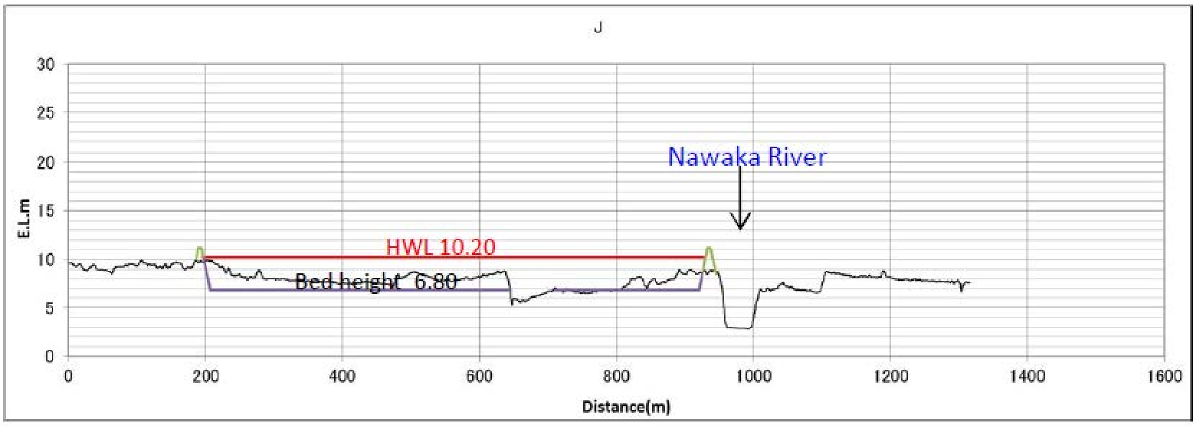
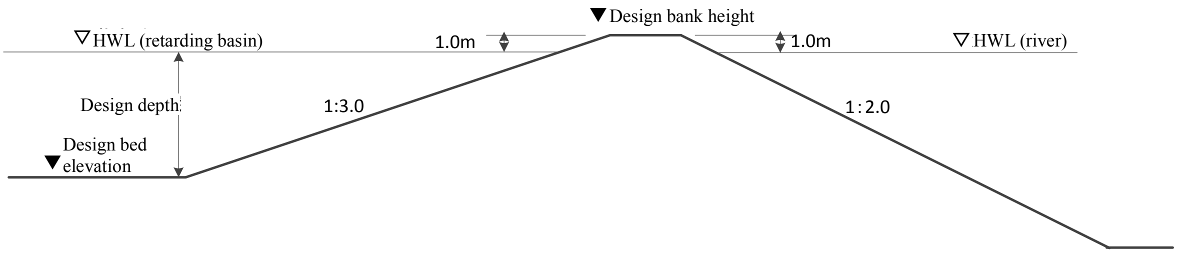


Figure 8-50 Representative Section of Retarding Basin J in Nawaka River



*Design water depth of retarding basin is as shown in Table 8-9.

Figure 8-51 Typical Section of Surrounding Dike of Retarding Basin J in Nawaka River

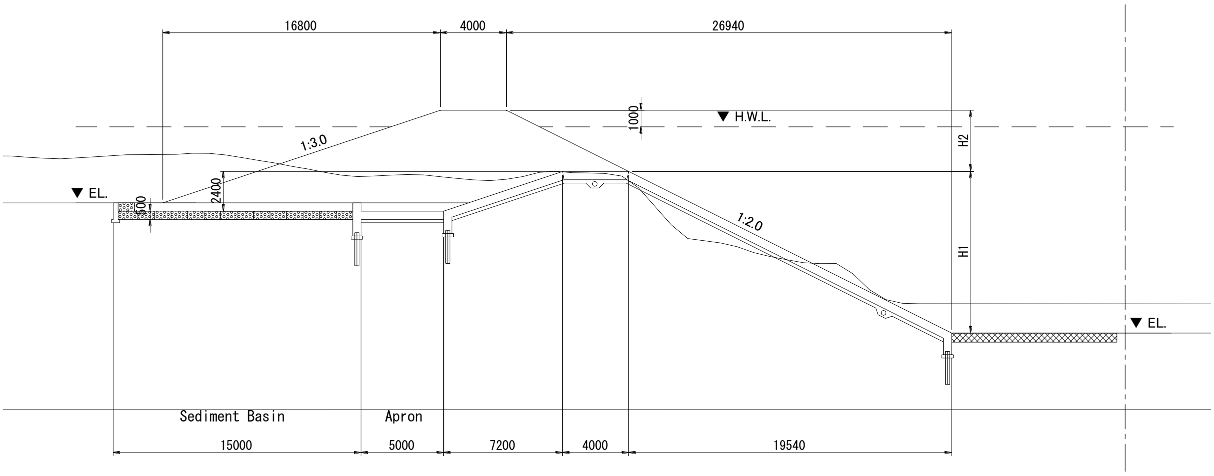


Figure 8-52 Typical Section of Diverting Weir of Retarding Basin J in Nawaka River

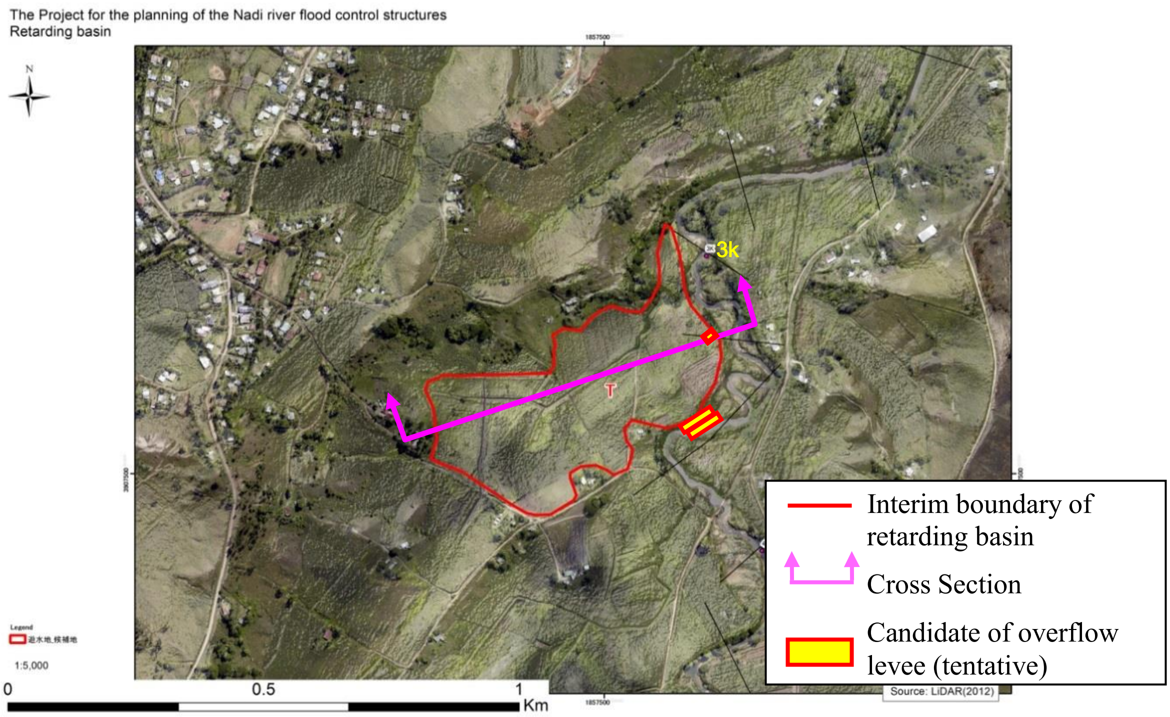


Figure 8-53 Plan of Retarding Basin T in Malakua River

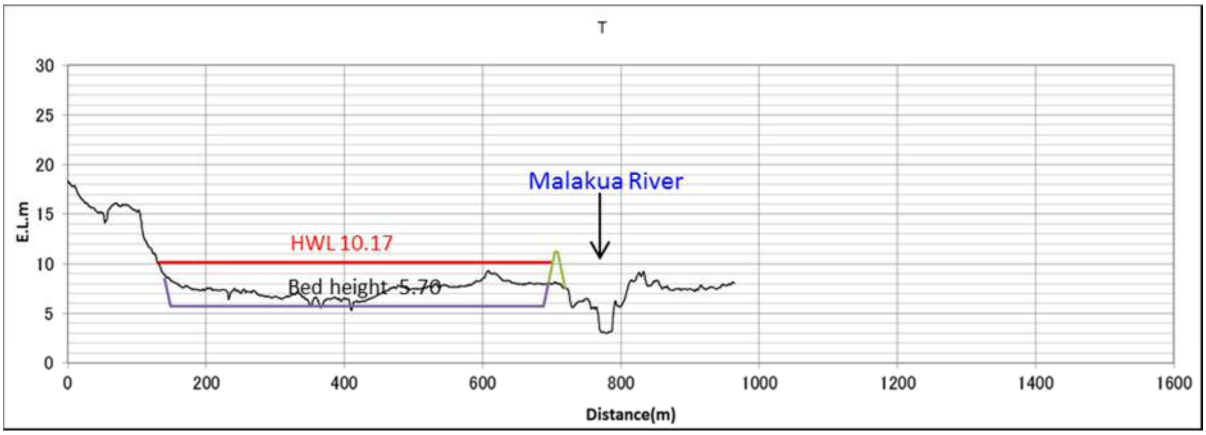
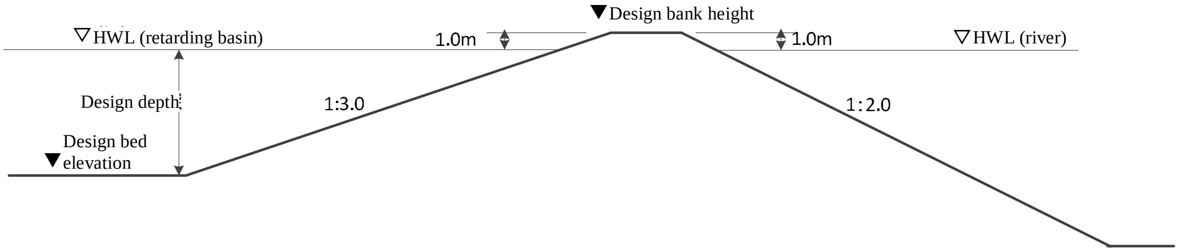


Figure 8-54 Representative Section of Retarding Basin T in Malakua River



*Design water depth of retarding basin is as shown in Table 8-9.

Figure 8-55 Typical Section of Surrounding Dike of Retarding Basin T in Malakua River

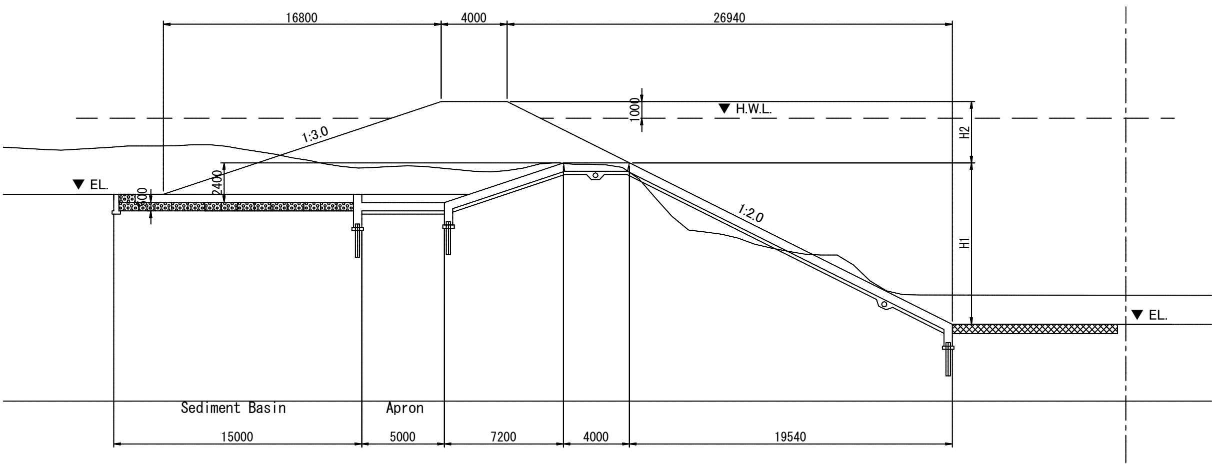


Figure 8-56 Typical Section of Diverting Weir of Retarding Basin T in Malakua River

8.4 Planning and Preliminary Design of Ring Dike

The ring dike in the downstream area is implemented to protect the specific community which is located in the downstream retarding basin which is established in the master plan.

The plan of the ring dike is as shown in Figure 8-57.

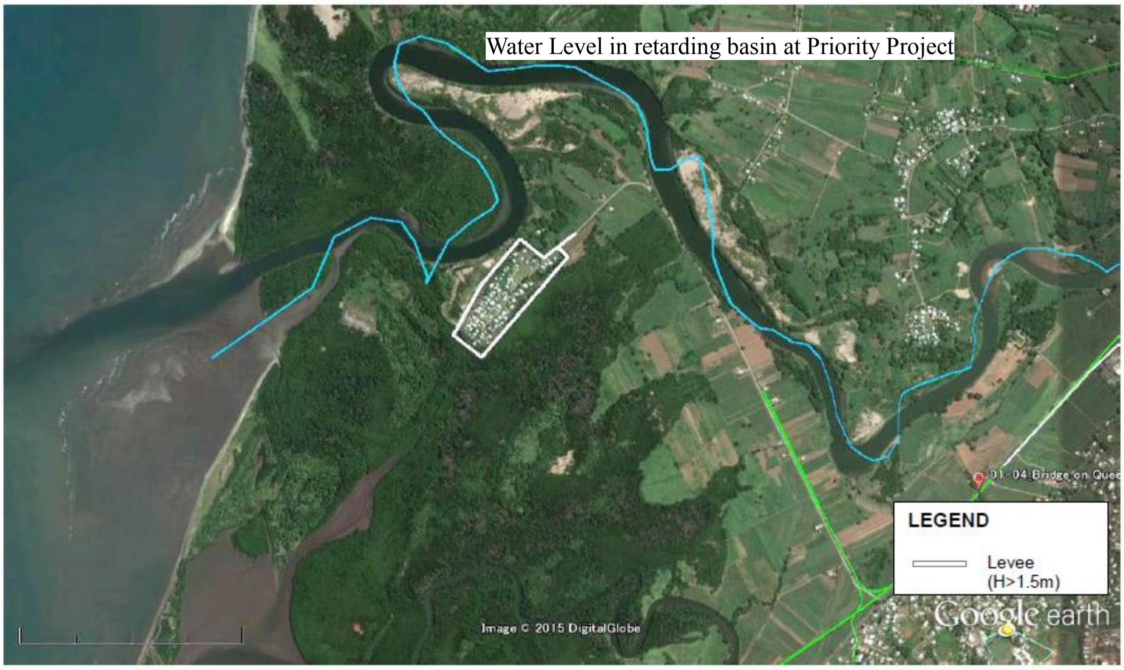


Figure 8-57 Plan of Ring Dike

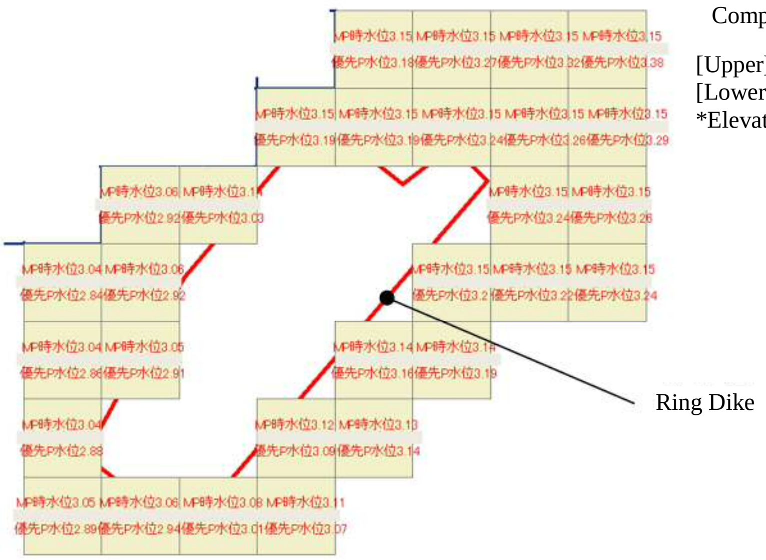
Relationship of the height of the ring dike and water level after the priority project against the target designed scale flood (2012 flood) is as follows considering the dam and retarding basins in upstream is not constructed;

HWL + Freeboard at Master Plan > Water level after priority project > HWL at Master Plan

Therefore, the elevation of the ring dike is set as the same elevation as HWL + Freeboard at Master Plan. In addition, the height difference at upstream side and downstream side of ring dike is only 10cm. Therefore, the elevation of the ring dike is set as EL.4.2m which is the highest elevation point of ring dike.

Water Level in retarding basin at Master Plan   Water Level in retarding basin at Priority Project

(a) Water Level in the Retarding Basin at Master Plan and at Priority Project



Comparison of inundation depth near ring dike

[Upper] Water Level in retarding basin at Master Plan
[Lower] Water Level in retarding basin at Priority Project
*Elevation of Design Dike of Nadi river is 4.2m

(b) Difference of Water Level between at Master Plan and at Priority Project

Figure 8-58 Comparison of inundation depth near ring dike

The top width of dike is to be 4.0m which is same width of the main stream, considering maintenance management. The slope of ring dike is to be 1:3.0 considering the stability of the dike.

Table 8-10 Outline of Ring Dike

Dike Crown Elevation (EL.m)	Crown Width (m)	Dike Height Average (m)	Slope Gradient Water Side (1:n)	Slope Gradient Land Side (1:n)	Length (m)
4.2	4.0	2.5	3.0	3.0	1,534

The typical section of the ring dike is as shown in Figure 8-59..

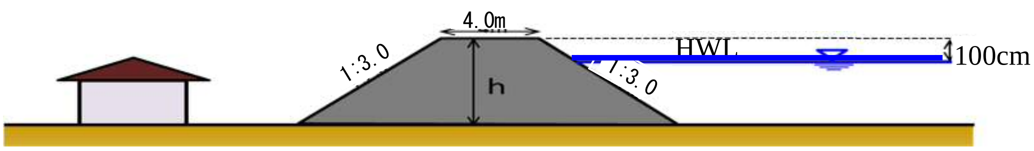


Figure 8-59 Typical Section of Ring Dike

8.5 Bridges

Many bridges have been constructed for roads and tramlines (for sugar cane transportation) to cross the Nadi River and its tributaries in the targeted basin. According to the hydraulic analysis and the river improvement planning based on it, which were mentioned in previous chapters, it was revealed that 6 road bridges and 2 tramline bridges could be affected from river improvement. The lengths of these bridges are too short for widened river width according to the plan, and clearances of them are lower than design high water levels except for some.

In this survey, the planned river cross sections based on estimated 50 year's probable flow volume are applied for bridge designing.

The table below shows the list of bridges required to be demolished and be reconstructed since they could be obstruction for the flow of the river because of lack of length and clearances for the planned river cross sections.

As for those bridges, it is getting closer to proper time to be renewed because years of built are old and there can be seen damages and deteriorations. Also, it is difficult to estimate structural stability from influences of external factors such as live loads, flood and earthquake because drawings and design reports of these bridges at the time of construction do not exist.

Table 8-11 List of reconstruction bridges

No.	Bridge Name	Route Name	River		Remarks
			Name	Distance (km)	
1-1	Nadi Town Bridge	Queens Road	Nadi	9.83	
1-2	Old Queens Road Bridge (Road)	Old Nadi Back Road	Nadi	16.84	shared substructures
1-2'	Old Queens Road Bridge (Tramline)	Tramline			
2-1	Navo Bridge (Road)	Queens Road	Nawaka	1.03	
2-1'	Navo Bridge (Tramline)	Tramline	Nawaka	1.01	
2-2	Bridge on Malakua – Tunalia Road	Malakua - Tunalia Road	Malakua	3.87	
3-1	Qeleloa Bridge	Unknown	Nawaka	2.00	
4-1	Bridge on Nausori Back Road	Nausori Back Road	Namosi	0.52	

Source: JICA Study Team

Hereafter, the result of on-site survey of existing bridges and the details of reconstruction plans of bridges are described. The conceptual drawings are shown in the last of the chapter.

8.5.1 Bridges

To proceeding consideration of bridge improvement planning, the study team gathered basic information about existing bridges.

(1) Bridge management

The table below shows organizations that manage bridges in the targeted basin.

Table 8-12 Organizations managing existing bridges

Type of bridges	Organization
Road bridges	FRA (Fiji Road Authority)
Tramline bridges	FSC (Fiji Sugar Corporation)

Source: JICA Study Team

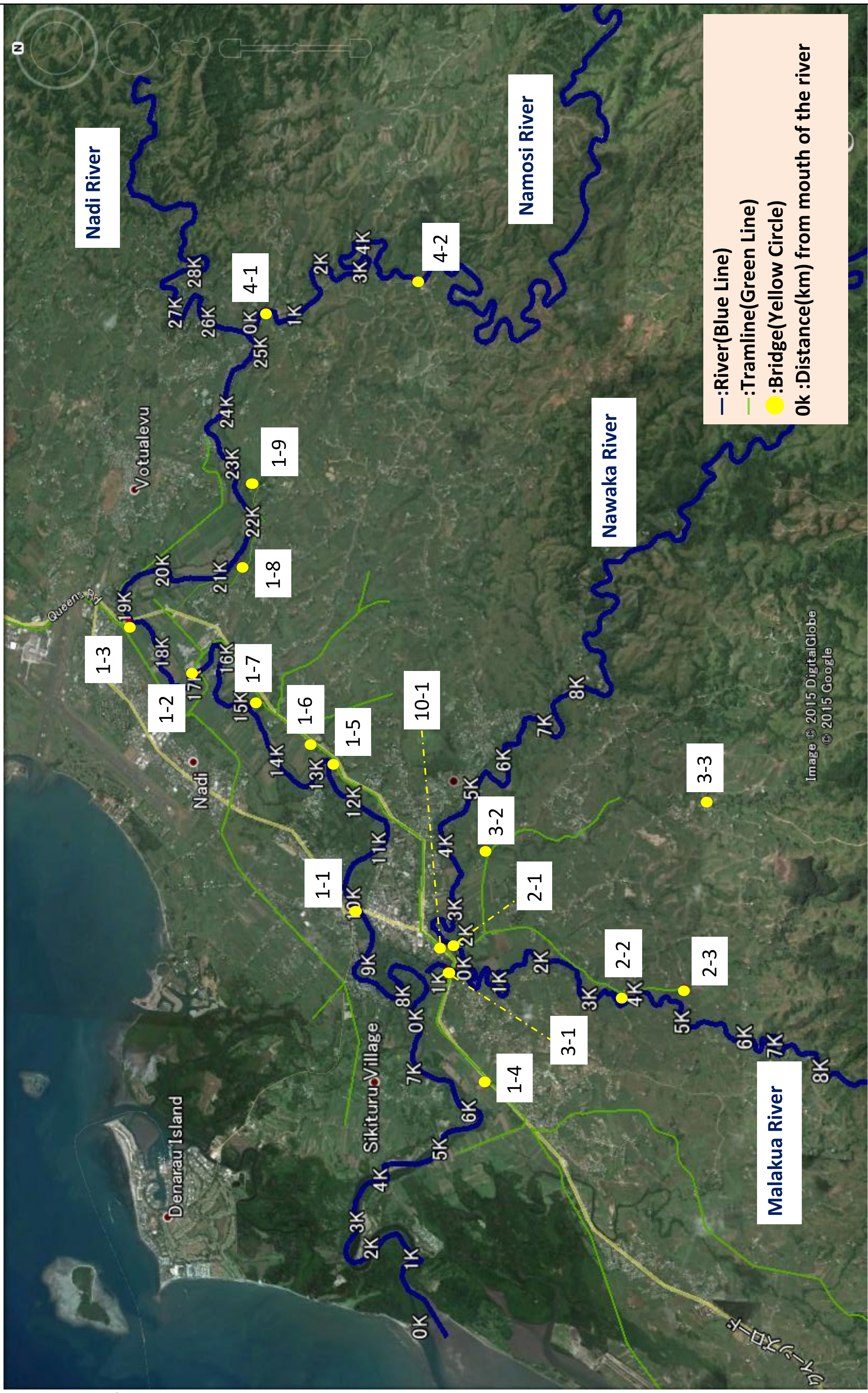
(2) Existing Bridges in the targeted basin

The table on the next page shows the list of 24 existing bridges (18 road bridges and 6 tramline bridges) at 18 locations in the targeted basin. For convenience, the consecutive numbers for bridges concerned are set as shown in the table and used in this report hereafter.

Table 8-13 Existing Bridges in the targeted basin

No.	Bridge Name [Year of Construction]	Channel		Route	Bridge Length	Bridge Width	Remarks
		Name	Distance				
1-1	Nadi Town Bridge [1965]	Nadi Rv	9.83	Queens Rd	72.00	10.39	There is a wreck of fallen former bridge 120m downstream of the bridge.
1-2	Old Queens Road Bridge (Road) [1936]	Nadi Rv	16.84	Old Nadi Back Rd	98.50	3.05	Substructures are shared with tramline bridge.
1-2'	Old Queens Road Bridge (Tramline) [1936]	Nadi Rv	16.84	Tramline	98.50	0.93	Substructures are shared with road bridge.
1-3	Back Road Bridge [1992]	Nadi Rv	18.74	Nadi Back Rd	80.00	9.40	
1-4	Br. on Queens Rd over channel (Road)	Channel to Nadi Rv	---	Queens Rd	13.00	10.50	
1-4'	Br. on Queens Rd over channel (Tramline)	Channel to Nadi Rv	---	Tramline	6.08	1.85	
1-5	Br. over Naividama Creek (Road)	Naividama Creek to Nadi Rv	---	Nadi Back Rd	13.80	9.70	
1-5'	Br. over Naividama Creek (Tramline)	Naividama Creek to Nadi Rv	---	Tramline	14.60	1.85	
1-6	Br. over Sa Creek (Road)	Sa Creek to Nadi Rv	---	Nadi Back Rd	8.75	9.70	
1-6'	Br. over Sa Creek (Tramline)	Sa Creek to Nadi Rv	---	Tramline	18.00	1.94	
1-7	Vunatogotogo Bridge (Road) [1990]	Vunatogotogo Creek to Nadi Rv	---	Nadi Back Rd	20.40	9.70	
1-7'	Vunatogotogo Bridge (Tramline)	Vunatogotogo Creek to Nadi Rv	---	Tramline	18.00	1.85	
1-8	Br. on Nausori Back Rd over channel #1	Channel to Nadi Rv	---	Nausori Back Rd	9.00	4.23	
1-9	Br. on Nausori Back Rd over channel #2	Channel to Nadi Rv	---	Nausori Back Rd	10.00	4.00	
2-1	Navo Bridge (Road) [1959]	Malakua Rv	1.03	Queens Rd	61.10	7.37	
2-1'	Navo Bridge (Tramline)	Malakua Rv	1.01	Tramline	55.20	1.85	This bridge has 3 types of piers.
2-2	Br on Malakua-Tunalia Rd	Malakua Rv	3.87	Malakua-Tunaria Rd	27.00	3.95	There is a wreck of old abutment at Nadi side.
2-3	Br on Nakia Rd over tributary to Malakua	Tributary to Malakua	---	Nakia Rd	10.00	3.05	
3-1	Qeleloa Bridge	Nawaka Rv	2.00	Unknown	21.00	8.98	There is a wreck of fallen tramline bridge upstream of the bridge.
3-2	Br on Togo Rd over tributary to Nawaka	Tributary to Nawaka	---	Togo Rd	27.75	3.65	There is a tramline on Nadi side of this bridge.(being cut before the bridge)
3-3	Box Culvert on Togo-Lavusa Rd over tributary to Nawaka	Tributary to Nawaka	---	Togo-Lavusa Rd	21.00	7.00	Precast Box
4-1	Br on Nausori Back Rd	Namosi Rv	0.52	Nausori Back Rd	11.45	4.00	The RC deck has several damages because of poor construction work. The width of river is narrow at the point of the bridge.
4-2	Malamura Bridge	Namosi Rv	5.50	Nausori Highland Rd	55.50	4.00	
10-1	Qeleloa Overpass [1999]	Tramline	---	Queens Rd	6.26	11.00	The bridge passed over a tramline.(Not used)

Source: JICA Study Team



Source: JICA Study Team

Figure 8-60 Location map of Existing Bridges

(3) Survey of Existing Bridges

1) Existing Documents of of existing bridges

In the site survey, the study team examines the existence of document of existing bridges. The table below shows 4 bridges that their drawings at the time of construction are confirmed to exist and gathered.

Table 8-14 Bridges Confirmed on Design Drawings

No.	Bridge Name	Drawings
1-3	Back Road Bridge	11 drawings (Location, Detail design of substructure and deck, etc.)
1-7	Vunatogotogo Bridge (Road)	7 drawings (Location, Detail design of substructureand deck, etc.)
2-1	Navo Bridge (Road)	8 drawings (Location, Detail design of substructure, etc.)
10-1	Qeleloa Overpass	2 drawings (General View etc.)

2) Tramline Bridges

In the site survey, the study team conducted interview with FSC (Fiji Sugar Corporation) to gather information about tramline and its bridges such as status of tramline service. The gathered information is as follows:

- ✓ In the targeted basin, tramline is only used for sugar cane transportation and nothing else.
- ✓ All sugar cane harvested in Nadi basin and its southern areas (Sigatoka area, etc.) is transported to FSC sugar factory in Lautoka.
- ✓ Both tramline and trucks are used for sugar cane transportation, and the ratio is 50% each.
- ✓ The period that the tramline is used for sugar cane transportation is from January to July. The other period is for maintenance.
- ✓ It is desirable that removal and reconstruction of tramline are completed in the maintenance period, but substitute transportation by trucks is also available if needed.
- ✓ Vertical alignment of tramline is almost level. Though there are some sections with slope, there happen accidents occasionally.
- ✓ As for the fallen tramline bridge next to Qeleloa Bridge, there is no plan for reconstruction because all sugar cane transportation is conducted by trucks.
- ✓ The tramline route from Denarau to Nadi Back Road is not used because sugar cane is not cultivated in Denarau area anymore.

3) Ploblems of Current Conditions

The table in the next page shows problems of existing bridges in their current conditions.

The number of bridges affected by river improvement plan is 6 road bridges and 2 tramline bridges in these 24 bridges.

In the site survey, it was examined that some bridges need to be repaired because of damages caused by deterioration over time, though, only those 8 bridges affected by river improvement plan would be discussed in this project since the other bridges could be maintained by road projects.

The characteristic problems of the existing bridge from the viewpoint of river flow are as follows:

- ✓ Foundations of many bridges are exposed because of erosion.
- ✓ Though road and tramline bridges stand close, the spans are different each other and it obstructs the flow of river.
- ✓ Woody debris stuck in superstructure, which was possibly caused by flood, are seen at some bridges.

Table 8-15 Problems of Existing Bridges in Their Current Conditions

No.	Bridge Name	Channel		Capacity of flow	Condition	Comment about Condition	
		Name	Distance				
1-1	Nadi Town Bridge	Nadi Rv	9.83	NG	Not good	Cracks can be seen on the road where beams are connected by hinge. The deck can be damaged as well in for the area.	
1-2	Old Queens Road Bridge (Road)	Nadi Rv	16.84	NG	Not good	Because of heavy vehicles from concrete factory nearby, large cracks can be seen on the surface and it is possible the deck is also damaged from the crack. Foundations can be seen because of erosion.	
1-2'	Old Queens Road Bridge (Tramline)	Nadi Rv	16.84	NG	Not good	Deterioration of anticorrosive function	
1-3	Back Road Bridge	Nadi Rv	18.74	OK	Good	Some crossbeams are missing. (stolen?)	
1-4	Br. on Queens Rd over channel (Road)	Channel to Nadi Rv	---	---	Good		*
1-4'	Br. on Queens Rd over channel (Tramline)	Channel to Nadi Rv	---	---	Mild damage	Deterioration of anticorrosive function	*
1-5	Br. over Naividama Creek (Road)	Naividama Creek to Nadi Rv	---	---	Good		*
1-5'	Br. over Naividama Creek (Tramline)	Naividama Creek to Nadi Rv	---	---	Mild damage	Deterioration of anticorrosive function	*
1-6	Br. over Sa Creek (Road)	Sa Creek to Nadi Rv	---	---	Good		*
1-6'	Br. over Sa Creek (Tramline)	Sa Creek to Nadi Rv	---	---	Mild damage	Deterioration of anticorrosive function	*
1-7	Vunatogotogo Bridge (Road)	Vunatogotogo Creek to Nadi Rv	---	---	Good		*
1-7'	Vunatogotogo Bridge (Tramline)	Vunatogotogo Creek to Nadi Rv	---	---	Mild damage	Deterioration of anticorrosive function	*
1-8	Br. on Nausori Back Rd over channel #1	Channel to Nadi Rv	---	---	Not Good	Deterioration of anticorrosive function	*
1-9	Br. on Nausori Back Rd over channel #2	Channel to Nadi Rv	---	---	Not Good	The middle of the span is sinking because of the traffic load and there is a fear of falling.	*
2-1	Navo Bridge (Road)	Malakua Rv	1.03	NG	Not Good	All piers are can be seen because of severe erosion.	
2-1'	Navo Bridge (Tramline)	Malakua Rv	1.01	NG	Mild damage	Deterioration of anticorrosive function	
2-2	Br on Malakua-Tunalia Rd	Malakua Rv	3.87	NG	Not Good	Old substructure damaged by erosion.	
2-3	Br on Nakia Rd over tributary to Malakua	Tributary to Malakua	---	---	Not Good	Deterioration of anticorrosive function	*
3-1	Qeleloa Bridge	Nawaka Rv	2.00	NG	Good		
3-2	Br on Togo Rd over tributary to Nawaka	Tributary to Nawaka	---	---	Not Good	Deterioration of anticorrosive function. Piers are leaned to the left by flood.	*
3-3	Box Culvert on Togo-Lavusa Rd over tributary to Nawaka	Tributary to Nawaka	---	---	Good	Newly built after 2012 flood because the former bridge was washed away by flood.	*
4-1	Br on Nausori Back Rd	Namosi Rv	0.52	NG	Bad	The deck is poorly constructed and there are many small holes that bees live inside. Dangerous.	
4-2	Malamura Bridge	Namosi Rv	5.50	OK	Not good	All piers are can be seen because of severe erosion.	
10-1	Qeleloa Overpass	Tramline	---	---	Good		*

Source: JICA Study Team *Not affected by the river improvement plan

(4) Improvement Policy

As mentioned above, 8 existing bridges affected by river improvement plan would be demolished and reconstructed as the reason follows.

Table 8-16 Bridge Improvement Policy

No.	Bridge Name	Bridge improvement plan	Reason	Remark
1-1	Nadi Town Bridge	Reconstruction	✓ Bridge length is too short for the widened river width. ✓ There can be seen damages such as exposed foundations caused by erosion.	
1-2	Old Queens Road Bridge (Road)	Reconstruction	✓ There are too many numbers of piers regarding of the length and it obstructs the river flow. ✓ There can be seen damages such as exposed foundations caused by erosion.	
1-2'	Old Queens Road Bridge (Tramline)	Reconstruction	✓ Since substructures are shared with the road bridge, it needs to be reconstructed along with it.	*1
2-1	Navo Bridge (Road)	Reconstruction	✓ Bridge length is too short for the widened river width ✓ Bridge clearance is lower than design high water level. ✓ There can be seen damages such as exposed foundations caused by erosion.	
2-1'	Navo Bridge (Tramline)	Reconstruction	✓ Bridge length is too short for the widened river width ✓ It has different spans with the nearby road bridge. Thus, the river flow is obstructed.	*2
2-2	Bridge on Malakua-Tunalia Road	Reconstruction	✓ Bridge length is too short for the widened river width ✓ Bridge clearance is lower than design high water level.	
3-1	Qeleloa Bridge	Reconstruction	✓ Bridge length is too short for the widened river width ✓ Bridge clearance is lower than design high water level.	
4-1	Bridge on Nausori Back Road	Reconstruction	✓ Bridge length is too short for the widened river width ✓ Bridge clearance is lower than design high water level.	

*1: The vertical alignment of tramline cannot be changed for safety operation and performance of the train. Although underside of the superstructure of reconstructed tramline bridges could be higher than the design high water level, it is assumed that securing freeboard is difficult. (at the time of writing the Interim report). It would be considered more in detail based on the topographic survey carried out in the Feasibility Study stage.
*2: This bridge would be designed as a submersible bridge because the vertical alignment of tramline cannot be changed.

At the detailed design stage, it should be noted that this bridge should be designed so as not interfere with the structural stability and serviceability as submersible bridge by considering measures such as reducing impediment ratio of river flow at cross sectional area and the risk of collision of driftwood.
Source: JICA Study Team

The table below shows the design condition for reconstruction of those bridges mentioned above.

Table 8-17 Design condition for reconstruction of bridges*

	Road Bridge	Tramline Bridge
Passage	Normal times: Passable During floods: Passable	Normal times: Passable During floods: Traffic closure could be permitted in case the flood exceeds the surface of the rail.
Bridge Plans	Vertical clearance: higher than design high water level plus freeboard, Length: longer than the widened river width	The bridges would be designed as submersible bridge in case floods exceeds the surface of the rail because the vertical alignment of tramline cannot be changed. (Similar cases have been done in Fiji)

*It is necessary to confirmed in the detailed design stage.

Source: JICA Study Team

8.5.2 Bridge improvement plan

This section set out the conceptual designs for reconstructed bridges. Structure types and specifications were determined based on past experiences of construction in Japan and those in Fiji which were examined in the site survey.

(1) Basic Condition

For planning reconstruction of bridges, the following conditions should be taken into account with the planned river cross sections mentioned before.

- ✓ Condition of bridge location (e.g. geometric structure of roads and tram lines in the both banks of river, the current road traffic conditions, proximity and density of private property, construction conditions)
- ✓ Construction experiences of each structure type (superstructure, substructure, and foundation) in Fiji
- ✓ Design standards applied for planning bridges over river.

1) Conditions around crossing point

While conditions of crossing point vary from bridge to bridge, the following conditions should be mentioned specially.

- ✓ Nadi Town Bridge; Intersection and commercial areas are close to the south side, there is also a residential area (including a primary school) on the north side.
- ✓ Old Town Bridge; There are a Cement plant and some houses are by the bridge. Although the road of approach section of the bridge has two lanes, bridge section becomes a bottleneck because it has only one lane and allows only one-way alternating traffic.
- ✓ Tramline bridge of Old Queens Road Bridge and Navo Bridge; The vertical alignment of tramline cannot be changed for safety operation and performance of the trains.

2) Bridge Construction Experience Study

a) Superstructure Type of Road Bridge

As a result of surveying past experiences of bridge construction in Fiji, it was revealed that PC I-beam, steel I-girder, steel box-girder, box culvert and many other superstructure types were adopted depending on the sizes of the bridges. In the targeted basin, steel I-girder was commonly adopted for old existing road bridges, and PC-I beam was for relatively new existing bridges. As for bridges constructed by foreign aid such as EU and China, PC structures were commonly adopted. The table below shows possible span lengths and ratio of beam height to span of each superstructure types, which have past construction experiences in Fiji.

Table 8-18 Ratio of beam height to length of each superstructure types

superstructure type	Possible Span lengths*	Ratio of beam height to span
PC I-beam	less than approximately 35m	1/18～1/23
PC box beam	30 - 60m	1/15～1/17
Steel I-girder	30 - 60m	1/16～1/22

*including construction experiences in Japan
Source: JICA Study Team

b) Superstructure Type of Tramline Bridge

Steel I-girders with short span (approximately 10m) were commonly adopted for old existing tramline bridges. According to FSC, there are some cases recently that PC structures were adopted for reconstruction of severely damaged bridges near the coast.

c) The type of substructure and foundation

As for substructures, RC-wall type piers, RC-rigid type piers and pile bent piers are common. As for foundation types, cast-in place piles by reverse circulation drill method, steel pipe piles, and RC piles have been adopted commonly in the past.

3) Design standards

In Japan, river structures need to comply with the provisions of "Cabinet Order concerning Structural Standards for River Management Facilities, etc." (Hereafter mentioned as "Cabinet Order concerning River Structure"). It is defined to secure the soundness of the flow of a river and stability of river structures such as revetments and embankments.

Also for bridges over a river, based on the past experience of natural disasters, the following provisions are defined as basic conditions to satisfy.

a) Provisions of the position and direction of the abutment, and embedment of footing, etc. (Article 61)

b) Provisions of the position, direction and of embedment of footing of the pier, and impediment ratio of river flow, etc. (Article 62)

c) Provisions of span length and neighboring bridge (Article 63)

d) Provisions of freeboard (Article 64)

Commonly in Japan, in determine span lengths and types of superstructures, consideration would be given to not only structural stability but also other perspective such as mobility, workability, maintainability and economic efficiency, as well as complying with the provisions above.

On the other hand, there are no similar applicable standards in Fiji. Therefore, the above mentioned "Cabinet Order concerning River Structure" would be applied to the bridge planning of this study because flowing form of the targeted river is similar to that in Japan. (River origin from high lands and flow into the sea)

(2) Span length (Number of piers)

There are two groups for bridges to be reconstructed, and construction conditions for each are shown as follows. Either of which, determining positions of abutments and piers for new bridges is not affected by that of existing bridges since reconstruction would be done after demolishing.

1) Case 1: Only Road Bridge (Bridges except Case 2)

- ✓ In order to secure the river flow during flood and current traffic, road bridges are planned to satisfy conditions for clearances and length, those are, vertical clearances should be higher than design high water level and lengths should be longer than widened river width.
- ✓ Positions of abutments would be determined based on Article 61 of "Cabinet Order concerning River Structure".
- ✓ From the point of view of impediment ratio of river flow, it is desirable that the number of piers is as small as possible. Thus, number of piers would be determined to satisfy structural stability with minimum number. Span length would be determined based on Article 62 and 63 of "Cabinet Order concerning River Structure", with consideration of construction experience in Fiji about superstructure(less than approximately

35m) .Article 62 specifies maximum impediment ratio of river flow as 5% of river width and Article 63 specifies standard span length.

2) Case 2: Tramline Bridge with Road Bridge nearby (Old Queens Road Bridge and Navo bridge)

a) Common

- ✓ Span length is determined based on conditions same as Case1 with one additional condition as follows for tramline Bridge since the vertical alignment of tramline cannot be changed.
- ✓ The positions of piers of tramline bridges would be placed next to those of road bridges so as not to obstruct river flow.

b) Old Queens Road Bridge

- ✓ Since the distance between superstructures of both bridges (tramline and road) is small (3m at present), shared substructures would be planned. Superstructures would be planned respectively because there is a difference in height of bridge surface since the vertical alignment of tramline bridge cannot be changed unlike road bridge.
- ✓ Although underside of the superstructure of tramline bridges could be higher than the design high water level, it is assumed that securing freeboard is difficult. (at the time of writing the Interim report). It would be considered more in detail based on the topographic survey carried out in the Feasibility Study stage

c) Navo Bridge

- ✓ Since the distance between superstructures of both bridges (tramline and road) is large (15m current), substructures would be planned respectively for each bridges.
- ✓ The tramline bridge would be designed as submersible bridge because the surface of the rail is approximately 2m lower than design high water level. From the point of view of impediment ratio of river flow, it is desirable to reduce not only number of piers but also height of beams as small as possible. Thus, it is unavoidable to adopt span length shorter than standard span length specified in Article63 of "Cabinet Order concerning River Structure", so that the beam height of tramline bridges could be reduced. To adopt that span, along with piers next to ones of road bridge, there need one additional pier for tramline bridge in the center of the river channel on the cross section.
- ✓ The position of abutments of tramline bridges would be determined in condition that the front surface of abutments would not exceed the surface of embankment slopes to river side.

(3) Superstructure Type

1) Road Bridge

As the reason follows, PC I-beam type would be adopted basically as a superstructure type, based on construction experiences in Fiji and Japan.

- ✓ There is little merit to adopt long span structures such as PC box beam or steel girder because high girder heights of those structures could affect approach sections of bridges.
- ✓ Although the number of piers of PC-I beam type is bigger than that of PC box beam or steel girder since possible span length is shorter, the height of the beam could be lower.
- ✓ It is assumed that it is not necessary to build large temporary structures such as sheet piles for construction of substructures since water levels during normal times are low.
- ✓ Since main beams are manufactured in factory, higher quality could be expected than on-site construction, and maintenance is easier than steel girders that need to be repainted occasionally.

2) Tramline Bridge

a) Old Queens Road Bridge

PC I-beam type would be adopted as well as road bridges since underside of the superstructure of tramline bridges could be higher than the design high water level, although it is assumed that securing freeboard is difficult. (at the time of writing the Interim report).It would be considered more in detail based on the topographic survey carried out in the Feasibility Study stage

b) Navo Bridge

In determining type of structure of this bridge, which would be planned as a submersible bridge, consideration should be given to structural stability and serviceability, and to impact of the structure on the flow of the river, due to the structure and collision of driftwoods. That is,

- ✓ It is desirable that the structure have resistance against the outflow of beams and buoyancy when it is submerged.
- ✓ It is desirable that the shape of beam does not obstruct the flow of the river during floods. (e.g. equal thickness rectangular cross-section)

As the conditions mentioned above, PC beam would be adopted basically, as well as road bridges, as a superstructure type as the reason follows. Also, equal thickness rectangular cross-section would be applied. (Based on construction experience in Fiji, filling between each member of PC I-beam is brought down to the underside of the beam).

- ✓ It has higher resistance against buoyancy than steel structure since it has heavier weight.
- ✓ Since it is a structure to be submerged, concrete structure is desirable because it is not necessary to be repainted.

The following devices can be considered as other countermeasures for the submersible bridge. Since it does not affect the basic structure of the bridge itself, it would be considered in detail in the detailed design stage.

- ✓ Countermeasure for lift force: Adoption of resistance device (In case buoyancy is large, it cannot resist only with self-weight of beam)
- ✓ Device of shape of beam: Rounded the beam side
- ✓ Reduction countermeasures of driftwood collision risk: Installation of counterfort pile or driftwood averter.(refer to Figure 8-62 and Figure 8-64)

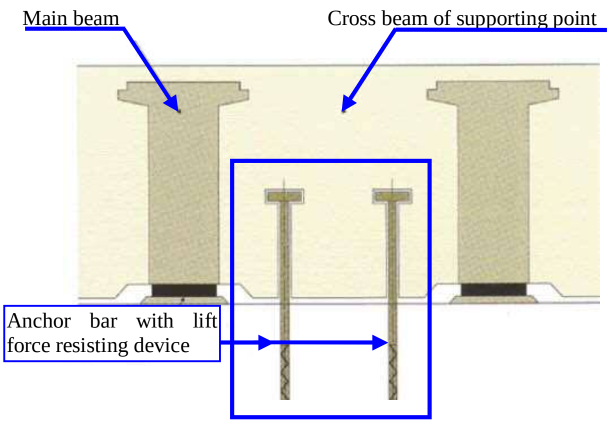


Figure 8-62 (1)Device for lift force

Source: Japan Prestressed Concrete Institute

Figure 8-62 (2) Reduction countermeasures of driftwood collision risk 1

Source: http://puppu.hamazo.tv/d2015-06-18.html

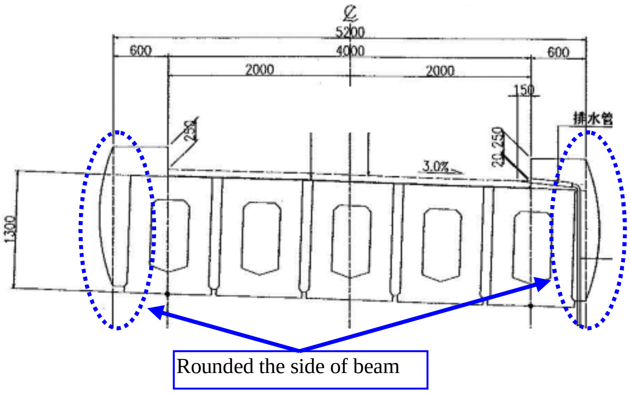


Figure 8-64 Countermeasure of reducing interfere with the river channel flow down

Source: Land, Infrastructure and Transportation Ministry

Figure 8-64 Reduction countermeasures of driftwood collision risk 2

Source: http://www.geocities.jp/fukadasoft/bridges/oppe/

(4) Substructures

1) Abutment Types

Various types of abutments could be adopted depending on structure heights, supporting soil conditions, and economic efficiency. Generally, it is said to be appreciate to decide abutment types depending on the height of structures. Designed heights for abutments of reconstructed bridges would be between 3.5 and 9.0 meters, and since supporting soil conditions are not good, inverted T-type (Cantilever Type) abutments would be adopted.

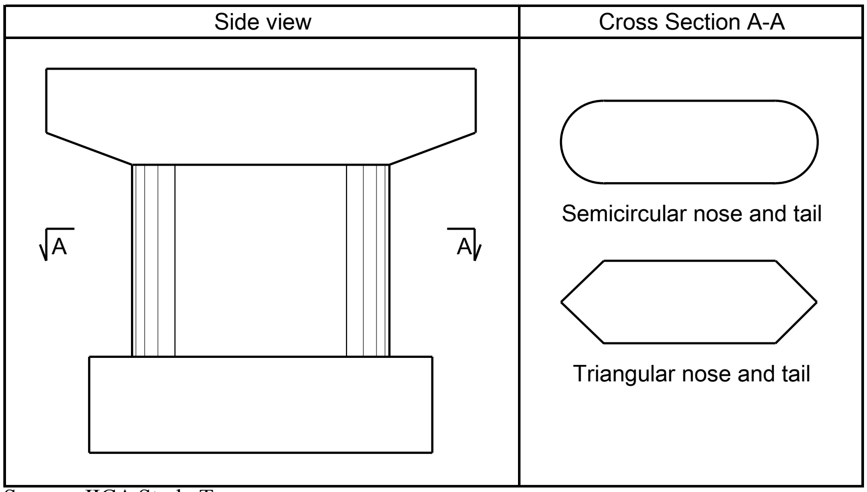
Table 8-19 Abutment Types and Standard Heights

Abutment Type	Height(m)			Remarks
	10	20	30	
Gravity Type	■■			
Semi-gravity Type	■■			
Cantilever Type	■■■	■		
Counterfort Type		■■■■		
Rigid Frame Type		■■■		

Source: JICA Study Team

2) Pier Types

In order to consider structure types of piers, it is important that the structure is not only satisfying the required conditions but also making it possible to reduce the amount of construction material used so that it can be economically efficient. Thus, from the perspective of economic efficiency, pile bent piers and rigid type pier, which have been adopted widely in Fiji, could be taken into consideration. However, since those structures have relatively wide bridge-axial width, they obstruct the flow of a river Thus, wall type piers (shown below), which have less effect on the flow of a river, would be adopted for reconstructed bridges. In addition, in consideration of possible future deterioration such as degradation of stability of the piers by local erosion and the influence on river management facilities, piers are designed to have footings with appropriate embedment from the riverbed.



Source: JICA Study Team

Figure 8-65 The wall type pier

3) Foundation Types

As for the ground conditions, the details are unclear because boring survey have not been done yet. Thus, according to an interview with a local construction consultant, the stratum constitutions in the level ground part around the targeted basin are as follows:

- ✓ The depth of bearing layer is approximately 25m deep constantly from Nadi to Lautoka.
- ✓ Bearing layer is regarded as soap stone.
- ✓ The layers above bearing layer are sandy soil and silty soil.

In consideration of the above, pile foundation is adopted basically for reconstructed bridges except a bridge on Nausori Back Road because it is possible to adopt direct foundation since rockbed is seen to be exposed on the site.

(5) Conceptual Drawings

Based on the condition above, conceptual drawings are published as follows.

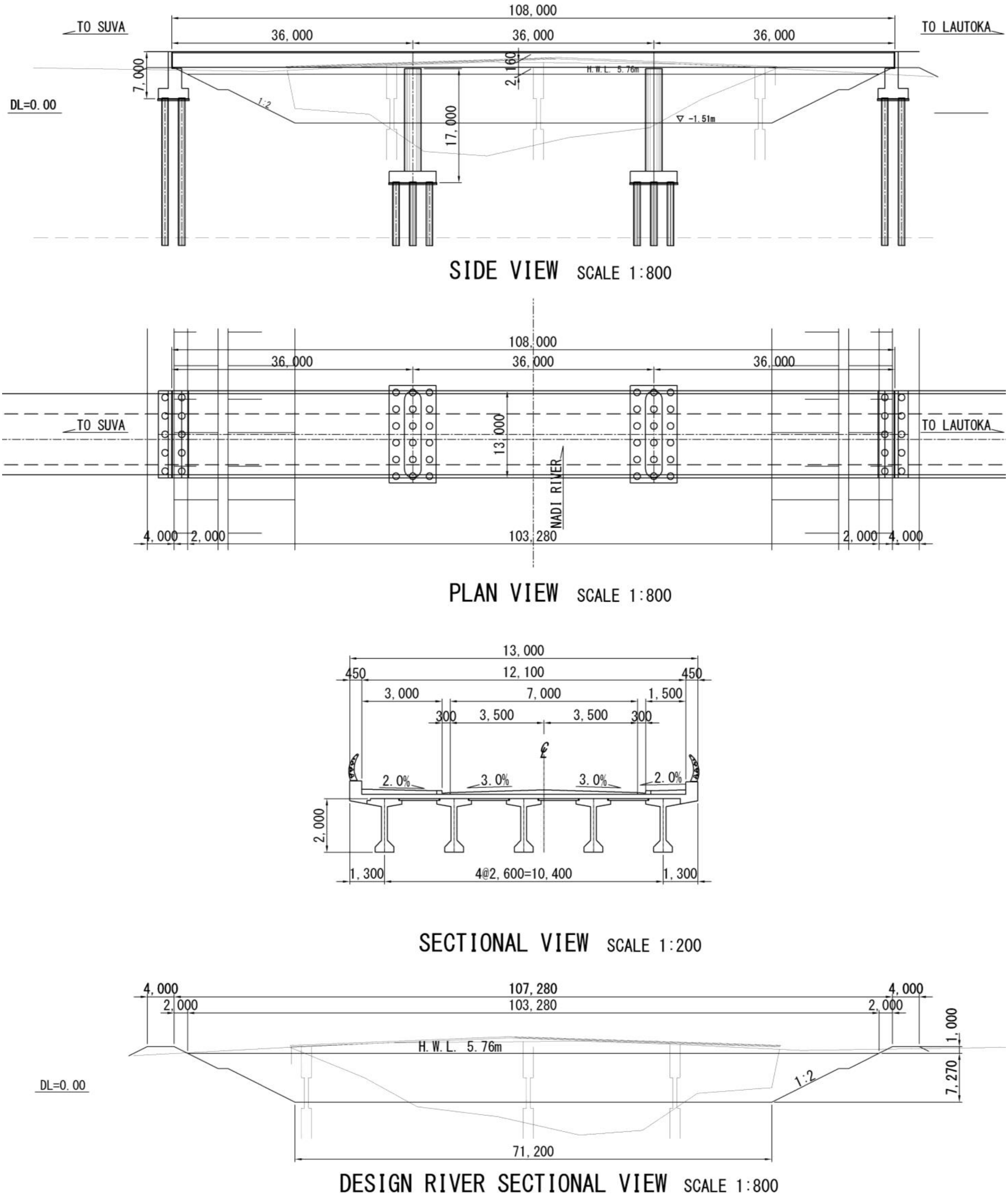


Figure 8-66 1-1 Nadi Town Bridge

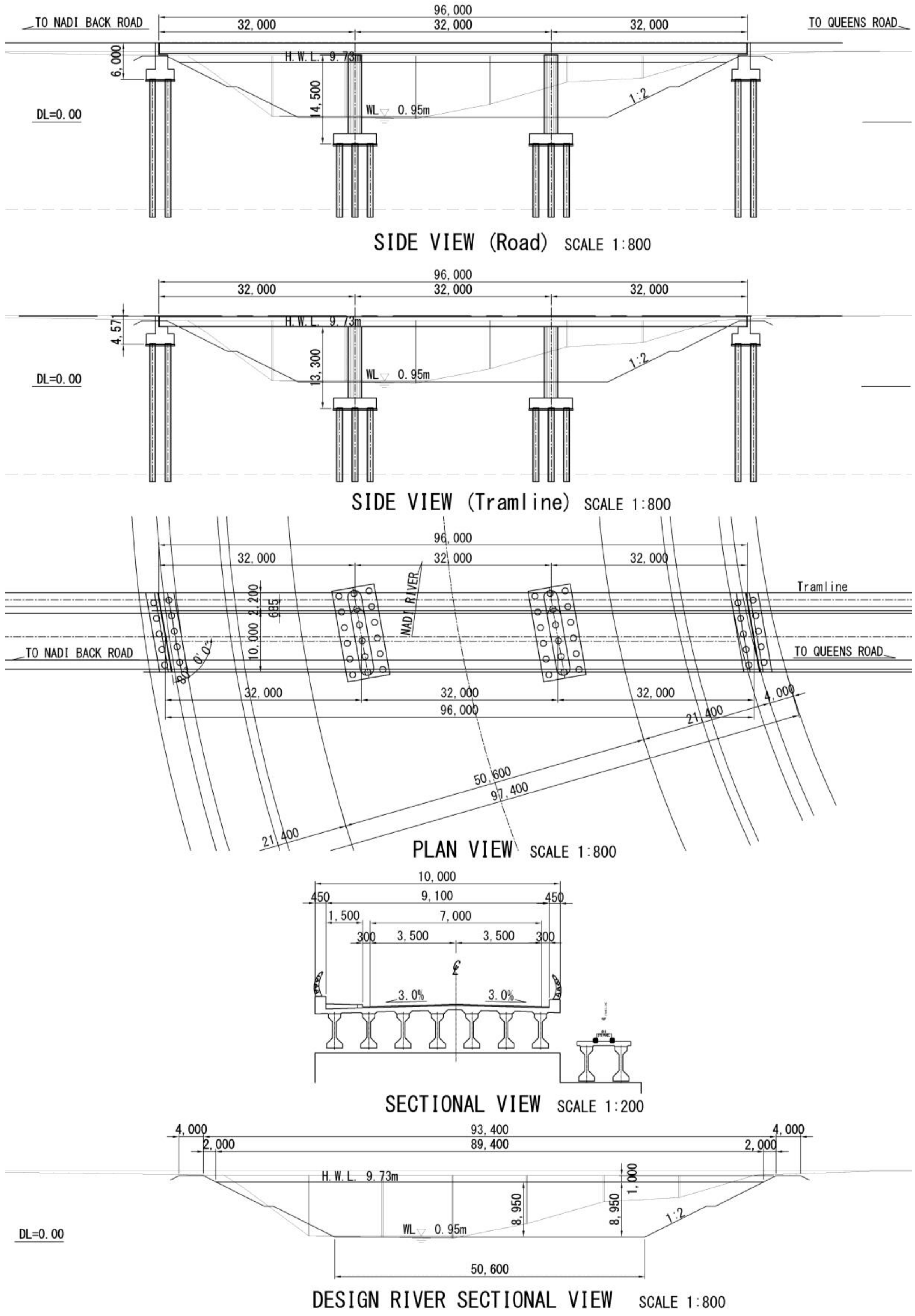


Figure 8-67 1-2 Old Queens Road Bridge

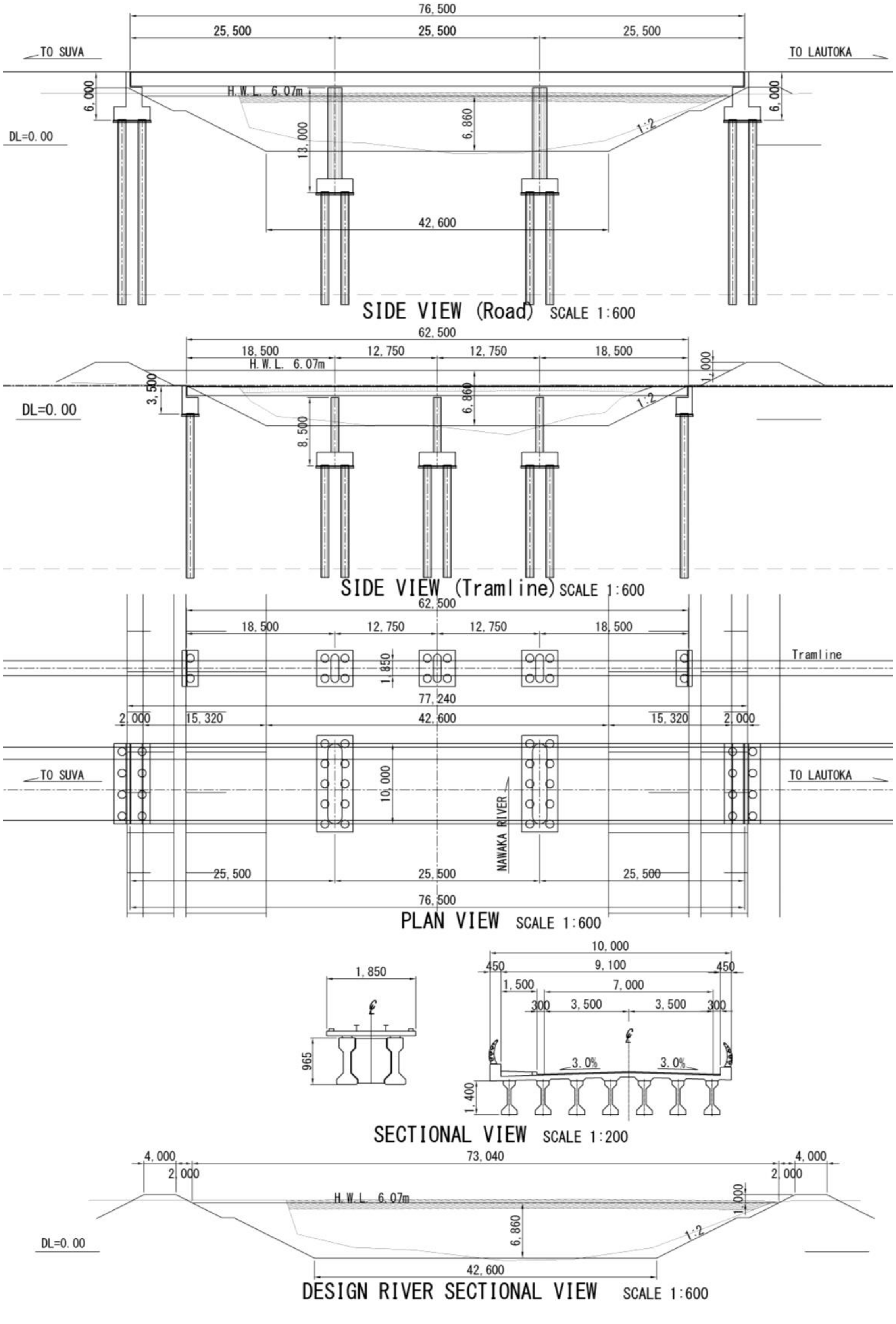


Figure 8-68 2-1 Navo Bridge

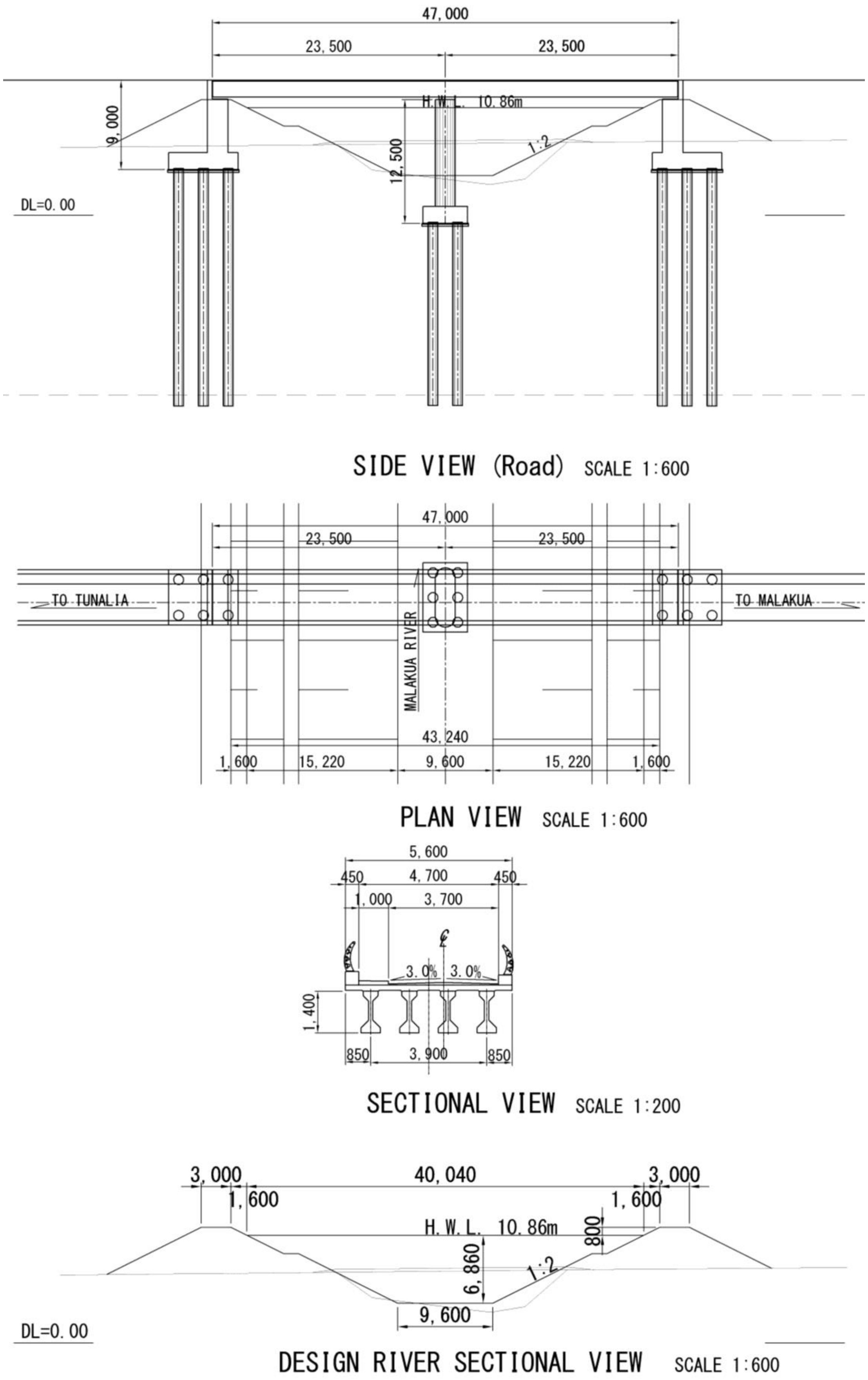


Figure 8-69 2-2 Bridge on Malakua – Tunalia Road

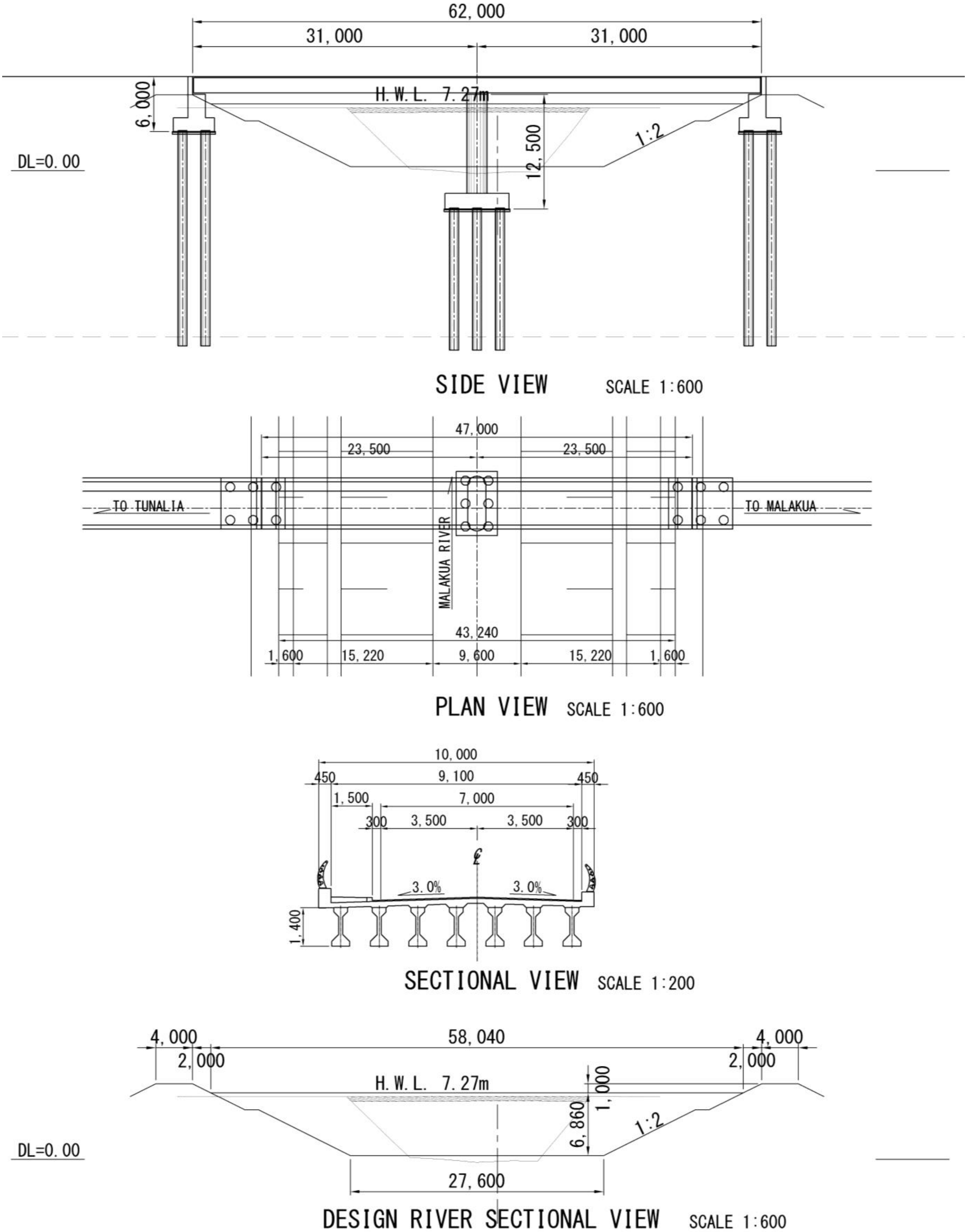


Figure 8-70 3-1 Qeleloa Bridge

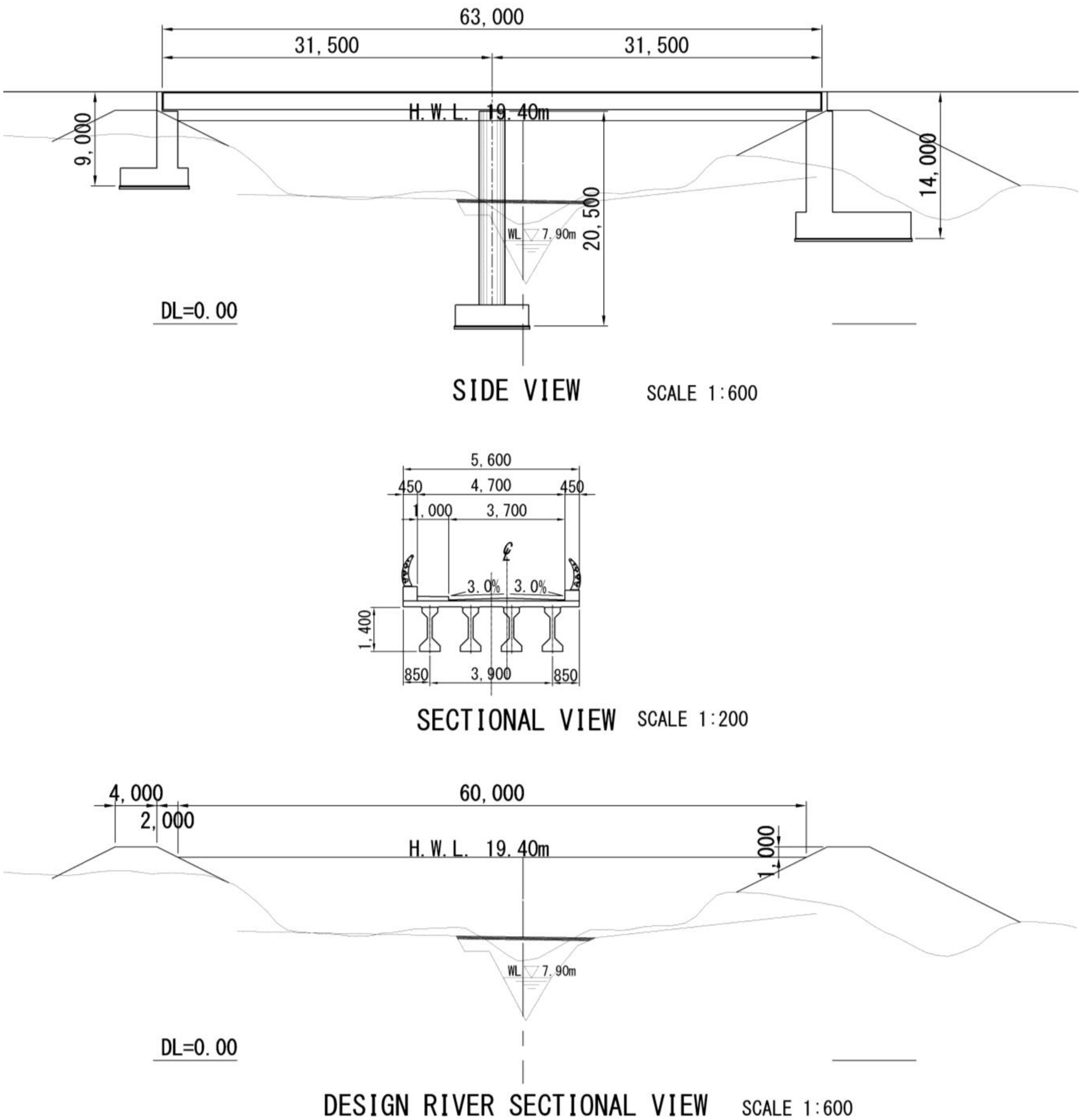


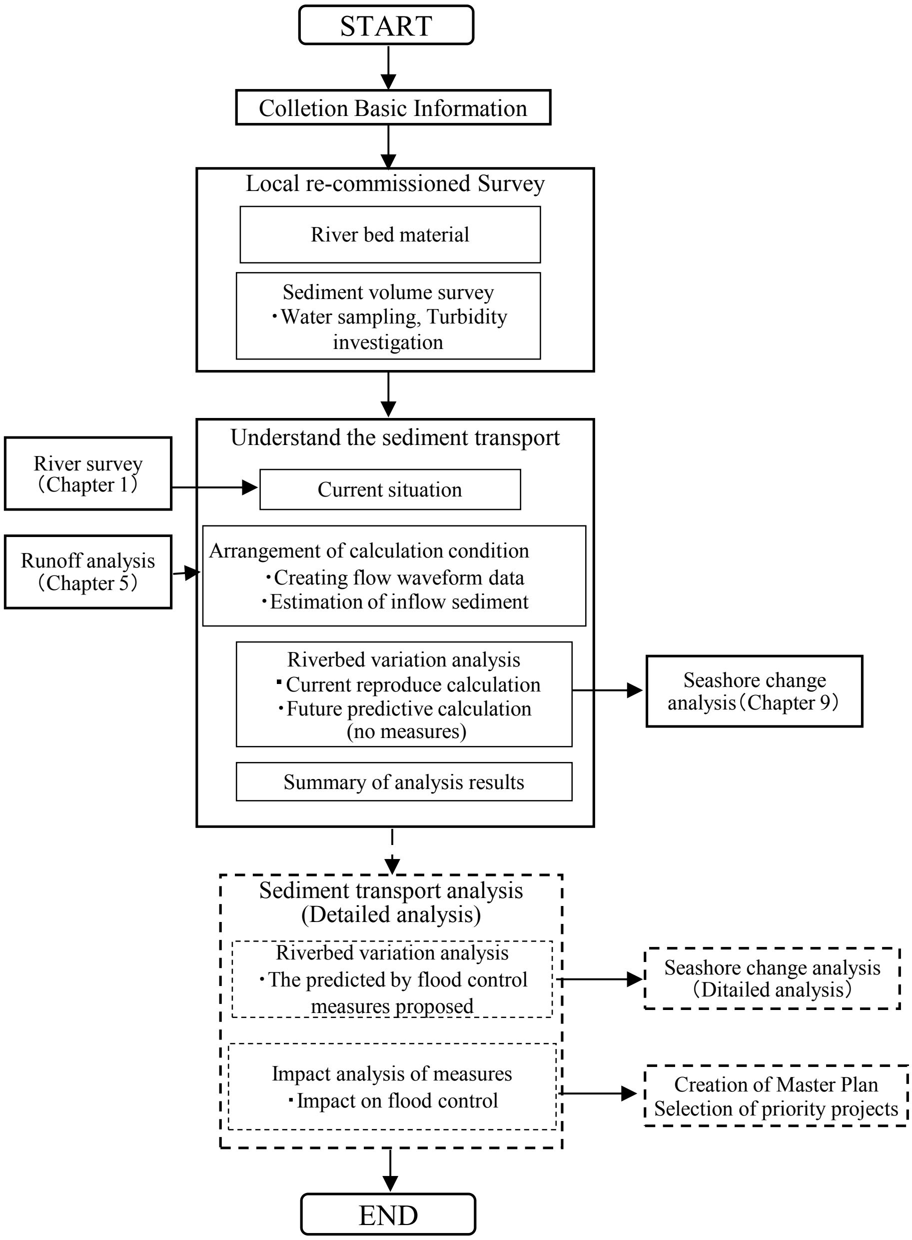
Figure 8-71 4-1 Bridge on Nausori Back Road

Chapter 9 Comprehensive Sediment Management

In this chapter, the sediment transport of the Nadi River is investigated and studied from the point of view of understanding the current situation.

It is particularly important to understand the amount of suspended sediment such as sand and silt which form the beach. The suspended sediment is estimated to be mainly produced from the surface erosion in the upstream and middle stream basin.

Therefore, we conducted a field research to understand the present state of the outflow of suspended sediment, and the bed variation analysis was performed using the flow analysis model and river sections which were surveyed in this project. Then, based on the analysis results, we calculated the sediment discharge of the river mouth at present and future situation in the river.



9.1 Collection and Arrangement of Basic Information

The basic information is collected and arranged for understanding of the river sediment transport.

9.1.1 Topography of River Channel

In order to know the variation of the topography of river channel, the comparison of river width, and the profile of the deepest riverbed elevation and the average riverbed elevation is carried out based on the results of river survey in the JICA study implemented in 1998 and in this Project

The location of cross section survey is as shown in the Figure 9-1 and the profiles are as shown in the Figure 9-2 to Figure 9-4. The river width and average riverbed elevation are determined by the land elevation of the left and right banks.

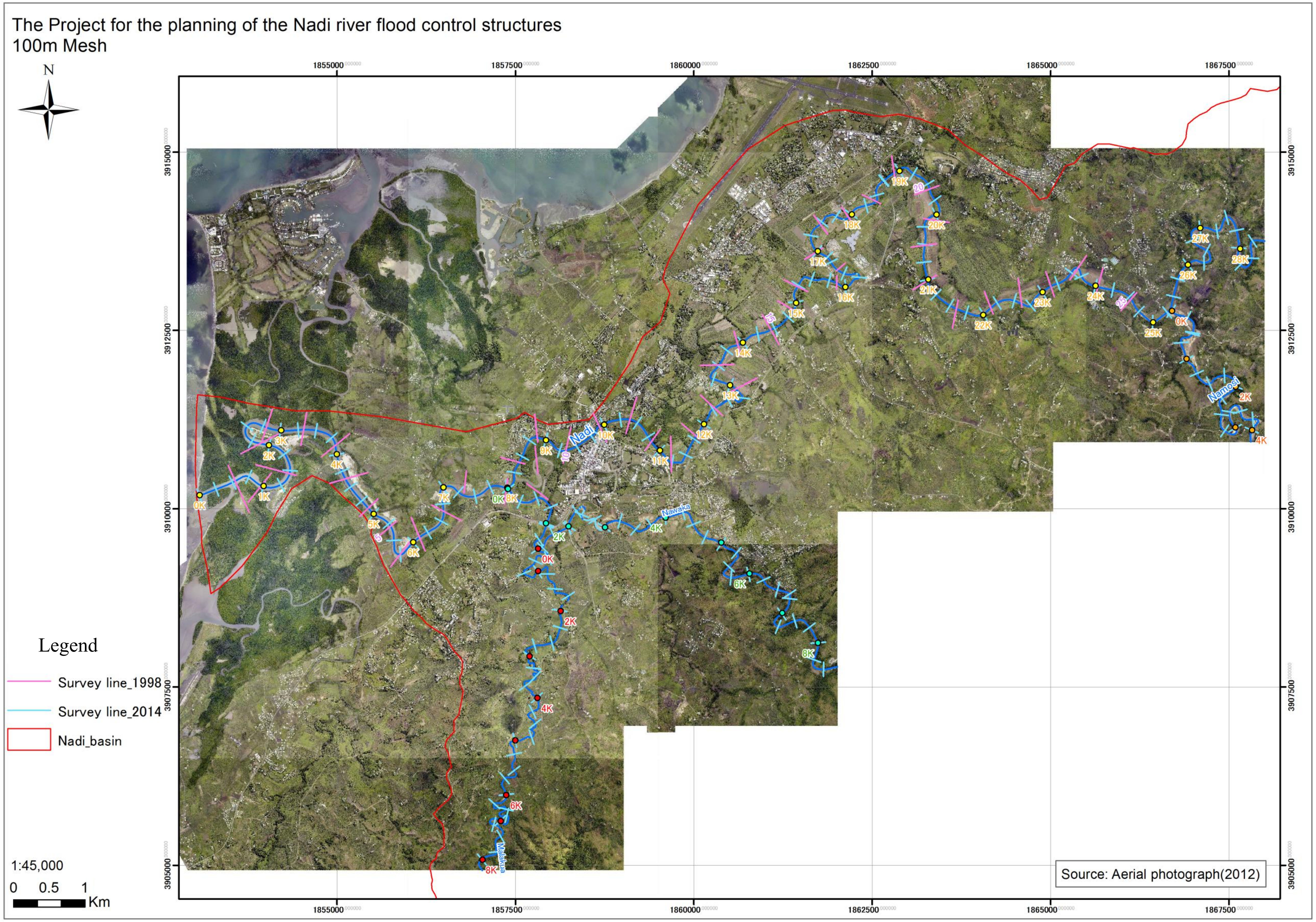


Figure 9-1 Location of River Cross Section Survey in 1998 and in this Project

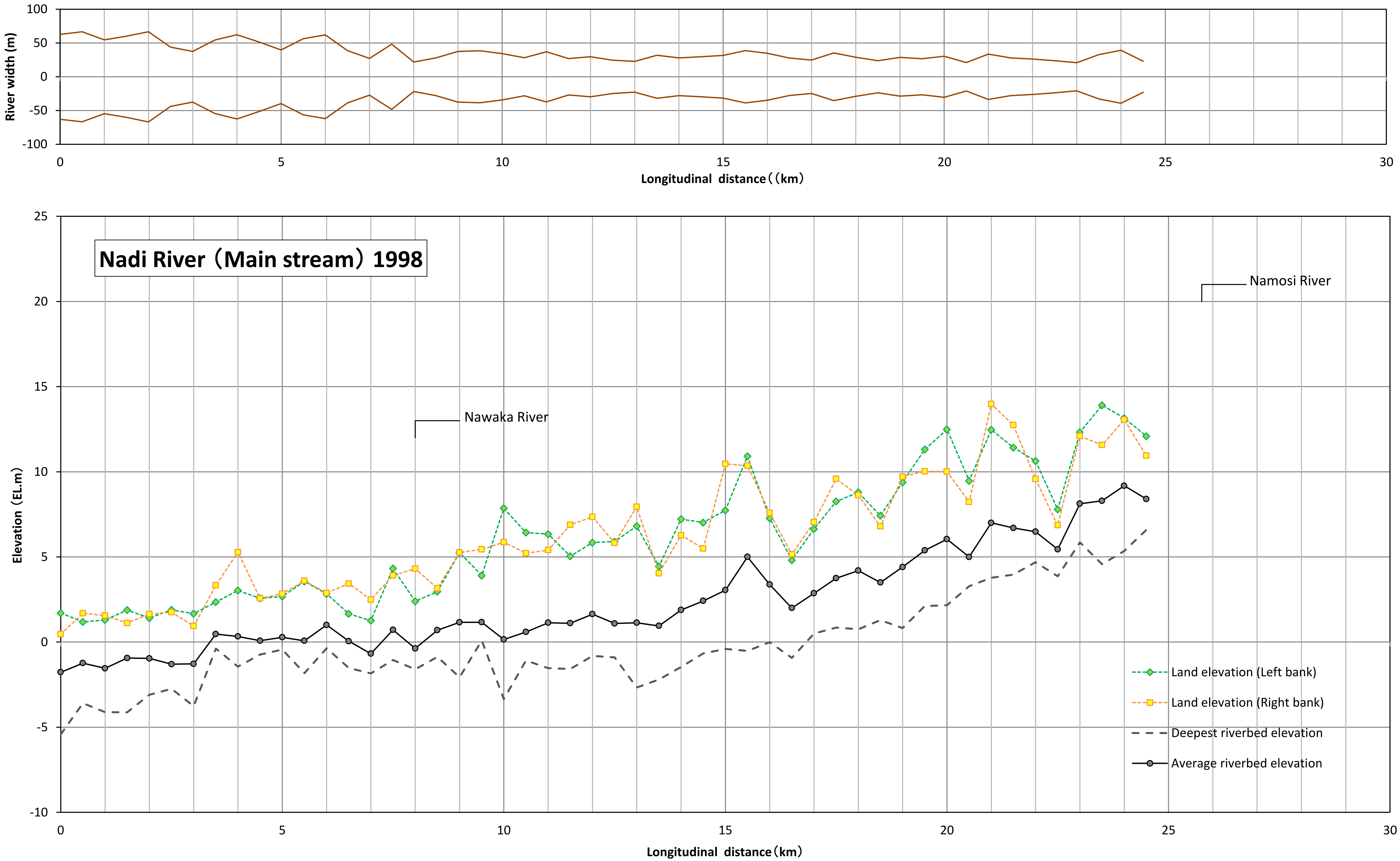


Figure 9-2 River Profile (1998, Nadi Main Stream)

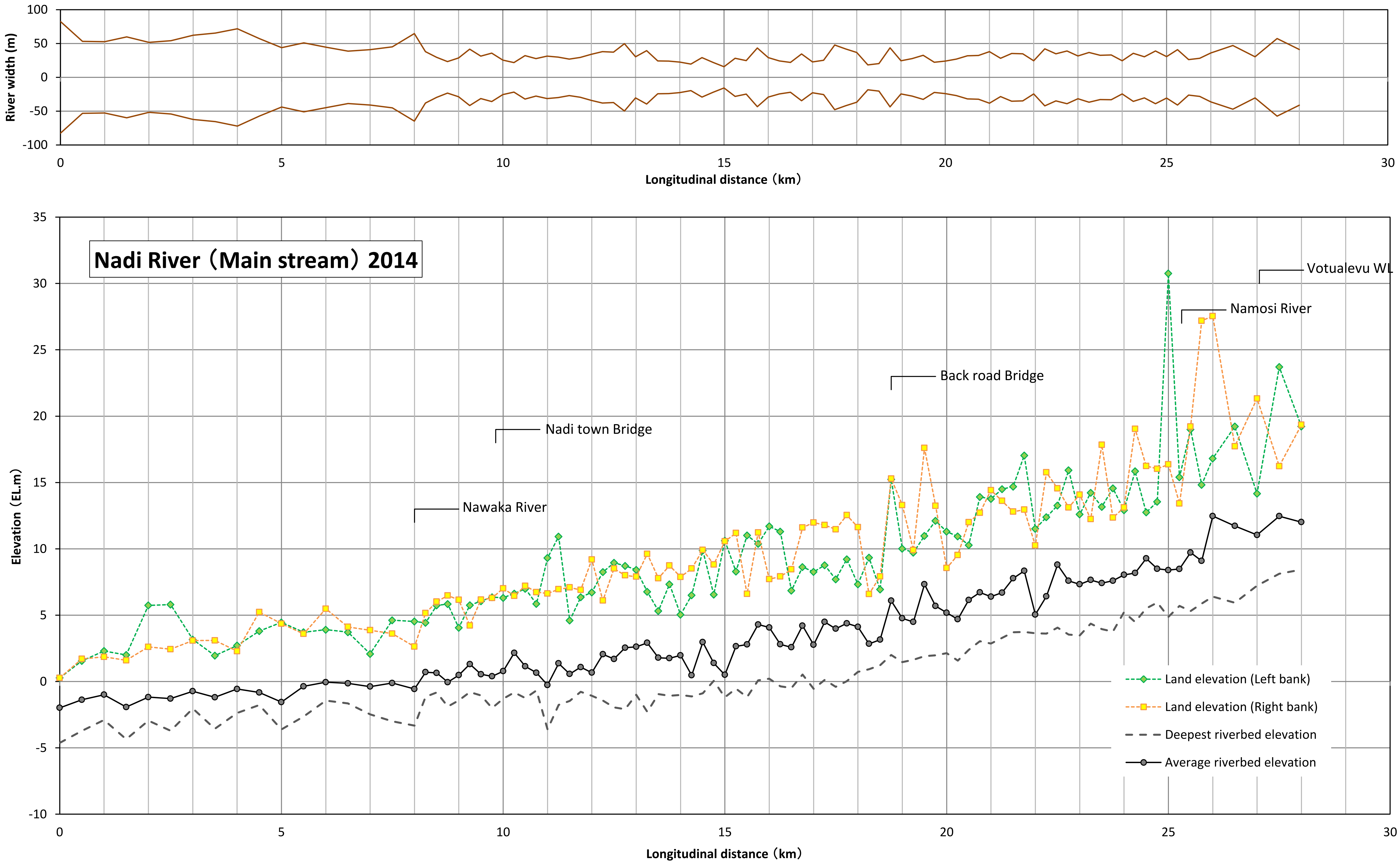


Figure 9-3 River Profile (2014, Nandi Main Stream)

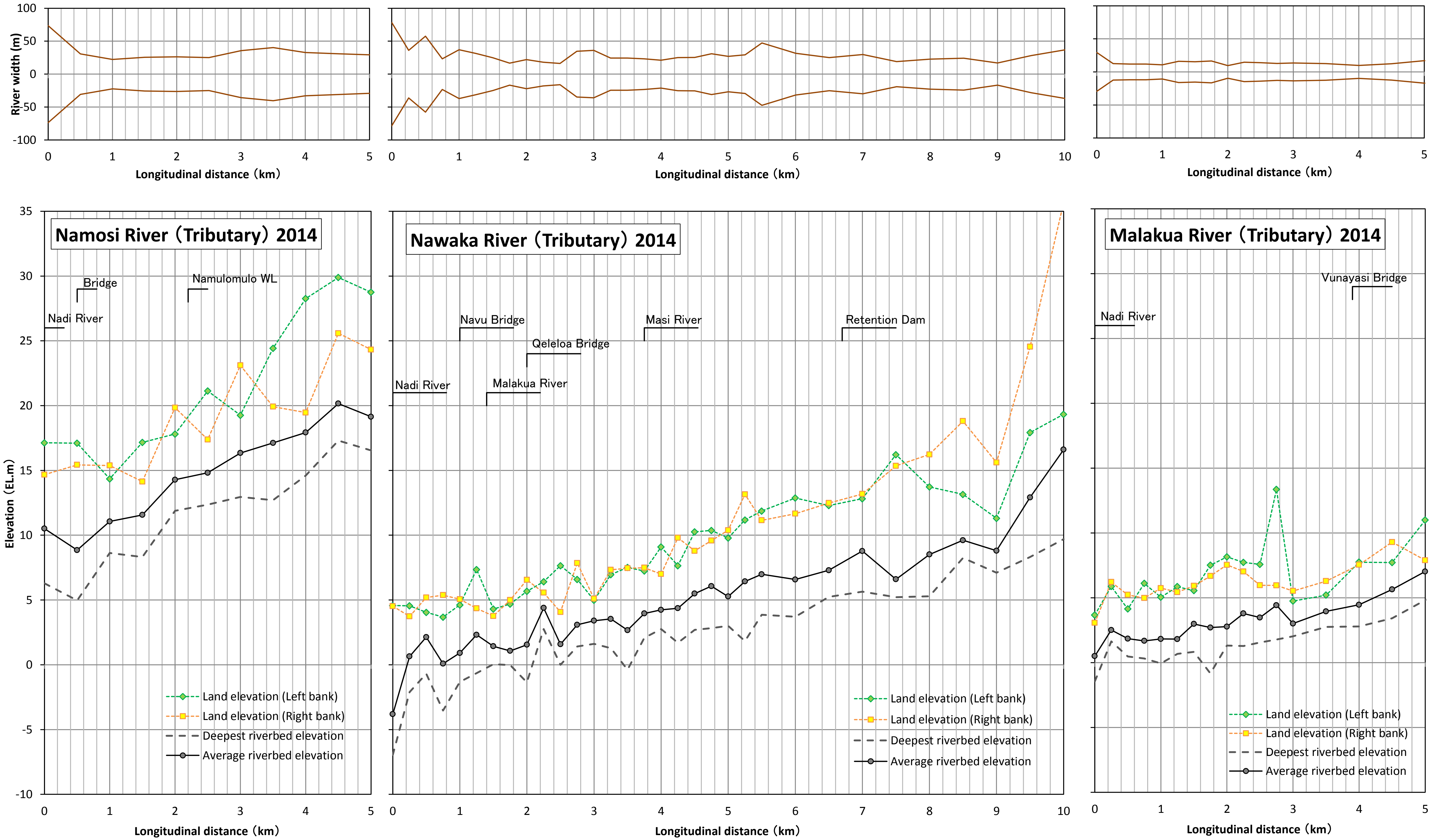


Figure 9-4 River Profile (2014, Nandi Tributaries: Namosi, Nawaka and Malakua)

9.1.2 River Channel Dredging

The river channel dredging and gravel quarrying carried out in the past in Nadi River was surveyed. The actual result of river channel dredging is as shown in the Table 9-1. The accumulated dredging volume of 1,651,000 m3 was implemented in the river mouth from 2008 to 2012 (for the location of dredging, refer to the Figure 9-5). The detail of implementation period is not identified.

Table 9-1 River Channel Dredging Record in Nadi River

Year	Section	Dredging Volume(m^3)	Remarks
2008	-1.2k to 0.5k	365,000	
2009	0.5k to 3.7k	409,000	
2010	3.7k to 7.775k	498,000	
2012	-1.2k to 6.975k	379,000	Dredged after the flood in March,2012
Total		1,651,000	

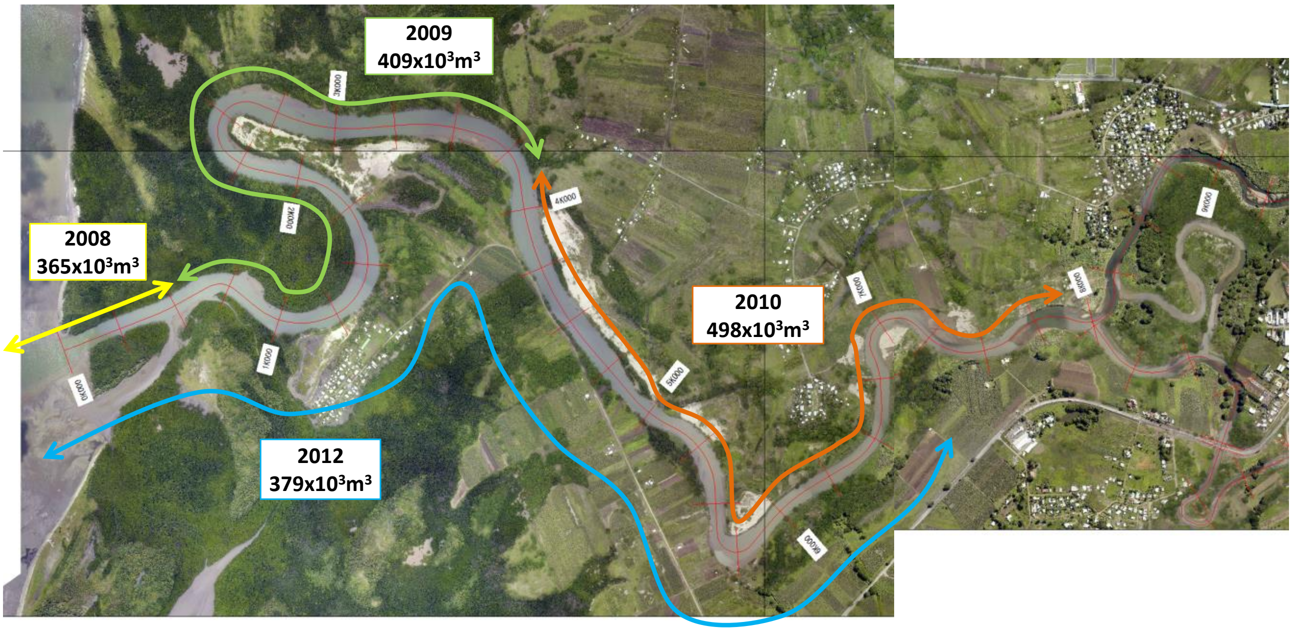


Figure 9-5 Location of River Channel Dredging

9.1.3 Others

(1) Sediment in Vaturu Dam

The sediment volume in the Vaturu dam could not be collected since the sediment survey in the reservoir was not carried out.

It has passed 32 years since the completion of dam in 1982. The catchment area at upstream of dam is 38.6 km2, which is about 7 % of the entire area of Nadi basin (516km2) so that about 7% of total sediment in the basin seems to be captured in the reservoir.

9.2 Subcontracting of Field Investigation

9.2.1 Riverbed Material Investigation

(1) Outline

The outline of the riverbed material investigation is shown in the Table 9-2. The work was carried out in November 11 to 13, 2014 in the location shown in the Figure 9-6. Number of location is 13 in total, which is composed of 6 in the Nadi main stream, 1 in Namosi River, 2 in Nawaka River and 2 in Denarau bay. 2 locations, 1 in branch river and 1 in Denarau bay, were added since it was fund that the main stream branches to Denarau bay.

Table 9-2 Outline of Riverbed Material Investigation

Item	Contents	Remarks
Period	November 11 to 13, 2014	
Location	13 points(Nadi main stream, tributaries, Denarau bay)	
Investigation Item	Grain size distribution of riverbed material	

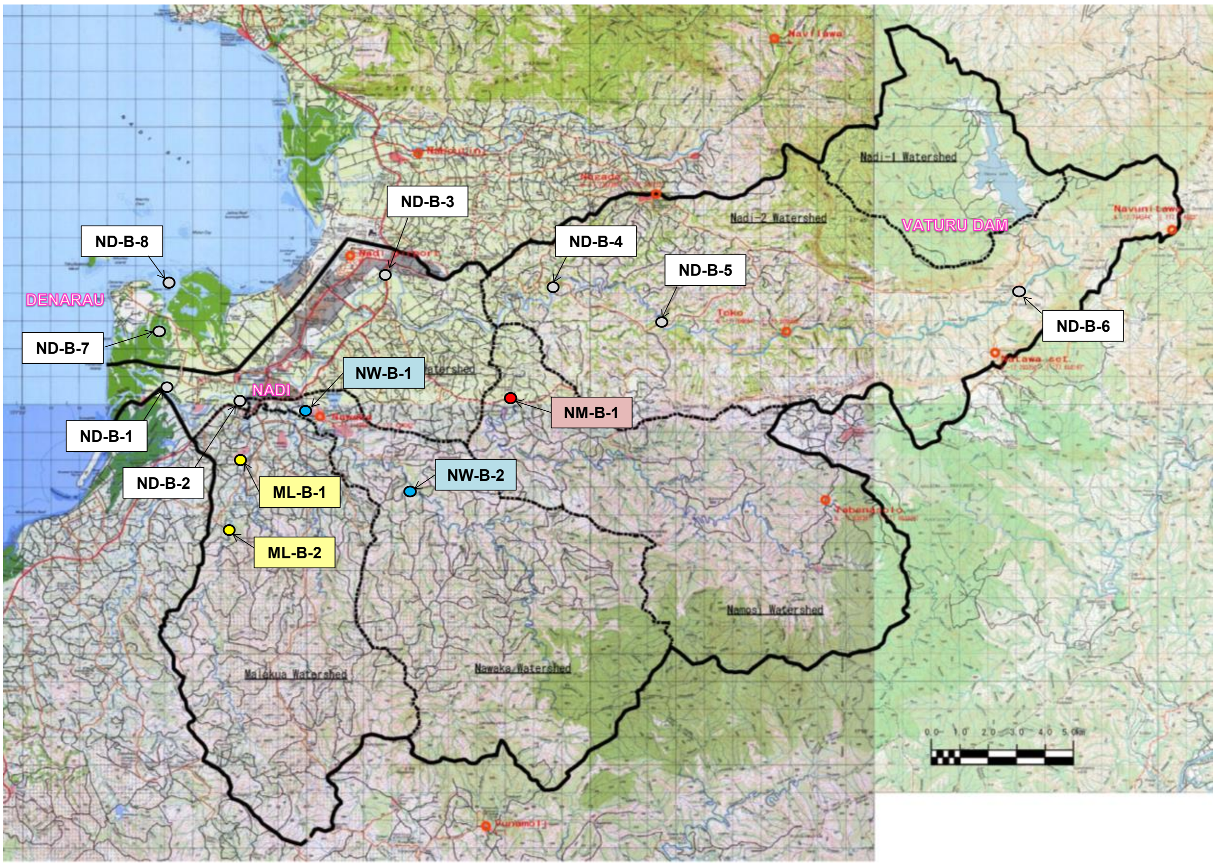


Figure 9-6 Location of Riverbed Material Investigation

The sampling method is as follows:

In the downstream tidal area the riverbed is underwater so that the Ekuman-berge type bottom sampler was used (refer to the Figure 9-7). In the other areas, the riverbed material of surface layer and lower layer near the water line were sampled (refer to the Figure 9-8). For the coarse grain size of the surface layer the grain size was measured in the longest, middle and shortest length. The lower layer was sampled after scraping off 0.5 m of surface layer

Figure 9-7 Sampling of Riverbed Material under Water (in Tidal Area and Denarau Bay)

Figure 9-8 Sampling of Riverbed Material (in Middle Stream and Up Stream)

(2) Implementation of Investigation

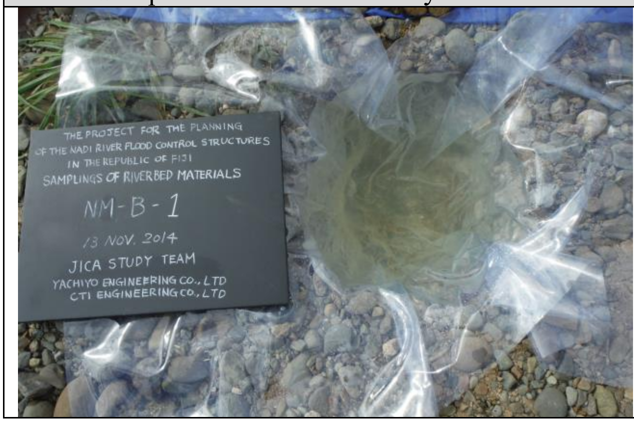
The implementation of investigation is as shown in the Table 9-3 and the typical sampling method is shown in the Table 9-4. The responsible member of JICA Study team accompanied local sampling team to all locations and decided the each sampling point and made the technical guidance of sampling method.

Table 9-3 Implementation of Riverbed Material Investigation

No	Location	Distance Post	Place of Sampling	Sampling Situation	Remarks
1	ND-B-1 (Nadi R.)	4.1k	Underwater	Flow Center (S L)	Tidal Area (normally underwater
2	ND-B-2 (Nadi R.)	7.9k	Dry Surface	Sands in River (SL,LL)	Tidal Area(Dry Surface in low tide)
3	ND-B-3 (Nadi R.)	18.8k	Dry Surface	Sands in River (SL,LL)	Back-Road Bridge
4	ND-B-4 (Nadi R.)	30.5k	Dry Surface	Sands in River (SL,LL)	
5	ND-B-5 (Nadi R.)	35.6k	Dry Surface	Sands in River (SL,LL)	
6	ND-B-6 (Nadi R.)	53.7k	Dry Surface	Sands in River (SL,LL)	Just downstream of Vaturu dam
7	ND-B-7 (Denarau Bay)	—	Underwater	Flow Center (S L)	Branch river from main stream
8	ND-B-8 (Denarau Bay)	—	Underwater	Flow Center (S L)	
9	NM-B-1 (Namosi R)	5.2k	Dry Surface	Sands in River (SL,LL)	
10	NW-B-1 (Nawaka R)	4.8k	Dry Surface	Sands in River (SL,LL)	
11	NW-B-2 (Nawaka R)	10.8k	Dry Surface	Sands in River (SL,LL)	
12	ML-B-1 (Malakua R)	2.8k	Dry Surface	Sands in River (SL,LL)	
13	ML-B-2 (Malakua R)	7.8k	Dry Surface	Sands in River (SL,LL)	

SL: Surface layer, LL: Lower Layer

Table 9-4 Typical Sampling Method(i.e. Namosi River, NM-B-1)

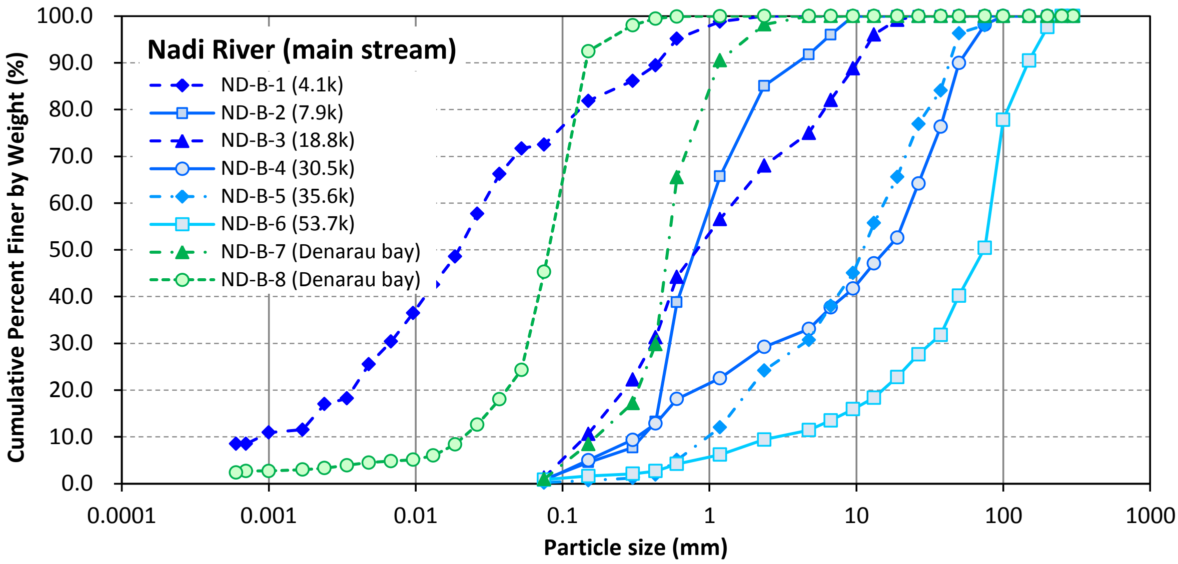
<table>
<tr><th>Sampling location (distant view)</th><th>Sampling location (near view)</th></tr>
<tr><td></td><td></td></tr>
<tr><th>Sampled material (surface layer)</th><th>Sampled material (lower layer)</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Sampled volume measured by river water</th><th>View of sampling</th></tr>
<tr><td>
</td><td></td></tr>
</table>

(3) Investigation Results

The results of investigation are as shown below.

- ➢ In the Nadi main stream the grain size widely distributes from clay and silt with the grain size less than 0.1mm to cobble with the grain size of 200mm at maximum.
- ➢ The grain size distribution in the tributaries is almost same except the middle stream location of Malakua (ML-B-1).
- ➢ The grain size of riverbed material at Nadi River mouth (ND-B-1) is less than 1mm.

  The particle with the size less than 1mm is discharged from river mouth to the sea



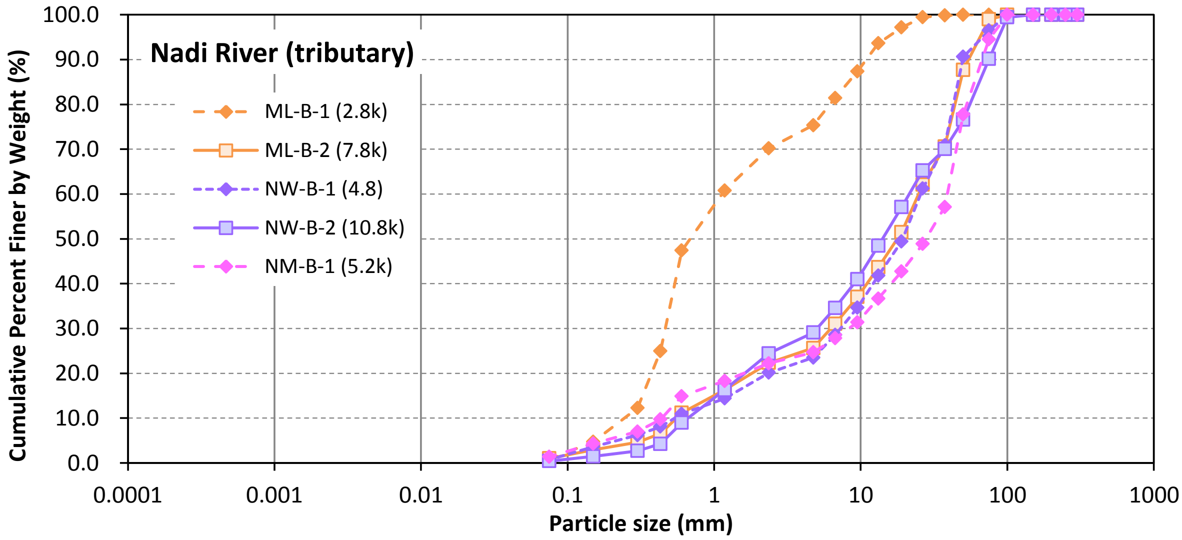


Figure 9-9 Results of Riverbed Material Investigation (Particle Size Accumulative Curve)

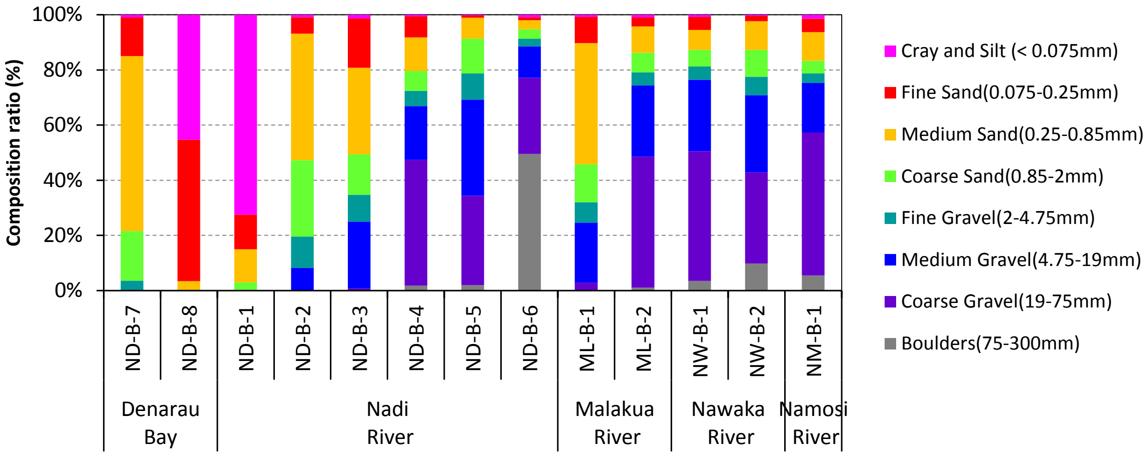


Figure 9-10 Results of Riverbed Material Investigation (Composition ratio of Grain Size)

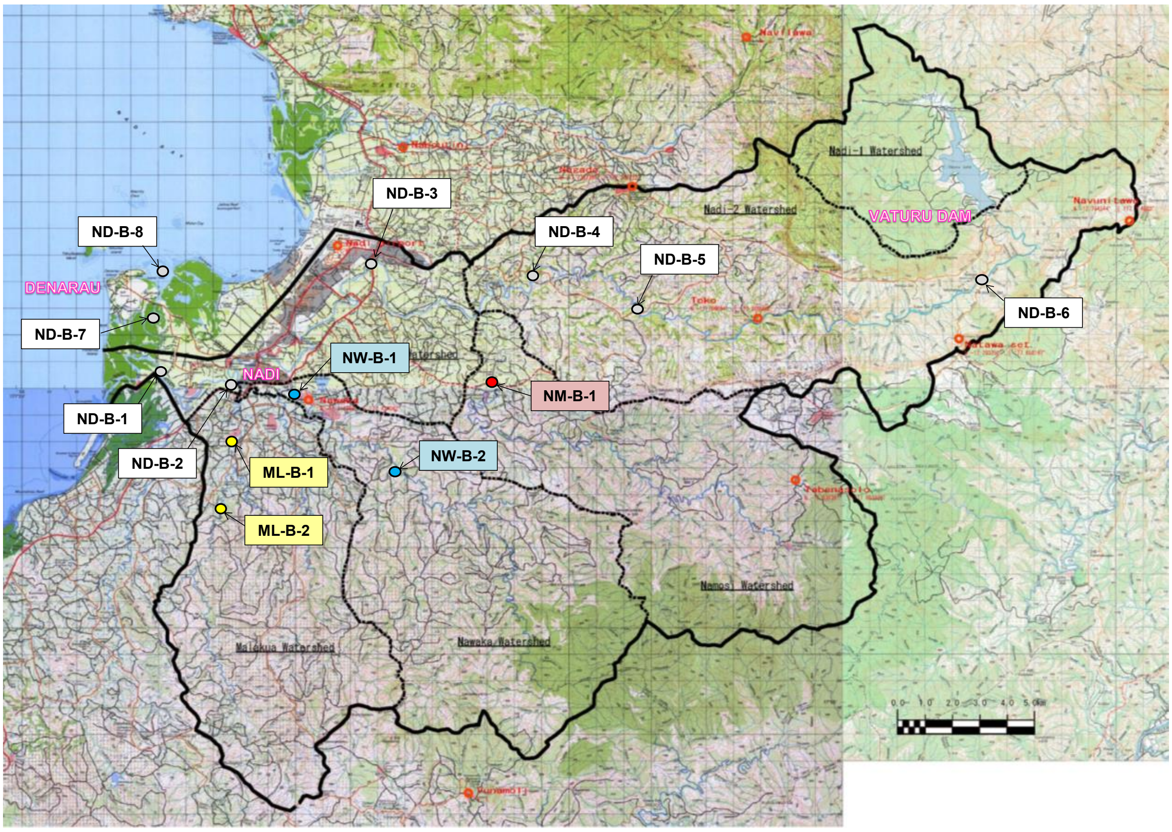
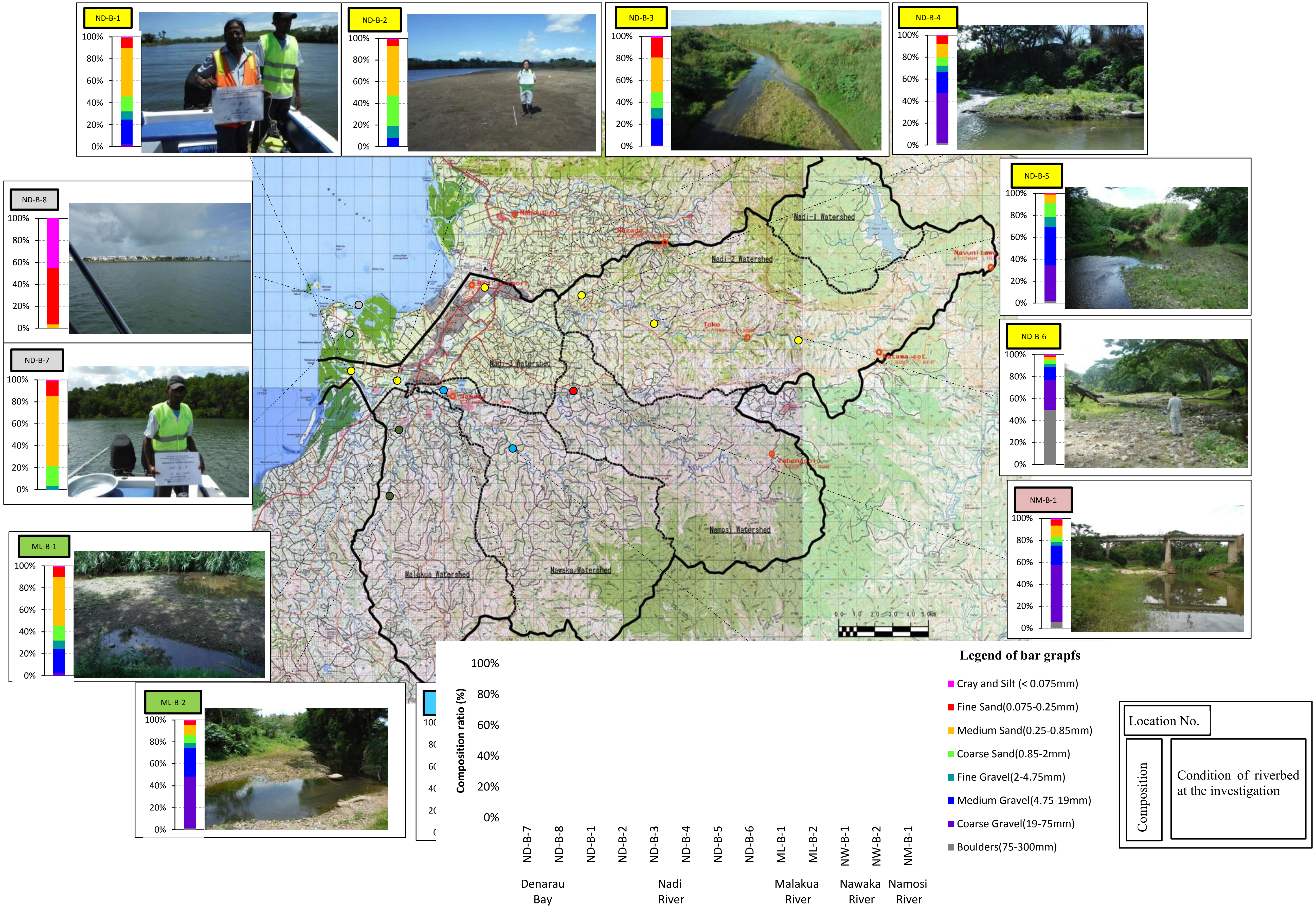
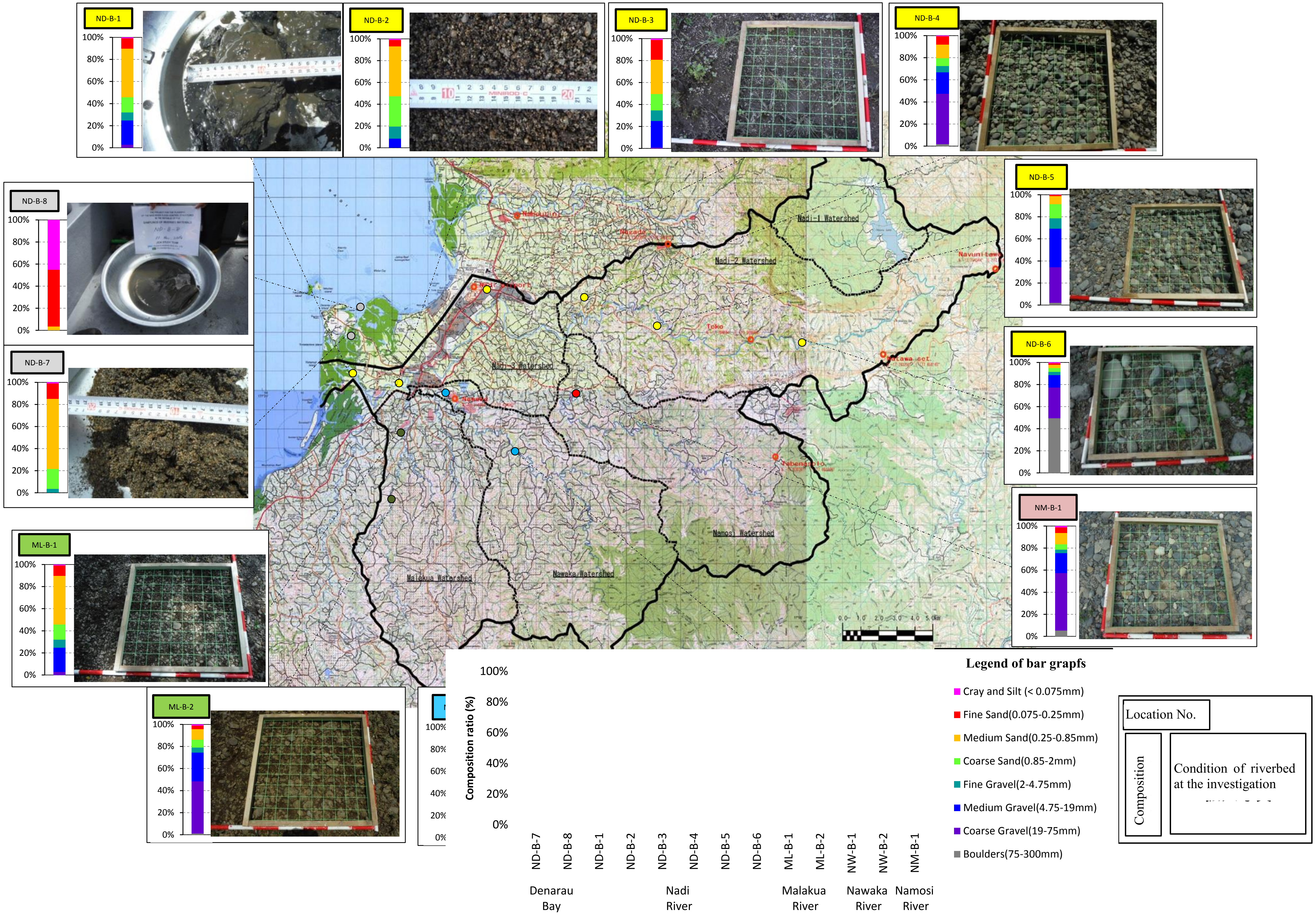


Figure 9-11 Location of Riverbed Material Investigation (repeated)


ND-B-1
ND-B-2
ND-B-3
ND-B-4
ND-B-5
ND-B-6
ND-B-7
ND-B-8
NM-B-1
ML-B-1
ML-B-2
100%
80%
60%
40%
20%
0%
Nadi-1 Watershed
Nadi-2 Watershed
Nadi-3 Watershed
Namosi Watershed
Nawaka Watershed
Malakua Watershed
Composition ratio (%)
ND-B-7
ND-B-8
ND-B-1
ND-B-2
ND-B-3
ND-B-4
ND-B-5
ND-B-6
ML-B-1
ML-B-2
NW-B-1
NW-B-2
NM-B-1
Denarau Bay
Nadi River
Malakua River
Nawaka River
Namosi River
Legend of bar grapfs
Cray and Silt (< 0.075mm)
Fine Sand(0.075-0.25mm)
Medium Sand(0.25-0.85mm)
Coarse Sand(0.85-2mm)
Fine Gravel(2-4.75mm)
Medium Gravel(4.75-19mm)
Coarse Gravel(19-75mm)
Boulders(75-300mm)
Location No.
Composition
Condition of riverbed at the investigation


ND-B-1
ND-B-2
ND-B-3
ND-B-4
ND-B-5
ND-B-6
ND-B-7
ND-B-8
ML-B-1
ML-B-2
NM-B-1
Nadi-1 Watershed
Nadi-2 Watershed
Nadi-3 Watershed
Namosi Watershed
Nawaka Watershed
Malakua Watershed
100%
80%
60%
40%
20%
0%
Composition ratio (%)
ND-B-7
ND-B-8
ND-B-1
ND-B-2
ND-B-3
ND-B-4
ND-B-5
ND-B-6
ML-B-1
ML-B-2
NW-B-1
NW-B-2
NM-B-1
Denarau Bay
Nadi River
Malakua River
Nawaka River
Namosi River
Legend of bar grapfs
Cray and Silt (< 0.075mm)
Fine Sand(0.075-0.25mm)
Medium Sand(0.25-0.85mm)
Coarse Sand(0.85-2mm)
Fine Gravel(2-4.75mm)
Medium Gravel(4.75-19mm)
Coarse Gravel(19-75mm)
Boulders(75-300mm)
Location No.
Composition
Condition of riverbed at the investigation

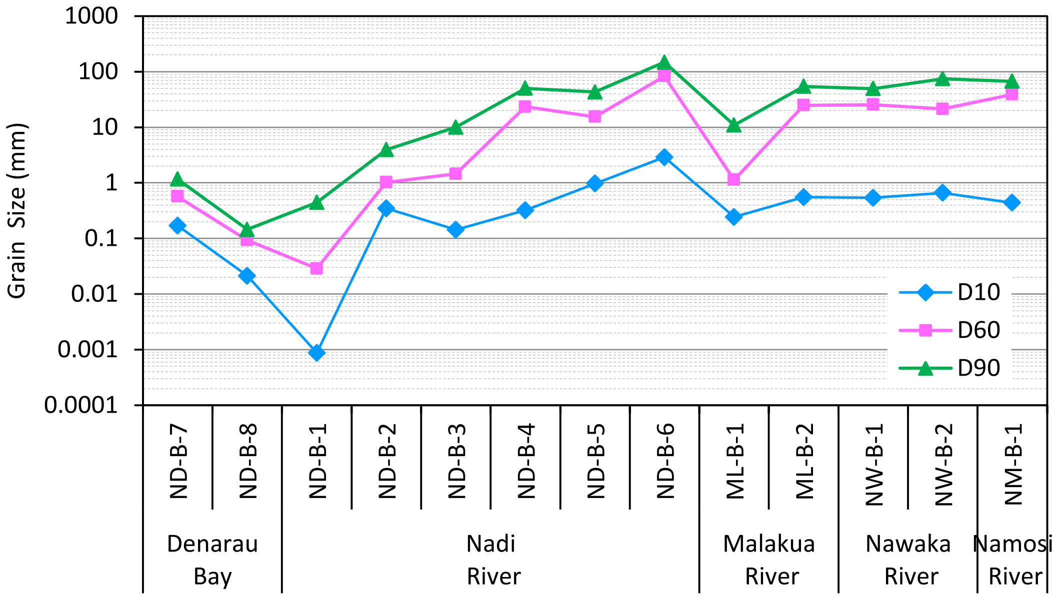


Figure 9-14 Results of Riverbed Material Investigation(D10, D60, D90)

9.2.2 Turbidity Investigation and Discharge Observation

To know the actual situation of sediment discharge in Nadi River, water sampling for the turbidity, installation of turbidity meter and water level gage were carried out. The outline and the survey results are described below.

(1) Water Sampling

1) Outline

The outline of the water sampling is shown in the Table 9-5. The water samplings were carried out in 4 times from November 2014 to March 2015 aiming at estimation of discharge condition and sediment discharge in low water. The location of sampling is shown in the Figure 9-15.

Table 9-5 Outline of Water Sampling

Item	Description	Remarks
Period	November, 2014 to March, 2015	
Number	5 times in total, once a month	
Location	7 points	3 in main stream, 1 in Namosi River, 2 in Nawaka River, 1 in Malakua River
Method	Bucket sampling	Sapling volume of 2 liters
Water Quality Item	Suspended Solid Density (SS)	

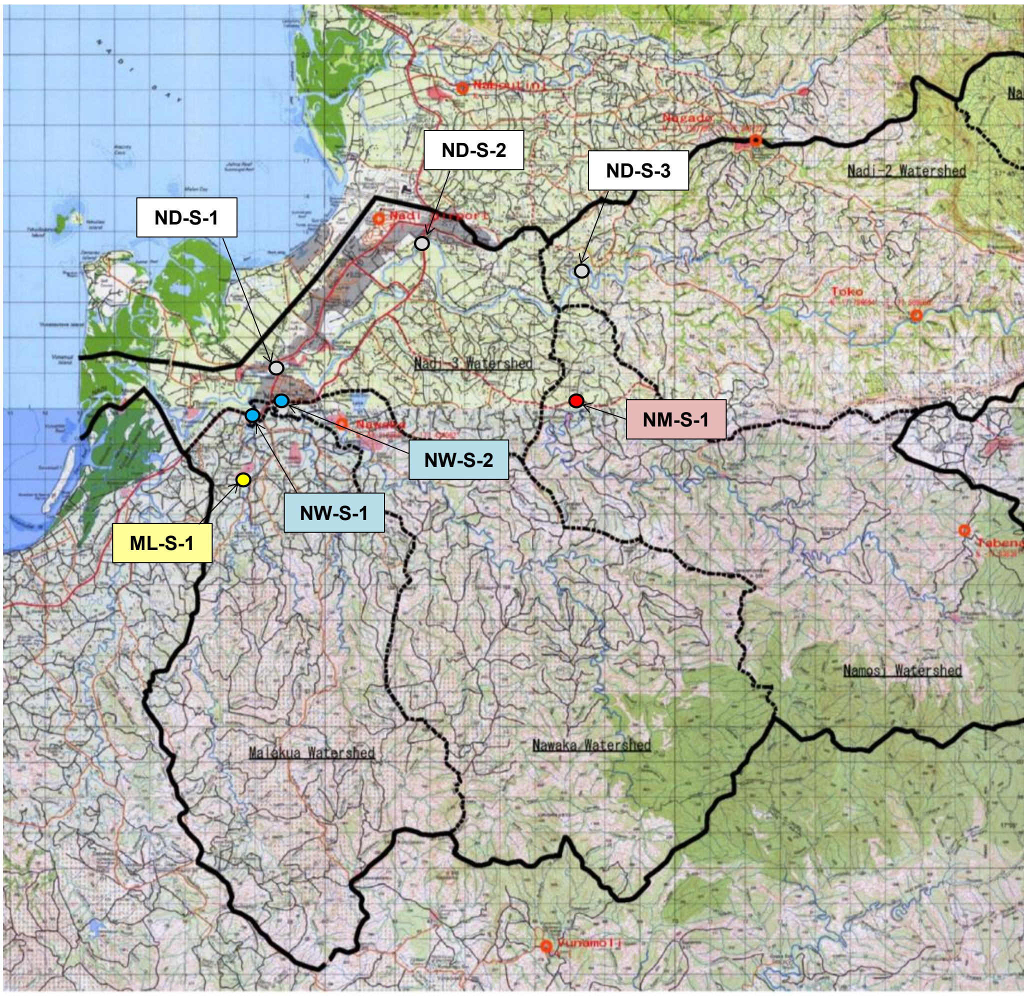


Figure 9-16 View of Water Sampling (i.e. ML-S-1 in Malakua River)

2) Results of Water Sampling

The water sampling result is shown in the Table 9-6 and the Figure 9-17.

- The sampling was carried out 5 times from dry season to wet season. The high turbidity was observed after January 2015.
- In the observation in February the high turbidity was observed in all points, especially in Namosi River.

Table 9-6 Water Sampling Results of Turbidity

Date	NadiMainRiver			NamosiRiver	NawakaRiver		MalakuwaRiver
	ND-S-1	ND-S-2	ND-S-3	NM-S-1	NW-S-1	NW-S-2	ML-S-1
	Nadi Town Bridge	Back road Bridge	Votua levu WL Station	Mulomulo Bridge	Navu Bridge	Qeleloa Bridge	Wooden Bridge
2014/11/18	5	7	6	10	6	7	1
2014/12/19	8.8	13	7.8	6	8.4	7	1.7
2015/1/21	47	180	177	170	48	34	18
2015/2/17	123	59	51.9	338	89	64	62.1
2015/3/20	39.4	17.4	10.9	13.2	11.4	12.2	18.1

（Unit：NTU）

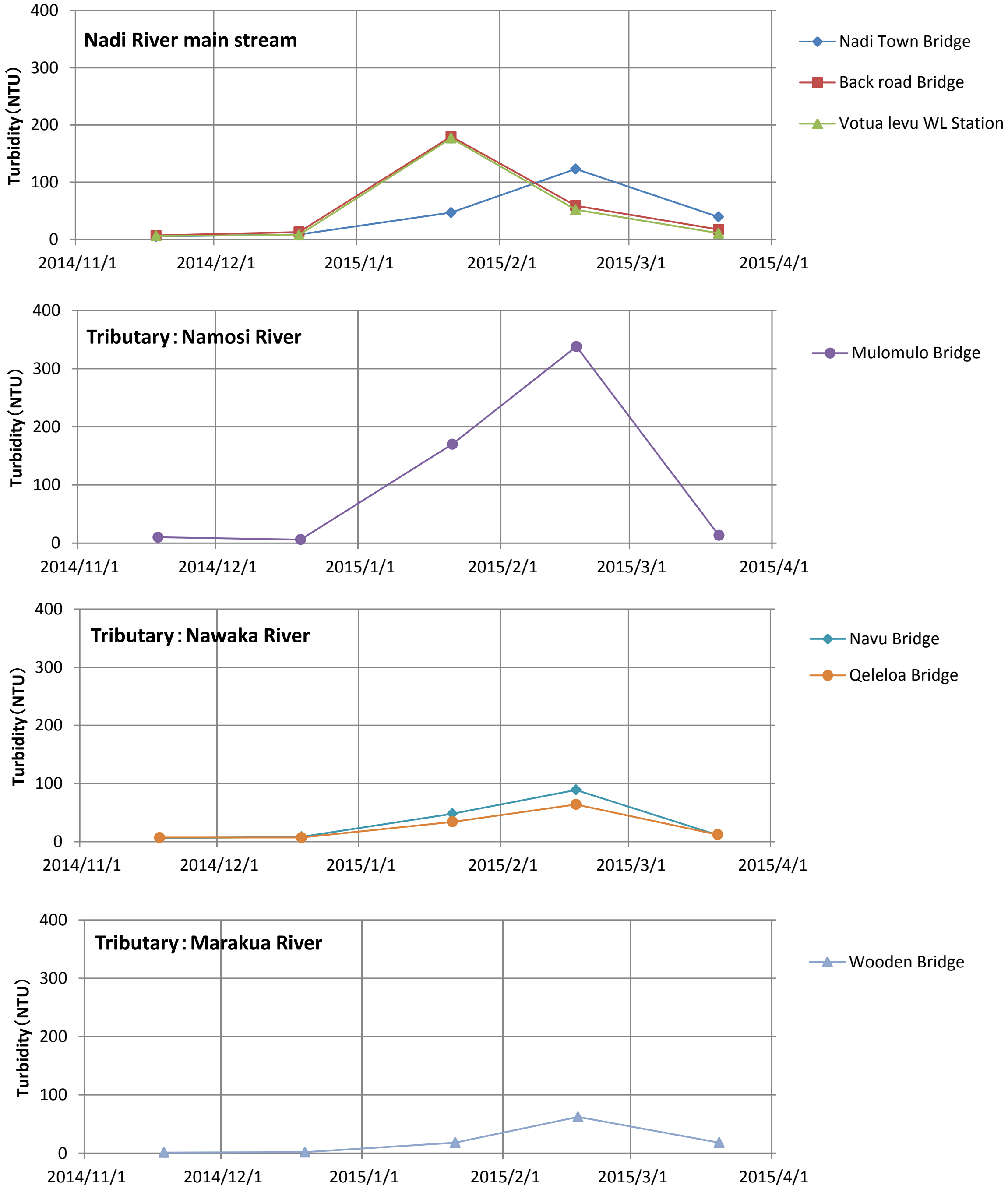


Figure 9-17 Water Sampling Results

9.2.3 Low Water Discharge Observation

1) Outline of Observation

The outline of low water discharge observation is shown in the Table 9-7. The purpose of the observation is to estimate the suspended sediment load in low water, and the observation was carried out once a month from December 2014 to March 2015. The location of observation line is same as that of high water observation. The rope with meter scale was spanned along the observation line, and the water depth and flow velocity were measured in 1-2m interval of cross section.

The section discharge was calculated by the section area and average flow velocity in each section, and the total discharge was calculated by accumulating the all interval sections. The discharge calculation method is shown in the Table 9-8 as an example.

Table 9-7 Outline of Low Water Observation

Item	Description	Remarks
Period	December 2014 - March 2015	
Observation Number	4 times, once a month	
Location Number	4 points	2 in main stream, 1 in Namosi River, 1 in Nawaka River
Observation Method	2 times measurement of water depth and flow velocity along observation line in 1 to 2m interval	Discharge is calculated by average measurement.
Item of Observation	Water depth and flow velocity	Measurement of flow velocity is applied by 1 point method or 2 point method depending on water depth at field

Figure 9-18 View of Low Water Observation (i.e. Main stream, ND-S-2)

Table 9-8 Example of Recording of Discharge Observation

THE PROJECT FOR THE PLANNING OF THE NADI RIVER FLOOD CONTROL STRUCTURES IN THE REPUBLIC OF FIJI
Flow Measurment by Current Meter

Site:	ND-S-1	(Nadi main road Bridge)
Date:	20/03/2015	
Time:start of obvervation	145 pm	
end of obvervation	220 pm	

No.of Measuring	Distance from ☐Left bank ☐Right bank	Water Depth 1st	Water Depth 2nd	Water Depth Average	Ratio of Water Depth	The depth of Current Meter	Velocity 1st	Velocity 2nd	Velocity Average	Average Velocity	Average Depth	Divided Wide	Divided Area	Area	Divided Discharge
Line	m	m	m	m	%	m	cm/s	cm/s	cm/s	cm/s	m	m	m2	m2	m3/s
No.1	0	0.00	0.00	0.00							0.12	2.00	0.24		
No.2	2	0.23	0.23	0.23	60	0.12	5.0	7.0	6.0	6				1	0.06
											0.38	2.00	0.76		
No.3	4	0.53	0.53	0.53											
											0.65	2.00	1.30		
No.4	6	0.74	0.79	0.77	20	0.15	6.0	4.0	5.0	8				2.98	0.24
					80	0.60	13.0	9.0	11.0						
											0.84	2.00	1.68		
No.5	8	0.89	0.90	0.90											
											0.98	2.00	1.96		
No.6	10	1.05	1.05	1.05	20	0.21	12.0	13.0	12.5	12.25				4.16	0.51
					80	0.84	12.0	12.0	12.0						
											1.10	2.00	2.20		
No.7	12	1.14	1.16	1.15											
											1.17	2.00	2.34		
No.8	14	1.19	1.19	1.19	20	0.24	18.0	16.0	17.0	16				4.76	0.76
					80	0.96	15.0	15.0	15.0						
											1.21	2.00	2.42		
No.9	16	1.22	1.22	1.22											
											1.29	2.00	2.58		
No.10	18	1.35	1.34	1.35	20	0.27	24.0	22.0	23.0	23.5				5.48	1.29
					80	1.08	24.0	24.0	24.0						
											1.45	2.00	2.90		
No.11	20	1.53	1.56	1.55											
											1.66	2.00	3.32		
No.12	22	1.75	1.77	1.76	20	0.35	25.0	30.0	27.5	30.25				6.94	2.1
					80	1.40	34.0	32.0	33.0						
											1.81	2.00	3.62		
No.13	24	1.81	1.91	1.86											
											1.81	2.00	3.62		
No.14	26	1.78	1.73	1.76	20	0.35	35.0	40.0	37.5	36.5				7.26	2.65
					80	1.40	33.0	38.0	35.5						
											1.82	2.00	3.64		
No.15	28	1.93	1.83	1.88											
											1.82	2.00	3.64		
No.16	30	1.76	1.74	1.75	20	0.35	37.0	38.0	37.5	33.25				7.12	2.37
					80	1.40	30.0	28.0	29.0						
											1.74	2.00	3.48		
No.17	32	1.71	1.73	1.72											
											1.72	2.00	3.44		
No.18	34	1.71	1.72	1.72	20	0.34	38.0	40.0	39.0	41				6.9	2.83
					80	1.36	41.0	45.0	43.0						
											1.73	2.00	3.46		
No.19	36	1.76	1.72	1.74											
											1.68	2.00	3.36		
No.20	38	1.62	1.59	1.61	20	0.32	41.0	45.0	43.0	40.5				6.62	2.68
					80	1.28	36.0	40.0	38.0						
											1.63	2.00	3.26		
No.21	40	1.64	1.64	1.64											
											1.61	2.00	3.22		
No.22	42	1.59	1.57	1.58	20	0.32	46.0	50.0	48.0	42.75				4.80	2.05
					80	1.28	37.0	38.0	37.5						
											0.79	2.00	1.58		
No.23	44	1.72	1.72	0.00											
Total														58.02	17.54

Q=	17.54	m3/s
A=	58.02	m2
V=	0.30	m/s

2) Observation Demonstration with FMS

The observation demonstration was carried out together with observation team and FMS members at MuloMulo Bridge in Namosi River on November 19, 2014 which is one of observation points of low water discharge. FMS displayed their observation method which is to be useful reference.

Figure 9-19 Low Water Observation Demonstration by FMS

3) Observation Results of Low Water Discharge

The observation results are shown in the Table 9-9.

- Although the observations were carried out in the normal flow condition, the discharge after January seems to be increased in main stream and tributaries.
- In rainy season the discharge in the tributaries Namosi and Nawaka is almost same.

Table 9-9 Observation Results of Low Water Discharge

Date	Nadi River		Namosi River	Nawaka River
	ND-S-1	ND-S-2	NM-S-1	NW-S-1
	Nadi Town Bridge	Back road Bridge	Mulomulo Bridge	Navu Bridge
2014/12/19	5.8	0.3	0.2	1.1
2015/1/16	3.6	—	—	—
2015/1/21	—	10.4	3.8	2.4
2015/2/17	17.2	14.5	11.2	12.8
2015/3/20	17.5	14.6	3.8	3.2

(Unit: m^3/s)

4) Estimation of Relation between Discharge and Suspended Sediment Load

The relation between discharge and suspended load was estimated applying discharge observed at each point and the turbidity obtained by water sampling at same point and in the same day.

The suspended sediment load calculated by discharge and turbidity is shown in the Table 9-10.

Table 9-10 Calculation of Suspended Sediment Load

Date	Nadi River		Namosi River	Nawaka River
	ND-S-1	ND-S-2	NM-S-1	NW-S-1
	Nadi Town Bridge	Back road Bridge	Mulomulo Bridge	Navu Bridge
2014/12/19	51	4	1	9
2015/1/21	169	1,879	638	117
2015/2/17	2,112	857	3,796	1,140
2015/3/20	691	254	50	36

(Unit: g/s)

Based on the observed suspended sediment load and discharge the relation between discharge and suspended sediment load is as shown in the Table 9-20 in each observation point.

- Since the suspended load estimation equation is obtained in the low water, the condition in high water is not estimated enough, the coefficient values of the estimation equation have been identified either in Japan rivers; by the way, at the location of Back Road Bridge, since the tendency of the coefficient values are different from the other points, another estimation equation is adopted according continuous observation of the turbidity and water level at the same location (ref. 9.2.1(2)).
- The fine sediment load is apt to be discharged from Namosi River among 4 points of observation.

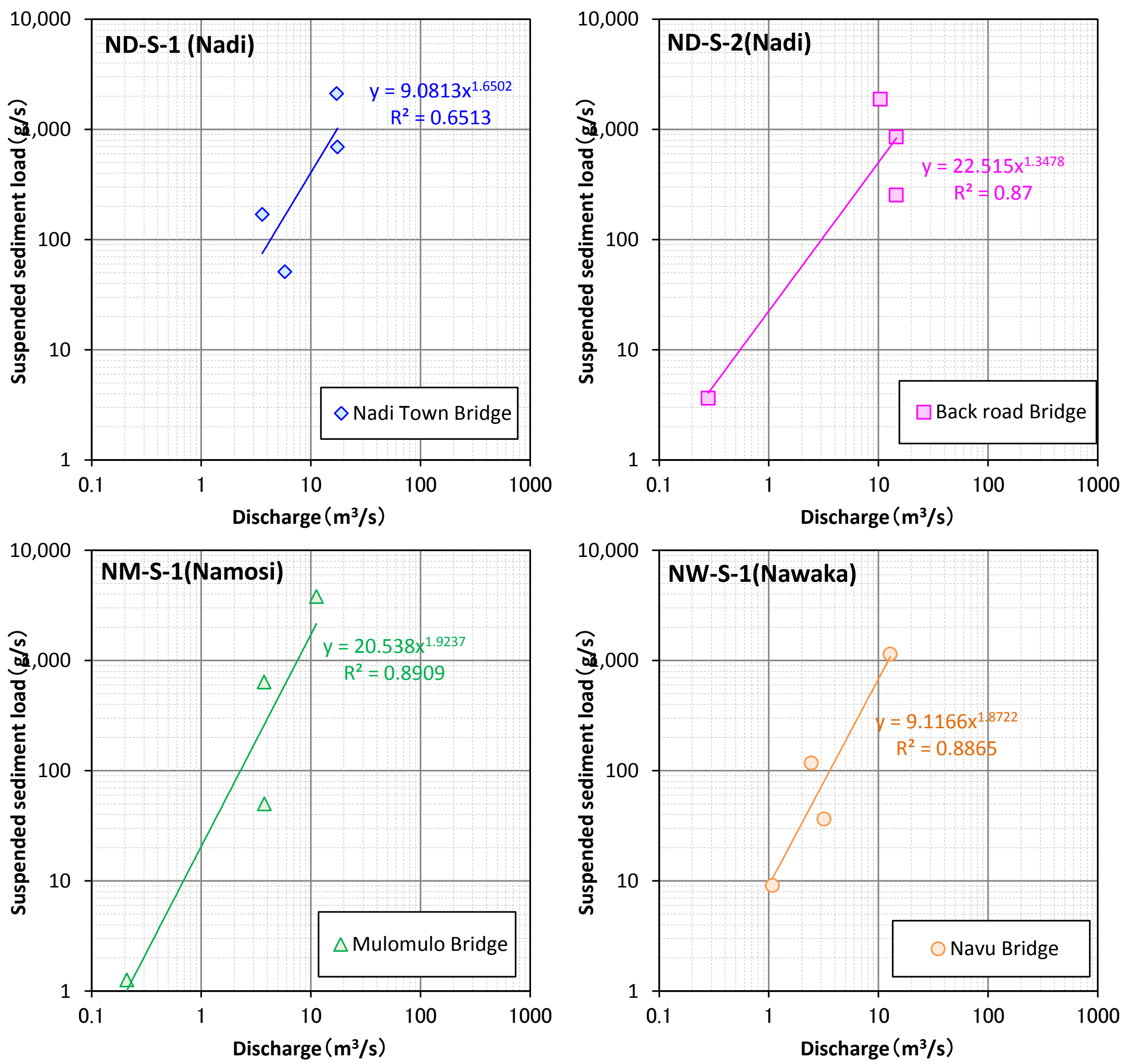


Figure 9-20 Estimation Equation of Suspended Sediment Load

(2) Installation and Measurement of Water Level Meter and Turbidity Meter

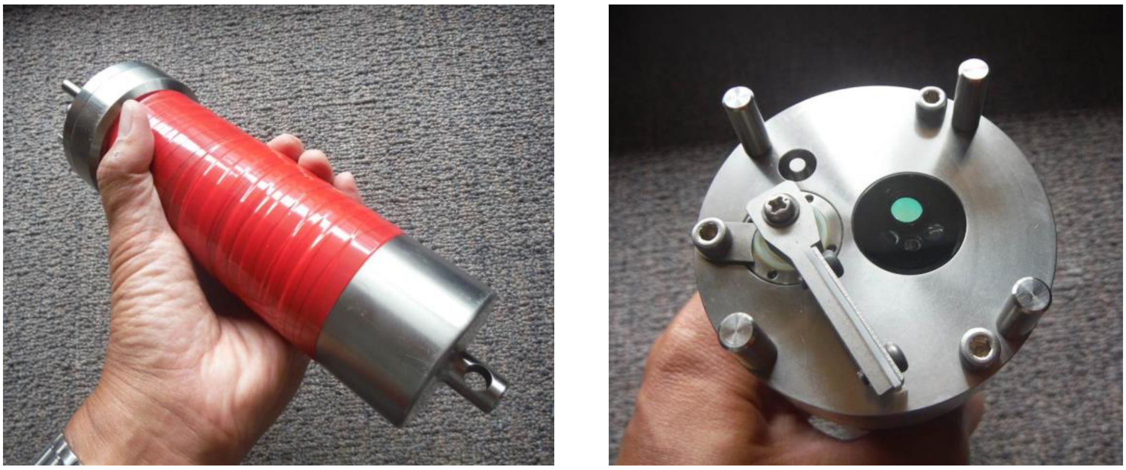
1) Outline of Installation

In order to observe the sediment discharge continuously the automatic water level meter and turbidity meter were installed at 2 points in Nadi River main stream and Nawaka River. The outline of installation is shown in the Table 9-11. In the measurement of water level the adjustment of influence of atmospheric pressure is required so that the atmospheric pressure is measured at the same time.

Table 9-11 Installation and Measurement of Turbidity Meter and Water Level Meter

Item	Description	Remarks
Period	November 2014 to March 2015	
Location	Back Load Bridge (Nadi main stream) Navu Bridge (Nawaka River)	
Equipment	Diver Water Level Meter (DIK-613A)※1 Small Size Memory Turbidity Meter (COMPACT-CLW)※2	※1 made by Daiki Rika Kougyou Co.,Ltd. ※2 made by JFE Advantec
Measurement Interval	Water level: 10minutes, Turbidity: 30minutes	
Item of Measurement	Water level, Turbidity	

Picture 9-1 Water Level Meter(water level: left side 2 pieces, pressure: right side 1 piece)



Picture 9-2 Turbidity Meter (left side: total view, right side: sensor face)

(i) Installation of Equipment

The equipment was installed not to be washed away in flood time. In the both locations, the equipment was inserted into the steel pipe and the top of pipe was protected by the lock not to be stolen.

At the Navu Bridge in Nawaka River, the pipe was fixed to the downstream side of the foundation pile of railway bridge pier so that the risk of washed away by the collision of drift wood and so on could be reduced (refer to the Picture 9-3). Since the area is incurred by tidal effect and the water level varies periodically, so that the equipment was installed under water even in low tide of the spring tide

At the Back Road Bridge in Nadi River, the pipe was fixed to the steel angle piled into riverbed since there is no appropriate method of fixing the pipe to the pier (refer to the

Picture 9-4). Since the area has no tidal effect and as it is low water season, the equipment was installed under water considering water level at that time.

Picture 9-3 Installation of Observation Equipment (Navu Bridge in Nawaka River)

Picture 9-4 Installation of Observation Equipment (Back Road Bridge in Nadi River)

(ii) Guidance for Maintenance

It is necessary that the data is to be collected periodically (once a month) and the condition of equipment installation is to be confirmed by the local staffs. To collect data, connection of personal computer with observation equipment by cable and use of data collection software are required, therefore the procedure of data collection and re-starting of measurement of equipment were guided to the local staffs (refer to the Picture 9-5).

Picture 9-5 Explanation of Using Method of Data Collection Software

2) Results of Observation

The observation results of water level and turbidity are as shown in the Figure 9-21 and the Figure 9-22. As to the turbidity the observation was interrupted for one month from the middle of January 2015 to the middle of February 2015 due to the out of order of equipment.

In Nawaka River, the constant noise of data was recognized in previous half period of observation period, however the data was revised by the turbidity data in water sampling carried out at the same point.

As to the water level, the observation was carried out through the almost entire objective period.

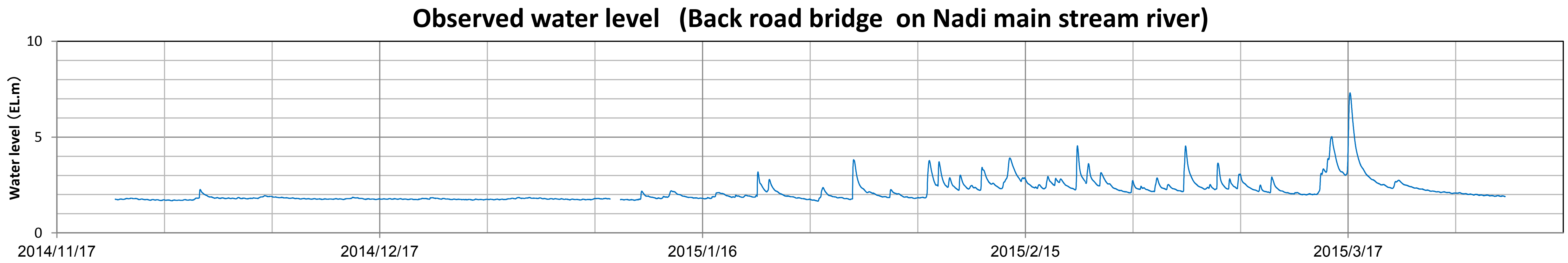
The characteristics of observation results are as shown below:

(Nadi main stream: Back Road Bridge)

- During November to December, although the water level was increased once in the beginning of December, the observed water level was almost steady and turbidity was also low in the other period.
- After February the rise of water level was observed frequently which showed the season shifted to rainy season, and the turbidity also rose up to the maximum of 600 to 800(NTU).

(Nawaka River: Navu Bridge)

- The water level repeated amplitude due to the tidal effect in normal time because the location belongs to tidal area
- The variation of turbidity is same as in Nadi River. During November to December the turbidity was increased once in the beginning of December and continued in low in the other period.
- After February the rise of water level was observed frequently, and the turbidity also rose up to the maximum of 800(NTU).



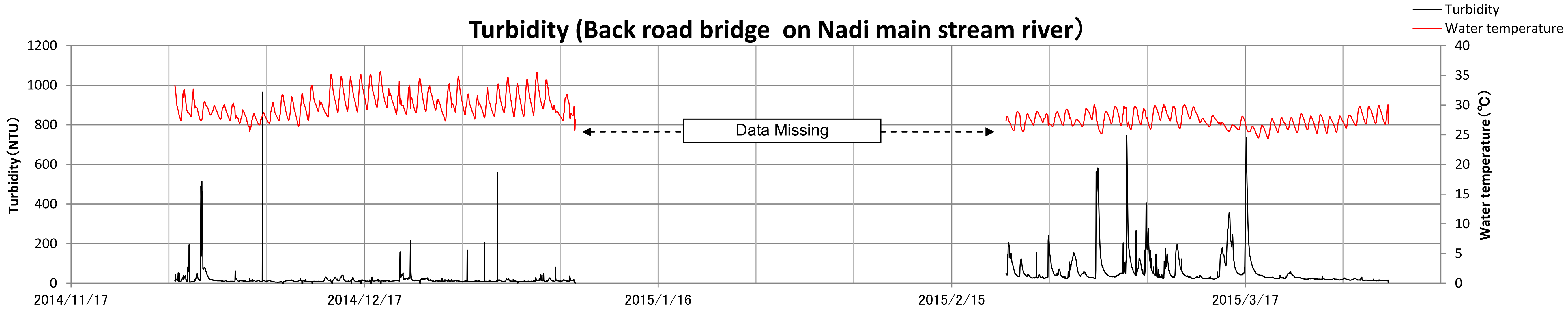
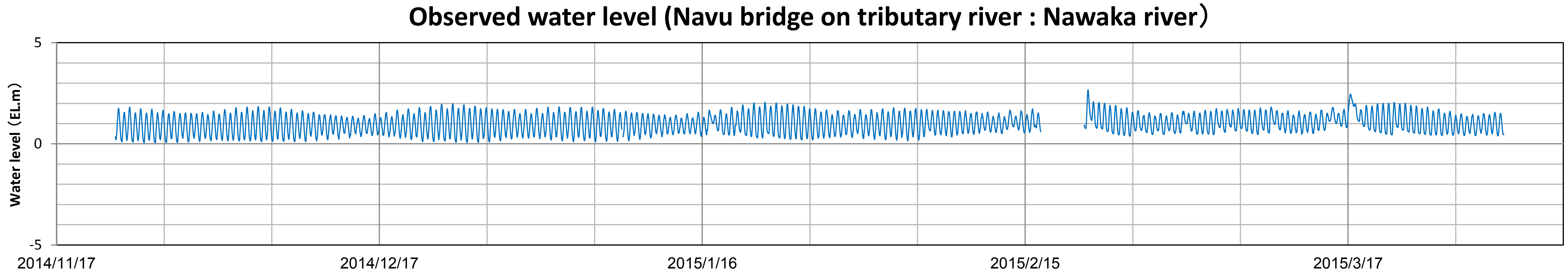


Figure 9-21 Continuous Observation of Water level and Turbidity (Nadi main stream: Back Road Bridge)



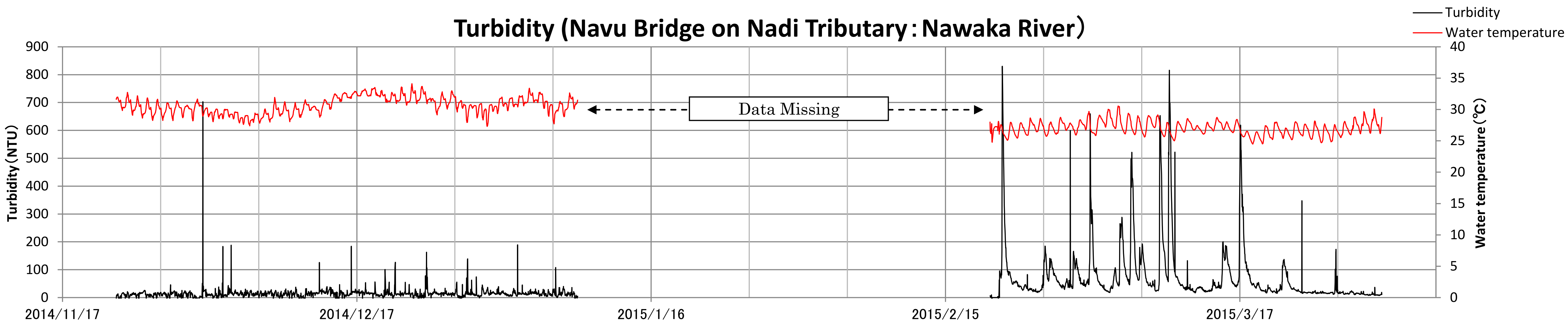


Figure 9-22 Continuous Observation of Water level and Turbidity (Tributary Nawaka River: Navu Bridge)

9.3 Sediment Transport Analysis

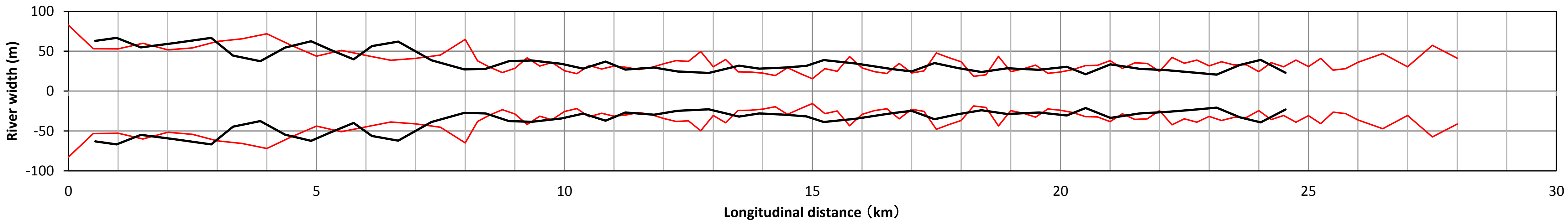
Based on the collected data and information, and the results of field investigation carried out in this Project, the sediment transport phenomenon is analyzed, and the present situation is reproduced and the future circumstance is predicted.

9.3.1 Present Situation of Sediment Transport

(1) Variation of River Profile

Based on the result of river surveys carried out in 1998 and in 2014, the variation of river profile is compared and examined. The river profiles are shown in the Figure 9-23. The findings are as shown below

- In the downstream area, the sections with tendency of riverbed upgrading and downgrading are continued. As mentioned before, the river dredging was implemented between the distance post 0k-7.8k in 2008-2012 which seems to be a factor of riverbed downgrade between the distance posts 4k-7k.
- The partial variation is observed between the distance post 10k-20k, which is not so much in that of downstream area.
- In the section of upstream of the distance post 20k, the riverbed downgrade is observed totally which is not so much in that of downstream area.
- Although the river width is enlarged in double after confluence with Nawaka River, it is considered that there is not much difference between in1998 and in 2014.



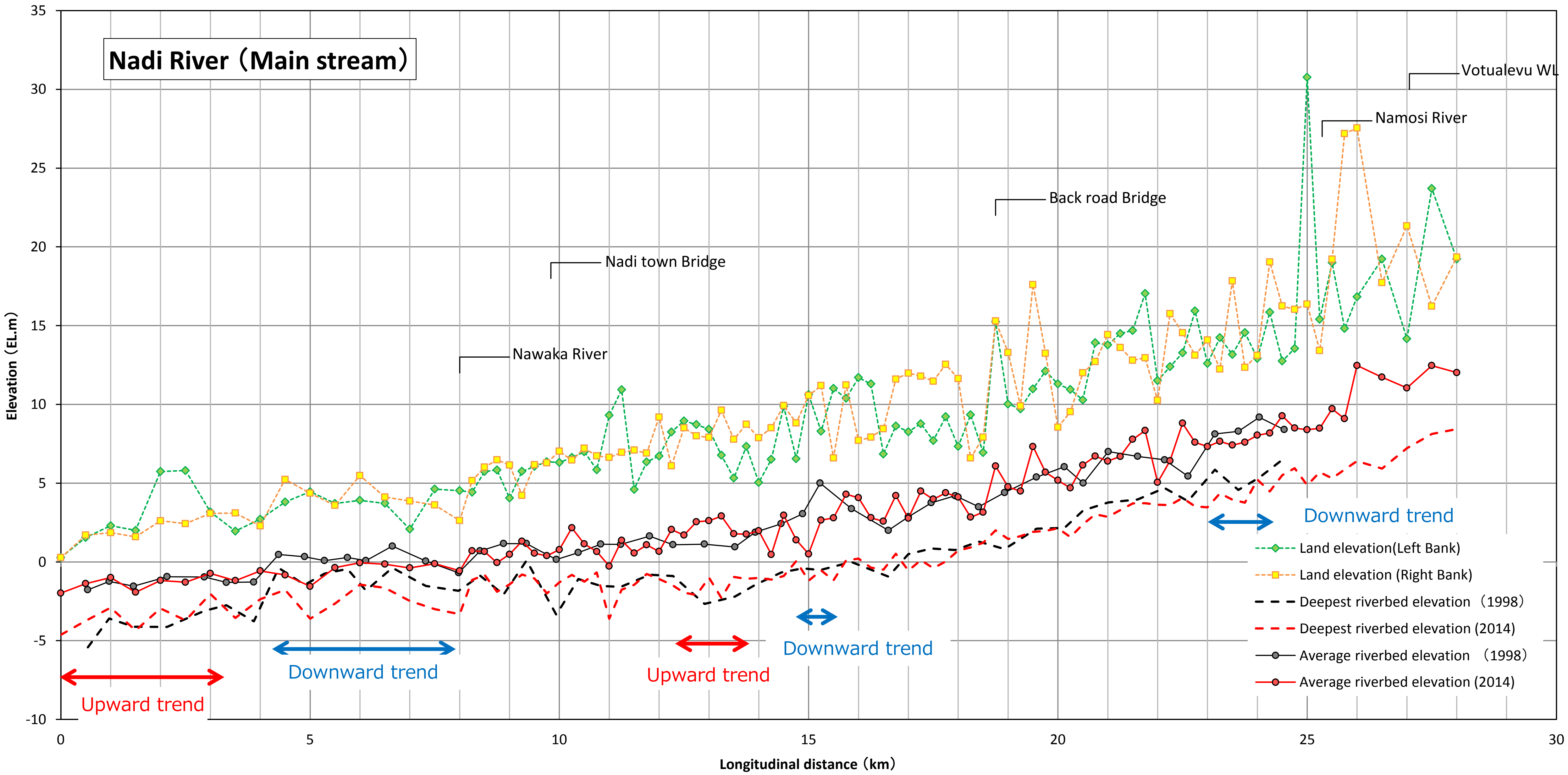


Figure 9-23 Variation of Riverbed (Nadi main stream: 0.0k- 28.0k)

(2) Variation of River Cross Section

The crossing section of the nearly surveying point is compared between two periods of 1998 and 2014. The results are as shown in the Figure 9-24 and the Figure 9-25 together with river profiles.

The findings are shown as below and the evaluation hereafter is qualitative consideration since the cross section survey lines are not always same in 1998 survey and in 2014 survey as shown in the Figure 9-23. However, the ground elevation of the river bank in showing cross section are almost the same as at the 9.3k point and 24.0k point, the reference of altitude is considered to be accordant.

- In the riverbed upgrade section in the river mouth area, the river width in 2014 is reduced than in1998 and the deepest portion of riverbed is observed to be buried by sediment.
- As to the cross section at near the distance post 10k, there seems not to be much difference in the riverbed shape although the detail analysis is difficult due to insufficient matching of cross section survey line.
- In the upstream of distance post 15k, although the river profile is observed downgrade of riverbed, the reason seems to be downgrade of the deepest portion of riverbed and enlargement of river width by bank erosion.

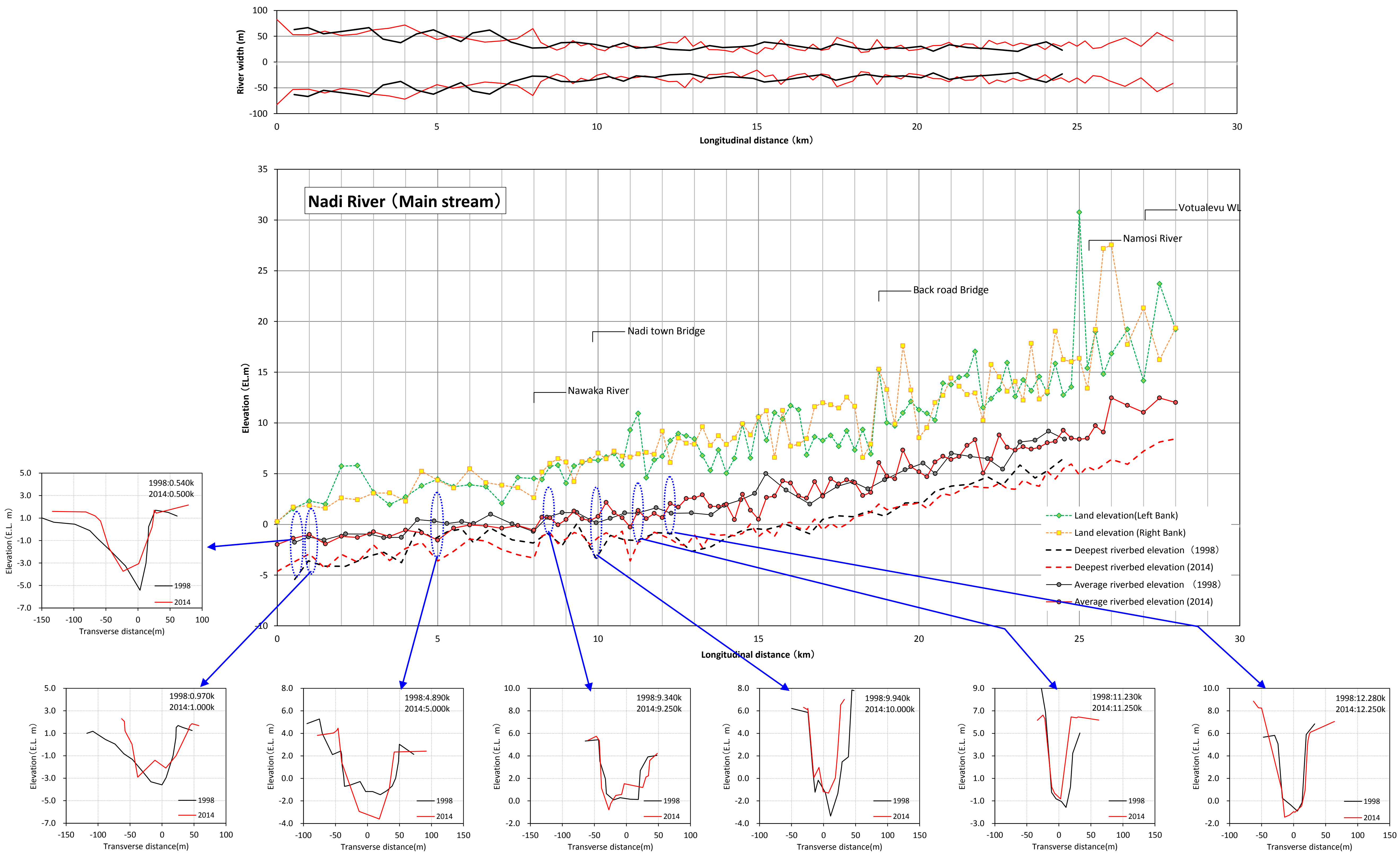


Figure 9-24 Variation of River Cross Section (Nadi main stream: 0.0k to 12.0k)

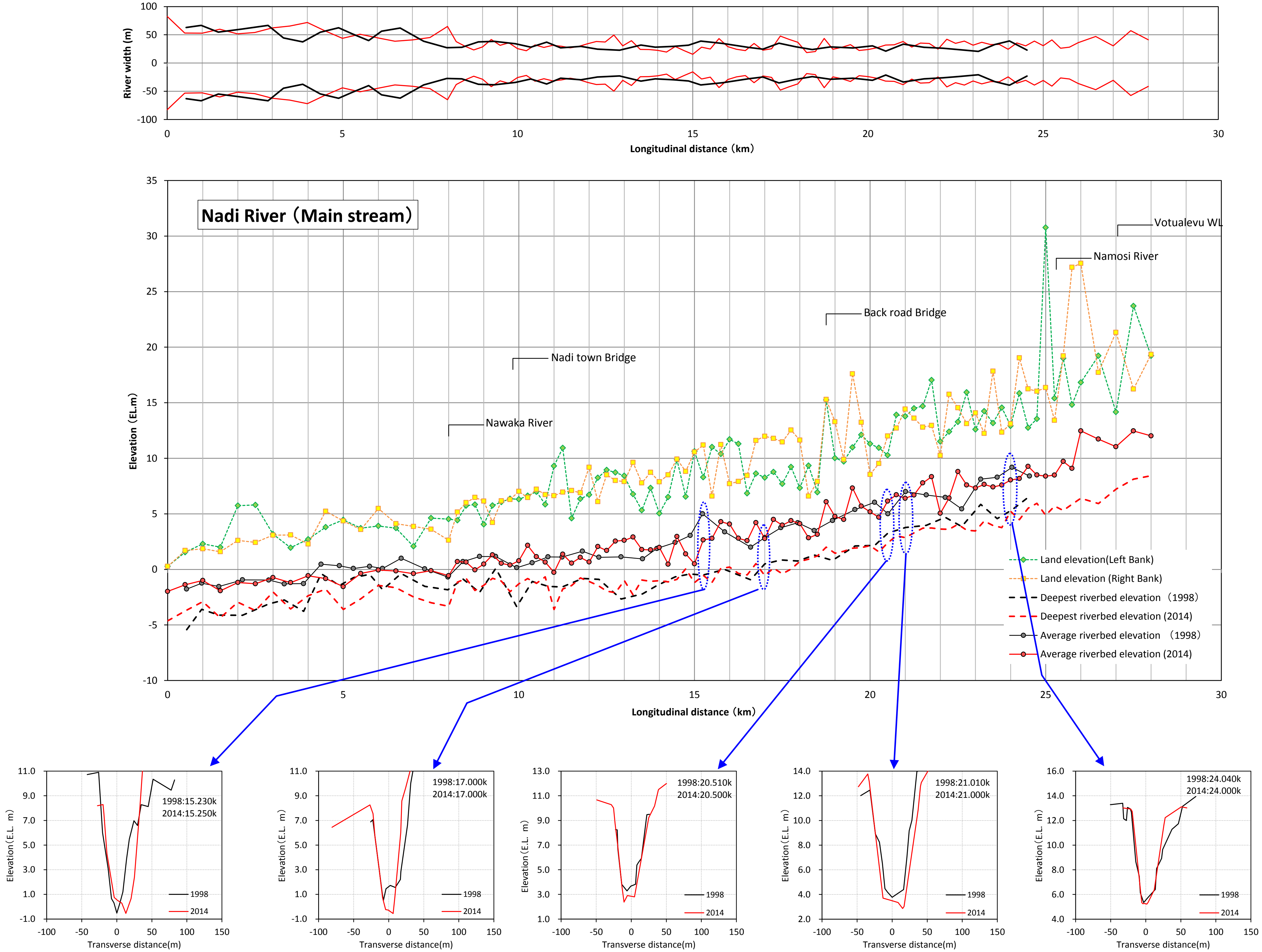


Figure 9-25 Variation of River Cross Section (Nadi main stream: 15.0k- 24.0k)

(3) Estimation of Sediment Runoff Discharge

The sediment runoff discharge (suspended sediment load) during observation period is estimated in the two locations of Back Road Bridge (Nadi River main stream) and Navu Bridge (tributary Nawaka River)

1) Calculation of H-Q Equation

In calculation of sediment runoff discharge, the conversion of observed water level into water discharge is necessary. H-Q equation is calculated by the results of low water observation and high water observation which was carried out on March 17, 2015 as one of training.

The calculated H-Q equation is shown in the Figure 9-26 and Figure 9-27.

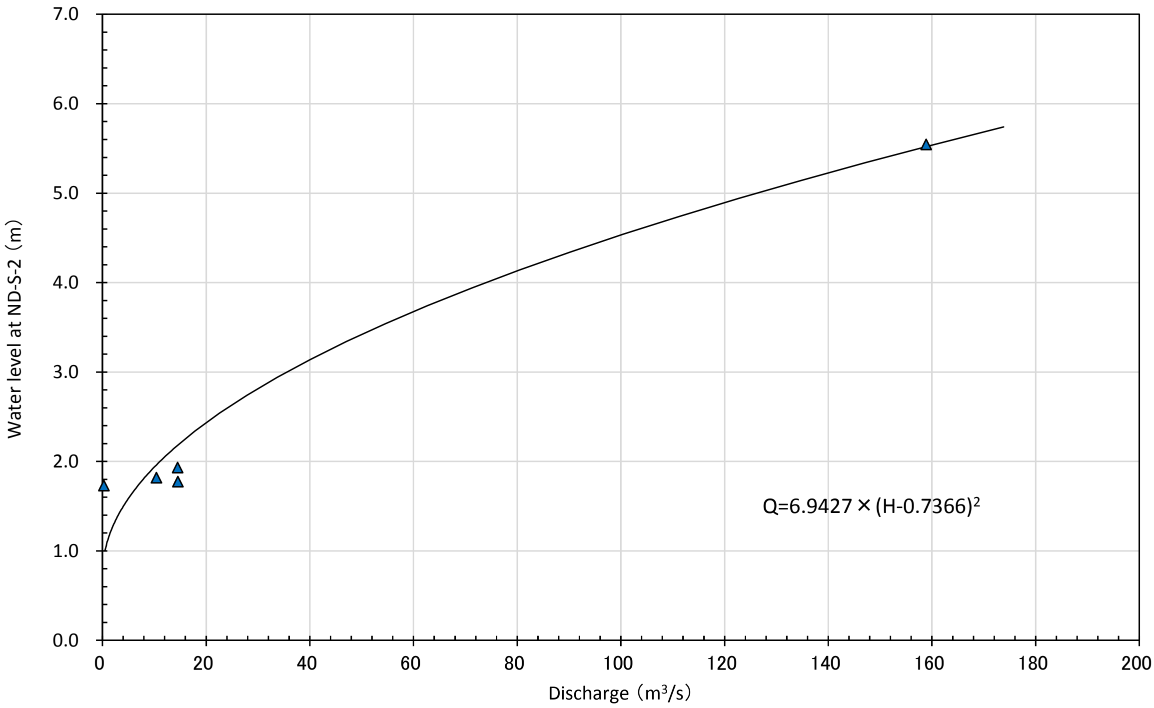


Figure 9-26 H-Q Equation (Nadi River main stream)

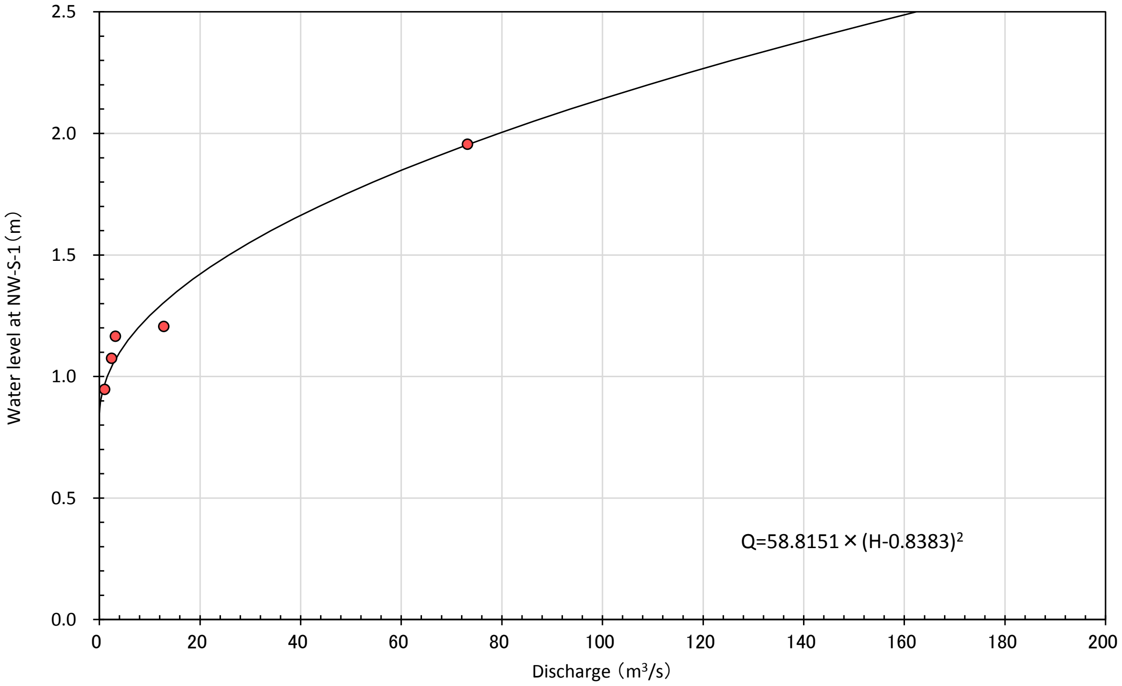


Figure 9-27 H-Q Equation (Tributary Nawaka River)

2) Calculation of Sediment Runoff Discharge

The sediment runoff discharge is calculated by using H-Q equation obtained in the previous section on the preconditions described below.

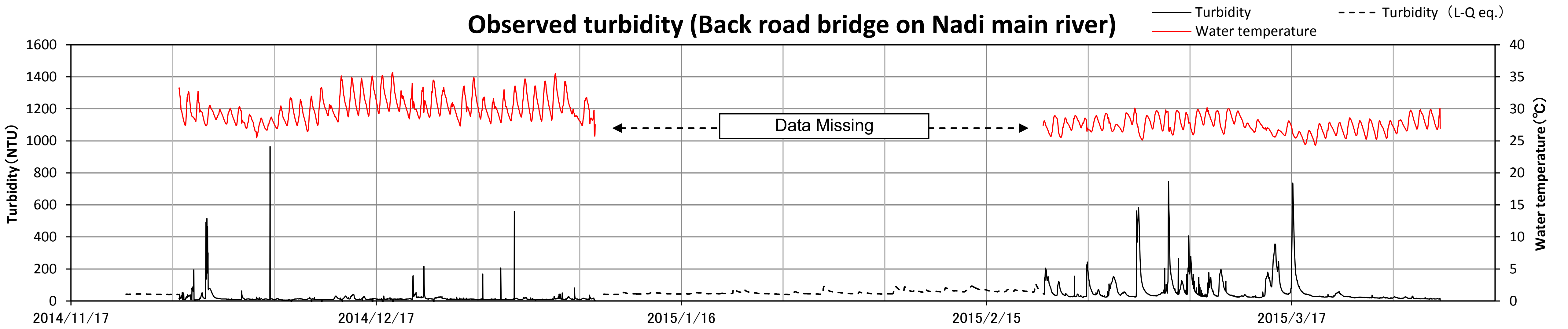
- During the period , middle of January to middle of February, in which the turbidity (L) could not be observed, the water level is converted to water discharge applying H-Q equation at each location, then the discharge is converted finally to the turbidity by applying L-Q equation.
- Navu Bridge in Nawaka River is in the tidal area so that the water level is changed periodically and the calculation of discharge by simple application of H-Q equation is difficult, therefore the discharge is estimated by using average water level in 24 hours excluding the tidal effect.

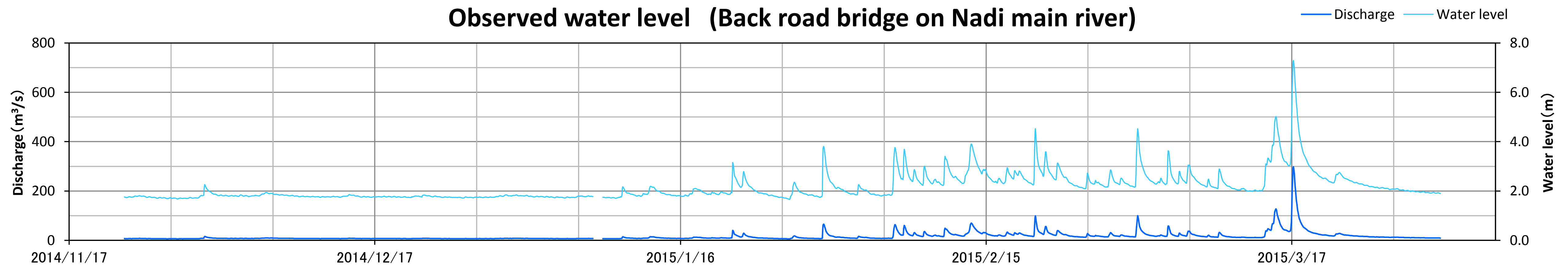
The sediment runoff discharge at each point estimated based on the observation results is as shown in the Figure 9-28 and Figure 9-29. The findings from the figures are as shown below:

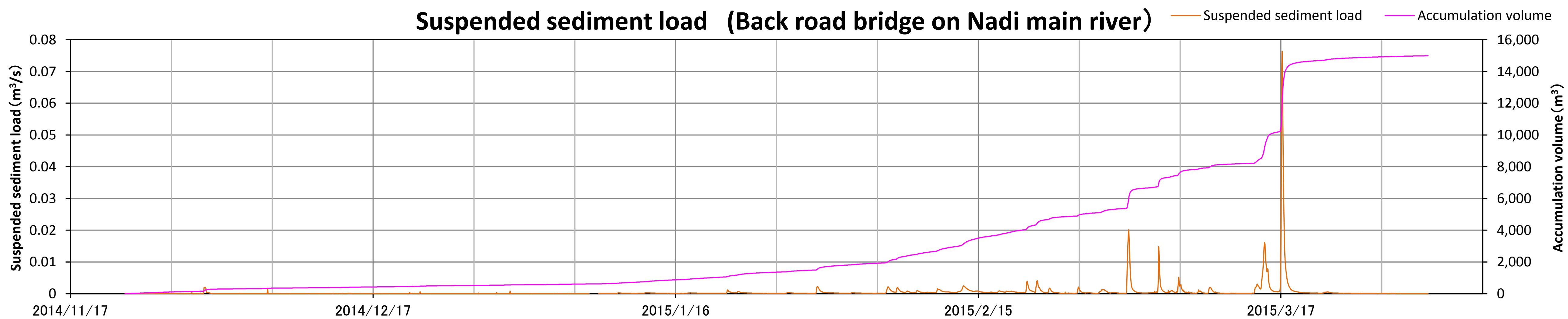
- At both points the sediment runoff discharge increases abruptly after entering into the rainy season.
- At Back Road Bridge in Nadi main stream and Navu Bridge in Nawaka River, the total sediment runoff discharge reaches 15,000 m3 and 3,000 m3 respectively. The ratio of total sediment runoff discharge is 5: 1.
- Since the turbidity itself has no big difference at both points, the reason of large difference of discharge amount is due to the area and topography characteristic of upstream catchment, and due to that the Nadi main stream includes Namosi tributary basin which has characteristics of yielding more sediment than other tributaries (refer to the Figure 9-13). Hereafter the verification from sediment yield potential due to topographic characteristics point of view is done.

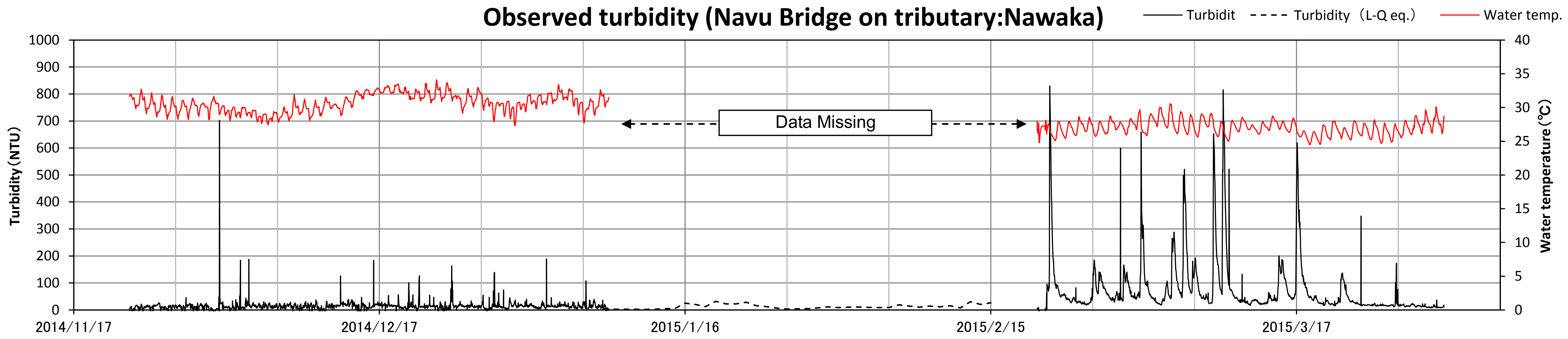
Table 9-12 Estimation of Sediment Runoff Discharge

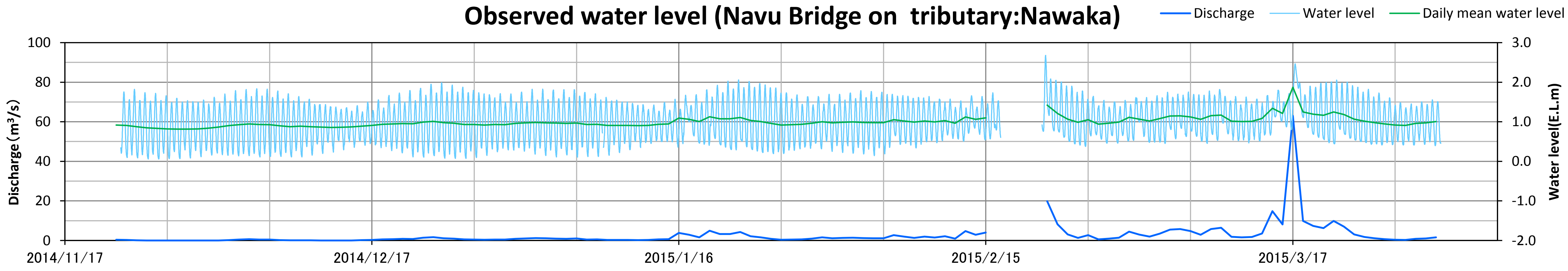
Location	Total Volume	Catchment Area
Back Road Bridge	15,000m^3	276km^2(59%)
Navu Bridge	3,000m^3	190km^2(41%)

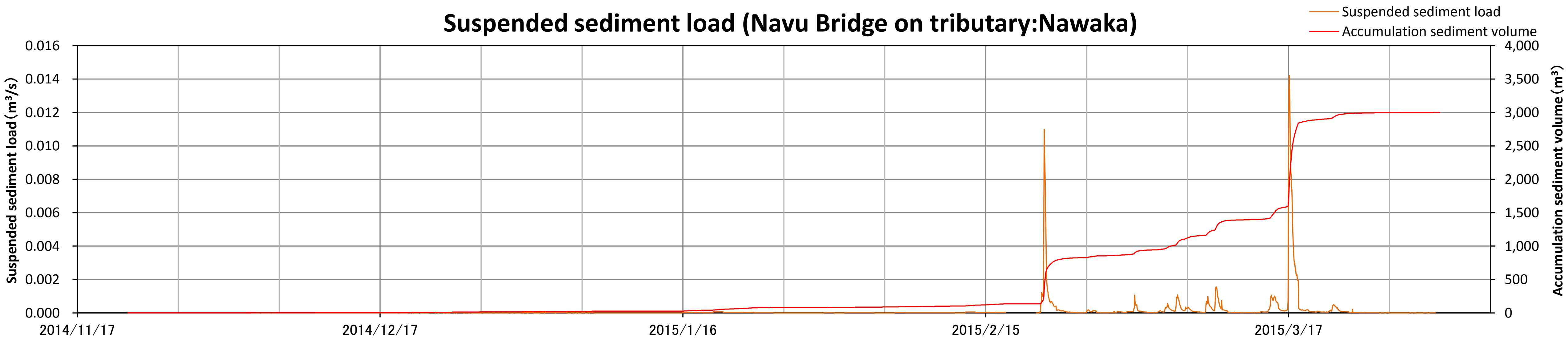

Observed turbidity (Back road bridge on Nadi main river)
Turbidity
Water temperature
Turbidity（L-Q eq.）
Turbidity (NTU)
Water temperature (℃)
Data Missing
1600
1400
1200
1000
800
600
400
200
0
40
35
30
25
20
15
10
5
0
2014/11/17
2014/12/17
2015/1/16
2015/2/15
2015/3/17


Observed water level (Back road bridge on Nadi main river)
Discharge
Water level
Discharge (m³/s)
Water level (m)
800
600
400
200
0
8.0
6.0
4.0
2.0
0.0
2014/11/17
2014/12/17
2015/1/16
2015/2/15
2015/3/17


Suspended sediment load (Back road bridge on Nadi main river）
Suspended sediment load
Accumulation volume
Suspended sediment load (m³/s)
Accumulation volume (m³)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2014/11/17
2014/12/17
2015/1/16
2015/2/15
2015/3/17


Observed turbidity (Navu Bridge on tributary:Nawaka)
Turbidit
Turbidity（L-Q eq.）
Water temp.
Turbidity (NTU)
Water temperature (°C)
Data Missing
1000
900
800
700
600
500
400
300
200
100
0
40
35
30
25
20
15
10
5
0
2014/11/17
2014/12/17
2015/1/16
2015/2/15
2015/3/17


Observed water level (Navu Bridge on tributary:Nawaka)
Discharge
Water level
Daily mean water level
Discharge (m³/s)
Water level(E.L.m)
100
80
60
40
20
0
3.0
2.0
1.0
0.0
-1.0
-2.0
2014/11/17
2014/12/17
2015/1/16
2015/2/15
2015/3/17


Suspended sediment load (Navu Bridge on tributary:Nawaka)
Suspended sediment load
Accumulation sediment volume
Suspended sediment load (m³/s)
Accumulation sediment volume (m³)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2014/11/17
2014/12/17
2015/1/16
2015/2/15
2015/3/17

3) Verification of Sediment Runoff Discharge by Characteristics Analysis of Basin Topography

In the previous section, the ratio of sediment runoff discharge of two areas, Nadi River main stream including tributary Namosi River and the other tributaries of Nawaka River and Malakua River is identified as 5: 1. Hereafter the large difference of the ratio is verified by the sediment yield potential estimated by topographic characteristic data.

(i) Estimation Method of Sediment Yield Potential

The sediment yield potential is estimated based on the method of sediment yield intensity map which is described in “Guidance for Estimation of Sedimentation of Dam (draft), Ministry of Land, Infrastructure, Transport and Tourism (MLIT), River Bureau, River Environment Section, April 2005”.

This method is used as one of estimation method in planning of sediment volume for newly built dam in MLIT, Japan. The sediment yield intensity map is established on the parameter of the topography of upstream basin of dam based on the actually accumulated sediment volume of 22 existing dams which belong to MLIT and Japan Water Agency.

The sediment volume is estimated by the following regression formula:

Specific Sediment Runoff Discharge = A x (Average EL.) x Relief Intensity + B

Where;

Specific Sediment Runoff Discharge: Sediment runoff discharge/Catchment area (m^3/km^2/year)

Average EL.: Average elevation in the upstream basin (m)

Relief Intensity: Topographic parameter defined in the sediment yield intensity map (As shown below)

A ,B : Coefficient determined by basin geology

The specific sediment runoff discharge is sediment yield per unit catchment area. The average elevation and relief intensity are calculated using the topographic data of the basin, then the sediment yield potential can be roughly calculated and compared in each basin by multiplying such figures.

Hereafter the sediment yield potential is calculated by this method for the Nadi main stream and each tributary.

■Relief Intensity

The relief is calculated by the difference between the highest elevation and lowest elevation in some selected mesh. The histogram is prepared by classification of range and its frequency in the basin. The relief intensity is calculated by the following formula (refer to the Figure 9-30).

Relief intensity = [Σ(Relief(classification) more than mode x frequency)]/ Catchment area

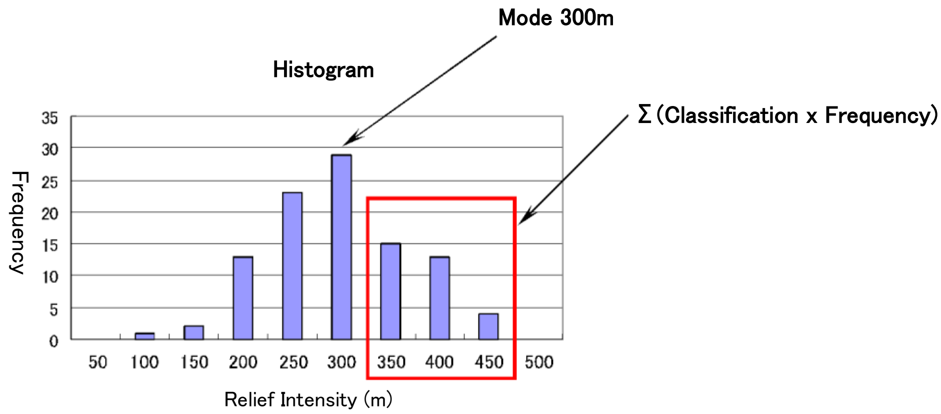


Figure 9-30 Relief Distribution and Calculation Method of Relief Intensity (example)

(ii) Topographic Data Preparation

The topographic data is prepared by the LiDAR data and the topographic map with scale of 1/50,000 published by the Government of Fiji. Nadi basin is divided into 100m mesh in which the highest elevation, lowest elevation and average elevation are listed.

(iii) Results of Estimation and Consideration

The topographic characteristics of each basin (average elevation and relief intensity) are shown in the Table 8-3-2 and the Figure 8-3-7. According to the table and figure the sediment yield potential is high in Nadi River and Namosi River. In Nawaka River the average elevation and relief intensity is rather low due to existence of many plains. In Malakua River the average elevation is the lowest so that the sediment yield potential is low.

The sediment yield potential in Nadi main stream basin including Nawaka River is 3 times that of the other tributaries Nawaka River and Malakua River

The results back up the observation results described above that the sediment yield of main stream basin is 5 times of the tributary basin, and the sediment yield in the main stream basin is very active rather than the other tributary basins

Table 9-13 Calculation Results of Sediment Yield Potential

No.	Basin	Basin area (km^2) ①	Average elevation (EL.m) ②	Relief intensity ③	Sediment yield potential ($\times 10^3$) ①×②×③	Comparison by target division
1	Nadi	184.0	359.9	24.4	1,617	2,381
2	Namosi	92.0	282.2	29.4	764	
3	Nawaka	134.0	219.3	21.0	617	774
4	Marakua	56.0	136.5	20.5	157	

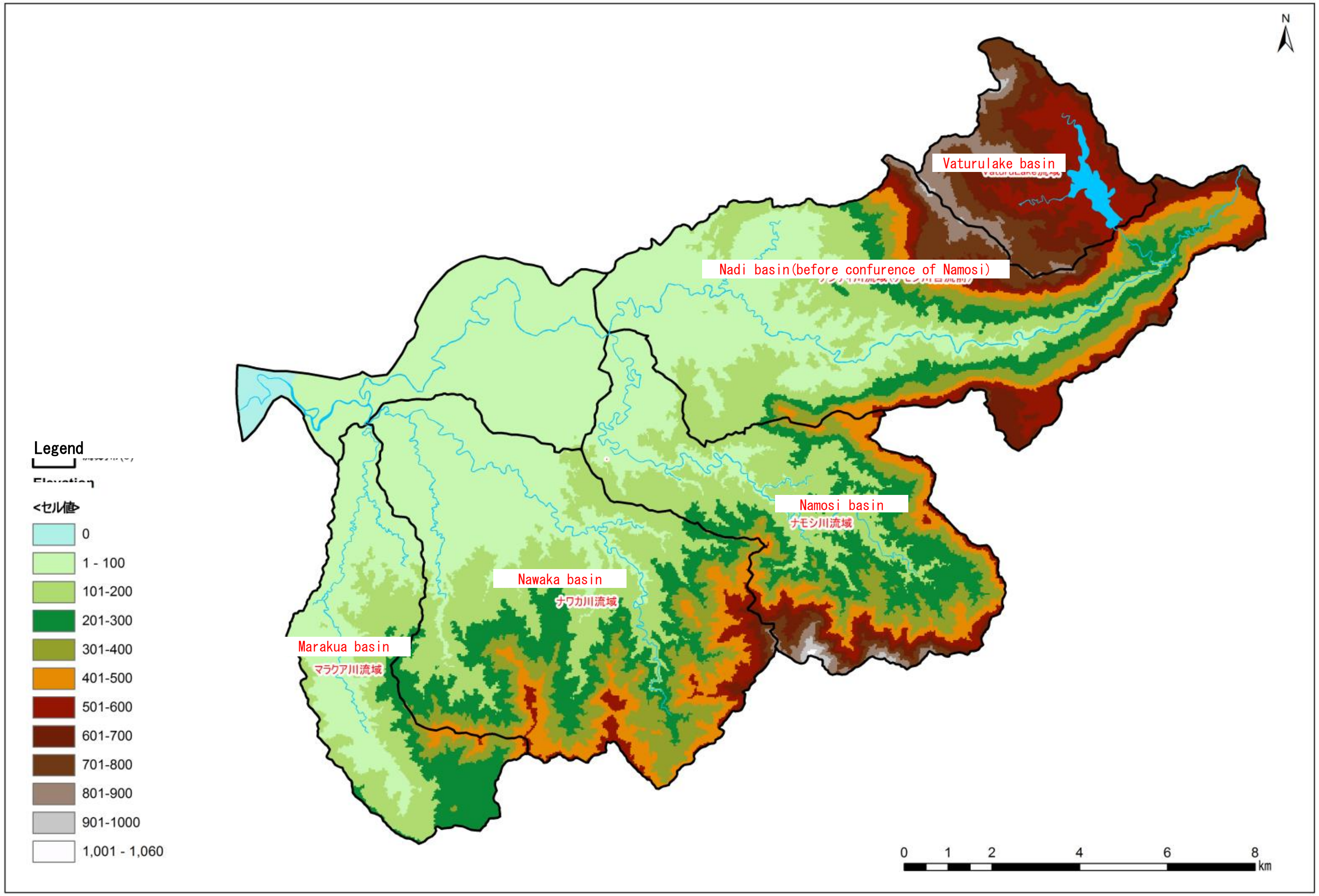
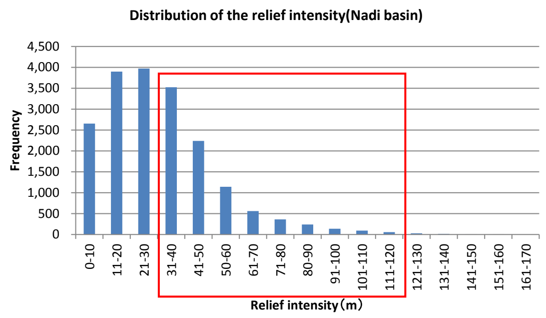
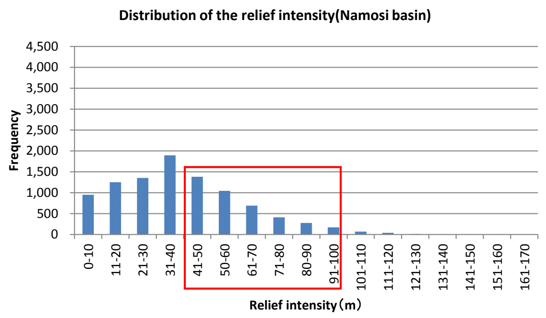
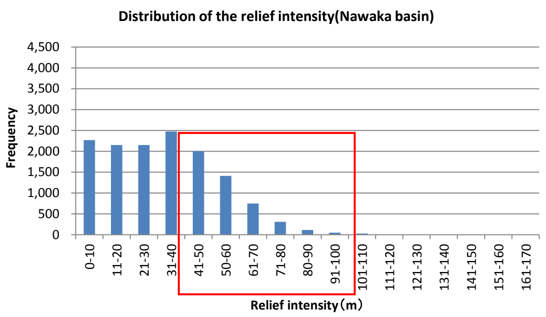
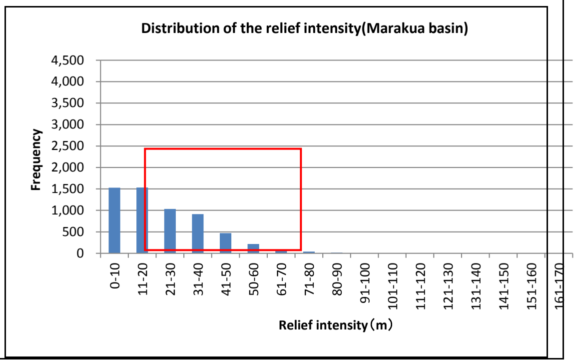


Figure 9-31 Topographic Characteristics in Study Area

Table 9-14 Calculation Result of Relief Intensity

Nadi main river	Namosi
	
Nawaka	**Marakua**
	

: Calculation target range of relief intensity

9.3.2 Summary of Present Sediment Transport

The present sediment transport in the study area is summarized below:

- In the mouth of Nadi River, the upgrade of riverbed is observed due to accumulation of fine grain sediment.
- In the distance post 4k to 7k of Nadi River, the downgrade of riverbed is observed which is considered that the past river channel dredging is one of factors.
- In the upstream of Nadi Town Bridge (distance post 10k), the downgrade of deepest riverbed is observed. In recent year there is some possibility of decreasing of sediment supply from upstream.
- According to the analysis of sediment runoff discharge of suspended load, the sediment runoff discharge in Nadi main stream area including Namosi River is 5 times that of the other tributaries Nawaka and Malakua Rivers. The Nadi main stream area has rather large influence to the sea shore area in supplying fine grain sediment
- Judging from L-Q equation and observed turbidity in Nadi basin, Nadi main stream and Namosi River have large discharge of suspended load. 2 tributaries of Nawaka River and Malakua River have same similarity in the scale of catchment area and sediment runoff discharge.

9.3.3 Preparation for Calculation

(1) Data Preparation of Discharge Pattern

1) Selection of Objective Floods

As to the discharge data which is one of the external forces to the calculation, the observed data is not enough and the discharge pattern is different for the main stream and tributaries so that the discharge data is prepared by the runoff analysis using the observed rainfall data, and the data is added to the calculation as boundary condition.

Since the sediment transport is activated in flood season, the flood data is especially important for the riverbed fluctuation analysis. The objective discharges are to be 23 floods (flood No.4 to No.26) which are selected among major 26 floods selected in the runoff analysis considering that they occurred from 1998 to 2014, which is objective period of reproduce calculation of present situation

Table 9-15 Objective Flood for Reproduction Calculation

No.	Date	Peak water level		Peak rain	
		Occurence time	Water Level(m)	Occurence time	Rainfall (mm)
1	1997/1/25-1/27	1997/1/25 22:00	6.20	1997/1/25 11:00	18.02
2	1997/1/30-1/31	1997/1/31 1:00	6.20	1997/1/30 11:00	10.43
3	1997/3/7-3/10	1997/3/8 2:00	8.70	1997/3/8 2:00	26.89
4	1999/1/18-1/19	1999/1/19 8:00	9.40	1999/1/19 4:00	33.66
5	2000/5/4	2000/5/4 17:00	6.90	2000/5/4 15:00	26.52
6	2000/12/5-12/7	2000/12/7 14:00	6.70	2000/12/7 10:00	26.89
7	2000/12/12	2000/12/12 16:00	6.50	2000/12/12 11:00	17.70
8	2001/3/14	2001/3/14 20:00	9.00	2001/3/14 17:00	76.28
9	2001/10/22	2001/10/22 17:00	6.20	2001/10/22 14:00	23.99
10	2002/2/23-2/24	2002/2/24 12:00	8.40	2002/2/24 9:00	20.36
11	2003/3/9-3/14	2003/3/12 16:00	7.10	2003/3/12 13:00	23.13
12	2005/4/18-4/19	2005/4/19 1:00	9.50	2005/4/18 19:00	24.30
13	2007/2/9-2/10	2007/2/9 22:00	6.30	2007/2/9 19:00	16.67
14	2007/2/12	2007/2/12 7:00	9.90	2007/2/12 21:00	27.90
15	2007/3/24-3/26	2007/3/25 10:00	9.50	2007/3/25 0:00	18.80
16	2008/1/28-1/30	2008/1/29 22:00	10.00	2008/1/29 3:00	19.63
17	2008/2/23	2008/2/25 5:00	6.60	2008/2/25 3:00	2.46
18	2008/3/29	2008/3/29 20:00	7.30	2008/3/29 14:00	18.39
19	2008/11/28-11/29	2008/11/29 5:00	5.80	2008/11/29 2:00	22.33
20	2009/1/7-1/12	2009/1/9 0:00	10.00	2009/1/10 21:00	38.50
21	2009/1/12-1/15	2009/1/13 19:00	9.80	2009/1/15 15:00	41.59
22	2011/2/18-2/19	2011/2/18 21:00	7.04	2011/2/18 18:00	18.77
23	2012/1/5-1/7	2012/1/7 4:00	6.52	2012/1/7 0:00	10.78
24	2012/1/23-1/25	2012/1/24 23:00	9.70	2012/1/24 21:00	17.26
25	2012/3/29-4/2	2012/3/30 7:00	11.88	2012/3/30 5:00	47.88
26	2014/1/29-1/31	2014/1/30 15:00	7.68	2014/1/30 12:00	17.56

No.4-No.26 for reproduction calculation

2) Method of Calculation

To estimate the discharge pattern for the main stream and tributaries (Namosi River, Nawaka River and Malakua River), the runoff analysis model which is established in this Project is used (refer to Chapter 5).

As to the equivalent roughness coefficient, K-value, P-value which are the parameters of surface land use, the verified values in the flood of March 2012 are used. And the verification was made between the discharge converted by observed water level at Votualevu using H-Q equation and the discharge calculated by the runoff analysis.

Rsa is changed due to rainfall pattern before flooding so that the value is appropriately adjusted based on the discharge of before flood, timing of discharge increase and so on.

In case that the observed water level and the calculated water level clearly differ so much in Votualevu point in the reproduce calculation, the observed water level is converted to the discharge using H-Q equation and the discharge pattern is calculated in each tributary in proportion to the catchment area.

3) Results of Calculation

The runoff analysis by the calculation method above is shown in the Figure 9-32 as an example.

The flood in February 9, 2007 with peak discharge of about 400m3/s is well reproduced on the discharge increase timing, peak discharge and discharge reduce process (refer to Case 13).

On the other hand the flood in March 14, 2001 has more than 1 of runoff ratio, and observed rainfall could not reproduce the observed water level at Votualevu point(refer to Case 8). The reason seems to be that the number of rainfall gage is not enough in objective basin so that the rainfall condition in the upstream basin could not be grasped in this flood. In such case the discharge pattern of Votualevu is calculated by H-Q equation assuming that the observed water level is reliable and the discharge pattern of other 3 tributaries are given in the basin area ratio based on Votualevu discharge.

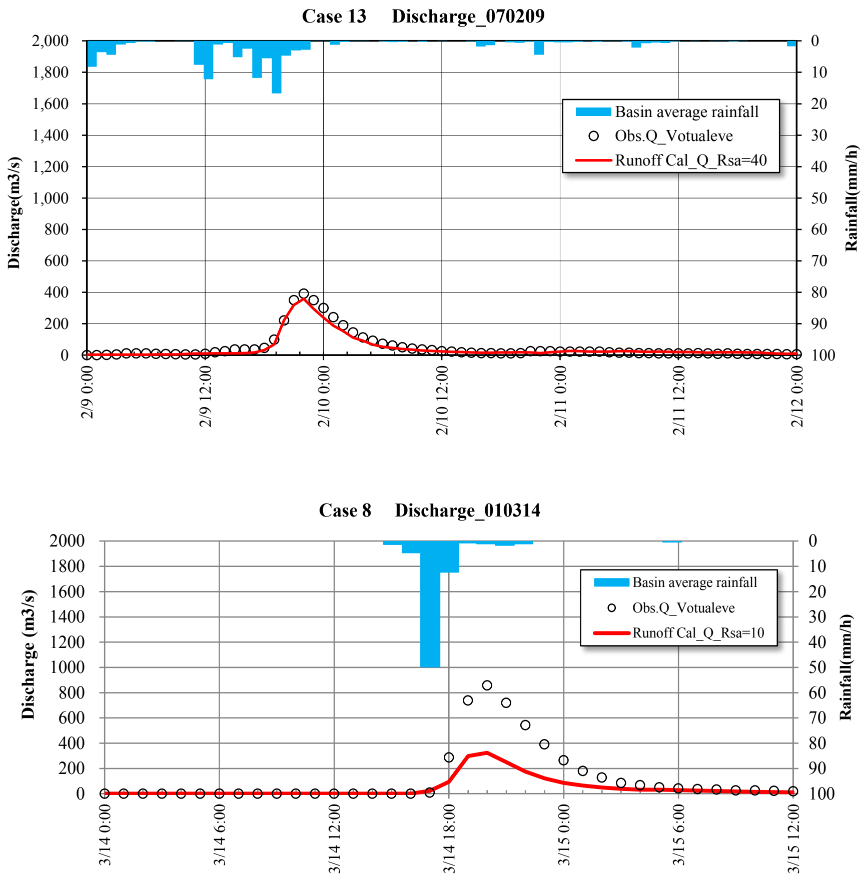
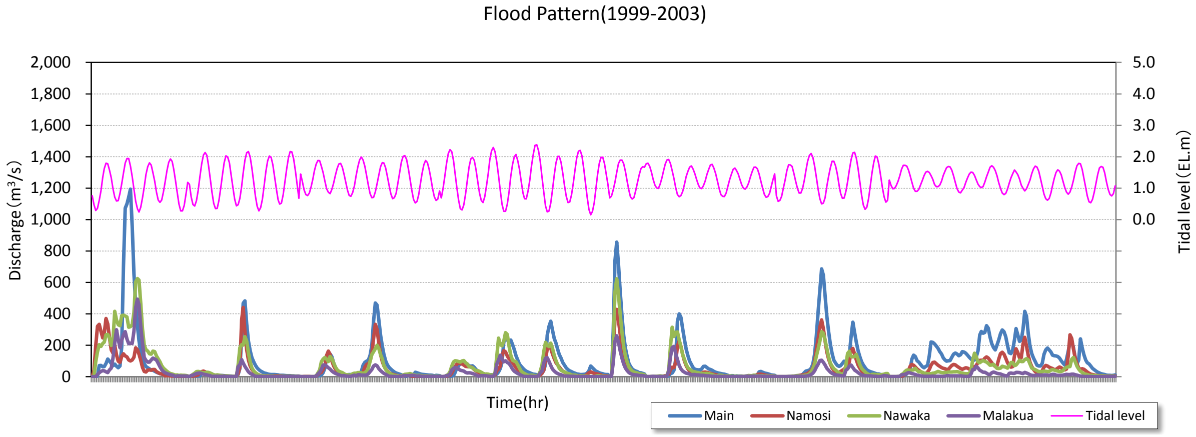


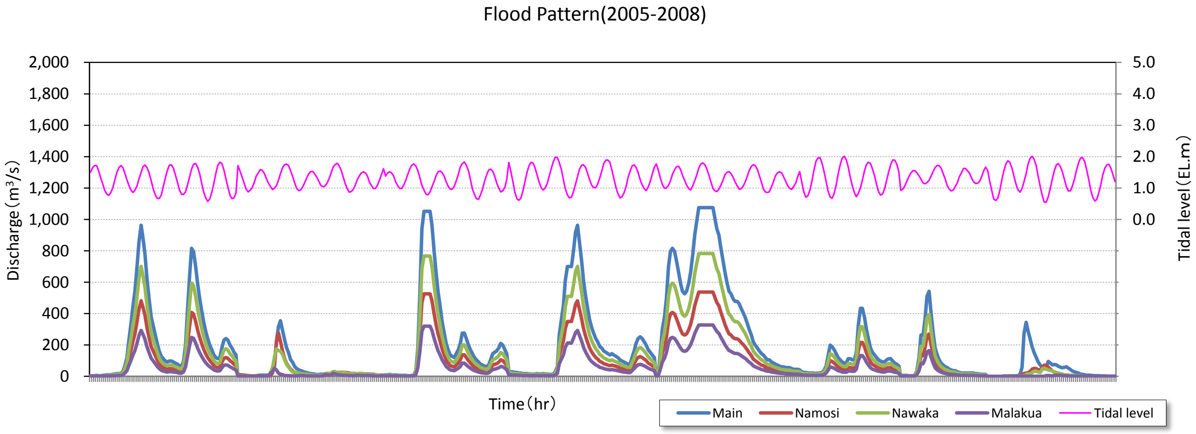
Figure 9-32 Example of Runoff Analysis for Riverbed Fluctuation Analysis

The final discharge pattern with peak discharge for objective 23 floods is shown in the Table 9-16 and Figure 9-33.

Table 9-16 Flood No. and Peak Discharge for Calculation (Main stream and Tributaries)

No.	Occurrence date	Peak discharge(m³/s)				Caluclation basis
		Nadi	Namosi	Nawaka	Malaka	
4	1999/1/19	1,194	370	625	494	Runoff analysis
5	2000/5/4	483	441	255	109	Runoff analysis
6	2000/12/7	469	333	200	76	Runoff analysis
7	2000/12/12	353	190	219	122	Runoff analysis
8	2001/3/14	857	428	624	261	HQ
9	2001/10/22	401	228	315	193	Runoff analysis
10	2002/2/24	686	361	287	106	Runoff analysis
11	2003/3/12	416	251	150	66	Runoff analysis
12	2005/4/19	963	481	701	293	HQ
13	2007/2/9	355	276	176	52	Runoff analysis
14	2007/2/12	1,052	526	766	320	HQ
15	2007/3/25	963	481	701	293	HQ
16	2008/1/29	1,075	538	783	327	HQ
17	2008/2/25	433	217	316	132	HQ
18	2008/3/29	542	271	395	165	HQ
19	2008/11/29	345	72	52	8	Runoff analysis
20	2009/1/10	1,134	452	533	250	Runoff analysis
21	2009/1/13	1,029	515	750	313	HQ
22	2011/2/18	501	250	365	152	HQ
23	2012/1/7	422	211	307	129	HQ
24	2012/1/24	1,007	504	734	307	HQ
25	2012/3/29	1,848	861	1,026	406	Runoff analysis
26	2014/1/30	607	303	442	185	HQ
	Ave.	723	360	440	197	





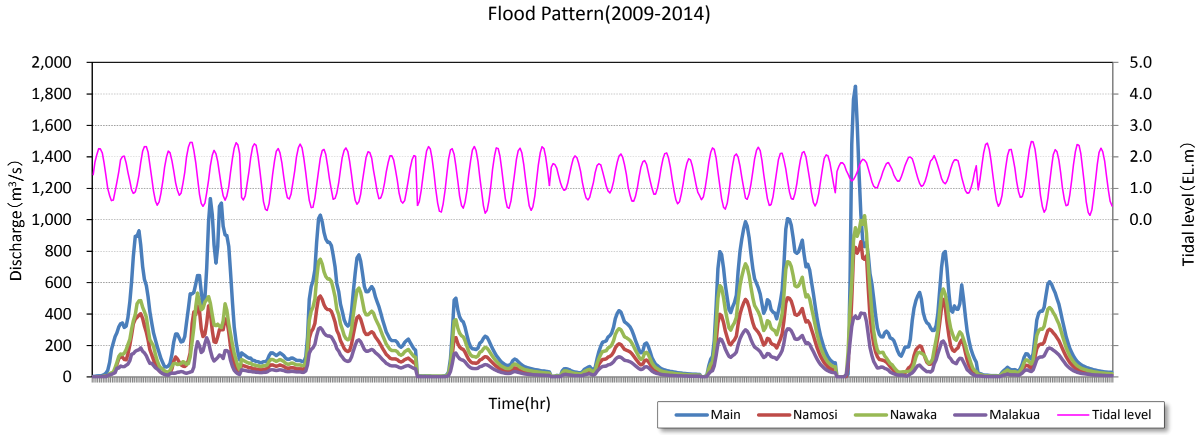


Figure 9-33 Flood Pattern for Calculation (Main stream and Tributaries)

(2) Estimation of Sediment Inflow

1) Method of Estimation

The sediment inflow is one of important factor in the reproduce calculation. The sediment inflow is divided into two categories, one is suspended sediment load and the other is bed sediment load. The suspended sediment load is composed of silt and sand which contribute to the formulation of topography in the downstream river and seashore. The bed sediment load is composed of mainly gravel which contributes to the formulation of topography in the upstream and middle stream river channel.

One of purpose of this Project is to grasp the influence of river improvement to the topography of seashore, therefore the suspended sediment load such as silt and fine sand is important.

Sediment Inflow

① Suspended load：mainly silt and sand contributing to formulation of downstream and seashore

② Bed load：mainly gravel contributing to formulation of upstream and middlestream

■Determination of Suspended Load Volume

The discharge and SS (Suspended Solid) load are studied at the outflow points of main stream and tributaries, based on which the experimental sediment load formula is established. And the calculation results are compared with the passing suspended sediment load observed at Back Road Bridge in main stream and Navu bridge in the tributary.

■Determination of Bed Load Volume

The direct observation of the bed load is difficult since the bed load shifts along the riverbed in flooding time; therefore the bed load is generally estimated by the theoretical sediment formula based on the riverbed material investigation in the section in which the cross sections of river channel are known. However since the sediment load is calculated as equilibrium load, the load has possibility of lager than actual value. It is necessary to reproduce the fluctuation of average riverbed elevation applying correction coefficient to the estimated value by the formula.

According to the above description, the estimation method of sediment inflow is determined as shown in the Table 9-17.

Table 9-17 Determination Method of Sediment Inflow

River	Suspended Sediment	Bed Sediment	Remarks
Nadi main stream	L-Q Eq.(observed) at Back Road Bridge	Theoretical Sediment Formula※	Excluding sediment from Namosi in proportion to basin area
Namosi	L-Q Eq.(observed) at Mulomulo Bridge	〃	
Nawaka	L-Q Eq.(observed) at Navu Bridge	〃	
Malakua	L-Q Eq.(observed) at Navu Bridge	〃	As the variation of turbidity is similar to Nawaka River by water sampling

※adjusted by applying correction coefficient so that the actually surveyed riverbed fluctuation is reproduced.

<L-Q Equation at Back Road Bridge>

Since the tendency of L-Q Equation at Back Road Bridge is different to those at the other points, the continuous observation turbidity data was reviewed and the coefficient values of L-Q equation was revised, so that the consistency with the equations at the other point increases. The revised equation is to be applied in the reproduction calculation and the future prediction.

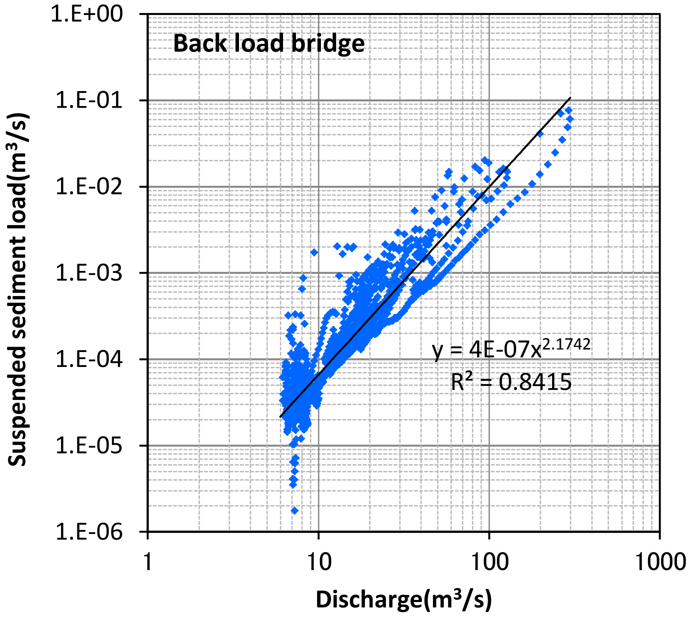


Figure 9-34 L-Q Equation at Back Road Bridge

2) Estimation Results

The final determination of sediment inflow for the reproduction calculation and future prediction is as shown in the Table 9-18.

Table 9-18 Sediment Inflow for Reproduction Calculation and Future prediction

River name	Cray	Silt	Fine Sand	Midium Sand	Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	Boulders
Nadi	295.2	519.0	142.7	69.7	1.0	0.0	0.2	0.0	0.0
Namosi	354.3	647.2	169.5	71.7	2.9	0.7	3.5	0.9	0.0
Nawaka	144.9	254.5	68.5	67.2	5.5	1.3	7.2	2.8	0.0
Malakua	10.3	18.2	5.0	55.8	2.2	1.0	2.5	0.2	0.0

Unit $10^3 m^3$

(3) Grain Size Classification used in Calculation

Although it is possible to calculate transport and accumulation of various grain size included in the riverbed, in actual calculation the grain size is classified into several categories (5 - 10) and the representative grain size is determined in each category.

Considering the investigation results of riverbed material in the objective rivers, the grain size category and representative size are determined in this analysis as shown in the Table 9-19.

Table 9-19 Grain Size Category for Calculation

Classification			Range of Grain Size(mm)			Representative Grain Size(mm)
Grain Size 1	Cobble Stone		300.0	to	75.0	106.0
Grain Size 2	Gravel	Coarse	75.0	to	22.4	37.7
Grain Size 3		Medium	22.4	to	6.69	9.5
Grain Size 4		Fine	6.69	to	2.00	3.08
Grain Size 5	Sand	Coarse	2.000	to	0.669	1.30
Grain Size 6		Medium	0.669	to	0.224	0.46
Grain Size 7		Fine	0.224	to	0.075	0.14
Grain Size 8	Silt		0.075	to	0.005	0.019
Grain Size 9	Clay		0.005	to	0.001	0.0022

9.3.4 Summary of Riverbed Fluctuation Analysis

One-dimensional Riverbed Fluctuation Analysis model is applied to the riverbed fluctuation analysis along longitudinal direction of river channel. The purpose of this analysis in the Project is to predict the influence to the riverbed topography and sediment runoff discharge caused by the implementation of flood structures in the middle and long term One-dimensional model seems to be appropriate to evaluate the purpose in the practical calculation time of computer.

(1) Outline of Riverbed Fluctuation Model

The outline and schematic diagram of riverbed fluctuation model are shown in the Table 8-3-9 and Figure 8-3-13 respectively. In this model general cross sectional topography of river and the various grain size (mixed grain size, large to small) can be considered. The possible applied section is from the river mouth to the upstream end, and in the downstream end the non-uniform flow model is applied considering the tidal variation. The movement of bed sediment and suspended sediment is taken into consideration. As to the suspended sediment, the non-equilibrium model which has relatively high accuracy of prediction is adapted.

Table 9-20 Outline of Riverbed Fluctuation Analysis Model

Item	Description
Flow Calculation	One-dimensional Non-uniform Flow Model
Sediment Calculation	One-dimensional Riverbed Fluctuation Model (Mixed grain size model)
Movement of bed sediment	・*Ashida-Michiue* equation
Movement of suspended Sediment	・Considering non-equilibrium. Turbidity in base is applied by *Ashida-Michiue* equation.
Analysis method	McCormak method

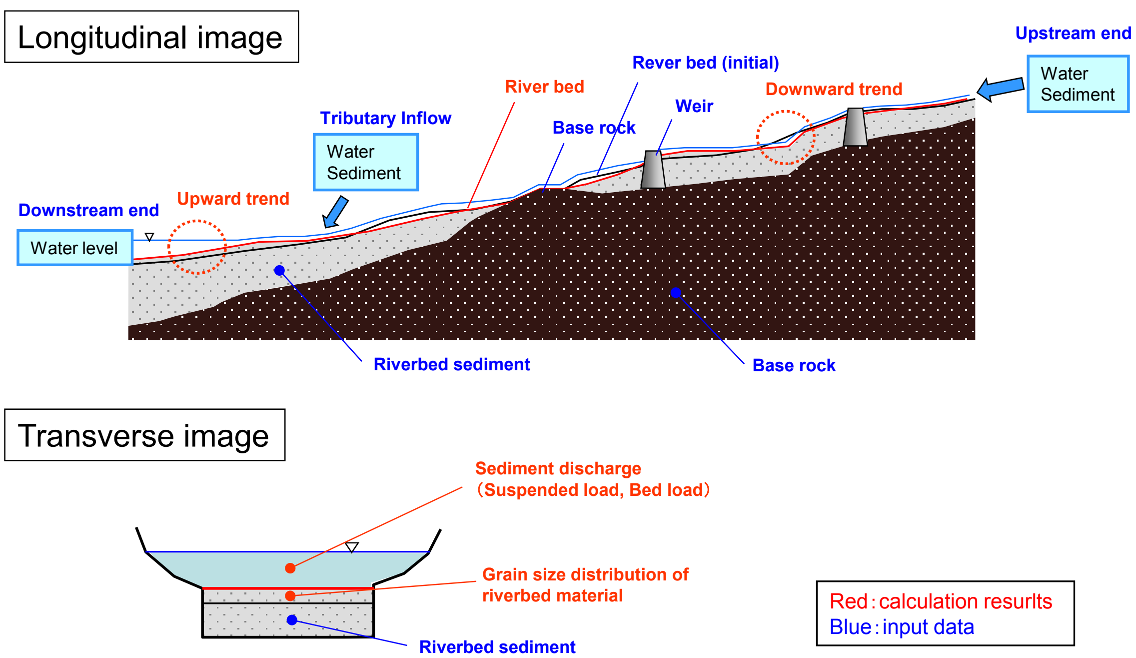


Figure 9-35 Schematic Diagram of Riverbed Fluctuation Model

(2) Basic Formula

The basic formula of sediment inflow movement is shown below.

<Basic Formula of One-dimensional Riverbed Fluctuation Calculation>

Continuous formula of sediment flow

$$\frac{\partial A_s}{\partial t} + \frac{1}{(1-\lambda)}\left\{\frac{\partial}{\partial x}\left(\sum_j Q_{Bj}\right) + \sum_j B_{su}\left(q_{sj} - q_{dj}\right)\right\} = 0 \qquad \text{Eq. (1)}$$

Transport formula of suspended sediment by grain size

$$\frac{\partial\left(\overline{C}_j A\right)}{\partial t} + \frac{\partial\left(\overline{C}_j Q\right)}{\partial x} = B_{su}\left(q_{sj} - q_{dj}\right) \qquad \text{Eq. (2)}$$

Sediment balance formula by grain size in exchange layer

In upgrade of riverbed

$$\frac{\partial\left(P_{sj} A_{sa}\right)}{\partial t} = -\frac{1}{\left(1-\lambda\right)}\left\{\frac{\partial Q_{Bj}}{\partial x} + B_{su}\left(q_{sj} - q_{dj}\right)\right\} - P_{s1j}\left(\frac{\partial A_{sb}}{\partial t}\right) \qquad \text{Eq. (3)}$$

In downgrade of riverbed

$$\frac{\partial\left(P_{sj} A_{sa}\right)}{\partial t} = -\frac{1}{\left(1-\lambda\right)}\left\{\frac{\partial Q_{Bj}}{\partial x} + B_{su}\left(q_{sj} - q_{dj}\right)\right\} - P_{oj}\left(\frac{\partial A_{sb}}{\partial t}\right) \qquad \text{Eq. (4)}$$

$$\begin{cases} q_{dj} = w_{sj} C_{Bj} & \text{Eq. (5)} \\ q_{dj} = w_{sj} \overline{C}_j & \text{Eq. (6)} \end{cases}$$

where ; A: Flow area (m^2), Q: Discharge (m^3/s), t: Time (s), x: Downstream distance (m), z: Height from base line in vertical direction (m), g: gravitational acceleration (m^2/s), H: Height of water surface (m), A_s: Cross sectional area of riverbed (m^2), λ: Void ratio of accumulated sediment , Q_B: Bed load by grain size (m^3/s), q_{sj}: Emergence flux of suspended sediment by grain size due to turbulence (m/s), q_{dj}: Submergence flux of suspended sediment by grain size (m/s), w_{sj}: Settling velocity of particle by grain size (m/s), C_{Bj}: Base turbidity of suspended sediment (m^3/m^3), C_j: Average section turbidity by grain size (m^3/m^3), R: hydraulic mean depth (m), C_{Bej}: Base turbidity of suspended sediment by grain size (m^3/m^3), P_{sj}: Ratio of each grain size in exchange layer, A_{sa} : Section area of exchange layer (m^2), A_{sb}: Riverbed area excluding exchange layer (m^2), P_{s1j}: P_{sj} before *t*, P_{oj}: Ratio of each grain size in soil block under exchange layer, a: Thickness of exchange layer (m), B_{su}: Water way width where suspended sediment emerges and submerges (m), I_e: Energy gradient, n: Manning's roughness coefficient, B_s: Width of water way in river bed, B_{su}: Equal to B_sを, w_{sj}: from experimental equation of Rubey, q_{sj}, q_{dj} : modeled by other study of the Project.

9.3.5 Procedure of Calculation

The general procedure of the riverbed fluctuation calculation is shown in the Figure 9-36.

Firstly the water surface profile and the longitudinal distribution of water velocity are calculated in the flow field and the sediment volume (bed load, suspended load) is calculated by the above hydraulic values and the theoretical sediment formula. Secondly the fluctuation of riverbed is calculated by the sediment load, and the riverbed shape is obtained. Lastly the grain size distribution in the exchange layer is calculated by the most up-to-date riverbed shape and sediment load.

The riverbed fluctuation calculation is carried out basically according to the above flow though there is the more or less difference by each calculation method in actual calculation of flow field and sediment load.

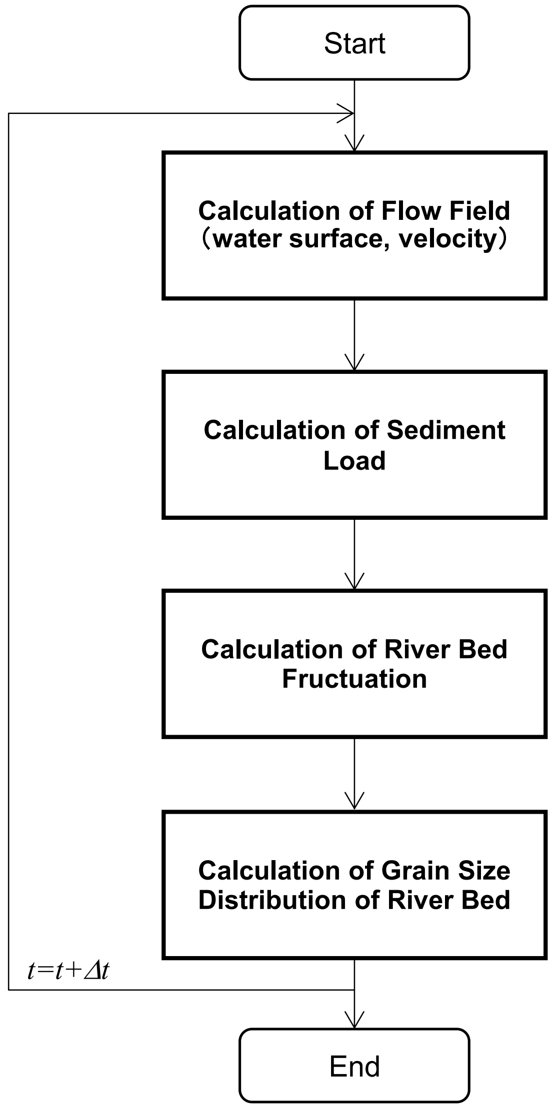


Figure 9-36 Procedure of Riverbed Fluctuation Calculation

9.3.6 Reproduction Calculation of Present Situation

The major calculation conditions are determined as shown in the Table 8-3-10.

(1) Calculation Policy

The reproduction calculation is made according to the following policy.

- The analysis model is verified by confirming mainly the tendency of longitudinal riverbed fluctuation along the main stream and the tendency of suspended sediment discharge in main stream and tributaries. As to the tributaries the verification is not carried out due to lack of the river survey data.

Table 9-21 Determination of Major Conditions for Reproduction Calculation

Item	Description	Remarks
Analysis Model	One-dimensional Riverbed Fluctuation Analysis Model	
Calculation Period	1998 to 2014(17years)	
Calculation Section	Nadi main stream: Nadi River (28.0km) Tributaries: Namosi River (5km), Nawaka River(10km), Malakua River (5km)	
Initial Riverbed	Main stream: Average riverbed elevation in 1998 (actually surveyed) Tributaries: Average riverbed elevation in 2014 (actually surveyed)	No survey work in the tributaries in 1998
Time Interval	Determined depending on convergence situation of calculation	
Distance Interval	Δx=250m(※)	※Interval of cross section survey in 2014
Number of Representative Grain Size	9 grain size Objective range: clay (0.005mm) to cobble stone (300mm)	
Riverbed Material	Determined by the investigation in 2014	
Upstream End	Discharge: Major flood discharge with chronological data Sediment: Bed load; estimated by theoretical sediment formula Suspended load; estimated by L-Q equation based on the observed data	Inputting chronological data from upstream end of main stream and tributaries
Downstream End	Water level: observed tide Sediment: pass through the river mouth	
River Channel Dredging	Consideration of dredging work in 2008 to 2012 in actual location and volume	
Roughness Coefficient	Determined value in each segment	
Void Ratio	0.4	

(2) Results of Calculation

The results of reproduction calculation are shown in the Figure 9-37 and Figure 9-38, and the Table 9-22. According to these figures and the table the followings are found out.

<Reproduction of Downstream Section>

- The river channel dredging was carried out in the downstream section. The downgrade of riverbed in 1 to 4m is calculated in that section. Although the downgrade of about 1m is observed in actual survey from distance post 4 to 8km, the remarkable riverbed variation could not be found in the distance post 0 to 4km.
- The reason of difference between the calculation and survey in the distance post 0 to 4km seems to be as follows:

  ① In the river mouth area, the sediment once flowing out from the river mouth has possibility of coming back into the river channel, however such mechanism cannot be represented in the riverbed fluctuation model.

  ② It is known that in the river mouth area the sea water returns to the river channel and the fine sediment contacts with the sea water and flocculates and settles which promotes the accumulation of riverbed material. Such mechanism may happen in the Nadi River mouth.

  As above mentioned are very complex phenomenon and the quantitative analysis requires advanced technology, the reproduction of the phenomenon is actually difficult.

<Reproduction of Middle Stream Section>

- In the middle stream section, the river degradation in the distance post 20 to 25 is around 1.0m recognized in the actual survey, however the remarkable variation is not found. In the calculation the degradation tendency in the same section is insufficient, however the riverbed seems to be reproduced almost stable.

<Reproduction of Sediment Load>

- The ratio of suspended sediment discharge is 5: 1 in this observation period(2014.11-2015.3) in Back Road Bridge and Navu Bridge. On the other hand in the reproduction calculation the total volume of suspended sediment (clay, silt and fine sand) in the both points is 120,000m3/year and 30,000 m3/year respectively of which ratio is 4: 1. There is some deference, however the tendency that the suspended load in mainstream is larger than in tributaries, seems to be relatively well reproduced.

It is considered that the applied model can reproduce the characteristics of overall riverbed fluctuation and sediment discharge such as the silt and fine sand which contributes to the sea shore topography.

Therefore this model can be judged to be effective to predict the sediment transport in Nadi River.

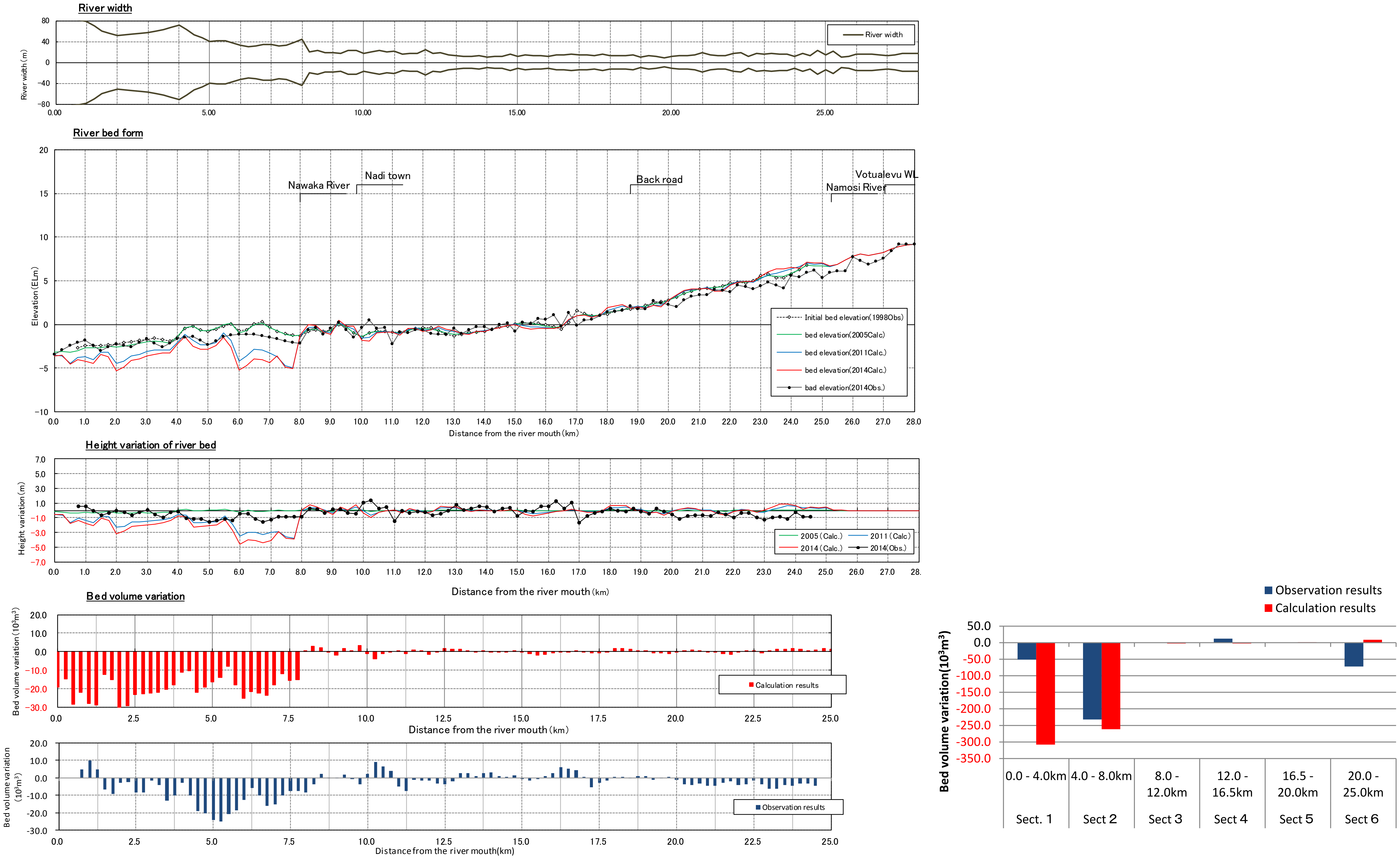


Figure 9-37 Reproduction Calculation Results (Nadi main stream)

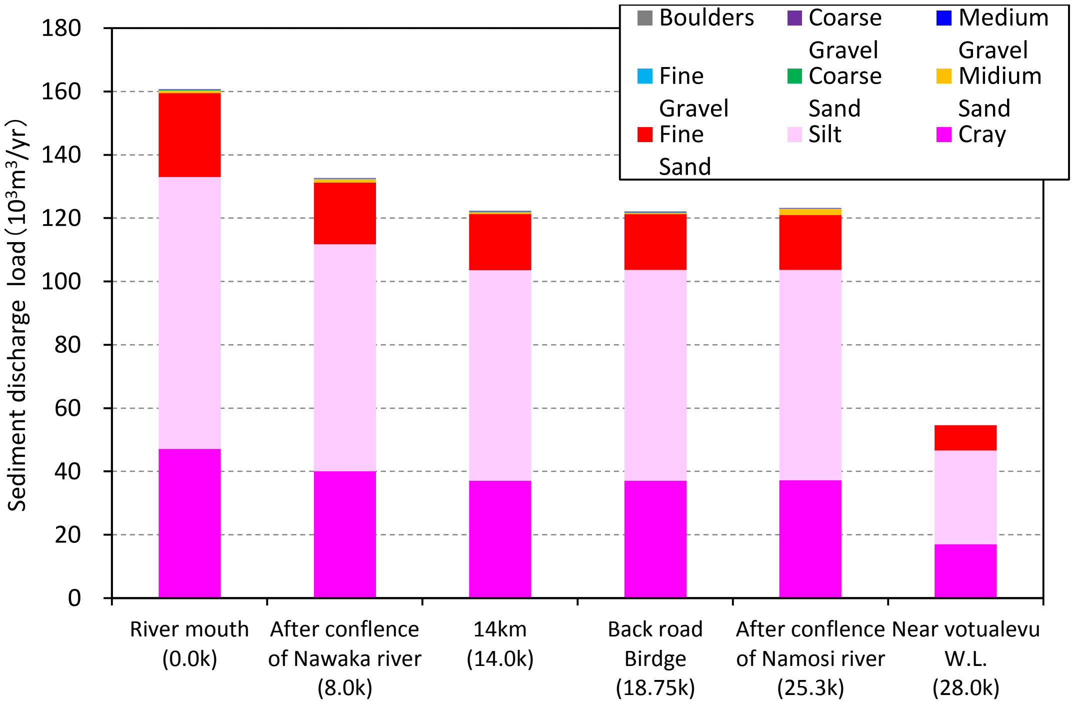


Figure 9-38 Reproduction Calculation Results (Sediment discharge volume by grain size)

Table 9-22 Reproduction Calculation Results (Sediment discharge volume by grain size)

Point	Cray	Silt	Fine Sand	Midium Sand	Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	Boulders	Sediment discharge load
River mouth (0.0k)	47.1	85.9	26.5	0.79	0.21	0.07	0.02	0.00	0.00	160.6
After conflence of Nawaka river (8.0k)	40.0	71.7	19.5	0.96	0.18	0.09	0.11	0.00	0.00	132.6
14km (14.0k)	37.1	66.5	17.9	0.46	0.19	0.09	0.07	0.00	0.00	122.2
Back road Birdge (18.75k)	37.1	66.5	17.6	0.46	0.14	0.09	0.13	0.00	0.00	122.0
After conflence of Namosi river (25.3k)	37.1	66.6	17.2	2.11	0.00	0.00	0.00	0.00	0.00	123.1
Near votualevu W.L. (28.0k)	16.9	29.7	8.0	0.00	0.00	0.00	0.00	0.00	0.00	54.6

(Unit: $10^3 m^3/yr$)

9.3.7 Future Prediction Calculation

(1) Conditions and Policy of Calculation

The future prediction calculation is implemented using the riverbed fluctuation model which is verified by the reproduction calculation of present situation. The major conditions in the future prediction calculation are shown in the Table 9-23 and the calculation policies are as sown below.

- The future predication calculation is carried out firstly in case of without flood control structures, therefore the river channel dredging in the past is not considered.
- The prediction period is to be 50 years.
- As to the discharge pattern in future 50 years, the discharge pattern during 17 years which was prepared in the reproduction calculation is to be repeated about 3 times. In the discharge pattern of 50 years, the flood in March 2012 is assumed to occur once in 50 years considering it occurrence probability.

Table 9-23 Determination of Conditions of Future Prediction Calculation

Item	Description	Remarks
Analysis Model	One-dimensional Riverbed Fluctuation Analysis Model	Already verified
Calculation Period	Future 50 years	
Calculation Section	Nadi main stream: Nadi River (28.0km) Tributaries: Namosi River (5km), Nawaka River(10km), Malakua River (5km)	
Initial Riverbed	Main stream: Average riverbed elevation in 2014 (actually surveyed) Tributaries: Average riverbed elevation in 2014 (actually surveyed)	
Time Interval	Determined in reproduction calculation	
Section Inteval	Δx=250m	
Number of Representative Grain Size	9 grain size Objective range: clay (0.005mm) to cobble stone (300mm)	
Riverbed Material	Determined by the investigation in 2014	
Upstream End	Discharge: repeating major floods for50 years Sediment: estimated value by grain size in theoretical sediment formula(※)	※Coefficient verified by reproduction calculation
Downstream End	Water level: observed tide Sediment: pass through the river mouth	
River Dredging	No consideration	
Roughness Coefficient	Same as reproduction calculation	
Void Ratio	0.4	

※blue portion is different form reproduction calculation

(2) Results of Calculation

The results of future prediction calculation are shown in the Figure 9-39, Figure 9-40 and Table 9-24. According to these figures and the table the followings are found out.

<Riverbed Fluctuation of Downstream Section>

- The degradation of riverbed in 1m is recognized in the distance post 0 to 4km. This seems to be due to the reason that the special sediment accumulation mechanism in the river mouth is difficult to be considered technically in this model as described in the preceding section of reproduction calculation. In fact, the deposition of the clay and silt component is presumed to be promoted by the waves and chemical action of salt water.
- Except above phenomena the riverbed is relatively stable though the partial upgrade and downgrade of riverbed within about 1m is recognized according to progress of years.

<Riverbed Fluctuation of Middle Stream Section>

- Although the sediment accumulation tendency is recognized slightly in the downstream of the confluence of Namosi River, the middle stream section seems to be also relatively stable within the riverbed variation of 1m.

<Sediment Discharge Load>

- In the future prediction the total volume of clay, silt and fine sand from the main stream and tributaries is 110,000m^3/year and 26,000 m^3/year respectively of which ratio is 4: 1. If there will be no big change in condition of the land use and the meteorology in the Nadi basin, the almost same amount of sediment load will be yielded in future.

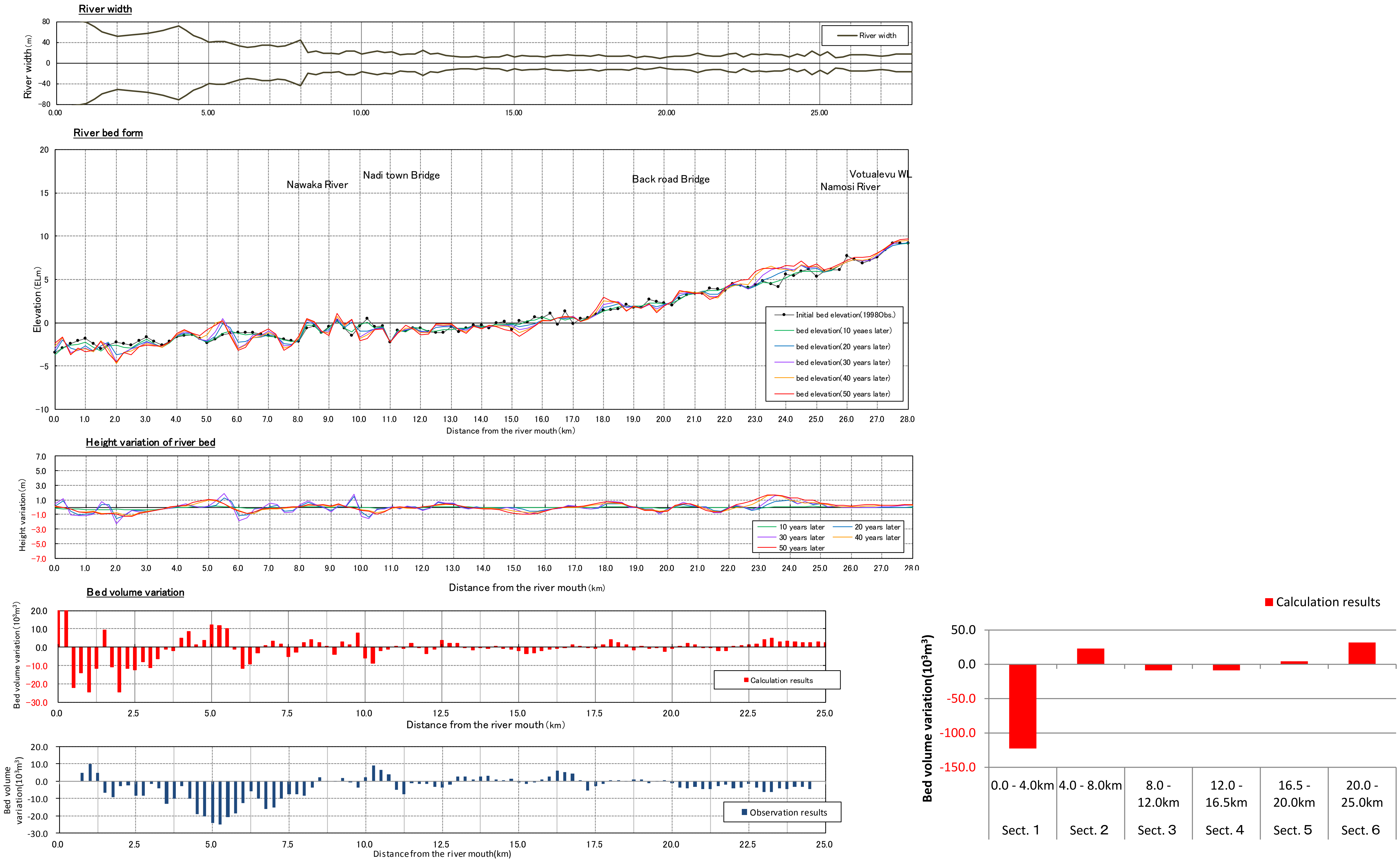


Figure 9-39 Future Prediction (without Flood Control Structures in Nadi main stream)

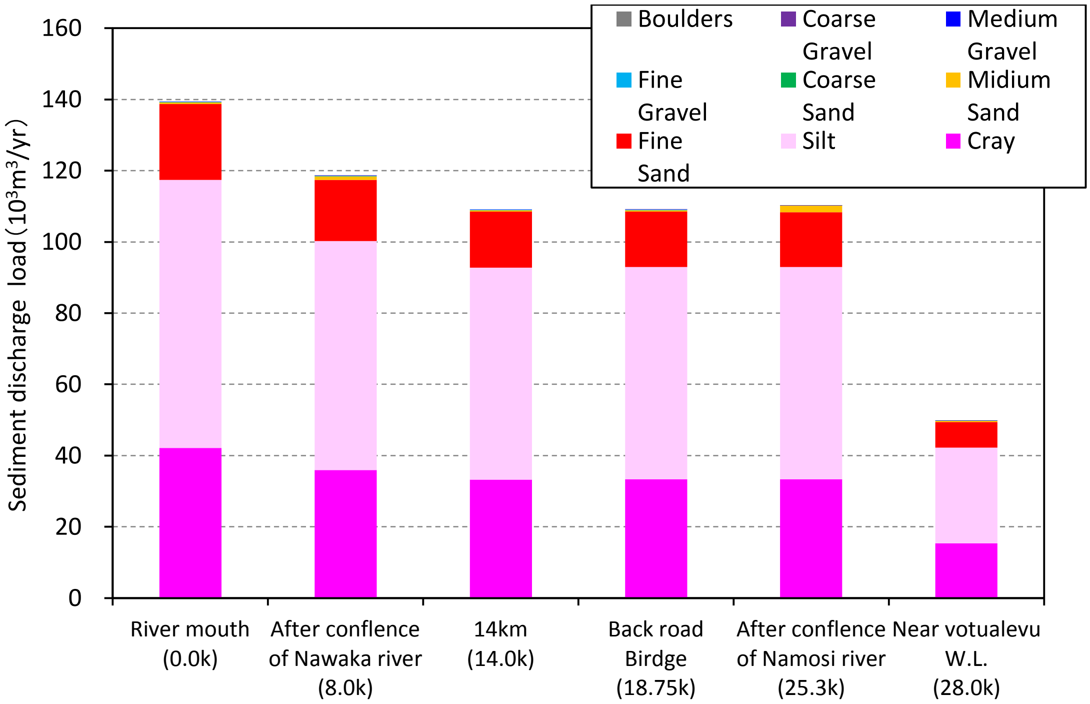


Figure 9-40 Future Prediction (Sediment Discharge Load by Grain Size)

Table 9-24 Future Prediction (Sediment Discharge Load by Grain Size)

Point	Cray	Silt	Fine Sand	Midium Sand	Coarse Sand	Fine Gravel	Medium Gravel	Coarse Gravel	Boulders	Sediment discharge load
River mouth (0.0k)	42.2	75.2	21.3	0.45	0.13	0.05	0.01	0.00	0.00	139.3
After conflence of Nawaka river (8.0k)	35.9	64.3	17.2	0.98	0.08	0.05	0.08	0.00	0.00	118.6
14km (14.0k)	33.2	59.6	15.7	0.32	0.14	0.07	0.07	0.00	0.00	109.1
Back road Birdge (18.75k)	33.3	59.6	15.6	0.36	0.10	0.06	0.11	0.00	0.00	109.1
After conflence of Namosi river (25.3k)	33.3	59.7	15.4	1.87	0.00	0.00	0.00	0.00	0.00	110.2
Near votualevu W.L. (28.0k)	15.3	26.9	7.2	0.38	0.00	0.00	0.00	0.00	0.00	49.8

(Unit: $10^3 m^3/yr$)

9.3.8 Summary of Examination Results

The results of this examination are described as shown below.

- It is considered that the riverbed is relatively stable. In the current situation, riverbed decrease in midstream portion is around 1m. In addition, the riverbed of downstream portion in the 4km to 8km interval is decreased 1 to 2m by river dredging which is carried out in 2008-2012 (a total of 1,651 thousand m^3). It should be noted in 0km to 4km interval, the riverbed height is same level of 1998, it is presumed the clay-silt have been redeposit after dredging.
- By reproduce results of the riverbed variation calculation from 1998 to 2014, the sediment runoff at the river mouth is 160 thousand m^3/year, and the particle size is approximately 0.2mm or less of clay, silt, fine sand. These silt and fine sand is considered to form the current beach around the river mouth.
- The results of the prediction calculation in future 50 years shows there is not particular large change of the riverbed topography in the case of not performing the flood control project. The current riverbed is stable and the outflow and inflow of sediment are balanced. Also, the sediment runoff from river mouth has become somewhat less sediment volume than the 139 thousand m3/year of current state.

In the future, we conduct a forecast in consideration of the flood control and create a map of watershed sediment dynamics giving conditions to seashore change analysis that is conducted in separately. In addition, in order to create the master plan and selection of priority project, it is planned to examine an influence on the flood control, and excavation and dredging volume to maintain the river channel.

9.4 Examination of Influence of Flood Control Structures and Mitigation Works

The riverbed fluctuation of selected flood control structures, River Improvement, M-1, was predicted by one-dimensional riverbed fluctuation analysis for 50 years which is equal period to the design period of flood control master plan. And compared with the case without flood control structure, the influence of the River Improvement is extracted and the examination of mitigation works to the influence was examined.

9.4.1 Prediction of Riverbed Fluctuation by River Improvement

(1) Calculation Conditions

The prediction calculation of the river improvement was implemented by the verified the riverbed fluctuation analysis model (hereafter called the counter measure prediction). The main calculation conditions are as shown in the Table 9-25. And the implementation policy is as shown below:

- The riverbed fluctuation is predicted for the River Improvement, M-1, which include river channel enlargement of main stream and tributaries, and retarding basins in Nadi River among the master plan. And the river dredging in the past is not considered.
- Prediction period is to be 50 years.
- The discharge pattern of future 50 years is prepared by repeating three times of the past 17 years flood which is prepared in the reproduction calculation (refer to 9.3.6) , is used in the future prediction calculation (refer to 9.3.7). In preparation of discharge pattern the flood in March, 2013 is determined to occur once in 50 years considering its occurring probability.

Table 9-25 Conditions of Predication Calculation of Counter Measure

Item	Description	Remarks
Analysis Model	One-dimensional Riverbed Fluctuation Analysis Model	Already verified
Calculation Period	Future 50 years	
Calculation Section	Nadi main stream: Nadi river (28.0km) Tributaries: Namosi river (5km), Nawaka river(10km), Malakua river (5km)	
Initial Riverbed	Main stream: Average riverbed elevation planned in the counter measure (actually surveyed) Tributaries: Average riverbed elevation planned in the counter measure (actually surveyed)	
Countermeasures	River channel enlargement : Main stream and tributaries Retarding basin: 2 locations (main stream 20.5k and 22.5k)	
Time Interval	Determined in reproduction calculation	
Section Interval	Δx=250m	
Number of Representative Grain Size	9 grain size Objective range: clay (0.005mm) to cobble stone (200mm)	
Riverbed Material	Determined by the investigation in 2014	

Upstream End	Discharge: repeating major floods for50 years Sediment: estimated value by grain size in theoretical sediment formula（※）	*Coefficient verified by reproduction calculation
Downstream End	Water level: observed tide Sediment: pass through the river mouth	
River Dredging	No consideration	
Roughness Coefficient	Same as reproduction calculation	
Void Ratio	0.4	

*blue portion is different from reproduction calculation

(2) Results of Prediction

The results of prediction are as shown in Figure 9-41, Figure 9-42 and Table 9-26, according to which the followings are found out.

<Riverbed Fluctuation of Downstream Section>

- The excavation scale of river channel in the section 0 to 5km is less than the upstream of 5 km. The degradation of riverbed in 1m is recognized in the distance post 0 to 5km. As described in the section 9.3.7, this is the limit of the this model to analyze in detail. In fact, the deposition of the clay and silt component is presumed to be promoted by the waves and chemical action of salt water.
- In the section 5 to 10km, the river channel is enlarged, however the river bed topography has no significant change and seems to be stable.

<Riverbed Fluctuation of Middle Stream Section>

- In the middle stream, the riverbed is lowered in the section upstream of river channel excavation (enlarged) section. This is estimated that due to the lowering of flood water level, the water level in the upstream non-improved section decreases and the velocity of flood discharge increases so that the riverbed degradation is progressed. The degradation section is in 19k to 21k, and maximum lowering depth is approximately 2m. The extent of this influence is examined the next section.

<Sediment Discharge Load>

- In the Countermeasures prediction the total volume of clay, silt and fine sand from the main stream and tributaries (Nawaka River and Malakua Rivers is 110,000m^3/year and 10,000m^3/year respectively. If there will be no big change in conditions of the land use and the meteorology in the Nadi River basin, the almost same amount of sediment load will be yielded in future.
- In the Countermeasures, the retarding basins are planned. According predication calculation, approximately 1,000m^3/year of sediment with particle of clay to medium sand will be trapped in the basins.

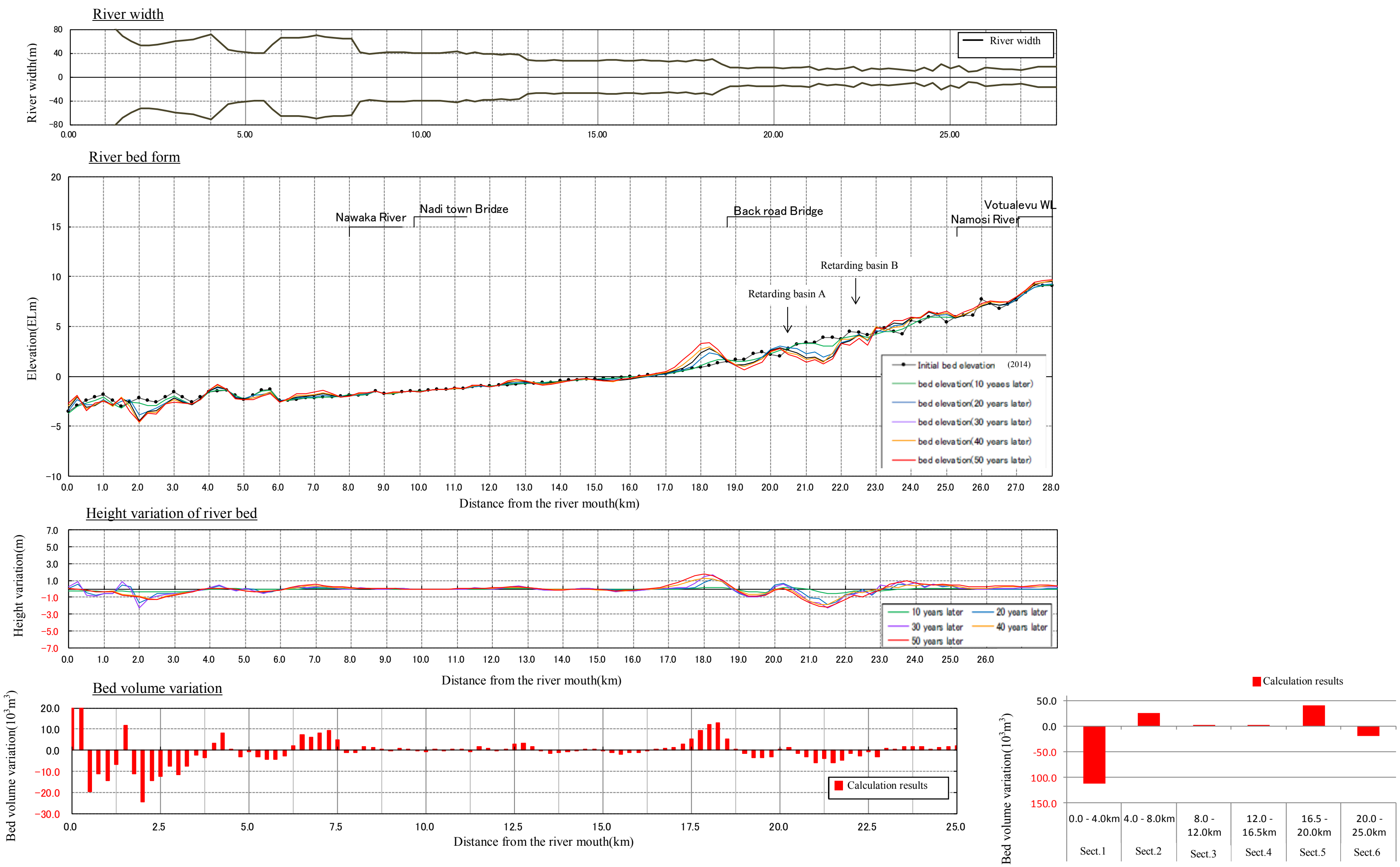


Figure 9-41 Prediction Results with Countermeasures: Nadi main stream

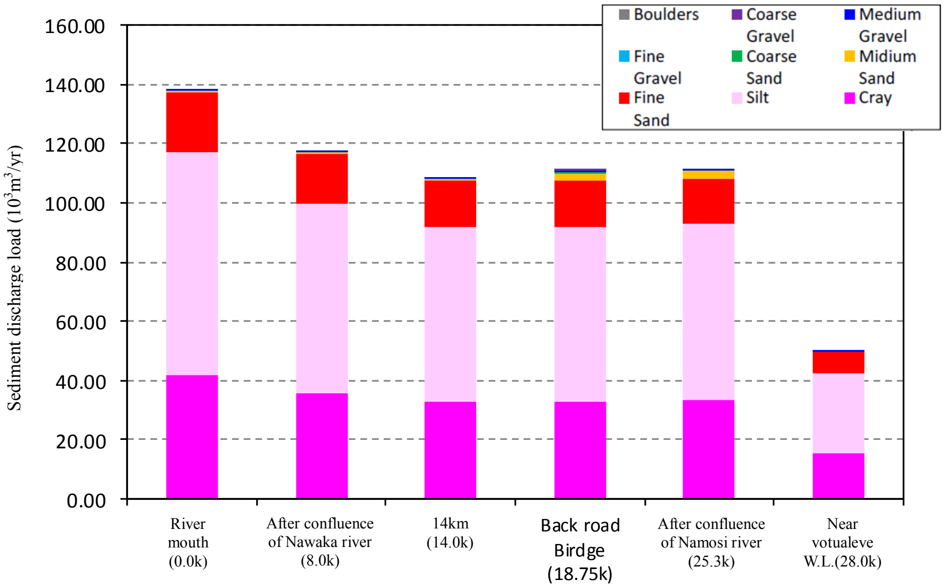


Figure 9-42 Prediction Results with Countermeasures: Nadi main stream (Sediment Volume by Grain Saize)

Table 9-26 Prediction Results with Countermeasures: Nadi main stream (Sediment Volume by Grain Saize)

	Cray	Silt	Fine Sand	Midium Sand	Coarse Sand	Fine Gravel	Midium Gravel	Coarse Gravel	Boulders	Sediment discharge load
River mouth (0.0k)	41.99	74.87	20.78	0.32	0.12	0.05	0.00	0.00	0.00	138.1
After confluence of Nawaka river (8.0k)	35.65	63.81	16.99	0.49	0.04	0.01	0.00	0.00	0.00	117.0
14km (14.0k)	32.94	59.04	15.76	0.23	0.18	0.07	0.02	0.00	0.00	108.3
Back road Birdge (18.75k)	32.95	59.04	15.73	2.08	0.35	0.23	0.51	0.00	0.00	110.9
After confluence of Namosi river (25.3k)	33.32	59.67	15.39	2.32	0.00	0.00	0.00	0.00	0.00	110.7
Near votualeve W.L.(28.0k)	15.34	26.91	7.19	0.49	0.01	0.00	0.00	0.00	0.00	49.9
Retarding basin (22.5k+20.5k)	0.28	0.51	0.13	0.10	0.00	0.00	0.00	0.00	0.00	1.0

(Unit : 10^3m^3/yr)

9.4.2 Influence Analysis of Countermeasures

Compared the prediction results of the case with Countermeasures with the case without Countermeasures, the influence of the Countermeasures is analyzed in quantities.

(1) Influence on Flood Control

The prediction of the case with countermeasures and the case without countermeasures after 50 years is compared. The results of comparison from the points of view of the average height of riverbed and the variation of riverbed height are as shown in Figure 9-43.

The general influences on flood control are reduce of discharge capacity by the aggradation of riverbed and the influence on flood control facilities such as destruction of bank protection. From the Figure 9-43, the degradation in the section 19k to 23k and the accumulation of sand with fine particles (aggradation of riverbed) are observed as relatively remarkable phenomena so that the influence on flood control of such phenomena are examined.

(i) Riverbed Degradation

The riverbed degradation occurs in relatively wide range in the section 19k to 23k. The maximum average degradation of riverbed is predicted approximately 2 m in 50 years. The maximum depth will be more than this figure which may cause some influence on flood control structures in future. However the degradation will not occur uniformly in all the section. Since the reverbed degradation will progress gradually from the easily erodible section, the necessity of urgent counter measure is likely to be low.

(ii) Riverbed Aggradation

The riverbed aggradation may occur in the section 0k to 5k. Although there is no difference in the variation of riverbed height in the both cases with and without Countermeasures, the dredging work was implemented in this section in the past.

Compared the passing sediment discharge at the river mouth with the both cases, they are 139 x 10^3 m^3/year in the case without Countermeasures and 138 x 10^3 m^3/year in the case with Countermeasures which means the Countermeasures will not contribute to the increase of sediment discharge. Therefore the dredging in the section of river mouth is not considered necessary for the influence of the countermeasures.

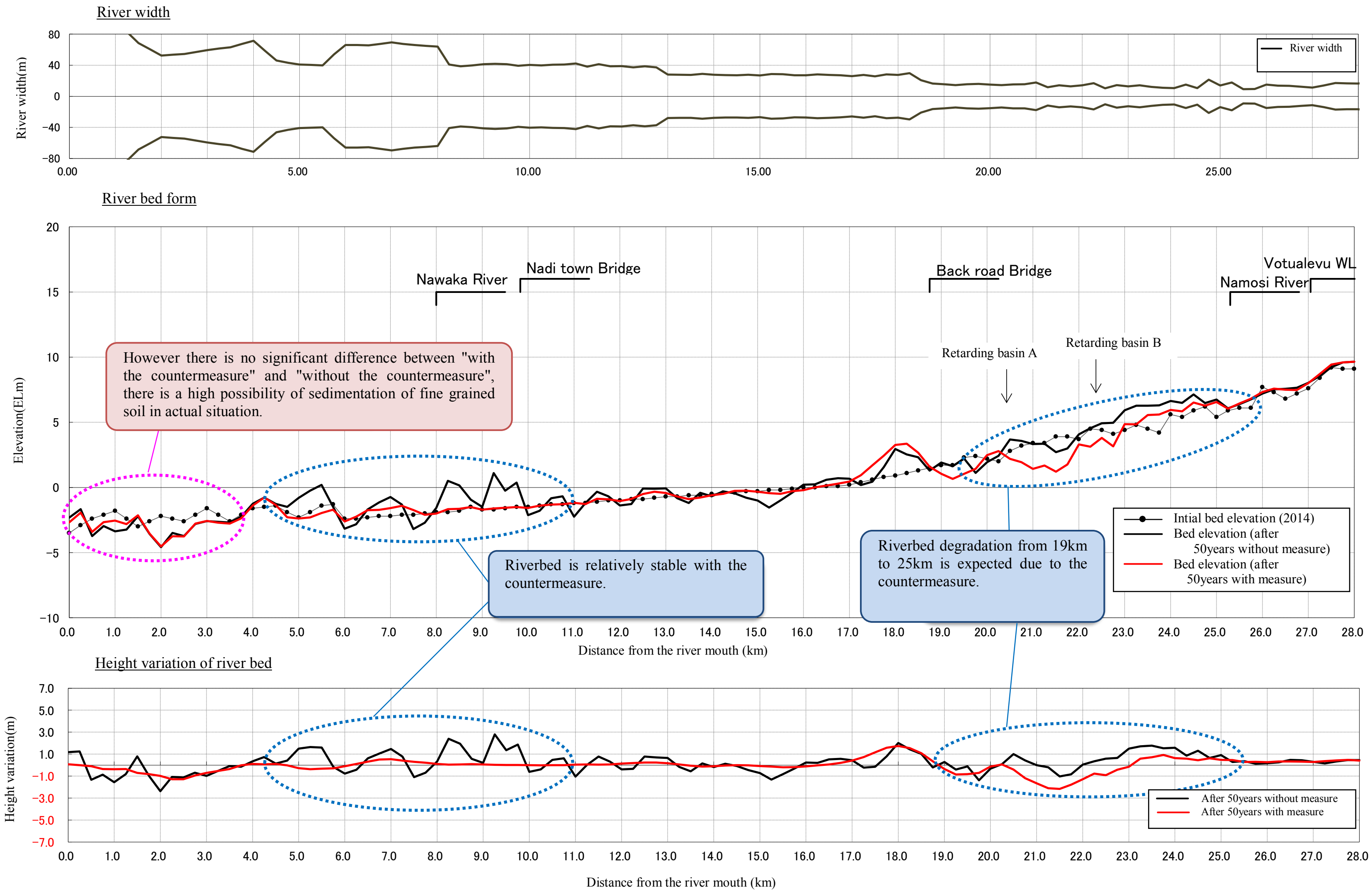


Figure 9-43 Comparison of Riverbed Change in Both Cases with and without Countermeasures

9.4.3 Examination of Mitigation Works

Based on the influence analysis of flood control Countermeasures, the problematic locations are identified and the necessity of mitigation works is considered, then the mitigation Countermeasures in future is examined

(1) Identification of Problematic Location

According to the influence analysis of Countermeasures, the relatively remarkable influence is found out in the riverbed degradation section from 19k to 23k. The reason is due to variation of flood flow conditions caused by the river channel enlargement, of which phenomena possibly occur qualitatively as generating mechanism.

The riverbed aggradation in the section 0k to 5k occurs independently with the Countermeasures mentioned in the previous section so that that section is not included in the problematic location.

Table 9-27 Identification of Problematic Location

Location	Problem	Relation with Countermeasures
19k to 26k	Riverbed degradation	Change of flood flow conditions by river channel enlargement

(2) Necessity of Mitigation Works

The necessity of mitigation works is examined on the riverbed degradation section identified in the clause above.

The situation of riverbed degradation is confirmed referring to the results of riverbed fluctuation analysis as shown below (refer to Figure 9-44):

- ✓ The degradation of riverbed will occur approximately by 1m in the section around 22k after 10 years of completion of Countermeasures.
- ✓ The degradation will be extended toward the downstream of 22k and the deep scouring will

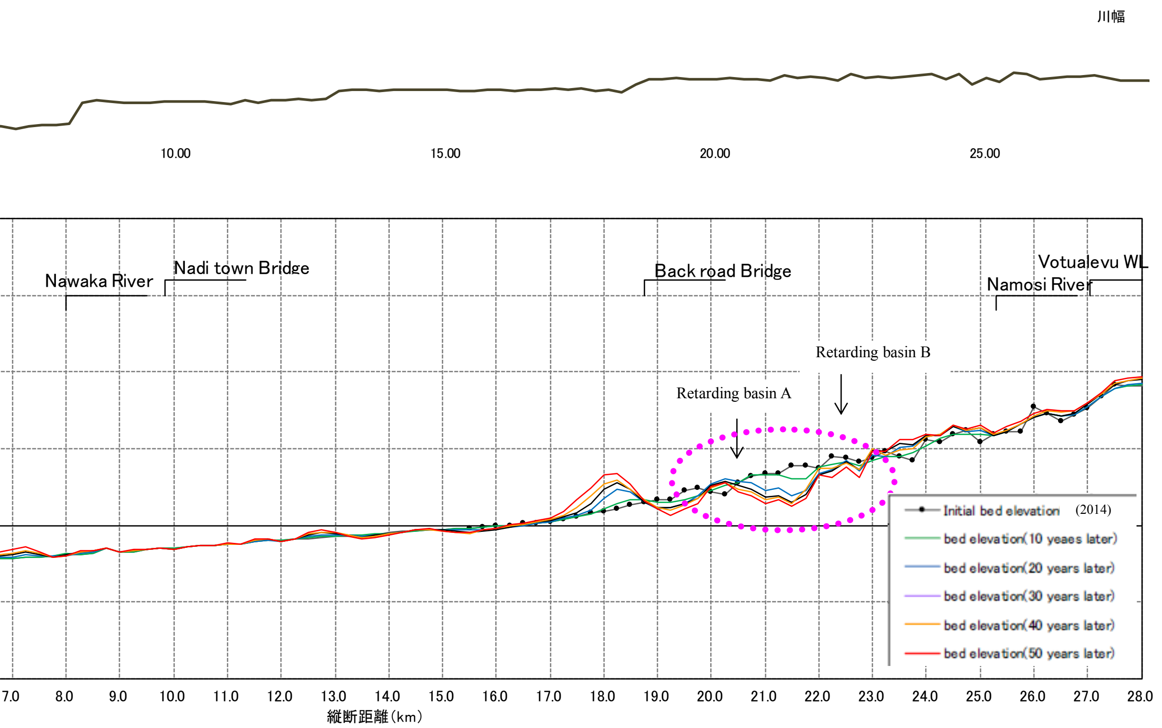
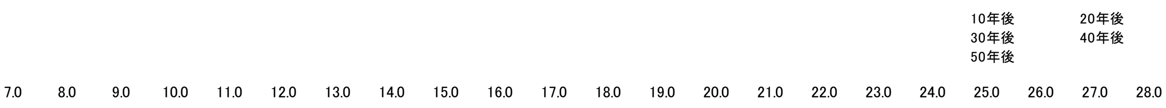


Figure 9-44 Riverbed Change in Problematic Location



One of the Countermeasures for the riverbed degradation is generally ground sill. There is such description as “The ground sill is required in case that the riverbed is unstable and the degradation tendency continues in long period” in the “Manual of Structure Design of Ground Sill, Japan Institute Country-ology and Engineering, November, 1998”.

The counter measure for riverbed degradation includes uncertainty which is difficult to estimate beforehand. The riverbed degradation above is a phenomenon developing gradually so that the Countermeasures are to be taken basically after occurrence of the degradation.

In conclusion, the mitigation works in the problematic location will not be implemented together with the flood control project, and will be implemented according to the change of riverbed topography in that location

(3) Response Policy to Problematic Location

As to the problematic location identified in the Comprehensive Sediment Management, which is the riverbed degradation section, the urgent mitigation work is not to be implemented as mentioned above, the response such as the monitoring the topographic change and limitation of gravel quarrying causing the direct riverbed degradation are likely to be appropriate.

Table 9-28 Response to Problematic Location

Problematic Location	Problem	Relation with Flood Control Project	Necessity of Mitigation Work	Response Policy
19k to 23k	Riverbed degradation	Change of flood flow conditions by river channel enlargement.	Urgent necessity is low.	• Periodical monitoring of riverbed topography • Limitation of sand quarrying in this section.