6.2 Kind of Measures for Flood Control (Structural Measures)

Following 5 schemes are considered as measures against flood disaster, which are structural measures, and then flood control plan combined with each scheme by structural measures would be formulated.

- ✓ Dam
- ✓ Retarding Basin
- ✓ Channel Improvement
- ✓ Diversion Channel
- ✓ Ring Dike

6.3 Initial Consideration for Flood Control (Structural Measures)

6.3.1 Dam

Dam is one of solutions for flood control structures. This is a preliminary study to identify the candidate of promising dam sites in Nadi basin for flood control purpose and to estimate the flood control effect of dam. In order to adopt the dam as flood control structure in the flood control master plan in Nadi basin, the more detail investigation is required including topography and geology at dam sites.

(1) Selection of Candidate Dam site

Preliminary selection of candidate dam site in the Nadi River, Namosi River and Nawaka River basin was carried out prior to a field reconnaissance based on the topographical map with scale 1:50,000.

Criteria of the preliminary selection of the candidate site is as follows,

- Narrow valley width and steep slope gradient for an economical construction of dam effective capacity of the reservoir
- Appropriate flood control capacity against Nadi area
- There is no col surroundings of reservoir and no worry about overflow of reservoir water
- No inappropriateness on the placement of spillway, dissipator, diversion channel and construction facilities, etc.

Based on above mentioned criteria, 7 candidate dam sites which are mentioned bellow and shown in Figure 6-6 were selected. There is no suitable dam site in the Malakuwa river basin because of gently sloping and wide valley width.

- Nadi River Basin; 4 locations (NAD-1 to 4)
- Namosi River Basin; 2 locations (NAM-1 and 2)
- Nawaka River Basin; 1 Location (NAW-1)

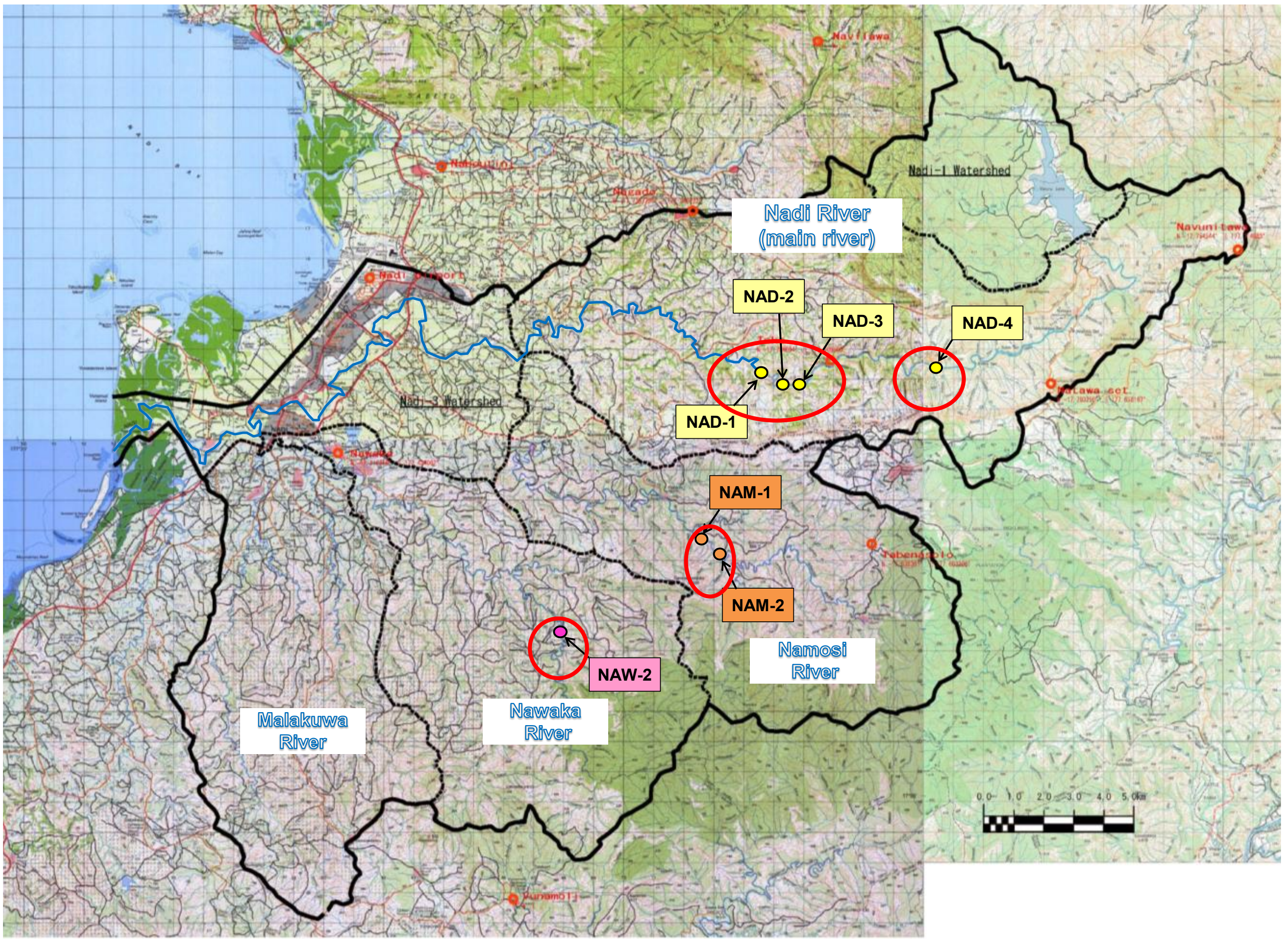


Figure 6-6 Location Map of the Candidate Dam sites

(2) Topography and Geology of Planned Dam site

It is impossible to approach directly to all of the candidate dam sites by a car. Therefore, depending on site condition, it takes about 45 to 90 minutes by foot from an ending point which is possible to approach by a car to dam site. During that time, it is needed to walk a mountain pass, such as animal trail, and river bed (river water depth is maximum up to knee-deep as of August 2014).

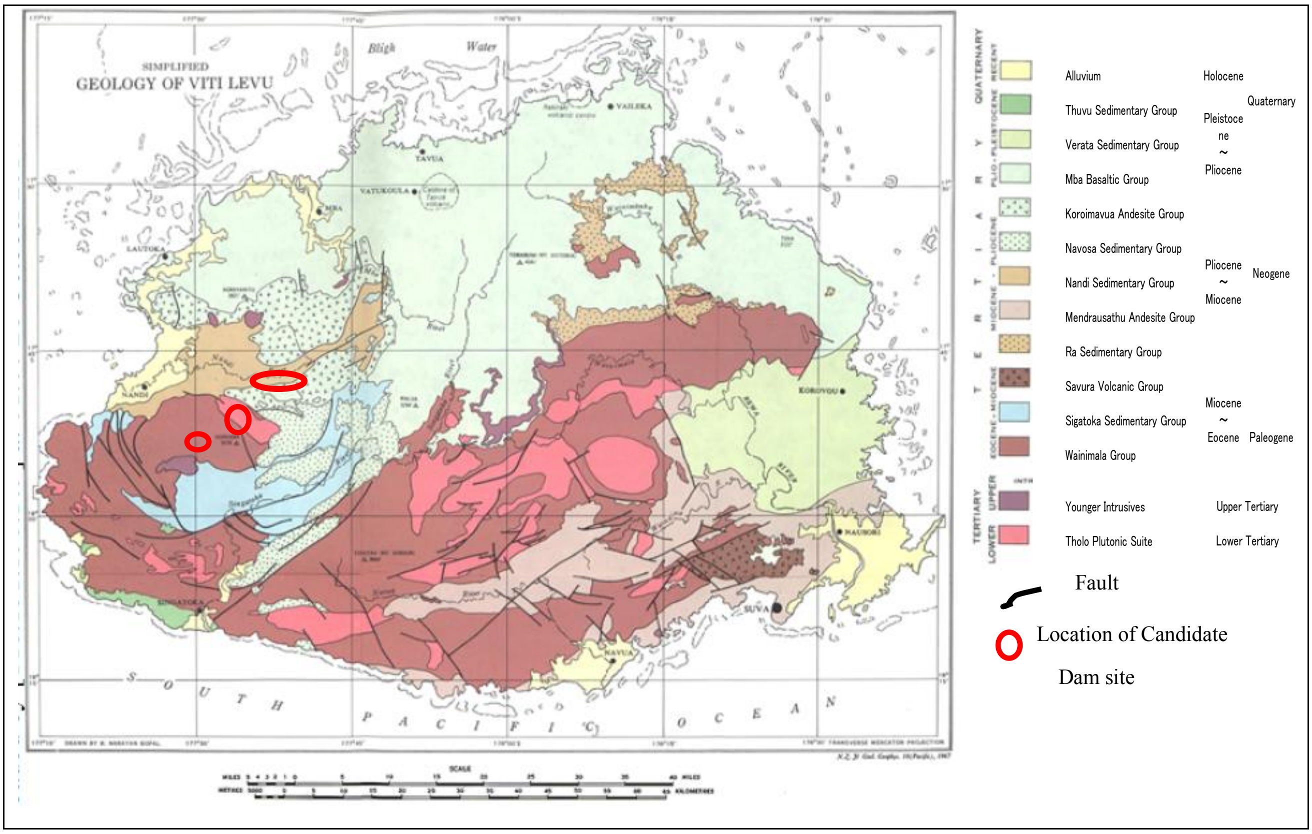
Local guide is an indispensable person to approach all of candidate sites. Furthermore, in the rainy season, a rubber boat is required because it has difficulty in walking river bed due to an increase in the volume of river water.

1) Geological Outline of Viti Levu Island of the Republic of Fiji

Figure 6-7 shows the geological outline of the Viti Levu Island.

Geology of the Fiji Islands including Viti Levu Island is composed of geology which is formed in the Cenozoic era. The oldest geological formation is the Winimala group and Sigatoka sedimentary group which are formed from the late Eocene epoch in the Paleogene period to the middle of Miocene in the Neogene. Thereafter, the Colo Orogeny was took place in the middle to late Miocene then the Colo Plutonic rocks were formed. After the Colo Orogeny, emergence/uplifting of Fiji Islands was started and volcanic activities increased in force and frequency. As a result, sedimentary rocks and volcanic rocks were formed.

As shown in Figure 6-7, distinguished existing fault system can be seen in the southern part of the island while remarkable fault system cannot be seen in the northern part of the island because volcanic rocks, which was formed in the Pliocene epoch, widely distributes the northern part of the island. Distinguished fault system with NE-SW and NW-SE direction can be seen in the southern part of the Viti Levu Island.



Source : Outline of Geology of Viti Levu. New Zealand Journal of Geology and Geophysics (2011)

Figure 6-7 Geological Outline of the Viti Levu Island

2) Topographical and Geological Outline of the Nadi River Basin

a) Topographical Outline

Topographical outline of the Nadi river basin is also shown in Figure 6-6. Figure 6-6 also shows the location of candidate dam sites in the Nadi river basin.

Green colored area in the Figure 6-6 is consisted of a mountain area with elevation more than 500m.

Elevation of ground surface decreases toward the west and mountain area changes to hilly land and flat rea in the coastal area.

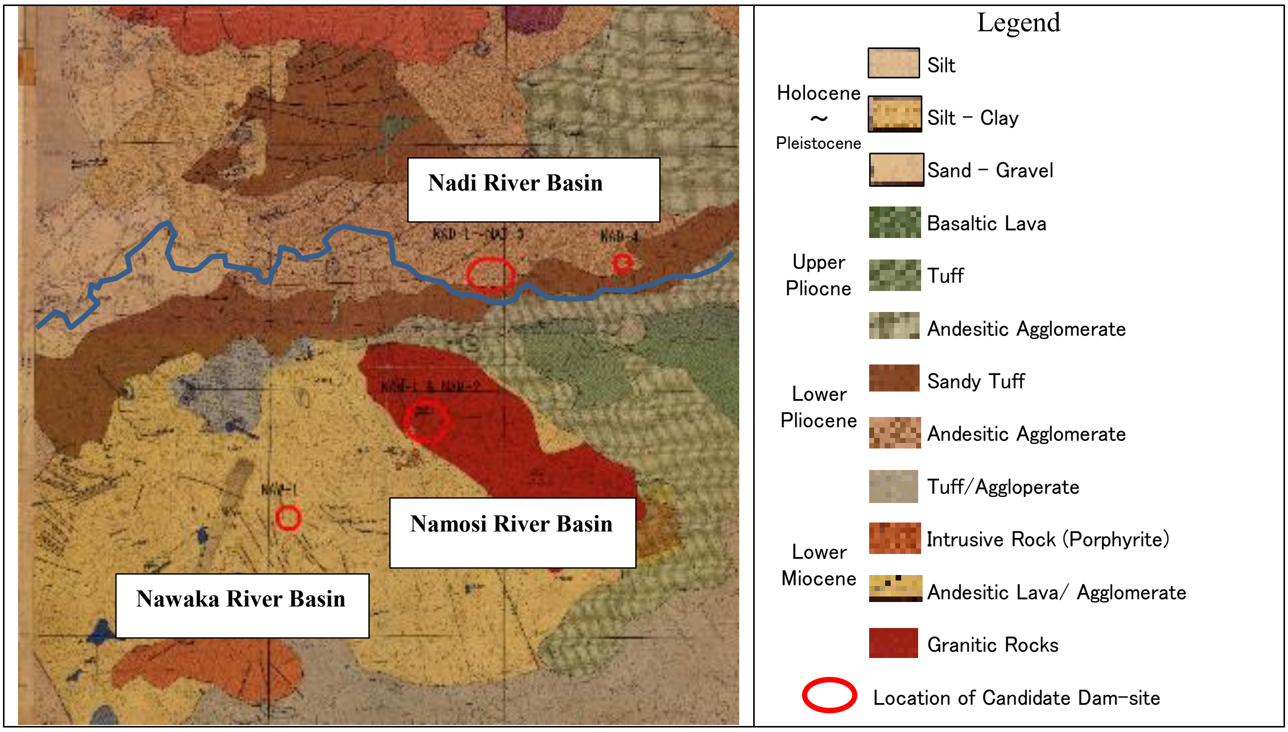
Around the central area of Nadi city, which Nadi airport is located, is surrounded by mountain ridge expanding from north to east and south-east, therefore, river systems of Nadi river basin including the Nadi River concentrates toward to the central area of Nadi city.

b) Geological Outline

The outline of geology of the Nadi River Basin is shown in Figure 6-8.
Since the geological map of Figure 6-8 was published in 1959, there are several differences on the formative period of geological formation between the geological map of Figure 6-7 which was published in 2011. However, geological outline of the candidate dam sites in the Nadi River Basin is as follows:

- Geological setting along the Nadi River and Nawaka River is mainly consisted on Andesite Lava and Andesitic pyroclastic rocks such as agglomerate. Formative period of rocks along the Nawaka River is older than rocks along the Nadi River. (Geology along the Nawaka River is composed of Wainimala group, Geology along the Nadi River is composed of Nadi Sedimentary Rocks, refer to Figure 6-7)
- Granitic rock, which is an intrusive rock of main components of the Colo/Tholo Plutonic Suite, distributes along the Namosi River.

Andesite Lava and Andesitic pyroclastic rocks that distribute along the Nadi River Basin were formed from Miocene (7 million years ago) to late Pliocene period in the Neogene and they were generated by large-scale volcanic activities. On the other hand, Andesite Lava and Andesitic pyroclastic rocks that distribute along the Nawaka River was inferred to be formed from the Eocene (around 33 million years ago) to Miocene period. In addition, Figure 6-8 shows the location of candidate dam sites. Geological setting / condition of each candidate dam site based on the result of field reconnaissance is described in 3).



Source：Geology of Nadi area 1959

Figure 6-8 Geological Outline of the Nadi River Basin

3) Candidate Dam site

a) Outline of each Dam site

I) Topographical Outline

As shown in Figure 6-6, topography around each candidate dam site forms mountainous area and hilly land. However, almost all candidate dam sites are located in a hilly land.

II) Geological Outline

Table 6-2 shows the geological outline around each candidate dam site.

As described in section (1) and (2), main geological components around each candidate dame site are composed of volcanic rocks such as andesite lava and andesitic pyroclastic rocks, and partially granitic rocks.

Table 6-2 Geological Outline of each Candidate Dam site

Name of River	Name of Candidate Dam site	Geological Outline	
Nadi River	NAD-1 ～ NAD-4	Agglomerate with Andesite Flow	Nadi Sedimentary Rocks Pyroclastic rocks: Hyaloclastite, tuff, tuff brecciated lava, agglomerate, etc.
Namosi River (Tributary)	NAM-1 & NAM-2	Hornblende Granit	Colo/Tholo Plutonic suite and Dyke (porphyrite)
Nawaka River (Tributary)	NAW-1	Basic Andesite Flows with Agglomerates Phases	Thick volcanic rocks and clastic rock of Winimala Group, etc.

Based on the result of field reconnaissance, each candidate dam site has outcrop of bedrock along the river bed and engineering property of bedrock can be summarized as follows, therefore bedrock of each candidate dam site is assumed to be able to use as a foundation of concrete dam with 60 to 80 heights.

- Although there are joint and small-scale fault can be identified at each dam site, hardness of rock is hard and well consolidated.
- These bedrock of each river bed is classified into CM or CM to CH class of rock classification

Topographical and geological condition of each candidate dam site of Nadi, Namosi and Nawaka river basin are described from next clause, respectively.

b) Nadi River

Location of candidate dam site in the Nadi River Basin is shown in Figure 6-9.

Elevation of river bed of each candidate dam site is ranges from 30 to 55m asl (above sea level). NAD-4 which is planned at upper most point, on the left side slope, geographical feature forms continuous slope from river bed to ridge of hill that has a ground elevation around 600m. Right side slope forms continuous slope from river bed to small ridge of hill with elevation 250m, then it forms continuous slope until the ridge of a mountain with elevation around 800m.

On the other hand, at NAD-1 to NAD-3, which are located lower reach of Nadi River, geographical feature forms hilly land with elevation ranges from 100 to 150m.

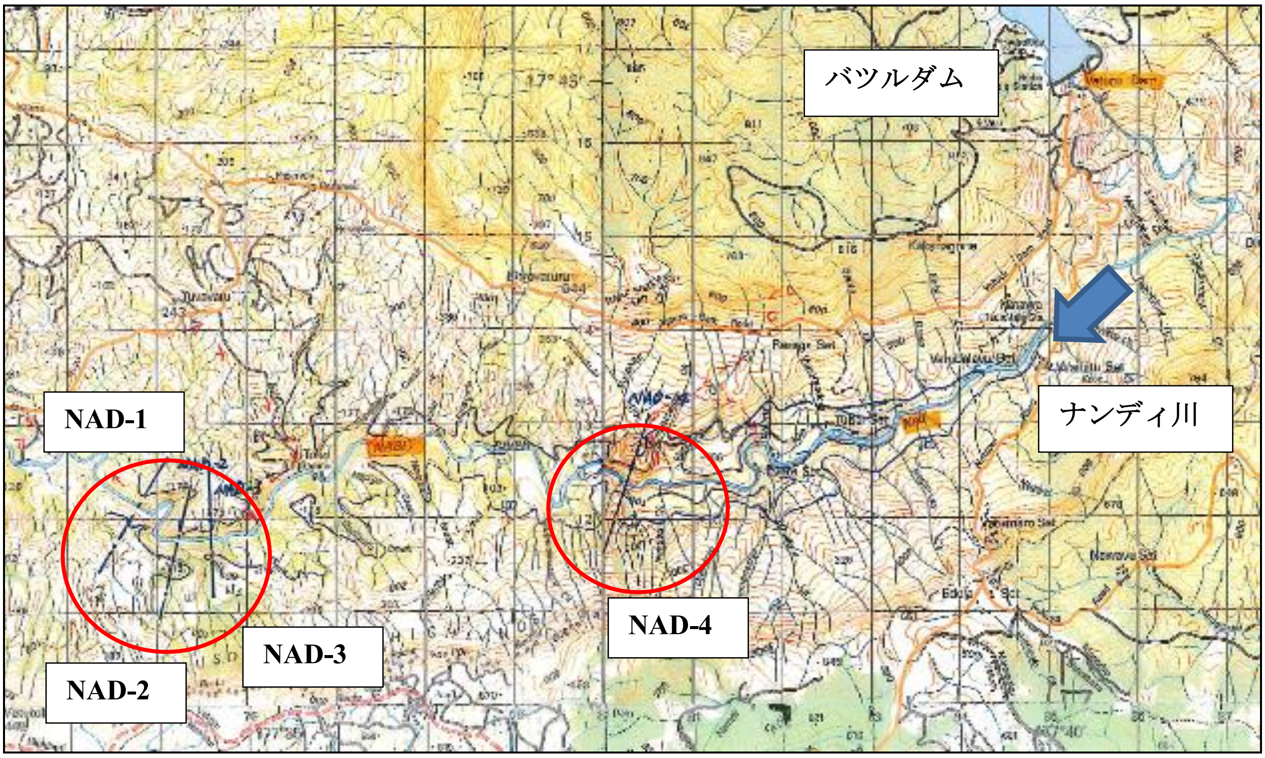


Figure 6-9 Location of candidate and topography around candidate dam site along the Nadi River

I) NAD-1

i) Topography

Width of river bed is around 30m. Left side slope forms steep slope from river bed to the mid-slope and continuous outcrop of bed rock can be seen. On the right side slope, sandy gravel layer (floodplain deposit) having a thickness of about 3 to 5m is deposited and talus deposit accumulates on the sandy gravel layer.

Photo 6-1 Condition around River bed (Candidate Dam site NAD-1)

ii) Geology/ Cover Layer
Andesite Lava and Andesitic pyroclastic rocks such as hyaloclastite and agglomerate distribute in the river bed.

A thin talus deposit accumulates on the right side slope. Generally cover layer on the left side slope is seemed to be thin.

iii) Condition of Rock Foundation
Condition of bed rock is well consolidated and hardness of rock is hard. It is expected that bedrock of this dam site is classified into CM class of rock classification

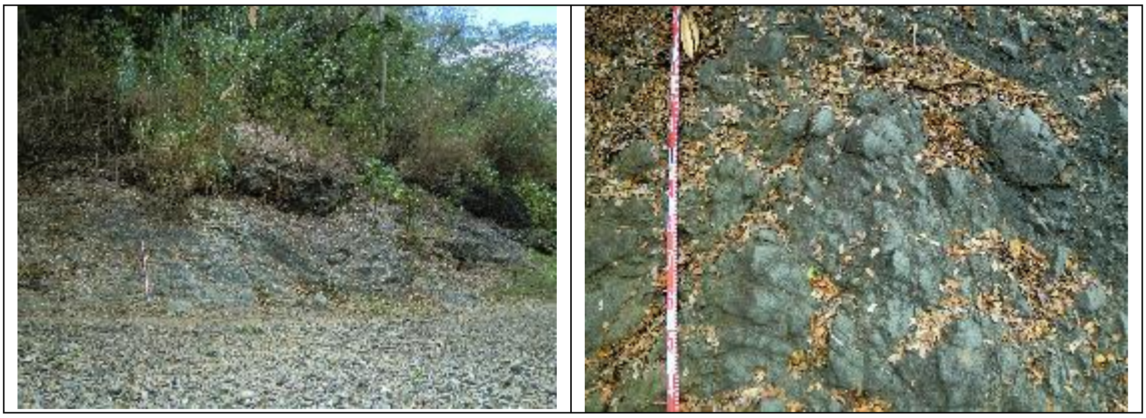


Photo 6-2 Condition of Geology and Bed Rock (River bed of NAD-1)

II) NAD-2
i) Topography
Width of river bed is around 27m. Outcrop of bed rock can be seen on the right and left side bank along the river bed. Gradient of the left side bank is relatively gentle. Tributary of which river width is slightly wide joins Nadi river at immediate upstream of dam site on the left bank of the river.

Photo 6-3 Condition around River bed (Candidate Dam site NAD-2)

ii) Geology/ Cover Layer
Andesite Lava and Andesitic pyroclastic rocks such as hyaloclastite and agglomerate distribute in the river bed.

It is inferred that thickness of talus deposit is slightly thick on the left side bank because of gentle slope.

iii) Condition of Rock Foundation
Condition of bed rock is well consolidated and hardness of rock is hard. It is expected that bedrock of this dam site is classified into CM class of rock classification

Photo 6-4 Condition of Geology and Bed Rock (River bed of NAD-2)

III) NAD-3

i) Topography

Width of river bed is around 27m. Outcrop of bed rock can be seen on the right and left side bank along the river bed. Gradient of the left side bank is relatively gentle. Tributary of which river width is slightly wide joins Nadi river at immediate upstream of dam site on the left bank of the river.

Photo 6-5 Condition around River bed (Candidate Dam site NAD-3)

ii) Geology/ Cover Layer

Andesite Lava and Andesitic pyroclastic rocks such as hyaloclastite and agglomerate distribute in the river bed.

It is inferred that thickness of talus deposit is thin.

iii) Condition of Rock Foundation

Condition of bed rock is well consolidated and hardness of rock is hard. It is expected that bedrock of this dam site is classified into CM class of rock classification

Photo 6-6 Condition of Geology and Bed Rock (River bed of NAD-3)

IV) NAD-4

i) Topography

This site is located the most upper reaches among candidate site of Nadi River Basin.

There are boulder stones in the river bed.

Width of river bed is around 28m. Left side bank forms steep slope and reaches to the top of ridge with elevation around 600m. Right side bank also forms steep slope and reaches to an independent peak with elevation 243m and right side bank continues to the top of ridge with elevation around 800m.

Photo 6-7 Condition around River bed (Candidate Dam site NAD-4)

ii) Geology/ Cover Layer

Geology of outcrop on the left side bank is composed of pyroclastic rocks such as tuff/tuffaceous sand and lapilli tuff/ tuff brecciated lava. Outcrops which are composed of agglomerate and tuff brecciated lava are scattered along the river bed. These rocks are well consolidated.

It is inferred that thickness of cover layer such as talus deposit is thin because slope gradient is steep.

iii) Condition of Rock Foundation

Condition of bed rock is well consolidated and hardness of rock is hard as well as the other candidate site in the Nadi river basin. It is expected that bedrock of this dam site is classified into CM class of rock classification

Left side bank

Right side bank

Photo 6-8 Condition of Geology and Bed Rock (River bed of NAD-4)

c) Namosi River (Tributary)

Location of candidate dam site in the Namosi River Basin is shown in Figure 6-10.
Elevation of river bed of each candidate dam site is ranges from 70 to 90m asl (above sea level).

Slope of left side bank of NAM-1 and NAM-2 continues to the ridge with elevation around 500m.

On the other hand, since landform of the right side bank forms hilly terrain, elevation of crest is ranges from 150 to 200m.

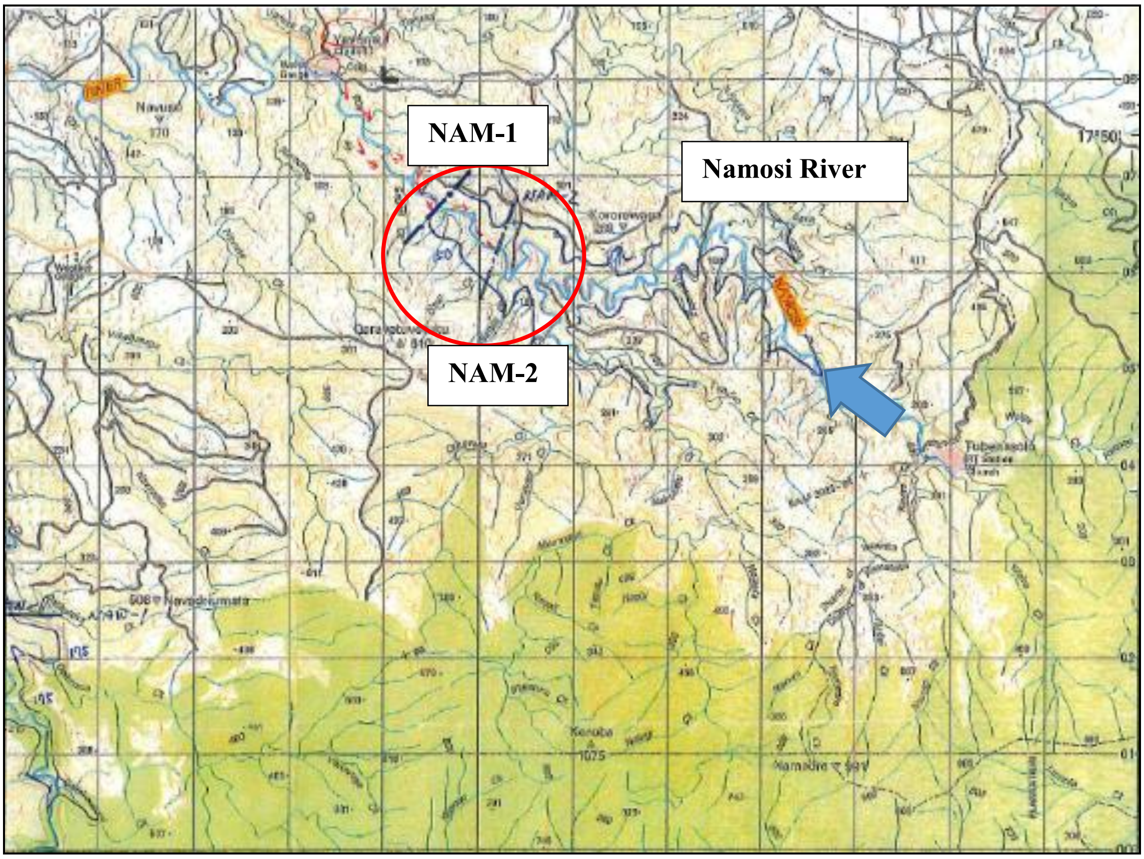


Figure 6-10 Location of candidate and topography around candidate dam site along the Namosi River

I) NAM-1

i) Topography

Width of river bed is around 14m. Left side bank forms steep slope whereas the right side bank forms gentle slope. River deposit accumulates on the right side of river channel however, thickness of river deposit is thin and outcrops of base rock can be seen partially.

Photo 6-9 Condition around River bed (Candidate Dam site NAM-1)

ii) Geology/ Cover Layer

Coarse grain plutonic rock such as granite distributes on the river bed. Intrusive rock such as porphyrie intrudes into plutonic rocks. Higher frequency of dykes of intrusive rock can be observed compared to NAM-2 site. Hardness of rock of granite and intrusive rock are hard, however, a part of granite is weathered and becomes sandy.

It is inferred that thickness of cover layer such as talus deposit is thin on the left side bank and relatively thick on the right side bank.

iii) Condition of Rock Foundation

Condition of bed rock is well consolidated and hardness of rock is hard. It is expected that bedrock of this dam site is classified into CM class or CM to CH class of rock classification.

Photo 6-10 Condition of Geology and Bed Rock (River bed of NAM-1)

II) NAM-2

i) Topography

Width of river bed is around 14m. Steep slope with 70m relative height can be seen on the left side bank from the river bed. Steep gradient of the right side bank is relatively gentle.

Photo 6-11 Condition around River bed (Candidate Dam site NAM-2)

ii) Geology/ Cover Layer

Coarse grain plutonic rock such as granite distributes on the river bed. Intrusive rock such as porphyries intruded into plutonic rocks. It is inferred that thickness of cover layer such as talus deposit is thin on the left side bank and relatively thick on the right side bank in the 5 to 6m upper part from river bed.

iii) Condition of Rock Foundation

Condition of bed rock is well consolidated and hardness of rock is hard. It is expected that bedrock of this dam site is classified into CH class.

Photo 6-12 Condition of Geology and Bed Rock (River bed of NAM-2)

d) Nawaka River (Tributary)

Location of candidate dam site in the Namosi River Basin is shown in Figure 6-11. Elevation of river bed of candidate dam site is around 90m asl (above sea level).

Location of NAW-1 dam site is located at the changing point of grades of mountainous area and hilly land. Elevation of the top of ridge is not exceeding from 150 to 200m.

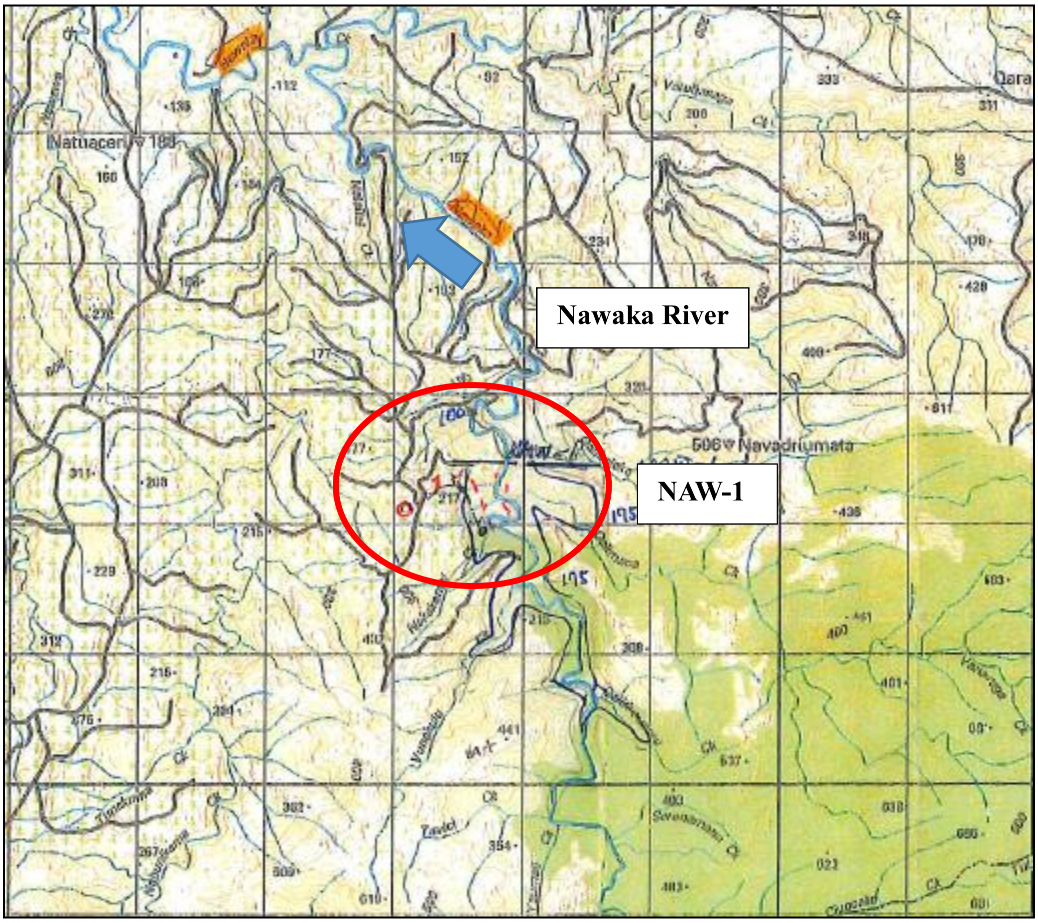


Figure 6-11 Location of candidate and topography around candidate dam site along the Nawaka River

I) NAW-1

i) Topography

Width of river bed is around 15m. Slope gradient of the left side bank is gentle due to an accumulation of talus deposit. On the other hand, slope gradient of the right side bank is relatively steep despite of accumulation of talus deposit.

There are boulder stones in the river bed. It is assumed that these boulder stone generated by a river bed erosion or collapse of slope.

Photo 6-13 Condition around River bed (Candidate Dam site NAW-1)

ii) Geology/ Cover Layer

Outcrop which is composed of base rock can be seen at the center, left and right side bank. Base rock is mainly comprised of andesite lava and agglomerate.

It is inferred that cover layer such as talus deposit distributes on the left and right side bank.

iii) Condition of Rock Foundation

Condition of bed rock is well consolidated and hardness of rock is hard. It is expected that bedrock of this dam site is classified into CM to CH class.

Photo 6-14 Condition of Geology and Bed Rock (River bed of NAW-1)

(3) Second Step Selection of Dam Site

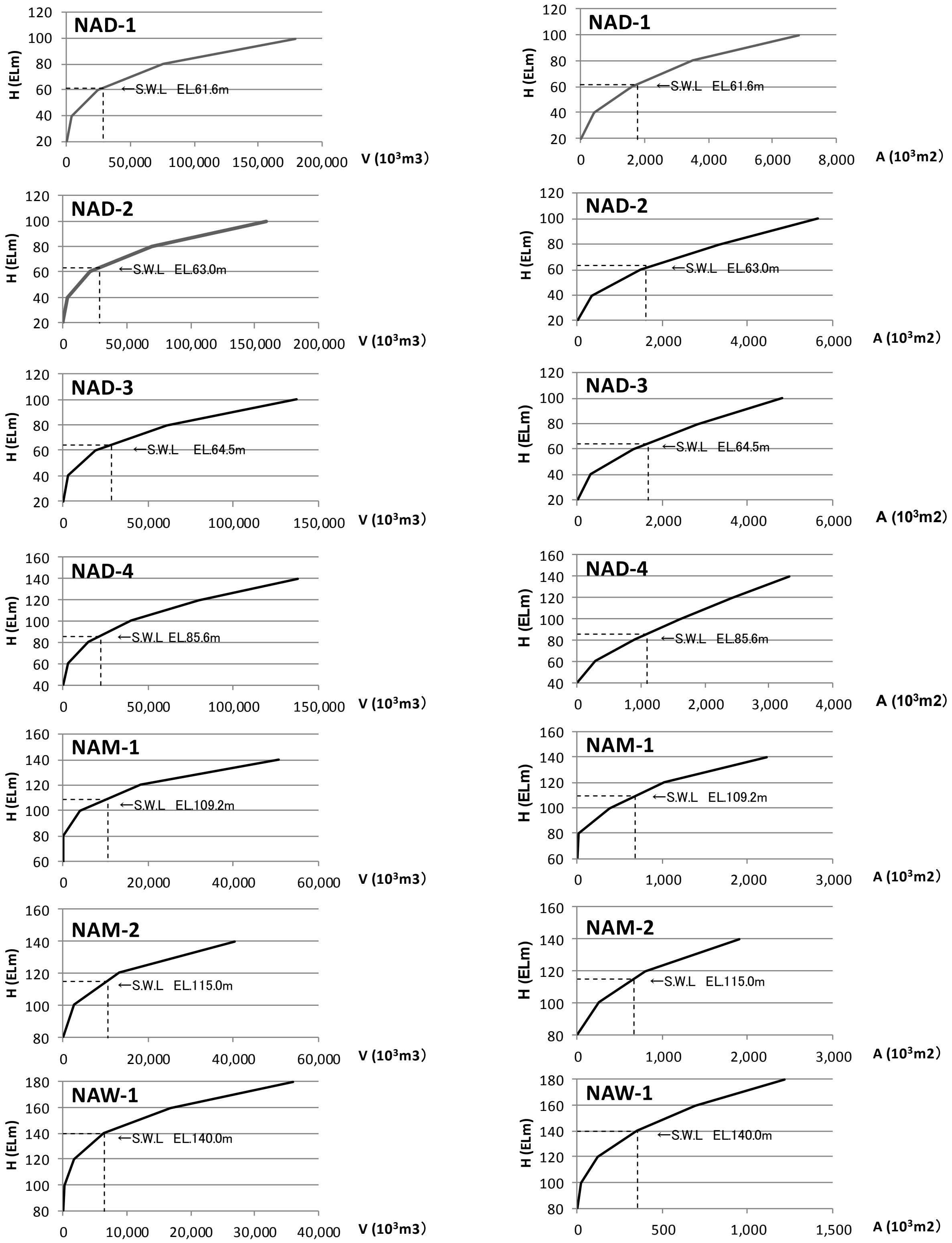
1) Reservoir Capacity and Cross Section along Dam Axis

Reservoir capacity curve (H-V curve) is prepared based on the topographic map with scale of 1/50,000 obtained from the Government of Fiji (Land and Survey Department). The interval of contour line in the above map is 20m so that at first the reservoir area at each contour line is calculated and the reservoir volume is calculated in 20m interval by average section area method, after that the reservoir capacity of each interval is accumulated at each elevation.

The topographic cross section along dam axis is drawn based on the same contour line above.

The reservoir capacity curve (H-V&H-A) and the cross sections along dam axis are as shown in the Figure 6-12 and the Figure 6-13 respectively.

The shape of dam body at each dam site is also shown in the Figure 6-13 of which design concept is as shown in (2), c) in the next section.



NAD-1

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
20	0	0		0
40	20	414	4,140	4,140
60	40	1,622	20,360	24,500
80	60	3,512	51,340	75,840
100	80	6,825	103,370	179,210

NAD-2

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
20	0	0		0
40	20	329	3,290	3,290
60	40	1,476	18,050	21,340
80	60	3,334	48,100	69,440
100	80	5,664	89,980	159,420

NAD-3

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
20	0	0		0
40	20	306	3,060	3,060
60	40	1,313	16,190	19,250
80	60	2,842	41,550	60,800
100	80	4,825	76,670	137,470

NAD-4

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
40	0	0		0
60	20	289	2,890	2,890
80	40	899	11,880	14,770
100	60	1,610	25,090	39,860
120	80	2,418	40,280	80,140
140	100	3,319	57,370	137,510

NAM-1

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
60	0	0		0
80	20	9	90	90
100	40	383	3,920	4,010
120	60	1,029	14,120	18,130
140	80	2,228	32,570	50,700

NAM-2

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
80	0	0		0
100	20	255	2,550	2,550
120	40	805	10,600	13,150
140	60	1,908	27,130	40,280

NAW-1

E.L.(m)	Interval(m)	Area(10^3m^2)	Δ V(10^3m^3)	Reservoir Capacity(10^3m^3)
80	0	0		0
100	20	24	240	240
120	40	120	1,440	1,680
140	60	351	4,710	6,390
160	80	696	10,470	16,860
180	100	1,214	19,100	35,960

Figure 6-12 Reservoir Capacity Curve （H-V, H-A）

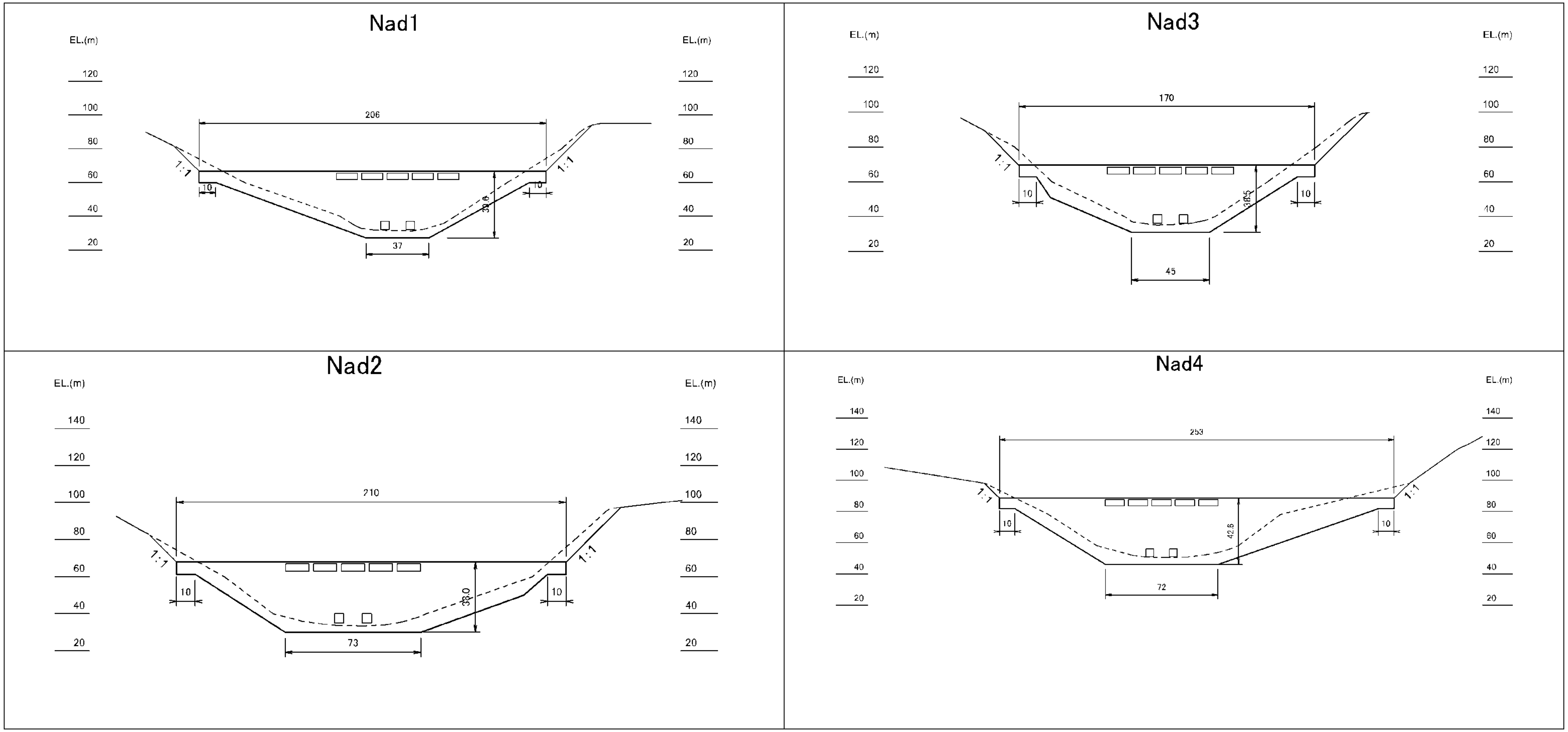


Figure 6-13 Cross Sections along Dam Axis (1/2)

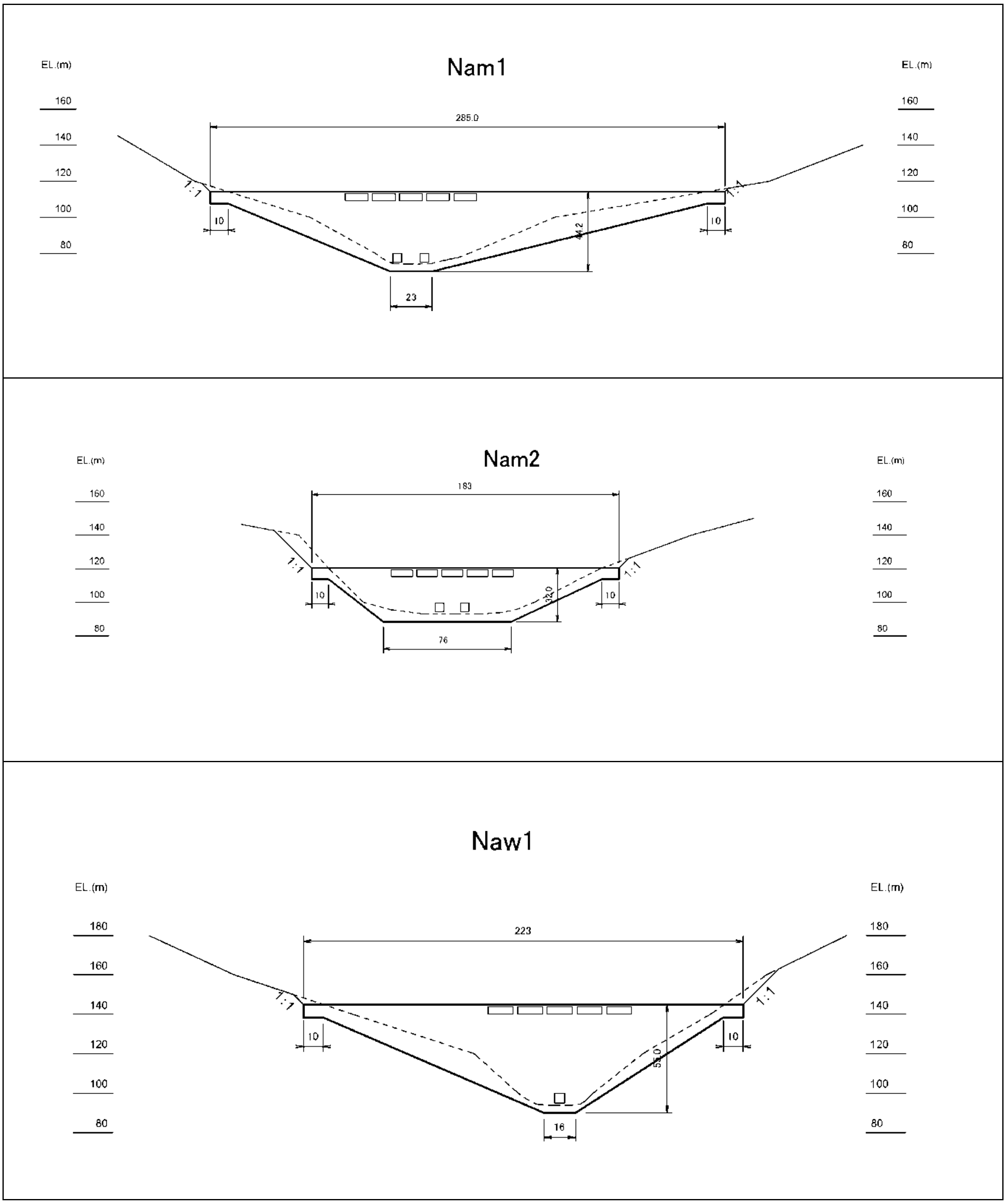


Figure 6-13 Cross Sections along Dam Axis (2/2)

2) Type of Dam and Typical Section

a) Type of Dam

The type of dam is to be Dry Type Flood Control Dam.

The purpose of this type of dam is flood control only. The dam has outlet without gate at the present riverbed level, through which the runoff and sediment sluice in normal period. However, in flood time the flood discharge over capacity of the outlet will be reserved temporally in the reservoir, after that according to receding of flood the reserved water will be released through the outlet, then water level of reservoir will go down to riverbed level, thus the flood control will be made.

Although in the detail study, sediment volume in the reservoir should be estimated by riverbed fluctuation analysis, the sediment accumulated in the reservoir will be decreased remarkably since the sediment is discharged thorough the outlet.

The type of dam is appropriate to be the concrete gravity type. In case of fill type dam, the reverbed outlet is to be installed inside the long diversion tunnel so that the possibility of sedimentation and clogging in the tunnel may be high and the maintenance is not easy since structural stability and erosion of tunnel and so on are concerned.

Therefore the type of dam is to be dry type flood control concrete gravity dam.

b) Capacity and Water Level of Reservoir

The reservoir capacity for selection of the dam sites is estimated by the flood control calculation applying the flood hydrograph of No.25 March 2012 flood, which was obtained in the Chapter 5 Rainfall and Run-off Analysis, to each dam site, Nadi main stream NAD-3, Namosi tributary NAM-2 and Nawaka tributary NAW-1.

The required reservoir capacity of NAD-3 is calculated by adding 20% of allowance to the required flood control capacity, which is 28,600,000m3. NAD-1 and NAD-2 have the almost same catchment area so that the required reservoir capacity of each site is to be assumed as same as NAD-3, 28,600,000m^3.

The required reservoir capacity of NAD-4 which is located at the upstream area of Nadi main stream is estimated in proportion to the catchment area of NAD-3 as shown below:

$$8,600,000 * 84km^2 / 110km^2=21,800,000m^3$$

NAM-1and NAM-2 in the tributary Namosi has the almost same catchment area so that the required reservoir capacity is 10,500,000m3 which is calculated for NAM-2.

The required reservoir capacity of NAW-1 in the tributary Nawaka is calculated in flood control calculation as 6,400,000m3

The required reservoir capacity of each dam site is as shown below:

NAD-1	28,600,000m^3
NAD-2	28,600,000m^3
NAD-3	28,600,000m^3
NAD-4	21,800,000m^3
NAM-1	10,500,000m^3
NAM-2	10,500,000m^3
NAW-1	6,400,000m^3

The reservoir water level corresponding to the reservoir capacity is calculated by interpolating between water level and capacity shown in the Figure 6-12, which is as shown in the Table 6-4. The maximum water level for flood control is called surcharge water level (S.W.L)

c) Typical Section of Dam

The type of dam is concrete gravity type with free over flow spillway for emergency flood and Dry Type Flood Control Dam with gate less outlet at the present riverbed level.

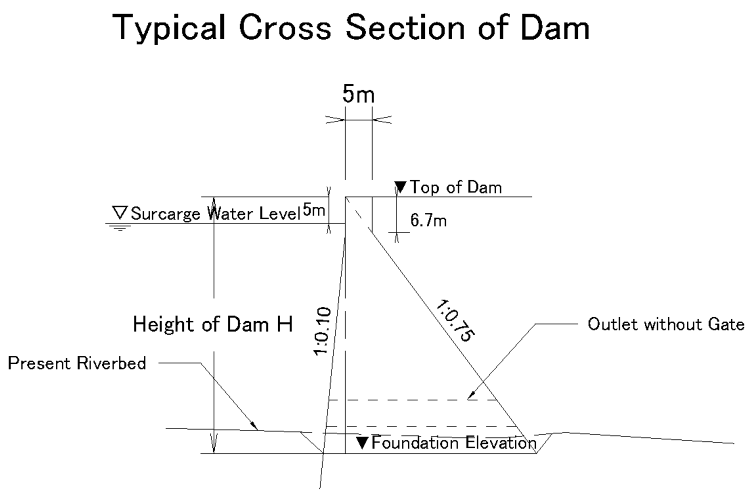
The foundation is to be based on the rock by excavating 5m from present riverbed since the foundation rock seems to be hard and sound with rock classification of CM～CH.

The top elevation of dam is to be the elevation by adding 5m, which is a total of free over flow depth and allowance height of dam, to the crest elevation of free over flow spillway.

The width of top of dam is to be 5m. The upstream slope of dam is to be 1:0.1 which is rather gentle compared with general dam since the dam is empty in normal time so that the stability of dam against upstream-ward earthquake force is required. The downstream slope of dam is to be 1:0.75 which is rather steep compared with general dam since the stability condition is better than general dam which reserves water behind dam in normal time.

The penetration length to the natural ground at both banks is assumed to be 10m.

The typical section of dam and typical section along dam axis are shown in the Figure 6-14.



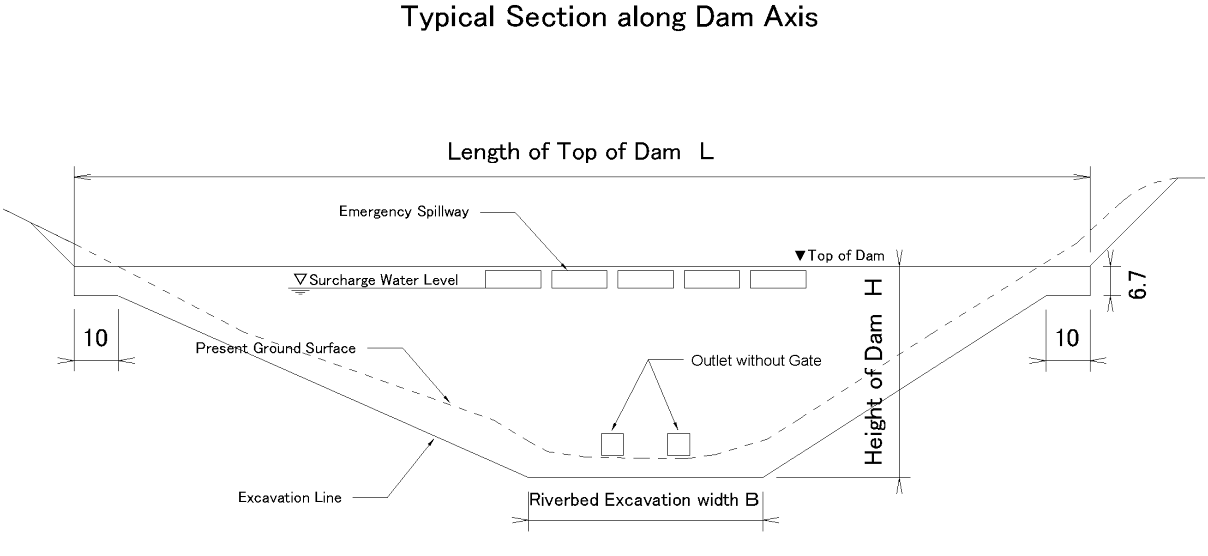


Figure 6-14 Typical Section of Dam

d) Dam Volume

The dam volume is roughly calculated by the following equations (refer to Figure 6-14).

$H = SWL-REL+10.0$

$A_1 = mH^2/2$, $A_2 = n\,(H-5.0/m)^2/2$, $A_3 = 5.0x5.0/m/2$, $A_4 = 2\,A_3 = 5.0^2/m$

$V_1 = A_1B+ A_3B+(A_1+A_3)(L-B-20.0)/2+A_3(L-B-20.0) = (A_1+ A_3)\ B$

$+ (A_1+3A_3)\ (L-B-20.0)/2$,

$V_2 = A_2\ B+A_2\ (L-B-20.0)/2 = A_2\ (B+L-20)/2$,

$V_3 = A_4 20.0$

$V = V_1+V_2+V_3$

Where;

H: Height of dam(m), SWL: Surcharge water level(EL), REL: Present riverbed elevation (EL), m:Downstream slope of dam, n:Upstream slope of dam, A1 : Cross section area at downstream of dam axis (m2),A2 : Cross section area at upstream of dam (m2), A3 : Cross section area at downstream of dam axis projected to the side of penetration block (m2), A4 : Cross section area of penetration block (m2),B: Excavation width at riverbed (m), L: Length of top of dam (m), V1 : Dam volume at downstream of axis (m^3), V2 : Dam volume at upstream of axis (m3), V3 : Volume of penetration block (m3), V:Total dam volume (m3)

The dam volume is calculated as shown in the Table 6-3 by applying the typical section shown in the Figure 6-14 to each dam site (refer to Figure 6-13).

Table 6-3 Calculation of Dam Volume

Name of River	Nandi Main Stream				Tributary Namosi		Tributary Nawaka
Dam Site	NAD-1	NAD-2	NAD-3	NAD-4	NAM-1	NAM-2	NAW-1
SWL	61.6	63.0	64.5	85.6	109.2	115.0	140.0
REL	32.0	35.0	36.0	53.0	75.0	83.4	95.0
H	39.6	38.0	38.5	42.6	44.2	32.0	55.0
m	0.8	0.8	0.8	0.8	0.8	0.8	0.8
n	0.1	0.1	0.1	0.1	0.1	0.1	0.1
A1	588.1	541.5	555.8	680.5	732.6	384.0	1,134.4
A2	54.2	49.1	50.7	64.6	70.4	32.1	116.8
A3	16.7	16.7	16.7	16.7	16.7	16.7	16.7
A4	33.3	33.3	33.3	33.3	33.3	33.3	33.3
B	37.0	73.0	45.0	72.0	23.0	76.0	16.0
L	206.0	210.0	170.0	253.0	285.0	183.0	223.0
V1	69,924.0	75,357.0	57,573.0	109,012.0	111,941.0	49,377.0	129,168.0
V2	6,043.0	6,457.0	4,943.0	9,852.0	10,138.0	3,836.0	12,790.0
V3	667.0	667.0	667.0	667.0	667.0	667.0	667.0
V	76,600	82,500	63,200	119,500	122,800	53,900	142,700

3) Comparison and Selection of Dam Site

The dam sites are compared each other and the final selection is made as shown in the Table 6-4

In Nadi main stream, 4 sites (NAD-1～NAD-4) were selected from middle stream to upstream. From view point of flood control the dam site with the lager catchment area is better. Three dam sites (NAD-1～NAD-3) in the middle stream area have around 22% catchment area of the total catchment area of 516km2 in the whole Nadi river basin. On the other hand the dam site (NAD-4) in the upstream area has around 16% of the total, and the catchment area of the latter is around 74% of the former, therefore the former is better for flood control.

In NAD-4 site the dam volume is larger and the water storage efficiency (Reservoir capacity/Dam volume) is lower. 3 sites in the middle stream have almost same catchment area, however the dam volume is smallest and water storage efficiency is highest in NAD-3. In addition, the evaluation of dam foundation rock is the best of all 3 dam sites. Therefore NAD-3 is finally selected in the Nadi main stream.

In the tributary Namosi, 2 sites (NAM-1& NAM-2) were selected. Although the catchment area of two sites is almost same, NAM-2 has smaller dam volume and higher water storage efficiency and the evaluation of foundation rock is good, therefore NAM-2 is finally selected.

In the tributary Nawaka, only 1 site (NAW-1) was selected because there is no other appropriate dam site. In NAW-1, the dam volume is large and the water storage efficiency is low. However NAW-1 is selected since there is no other appropriate site.

In the tributary Malakua, no dam site was selected since there is no appropriate dam site as described in 2.First Step Selection of Dam Site.

Table 6-4 Comparison and Selection of Dam Site

Name of River	Nadi Main Stream				Tributary Namos		Tributary Nawak
Dam site	NAD-1	NAD-2	NAD-3	NAD-4	NAM-1	NAM-2	NAW-1
Catchment Area (km2)	114	113	110	84	48	47	25
Height of Dam (m)	39.6	38.0	38.5	42.6	44.2	32	55
Length of Top of Dam (m)	206	210	170	253	285	183	223
Dam Volume (m3)	76,600	82,500	63,200	119,500	122,800	53,900	142,700
Reservoir Area (km2)	1.77	1.76	1.66	1.1	0.68	0.67	0.35
Rock Class of Foundation	C_M	C_M	C_H～C_M	C_H～C_M	C_M～C_H	C_H	C_M～C_H
Reservoir Capacity (1,000m3)	28,600	28,600	28,600	21,800	10,500	10,500	6,400
Water Storage Efficiency	373	347	453	182	86	195	45
Result of Selection			○			○	○

Note: Water storage efficinecy =Reservoir capacity/Dam volume

✧ ***Rock Mass Classification of Foundation Rock of Dam***
(Public Works Research Institute (PWRI) Ministry of Construction, 1996)

Factor and Subdivision of Rock Mass Classification

Factor	Subdivision	Description
Hardness of Rock	A B C	Hard, a tiny spark when hit by hammer Partially hard, partially soft, slightly soft on the whole. When hit once by hammer, it break Soft, easily broken by a hit of hammer
Interval of Crack/Joint	I II III	More than 50cm 20 to 50cm Less than 20cm
Appearance of Crack	a b c	Stick Slightly open. Thin clay film in the open crack. Open. Clay in the open crack.

Rock mass Classification

Class of Rock Mass	Combination of Subdivision
B	A I a
C_H	A I b, A II a
C_M	A I c, A II b, A III a, B I a, B I b, B II a
C_L	A II c, A III b, B I c, B II b, B III a, B III b, C I a, C II a
D	A III c, B II c, B III c, C I b, C I c, C II b, C II c, C III a, C III b, C III c

(4) Examination of Regulatory Effect by Dam

Regulatory effect by dam is examined with NAD-3, NAM-2 and NAW-1 as a target whose dam volume is the smallest and water storage efficiency is the best in each river. Regulation method is natural regulation by outlet without gate, constructed at the level of present riverbed. The size of the outlet is to be smallest for the maximum regulation volume. The number of outlet should be 2 principally to avoid the clogging by the sediment, drift wood and so on. However in NAW-1, the number of outlet is to be 1 since 2 outlets are too large to exert the effective regulation. The size and number of outlet are as shown in the Table 6-4.

Table 6-5 Outline of Outlet

Dam	Size and Number of Outlet
NAD-3	W：2.0m×H：2.5m, 2
NAM-2	W：2.0m×H：2.5m, 2
NAW-1※	W：1.5m×H：1.5m, 1

1) Calculation Result of Flood Control

Calculation result of flood control at each dam is shown in following figures, which was conducted under above condition with “No.25 March, 2012 Flood (actual)” as a target.

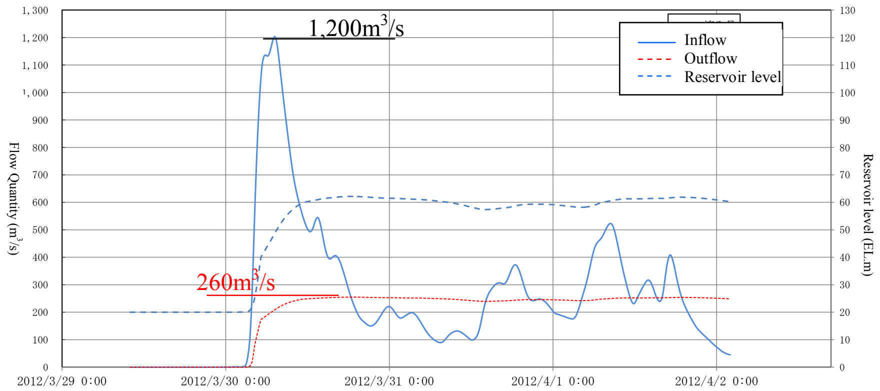


Figure 6-15 Flood Control by NAD-3

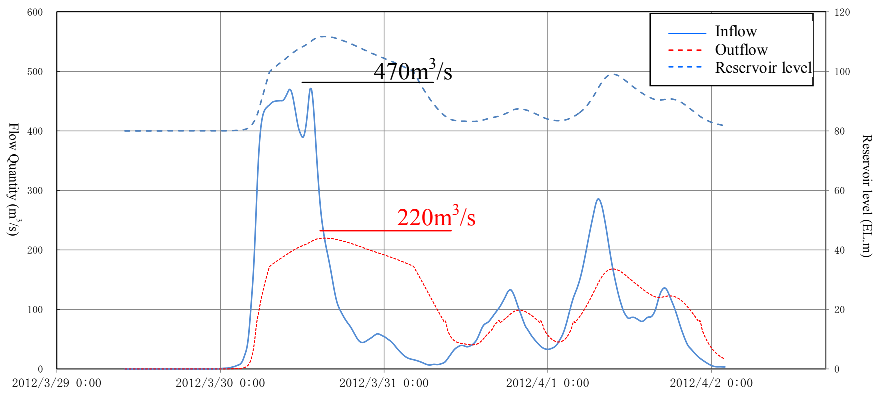


Figure 6-16 Flood Control by NAM-2

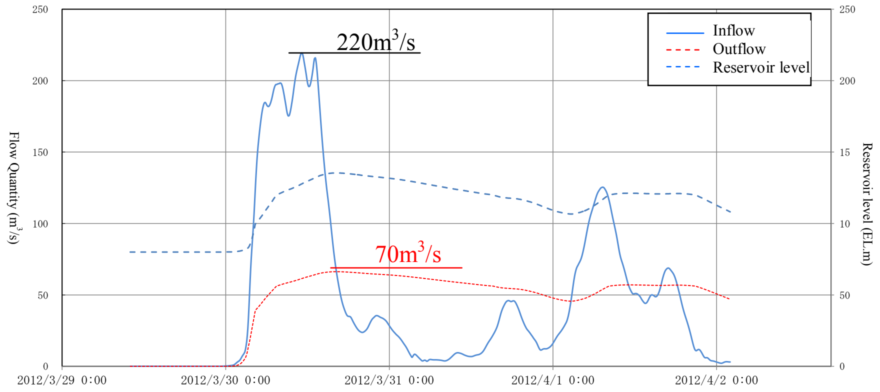


Figure 6-17 Flood Control by NAW-1

Peak flood discharge, regulated discharge and discharge from dam after regulation at each dam are as shown in Table 6-5.

Table 6-6 Flood Control Effect of Dam

Name of Dam	Flood Peak Discharge (m^3/s)	Max. Discharge after Regulation (m^3/s)	Regulated Flood Discharge (m^3/s)	Required Reservoir Capacity (10^3m3)
NAD-3	1,200	260	940	23,780
NAM-2	470	220	250	8,750
NAW-1	220	70	150	5,300

2) Discharge Distribution after Flood Control

Discharge distribution after flood control is shown in following figures and the condition of dam layout is shown in Figure 6-18～Figure 6-21.

Table 6-7 Condition of Dam Layout

Dam Layout
NAD-3 alone
NAM-2 alone
NAW-1 alone
NAD-3、NAM-2

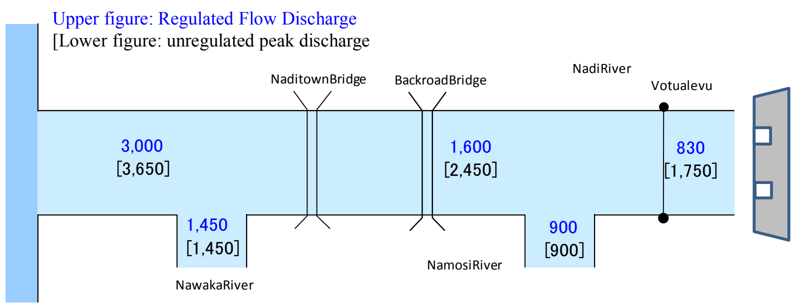


Figure 6-18 Discharge Distribution after Flood Control by NAD-3

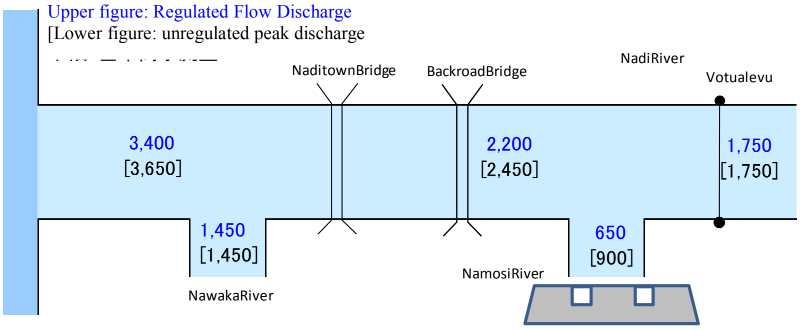


Figure 6-19 Discharge Distribution after Flood Control by NAM-2

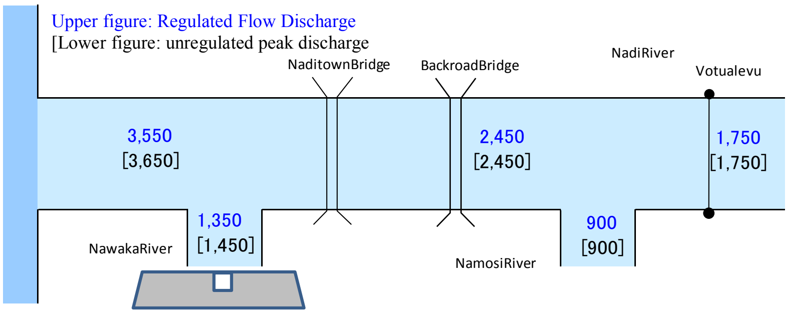


Figure 6-20 Discharge Distribution after Flood Control by NAW-1

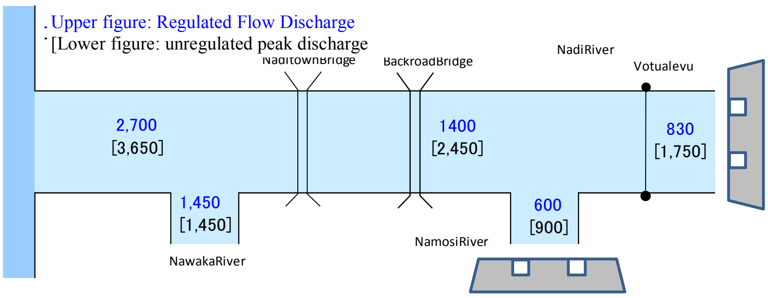


Figure 6-21 Discharge Distribution after Flood Control by NAD-3、NAW-2

6.3.2 Retarding Basin

(1) Consideration of Effect by Natural Retarding Basin

Effect by natural retarding basin was conducted in inundated area in March, 2012 Flood, expecting existing downtown and planned expansion area of Nadi Town as natural retarding basin.

Houses locate in the area planned retarding basin was needed to remove or construct ring dyke.

1) Objected Natural Rtarding Basin

Natural retarding basin was defined as the inundated are shown in Figure 6-23 excluding existing downtown and planned expansion area of Nadi Town.

Objected retarding basin area is shown in Table 6-8 and Figure 6-22.

Table 6-8 Objected Area for Natural Retarding Basin

■Inundated Volume in objected natural retarding basin area by March, 2012 Flood

Section		Block	March, 2012 Flood (only river water)			Section	
			Inundation Area (ha)	Inundated volume (Km^3)	Average inundation depth (m)	Inundation Area (ha)	Inundated volume (Km^3)
Nadi downstream	Estuary ~ Nawaka	NAD-L1	813	4,953	0.61	813	4,953
Nadi middlestream	After Nawaka confluence ~ Nadi Town Bridge	NAD-L2	47	1,355	2.85	47	1,355
Nadi upstream	Back Road Bridge ~ Namosi confluence	NAD-L5	46	1,464	3.21		
		NAD-L6	41	1,198	2.91		
		NAD-L7	61	1,185	1.95		
		NAD-L8	17	835	4.91		
		NAD-R4	176	4,649	2.64		
		NAD-R5	47	1,574	3.34	388	10,904
	After Namosi confluence	NAD-L9	31	1,031	3.34		
		NAD-L10	5	226	4.53		
		NAD-R6	3	76	2.54		
		NAD-R7	5	240	4.80		
		NAD-R8	4	129	3.44		
		NAD-R9	9	429	4.78	57	2,132
Namosi River	After Nadi confluence	NAM-L1	8	361	4.51		
		NAM-L2	4	128	3.21		
		NAM-L3	6	229	3.81		
		NAM-L4	2	47	2.36		
		NAM-L5	6	155	2.59		
		NAM-R1	24	963	4.04		
		NAM-R2	2	43	2.14		
		NAM-R3	4	66	1.67		
		NAM-R4	4	80	2.02	60	2,072
Nawaka River	Marakua confluence ~ Masi confluence	NAW-L1	164	4,128	2.52	164	4,128
	After Masi confluence	NAW-L2	43	572	1.34		
		NAW-L3	14	231	1.65		
		NAW-L4	7	76	1.09		
		NAW-L5	8	122	1.53		
		NAW-R1	77	1,609	2.09		
		NAW-R2	10	150	1.50	159	2,760
Mawakua River	Nawaka confluence ~ 3K	MAL-L1	4	203	4.58		
		MAL-L2	33	791	2.42	37	994
	3K ~ upper stream	MAL-L3	50	804	1.61		
		MAL-L4	7	94	1.35		
		MAL-R1	30	514	1.72		
		MAL-R2	29	333	1.15		
		MAL-LR1	14	265	1.89	130	2,009

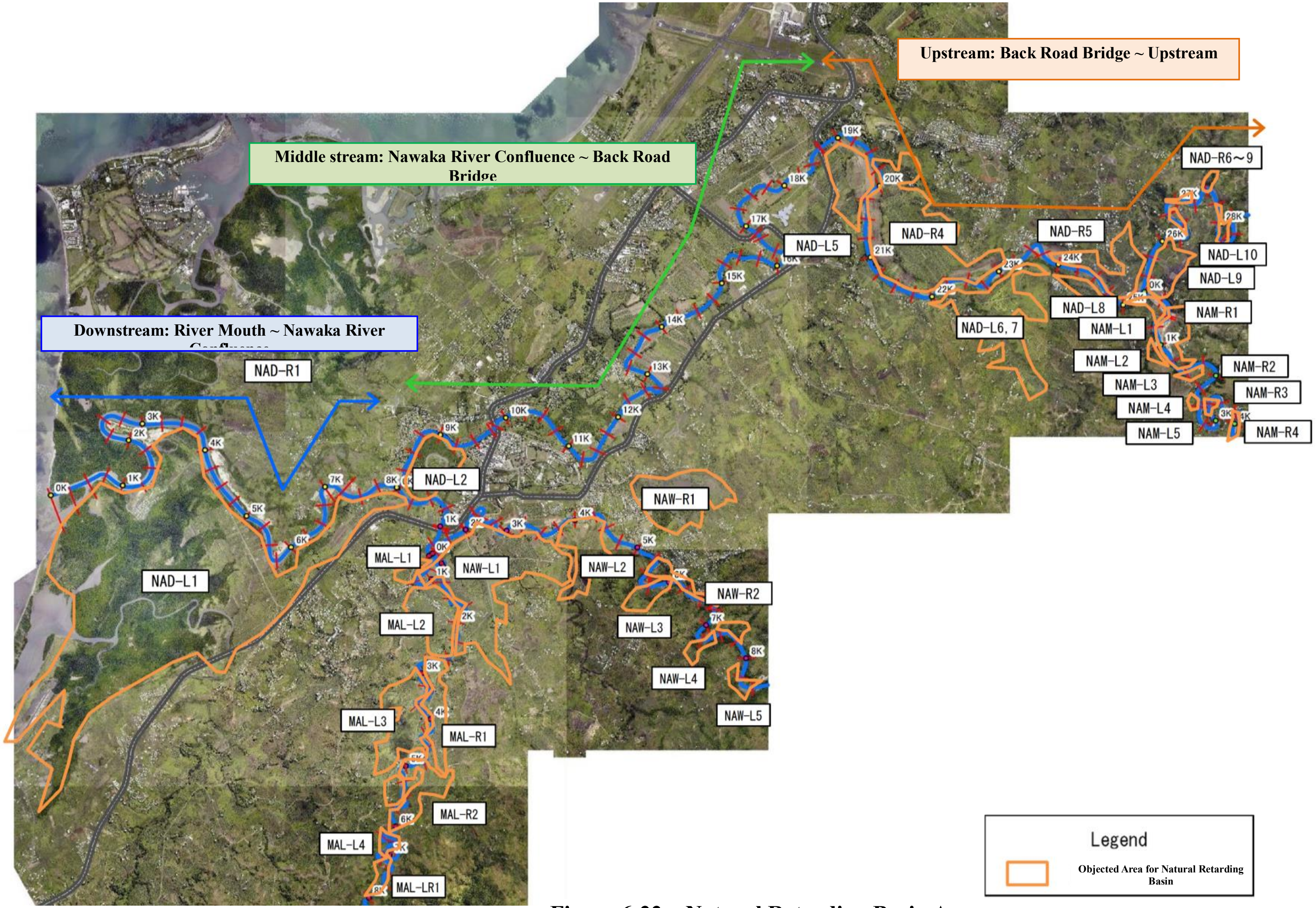


Figure 6-22 Natural Retarding Basin Area

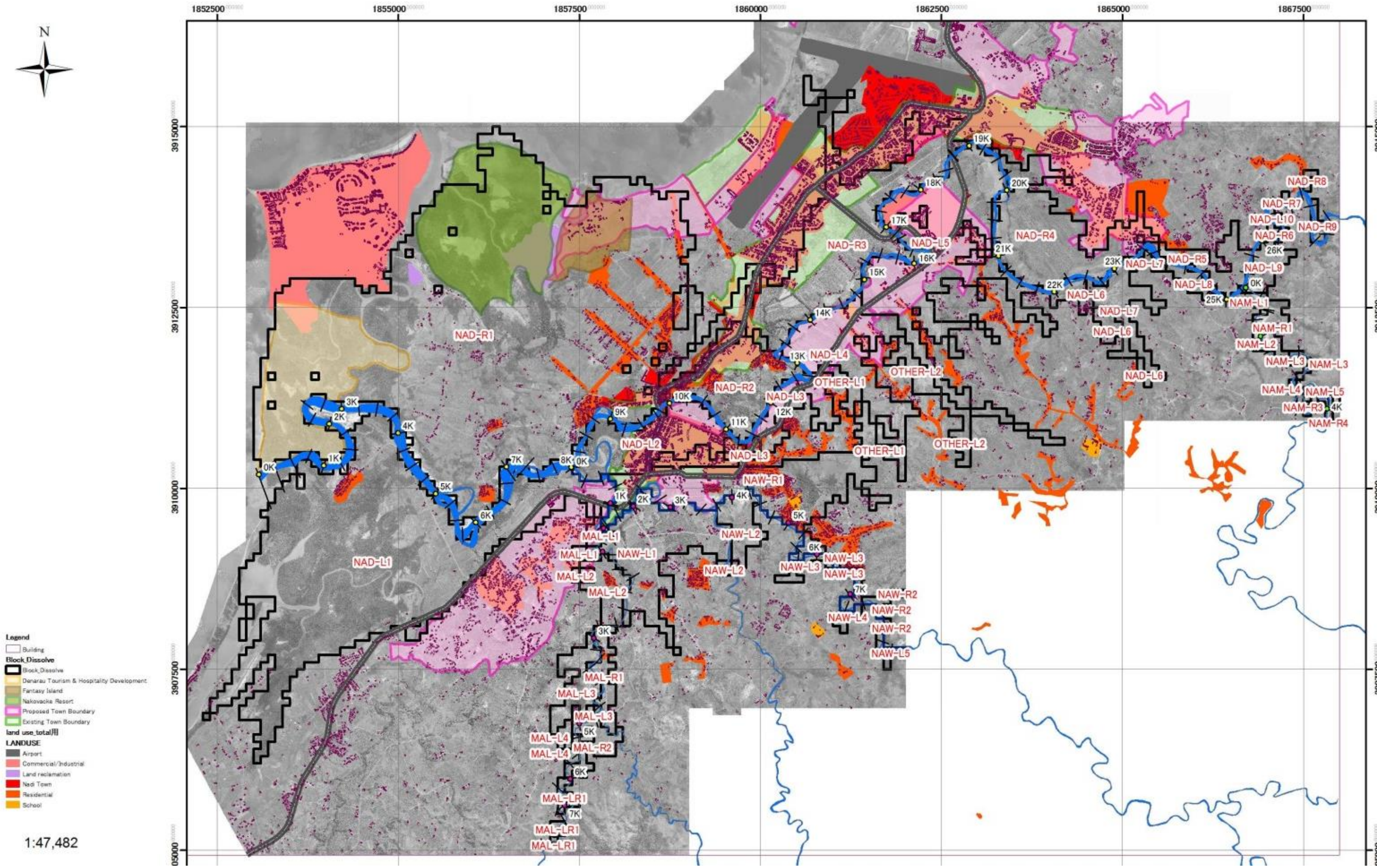


Figure 6-23 Inundation Block ,Present and Planned Town Area, and under Development Area

2) Retarding Effect

Retarding effect was analyzed in counting above area as natural retarding basin. Discharge in river channel became 1550m^3/s at Backroad Bridge and 1600m^3/s at Nadi Town Bridge by retarding effect.

Discharge distribution is shown in Figure 6-24 and hydrograph at Backroad Bridge and Nadi Town Bridge are shown in Figure 6-25.

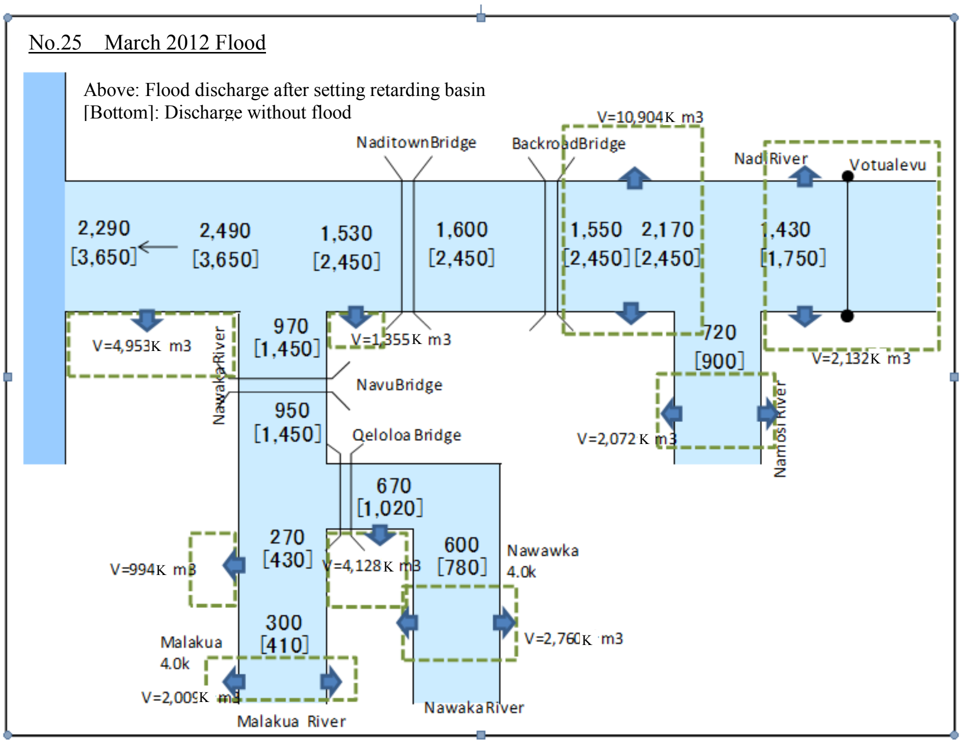


Figure 6-24 Discharge Distribution with/without Retarding Effect

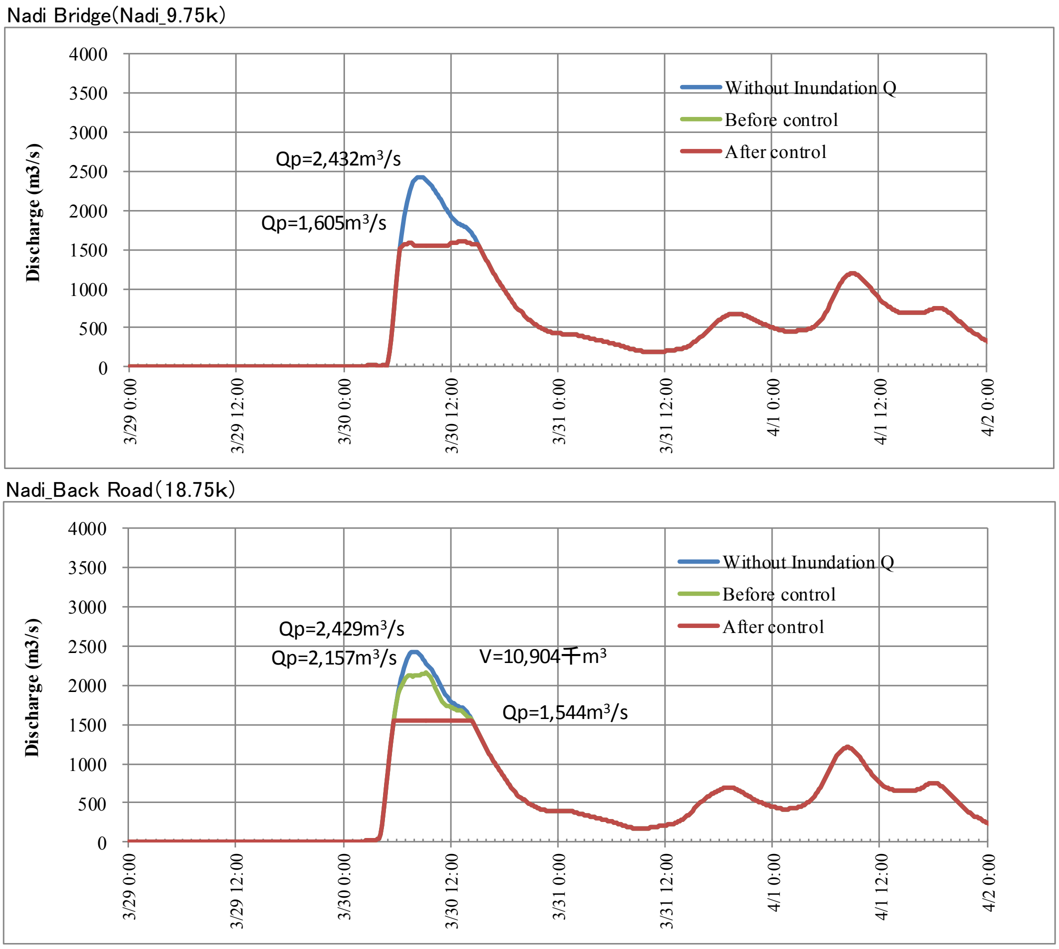


Figure 6-25 Hydrograph with/without Retarding Effect

(2) Examination of Design Retarding Basin

1) Upstream of Nadi River, Nawaka and Marakua Area

Design retarding basin for temporary storage of flood discharge was examined. The design retarding basin was planned by layout of dike and side overflow weir along river channel.

a) Selection of Candidate Site for Design Retarding Basin

Candidate site for design retarding basin was selected considering following points.

- Inundated area in March, 2012 Flood, excluding present and planned Nadi Town area
- Among the above, the objective areas were selected where the scattered houses were not included as much as possible.

Selected candidate site for retarding basin is shown in Table 6-9 and Figure 6-27. Map of land use near candidate site is shown in Figure 6-28 and Figure 6-29.

- Upstream in Nadi River Basin: 6 sites (Embankment Type: 5 sites, Natural Retarding Type: 1 site)
- Namosi River: 3 sites (Embankment Type: 2 sites, Natural Retarding Type: 1 site)
- Nawaka River: 8 sites (Embankment Type: 7 sites, Natural Retarding Type: 1 site)
- Marakua River: 7 sites(Embankment Type: 6 sites, Natural Retarding Type: 1 site)

The image of design cross section and design profile of retarding basin is shown in Figure 6-26.

HWL in retarding basin was established by HWL of inflow river which was calculated by non-uniform flow calculation.

Cross section and H-V curve graph at each candidate site is shown in Figure 6-30

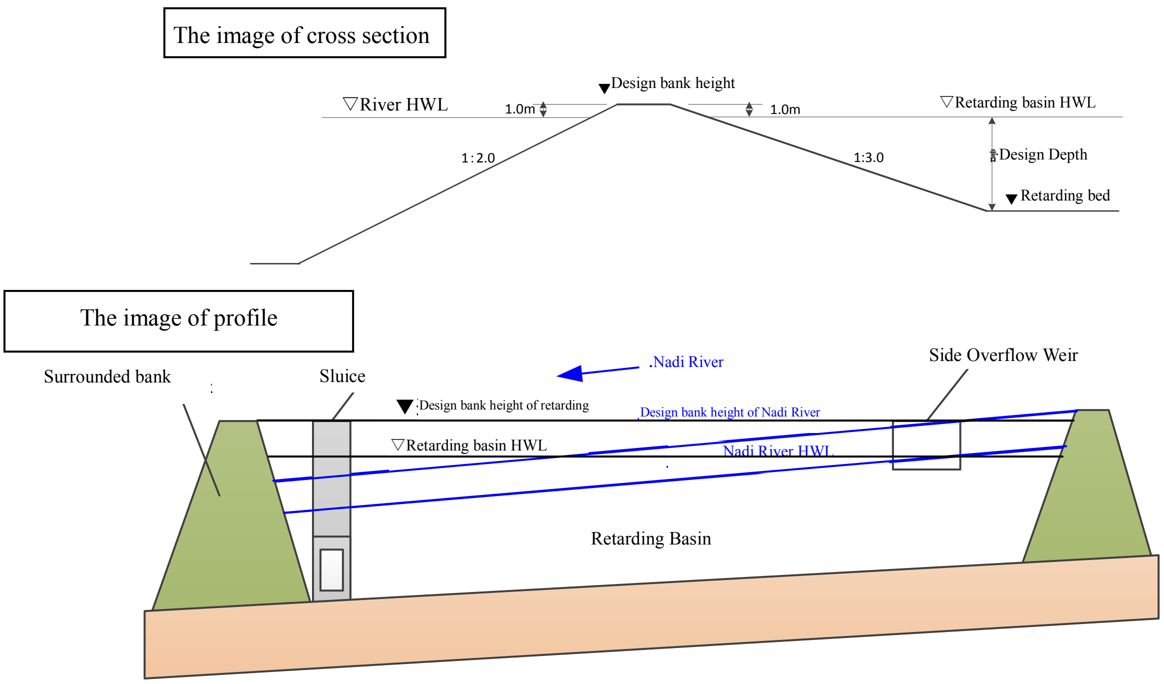


Figure 6-26 Image for Design Retarding Basin

Table 6-9 List of Selected Candidate Site for Retarding Basin

Site		River	Bank Side	Start point K	Finish point K	Outflow point K	HWL of Retarding (EL.m)	Freeboad (m)	Design bank height (EL.m)	Bottom of Retarding (EL.m)	Design depth (m)	Area (ha)	Design volume ($1000m^3$)	Removed houses (house)	Notes
A		Nadi	Left	18.75	20.50	20.50	15.50	1.00	16.50	8.63	6.9	44.1	2,867	1	Evacuation about 2~5m (1,280Km3)
B		Nadi	Right	19.50	23.00	23.00	17.60	1.00	18.60	9.03	8.6	153.1	11,508	4	Evacuation about 1~4m (5,100Km3)
C	C1	Nadi	Left	22.75	24.75	24.50	19.10	1.00	20.10	10.19	8.9	34.2	3,727	0	Evacuation about 1~5m (1,730Km3)
	C2	Nadi	Left	22.75	24.75		19.10	1.00	20.10	13.10	6.0	34.4		2	Unification with C1
DEF	D	Nadi	Right	23.75	24.00	25.00	19.56	1.00	20.56	10.19	9.4	4.4	1,049	0	Unification with E
	E	Nadi	Right	24.25	25.00		19.56	1.00	20.56	11.86	7.7	12.5		0	
	F	Nadi	Right	25.00	26.00		19.56	1.00	20.56	11.86	7.7	7.3		0	Unification with E
G		Nadi	Left	25.25	26.50	25.75	20.41	1.00	21.41	12.63	7.8	23.4	683	0	
NRB1		Nadi	Both	26.50	28.75	27.75	21.83	1.00	22.83	-	4.3	26.0	1,100	0	NAD-L10,R6,R7,R8,R9
Subtotal												339.4	20,934	7	
H		Namosi	Left	0.00	0.50	0.25	19.11	1.00	20.11	14.59	4.5	2.2	78	0	NAML1
I		Namosi	Right	0.50	1.50	1.50	25.01	1.00	26.01	13.88	11.1	14.9	1,125	0	
NRB2		Namosi	Both	1.50	-	3.00	28.21	1.00	29.21	-	2.7	28.0	748	0	NAM-L2,L3,L4,L5,R2,R3,R4
Subtotal												45.1	1,950	0	
AA		Nawaka	Left	0.00	0.75	0.75	6.08	1.00	7.08	2.20	3.9	47.0	683	0	Confluence with Nadi River
N		Nawaka	Left	1.50	2.00	1.75	9.02	1.00	10.02	2.72	6.3	48.5	1,859	0	
MLK	M	Nawaka	Left	2.00	3.75	3.50	10.57	1.00	11.57	3.99	6.6	36.2	2,489	5	
	L	Nawaka	Left	2.00	3.75		10.57	1.00	11.57	5.49	5.1	14.6		0	Unification with M
	K	Nawaka	Left	2.00	3.75		10.57	1.00	11.57	6.77	3.8	10.0		0	Unification with M
J		Nawaka	Left	3.75	4.75	4.50	11.30	1.00	12.30	5.70	5.6	39.4	1,334	6	
Q		Nawaka	Right	5.25	-	5.25	11.93	1.00	12.93	6.87	5.1	52.3	2,220	0	Nawaka Lake, Connection at 5.25k
R		Nawaka	Right	5.25	6.00	6.00	12.43	1.00	13.43	8.04	4.4	4.3	104	0	
S		Nawaka	Left	5.50	6.25	5.75	12.30	1.00	13.30	8.13	4.2	18.4	170	0	
NRB3		Nawaka	Both	6.25	-	7.00	13.21			-	1.4	25.0	349	0	NAW-L4,L5,R2
Subtotal												295.7	9,208	11	
Z		Malakua	Right	0.75	2.00	1.75	9.17	0.80	9.97	4.33	4.8	9.5	333	0	
O		Malakua	Left	2.00	2.50	2.50	9.79	0.80	10.59	6.18	3.6	5.0	151	0	
P		Malakua	Right	2.50	3.25	3.00	10.26	0.80	11.06	6.27	4.0	5.6	171	0	
T		Malakua	Left	3.25	3.50	3.25	10.45	0.80	11.25	5.90	4.5	14.5	384	0	
UXW	X	Malakua	Left	4.00	4.75	4.50	11.43	0.80	12.23	6.85	4.6	4.5	1,020	0	Unification with U
	W	Malakua	Left	4.30	5.00		11.43	0.80	12.23	7.44	4.0	1.5		0	Unification with U
	U	Malakua	Left	3.75	5.00		11.43	0.80	12.23	7.16	4.3	33.2		0	
V		Malakua	Right	4.00	4.50	4.75	11.31	0.80	12.11	7.44	3.9	9.7	221	0	
NRB4		Malakua	Both	4.50	-	5.00	12.18			-	1.4	50.0	691	1	MAL-L4,R2,LR1
Subtotal												133.5	2,971	1	

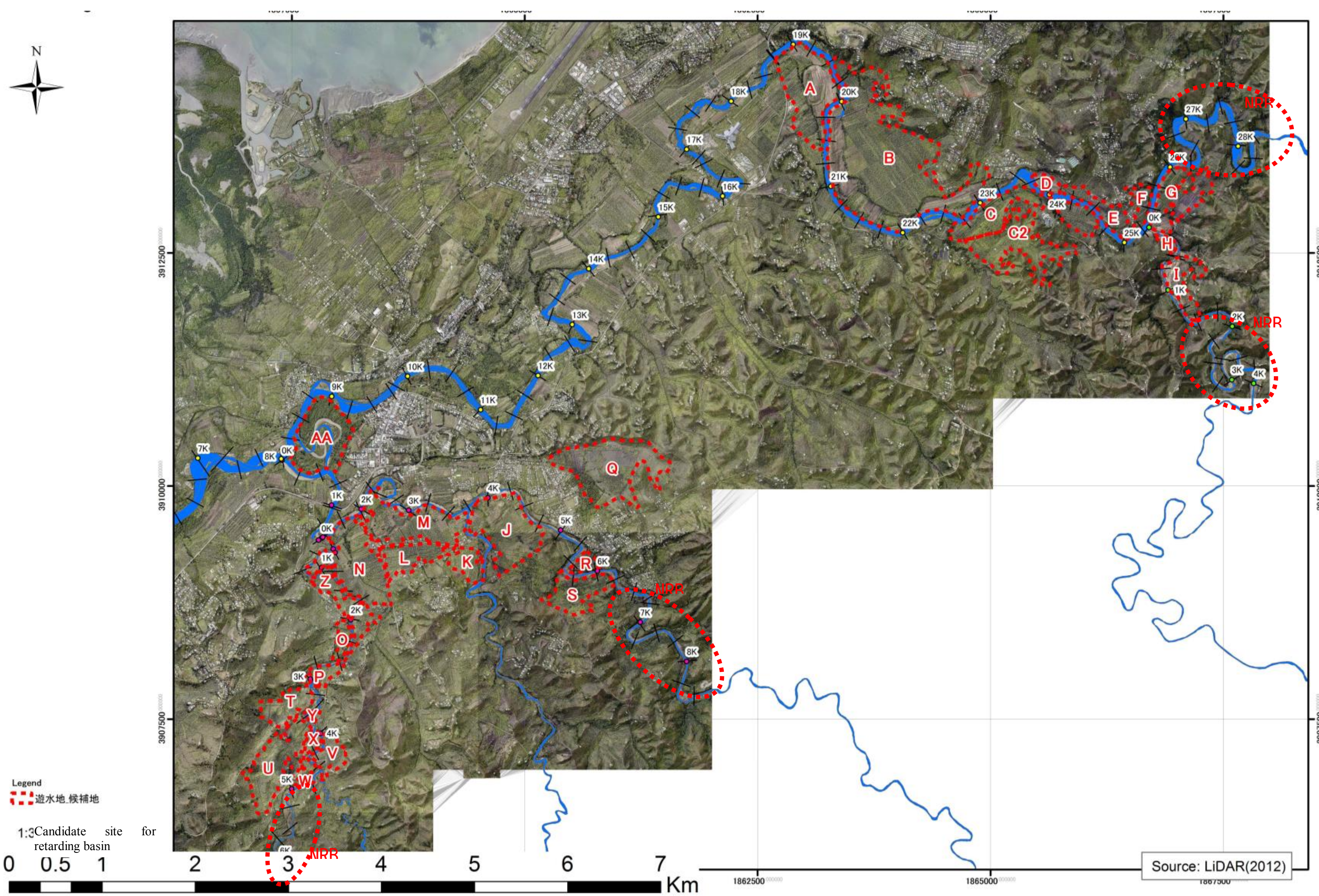


Figure 6-27 Map of Selected Candidate Site for Retarding Basin

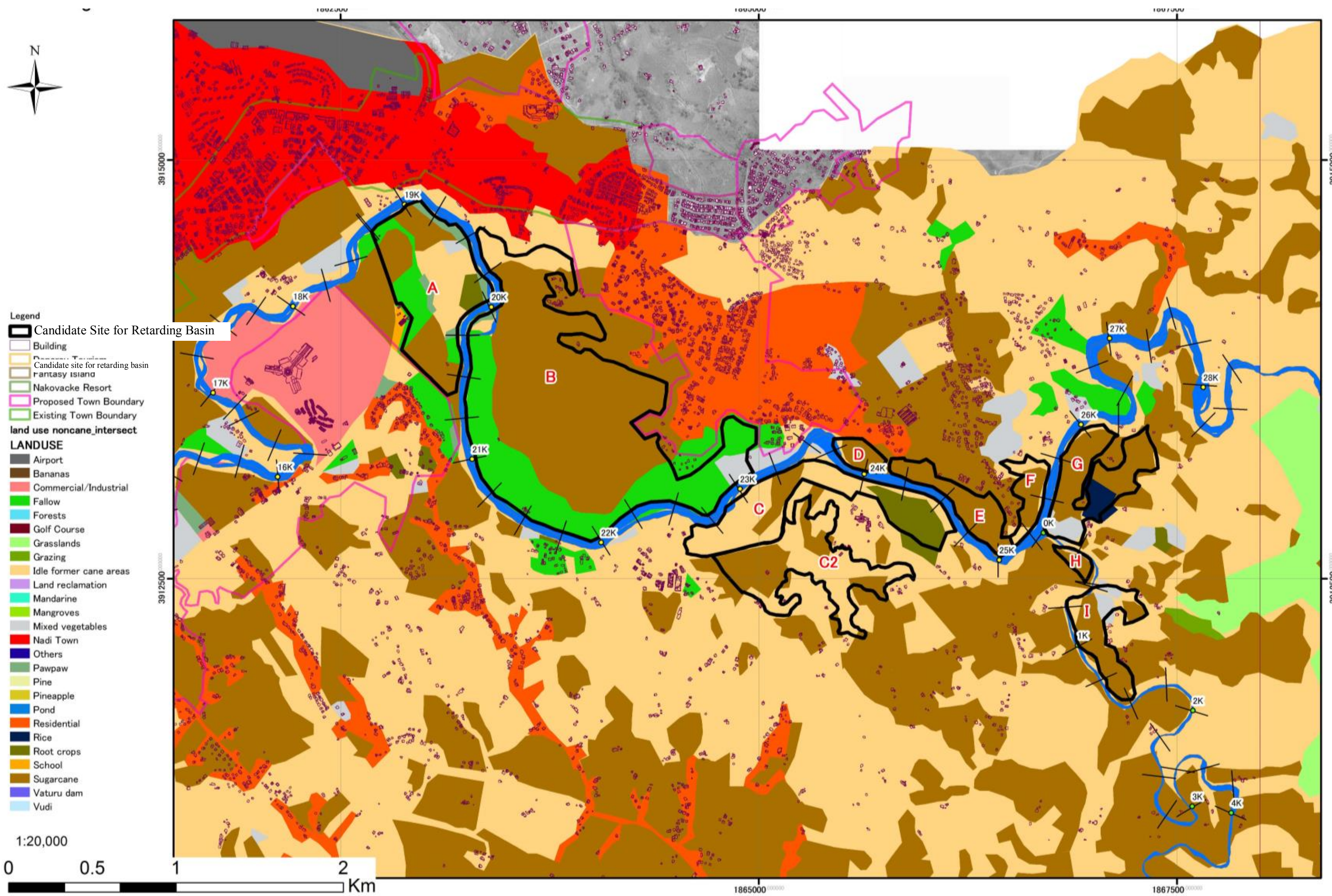


Figure 6-28 Map of land use near candidate site (Upstream of Nadi River)

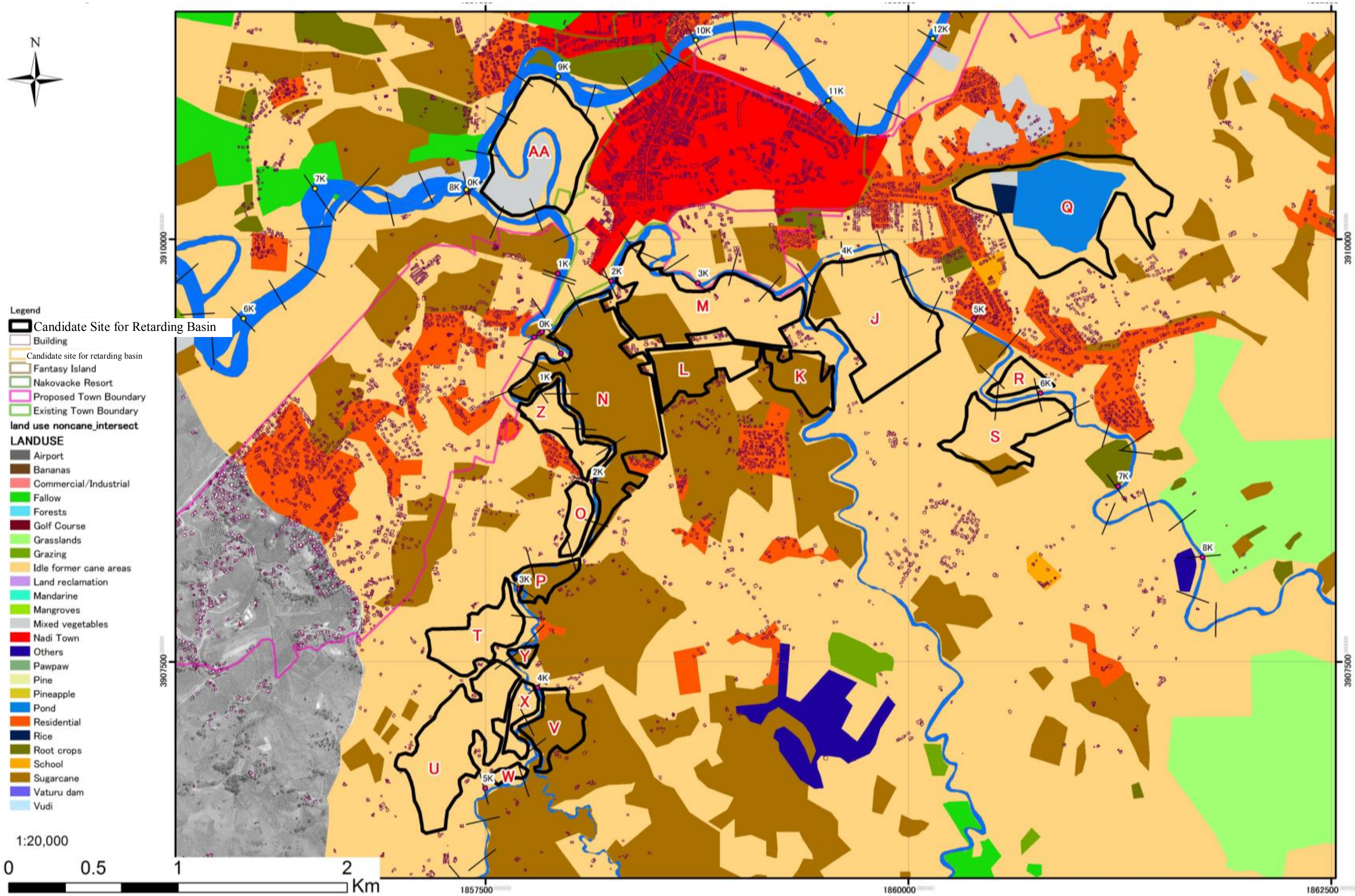


Figure 6-29 Map of land use near candidate site (Nawaka River and Malakua River)

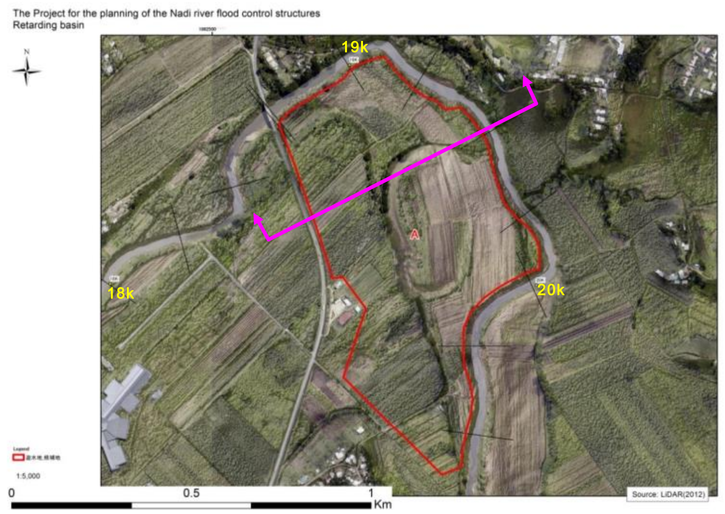
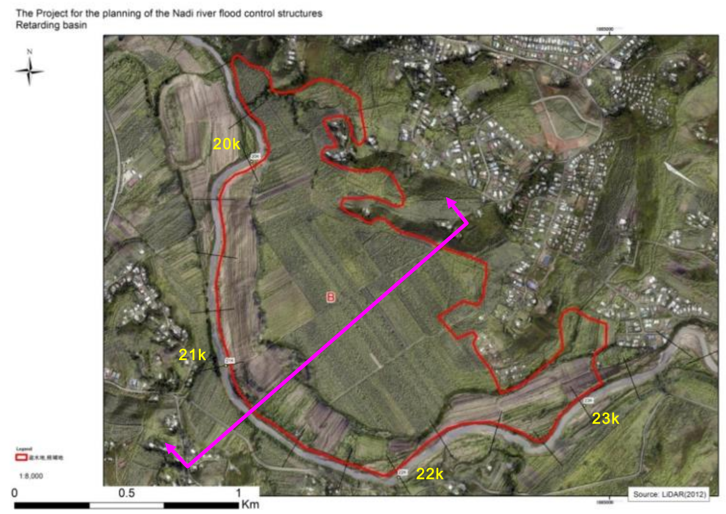
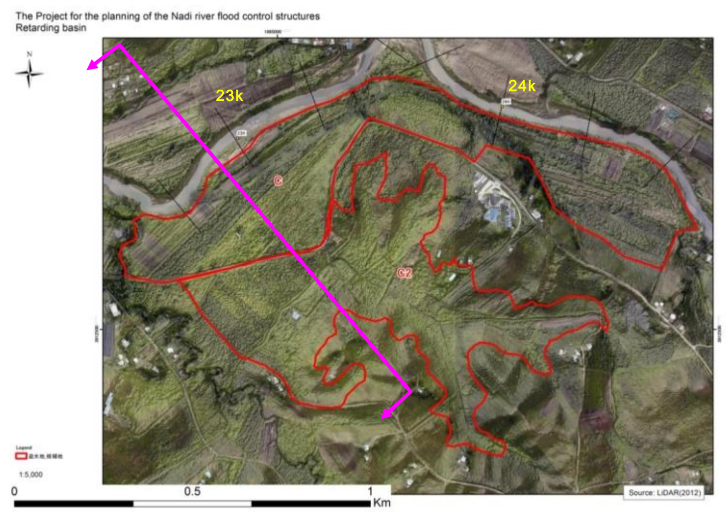
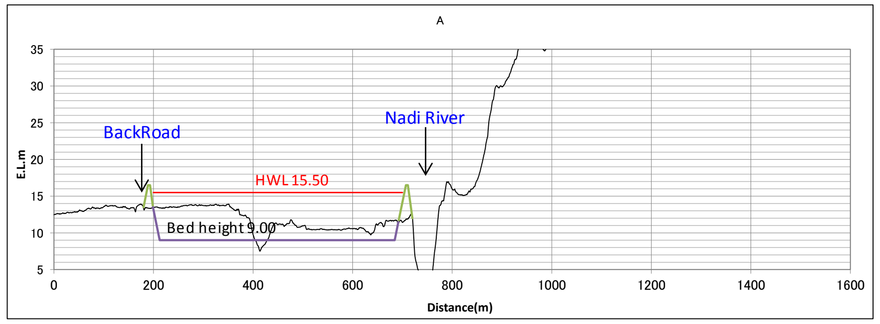
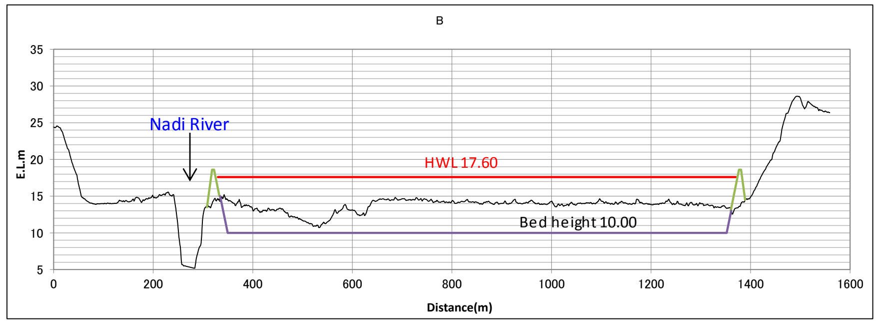
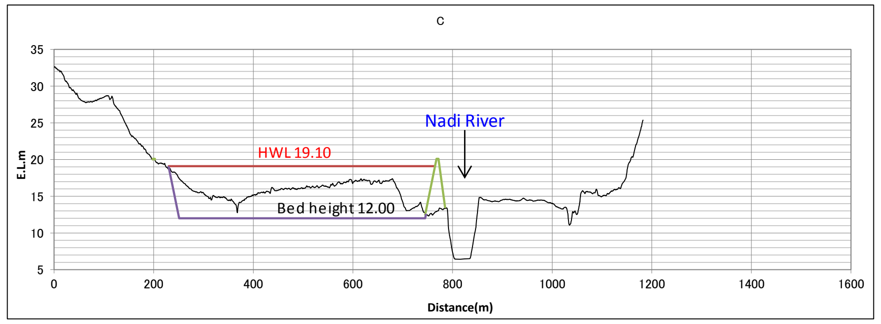
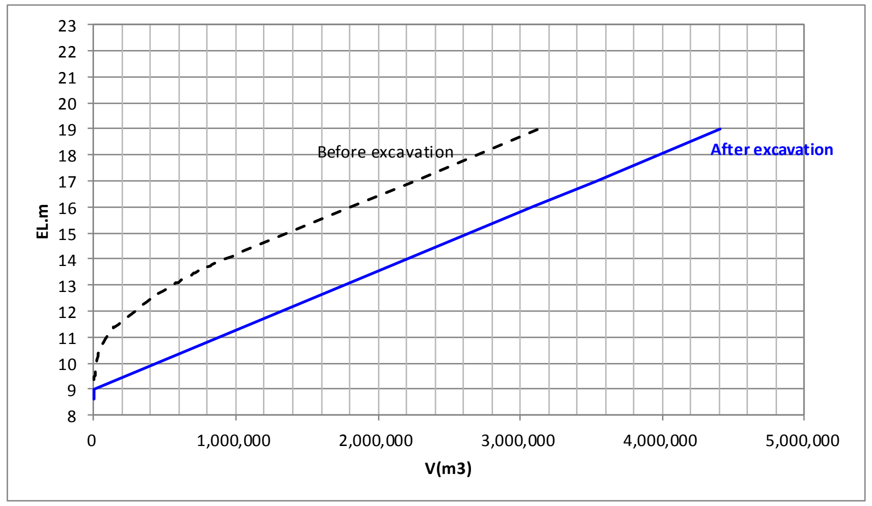
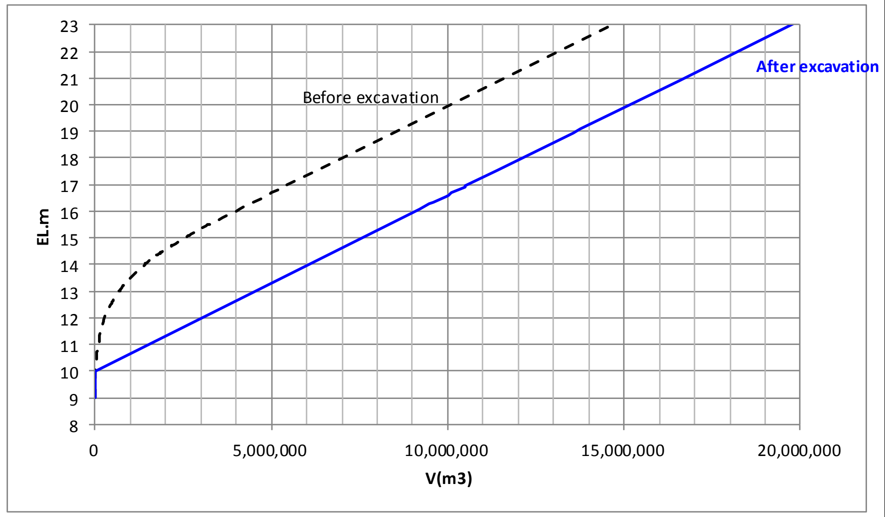
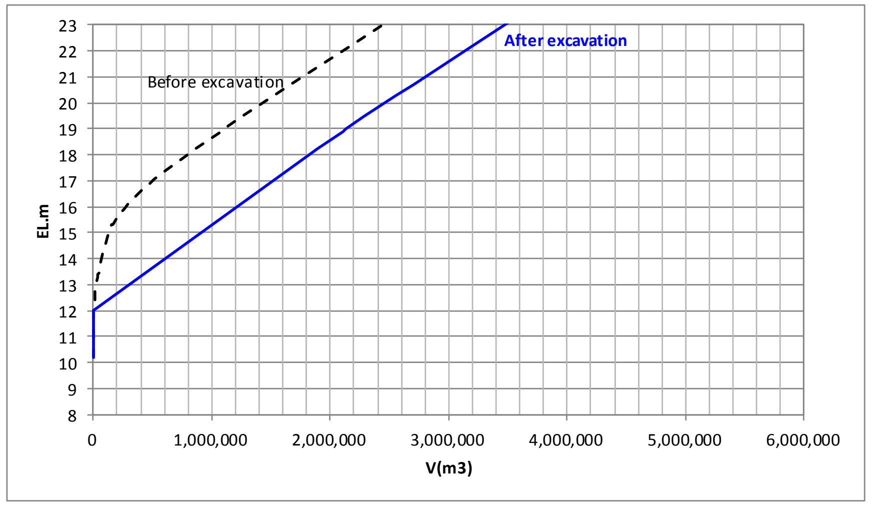
	Retarding Basin A Nadi River(18.75k～20.5k)	Retarding Basin B Nadi River (19.5k～23k)	Retarding Basin C(C1+C2) Nadi River (22.75k～24.75k)
Plane Figure			
Cross Section			
H-V Curve			

Figure 6-30 (1) Cross section and H-V Curve

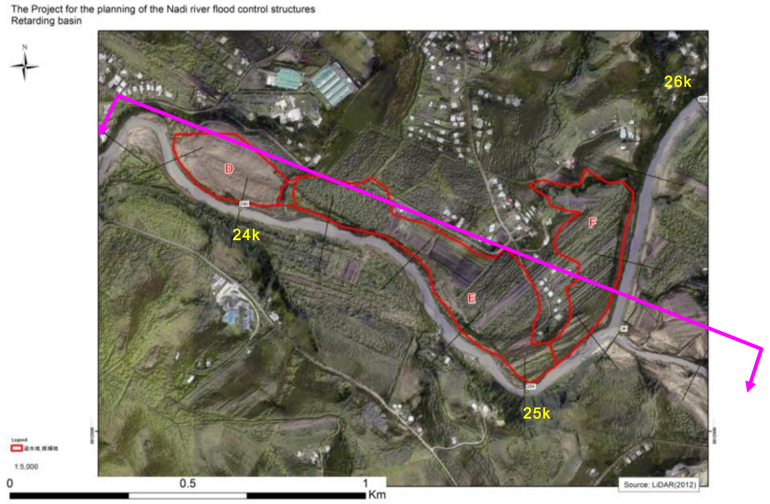
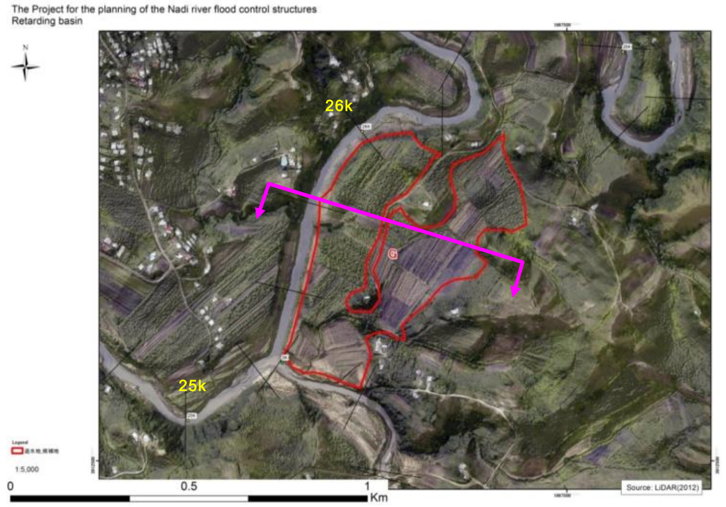
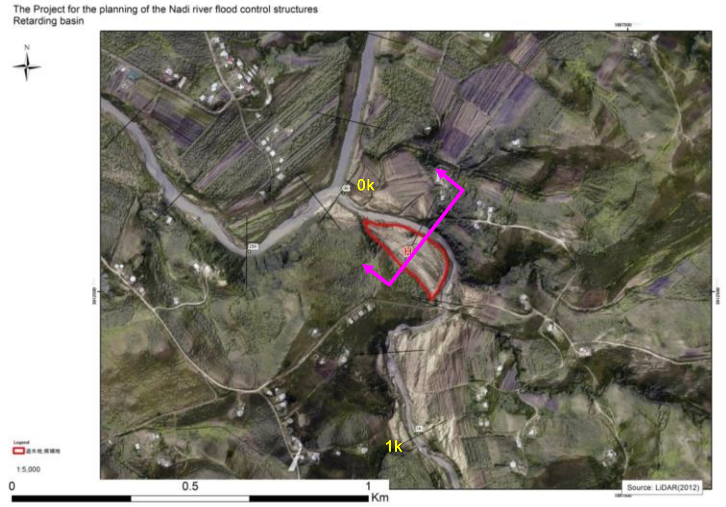
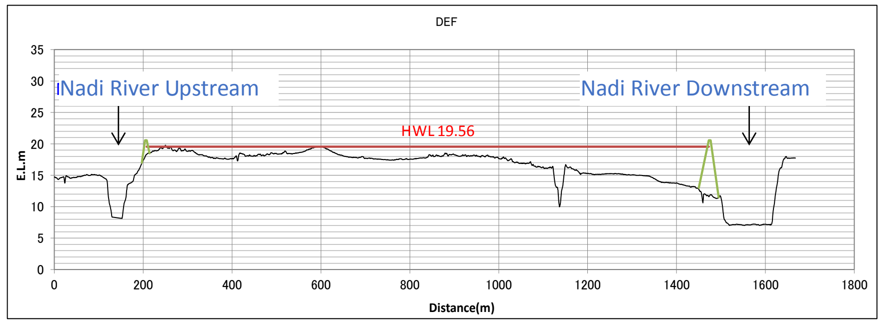
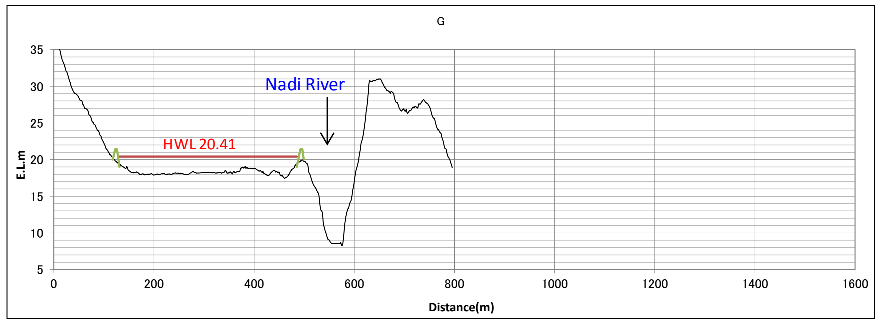
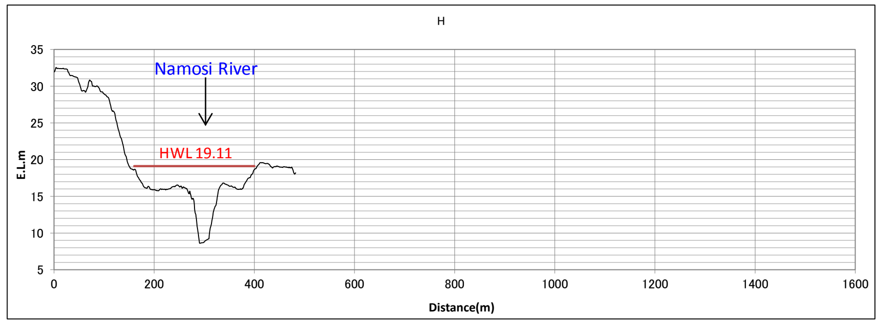
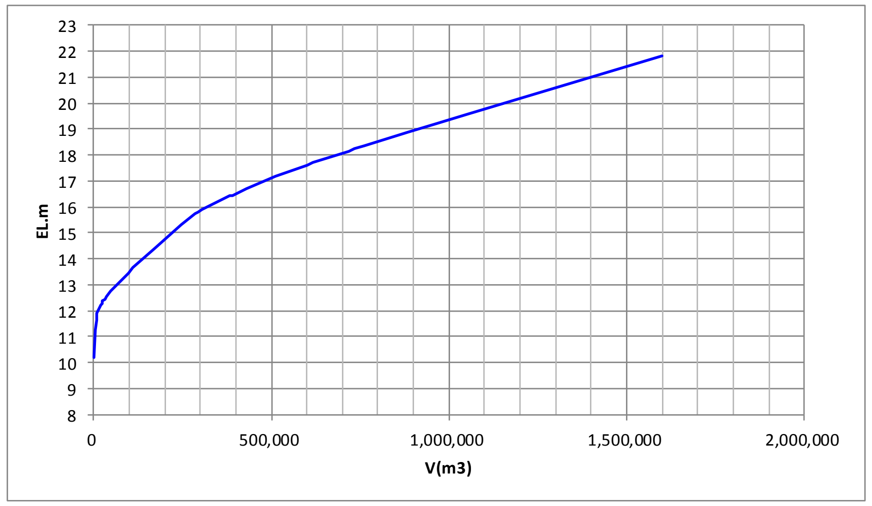
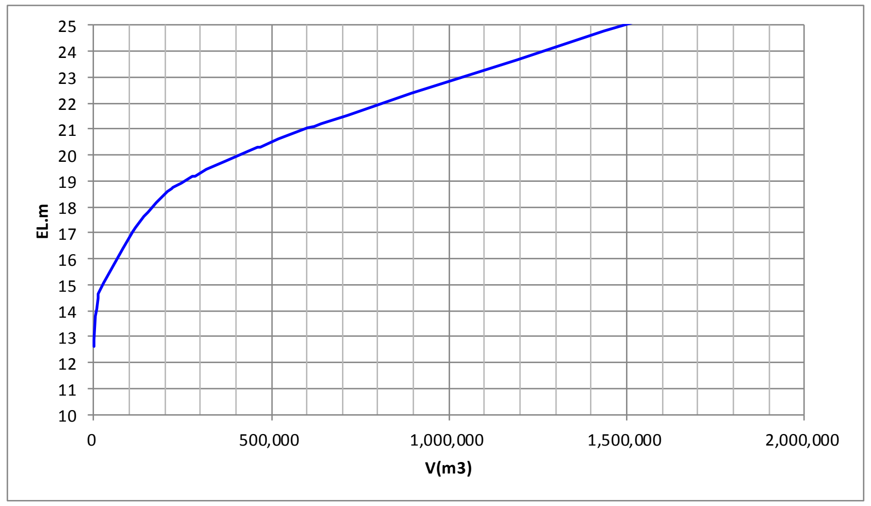
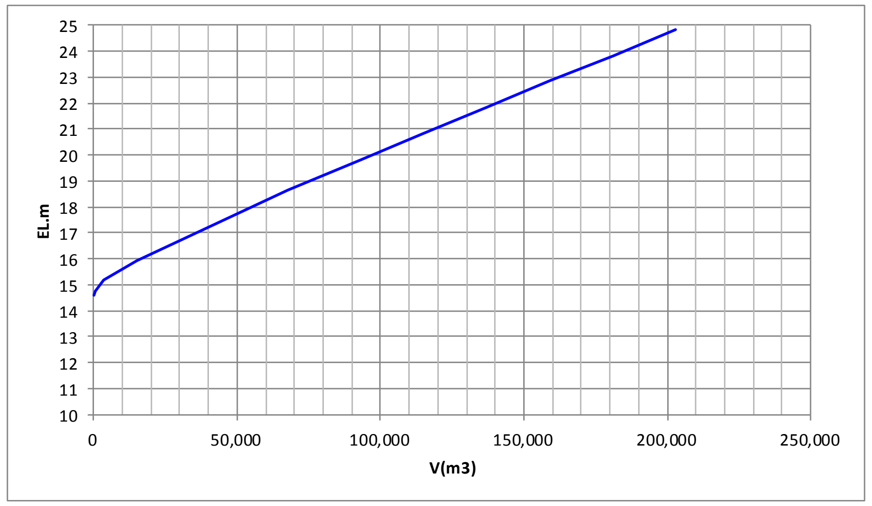
	Retarding Basin D E F　Nadi River (23.75k～26k)	Retarding Basin G　Nadi River (25.25k～26.5k)	Retarding Basin H　Namosi River (0k～0.5k)
Plane Figure			
Cross Section			
H−V Curve			

Figure 6-30 (2)　Cross section and H-V Curve

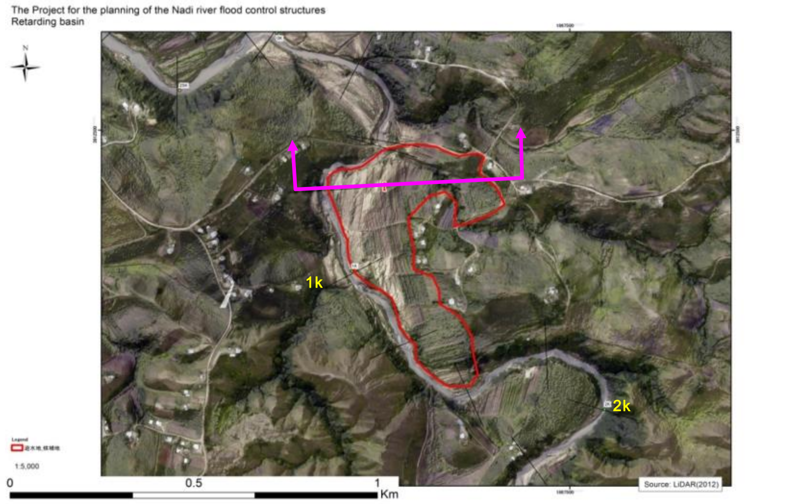
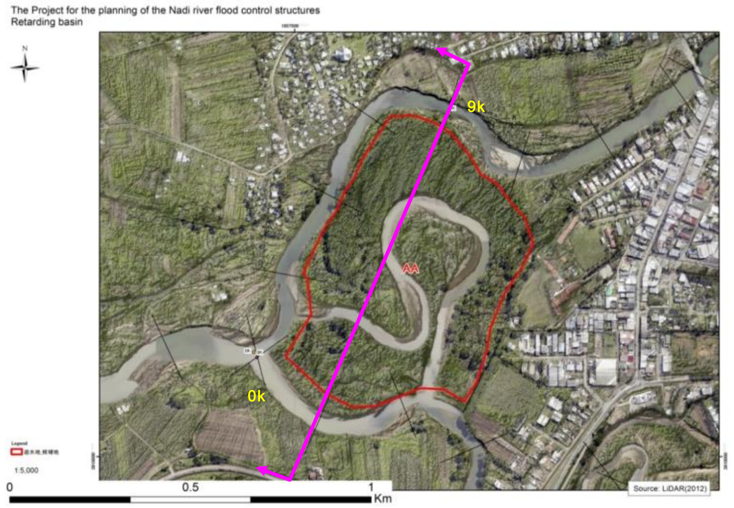
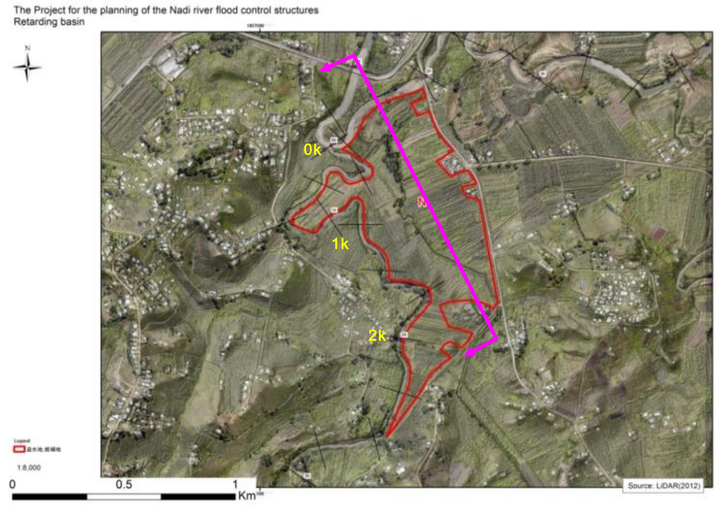
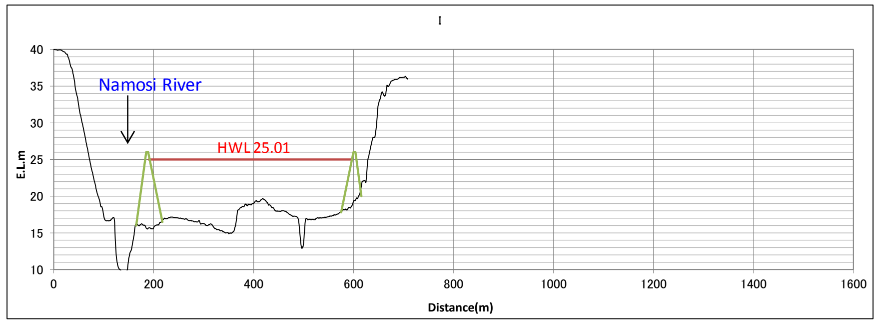
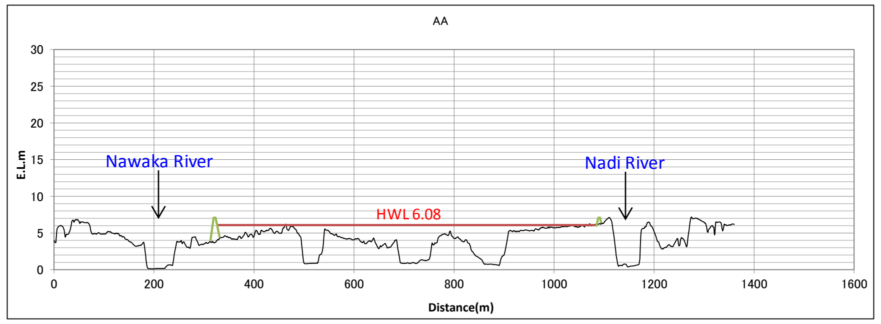
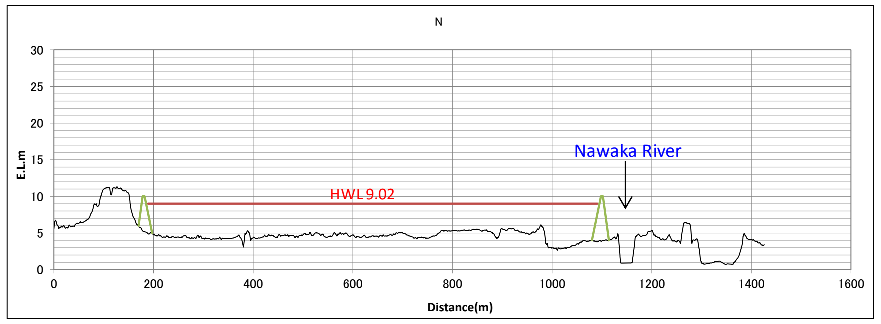
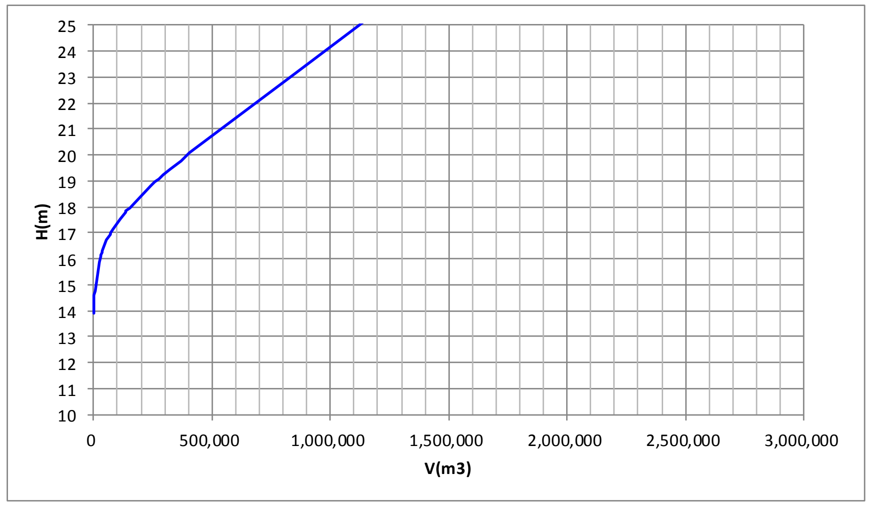
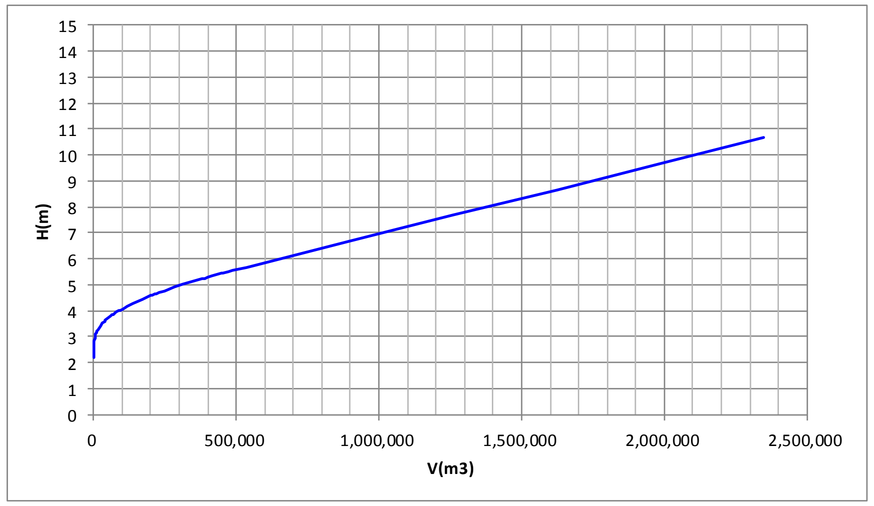
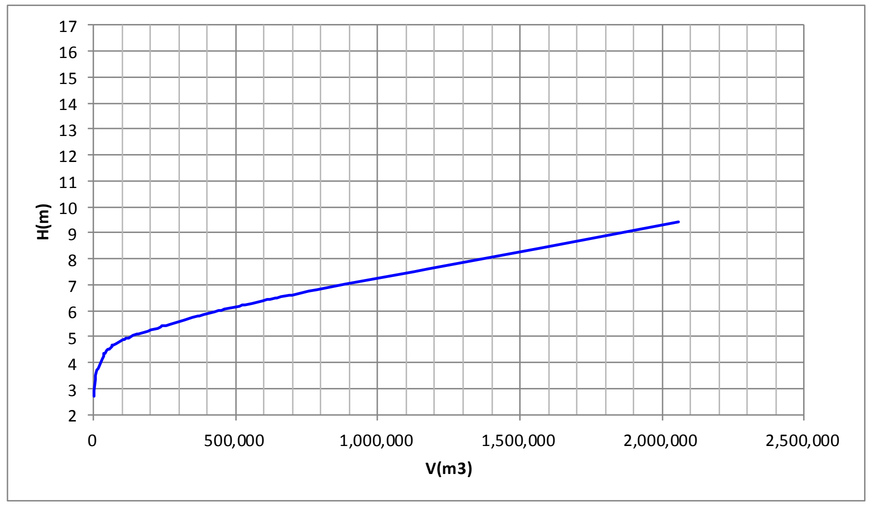
	Retarding Basin I **Namosi River (0.5k～1.5k)**	Retarding Basin AA **Nawaka River (0k～0.75k)**	Retarding Basin N **Nawaka River (1.5k～2k)**
Plane Figure			
Cross Section			
H-V Curve			

Figure 6-30 (3) Cross section and H-V Curve

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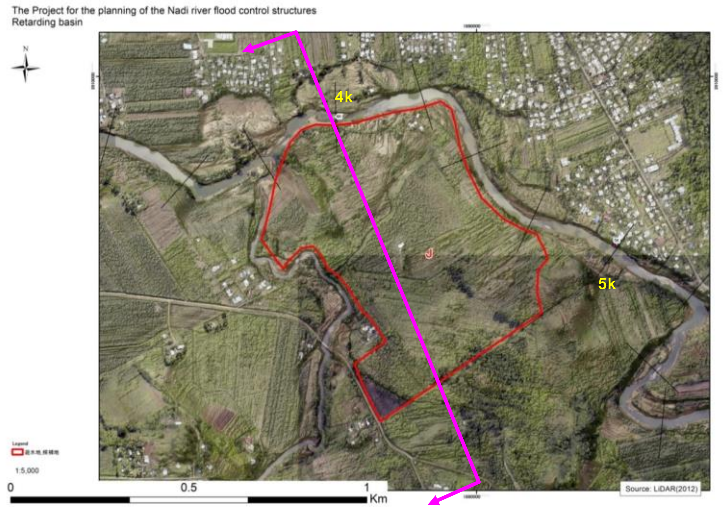
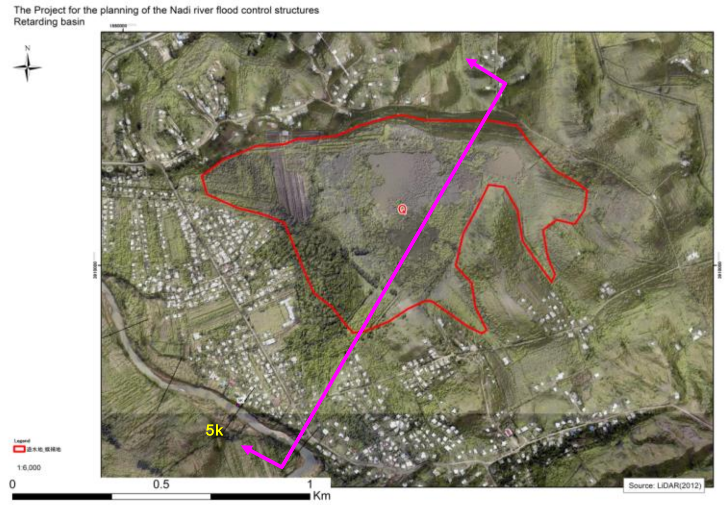
</td><td>
</td><td>
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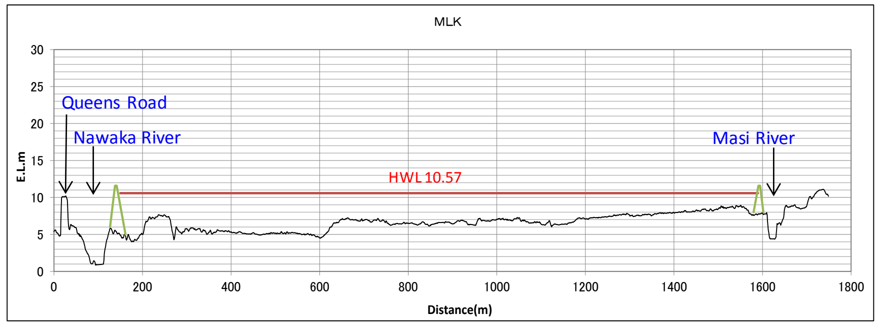
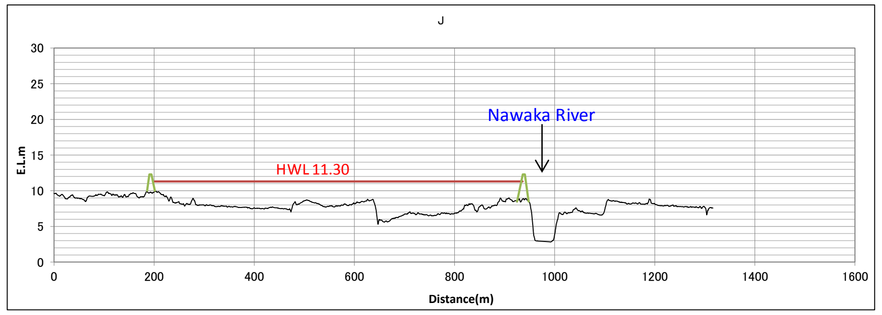
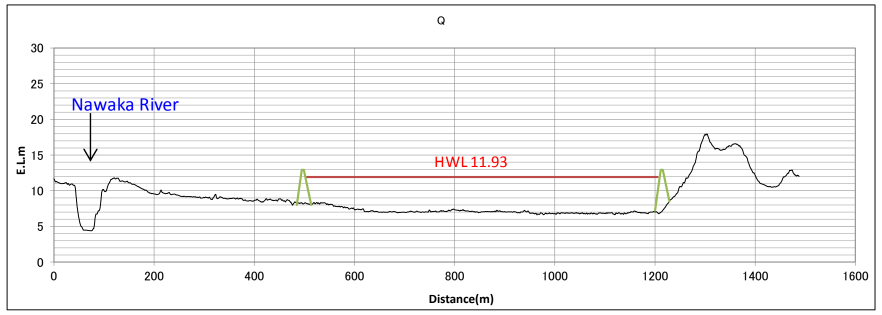
<tr><td>Cross Section</td><td>
</td><td>
</td><td>
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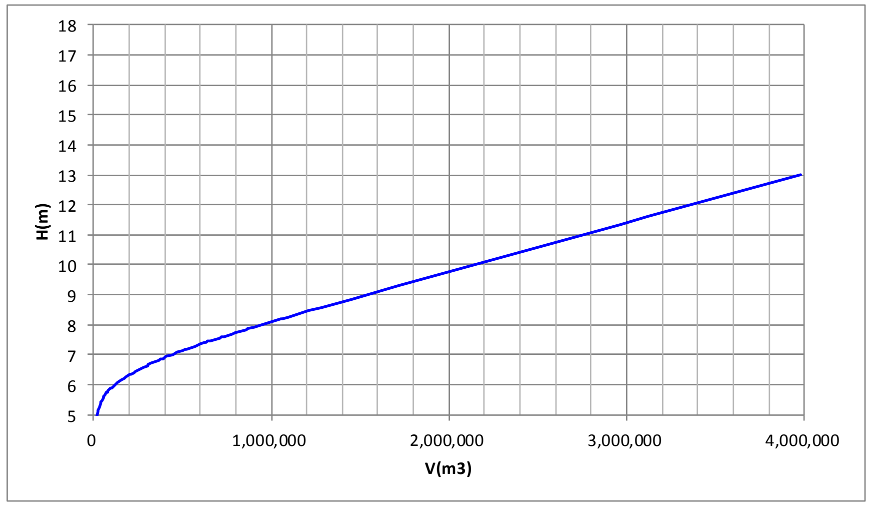
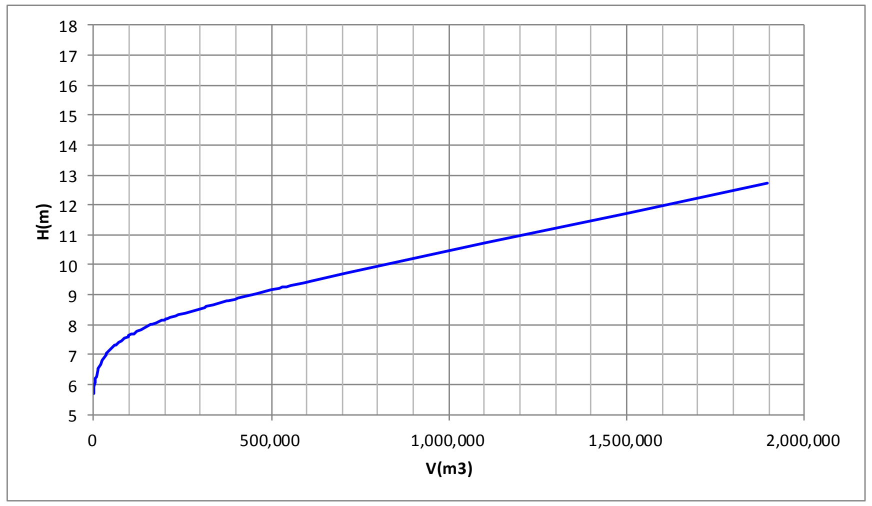
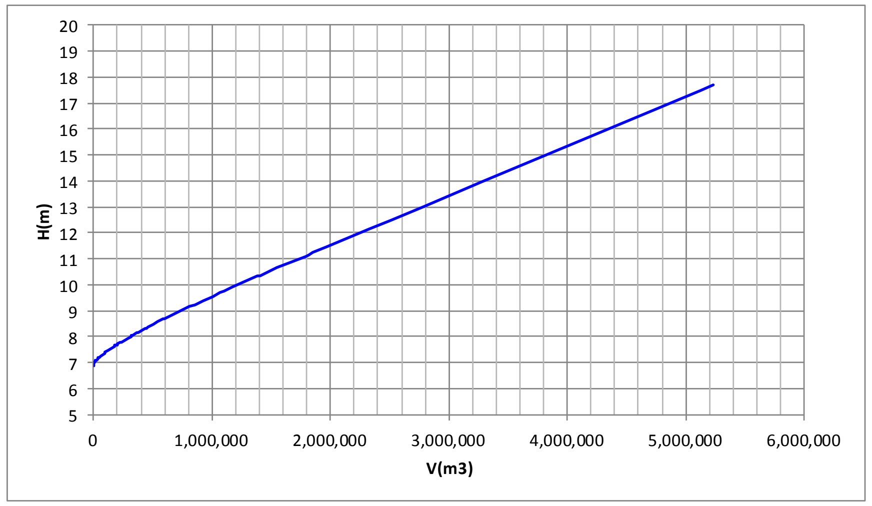
<tr><td>H-V Curve</td><td>
</td><td>
</td><td>
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Figure 6-30 (4) Cross section and H-V Curve

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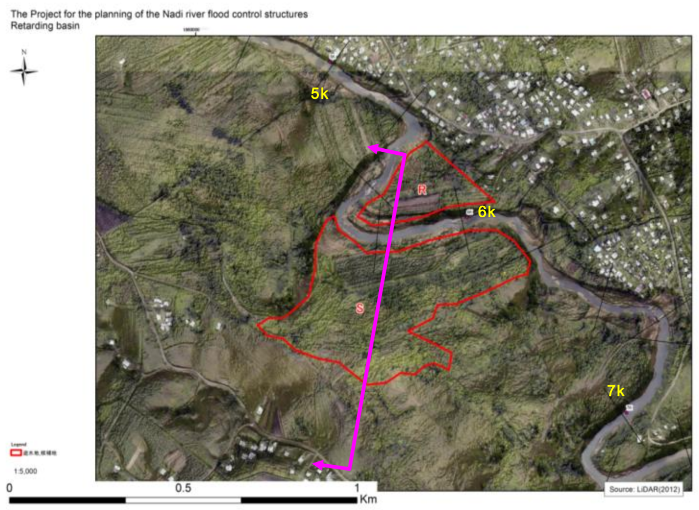
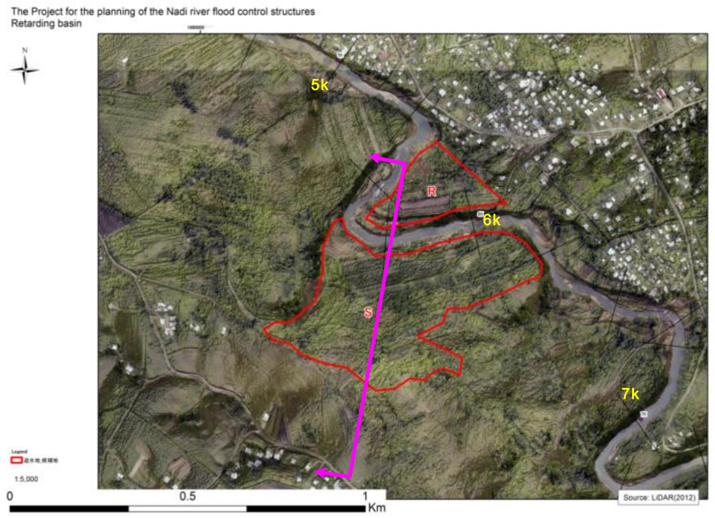
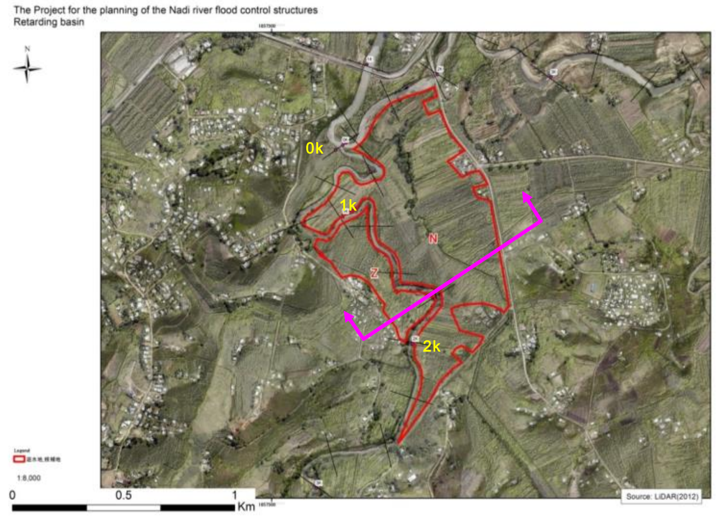
Nawaka River (5.25k～6k)</th><th>Retarding Basin S
Nawaka River (5.5k～6.25k)</th><th>Retarding Basin Z
Malakua River (0.75k～2k)</th></tr>
<tr><td>Plane Figure</td>
<td></td>
<td></td>
<td></td></tr>
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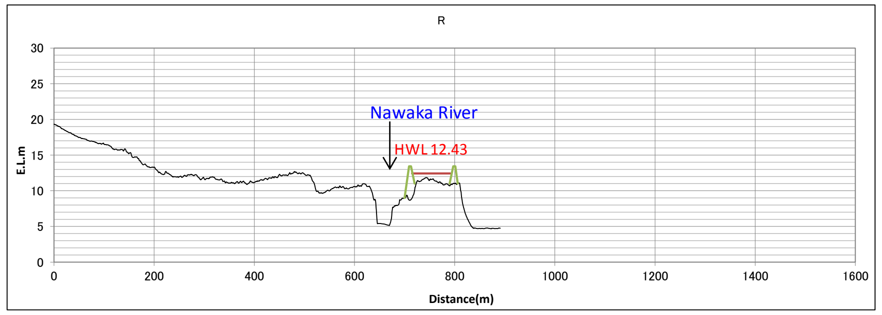
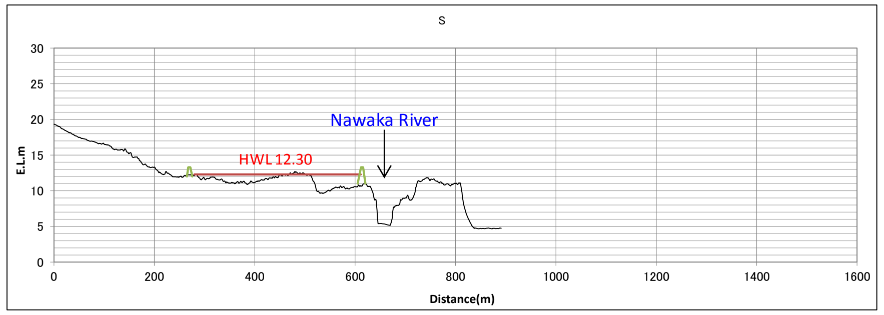
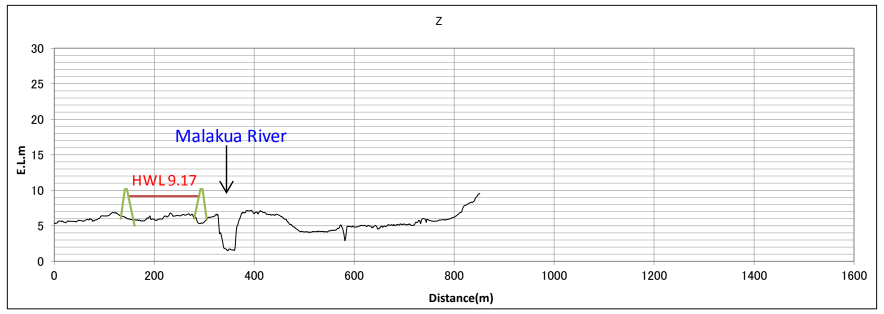
<td></td>
<td></td>
<td></td></tr>
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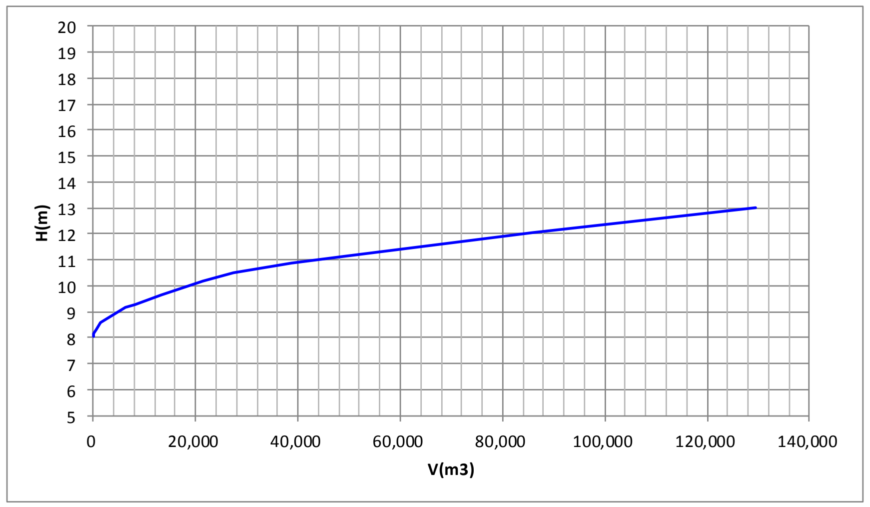
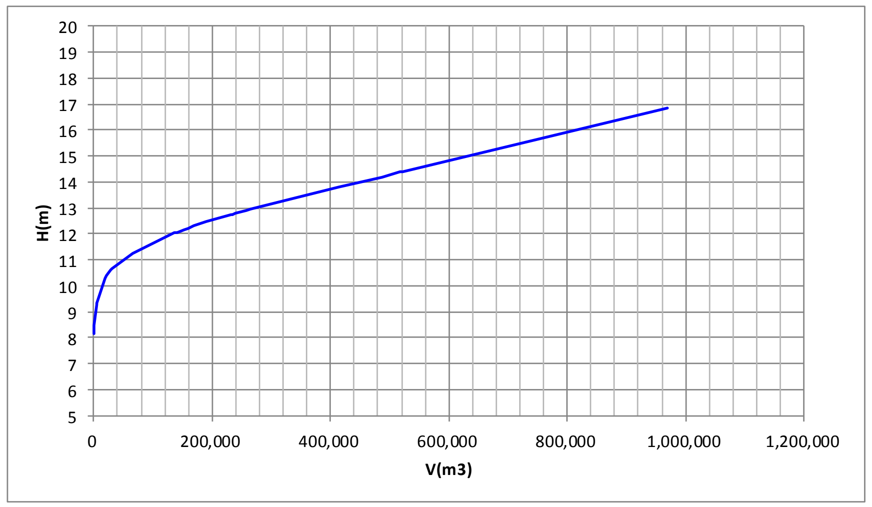
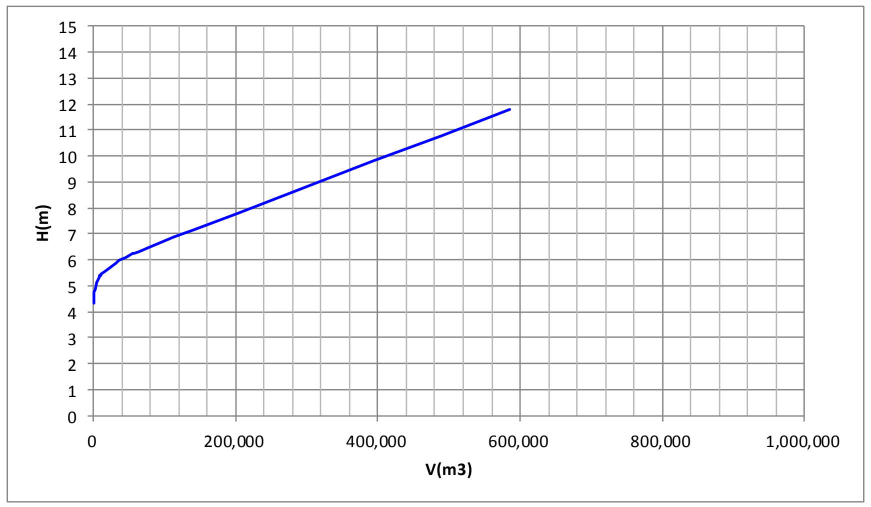
<td></td>
<td></td>
<td></td></tr>
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Figure 6-30 (5) Cross section and H-V Curve

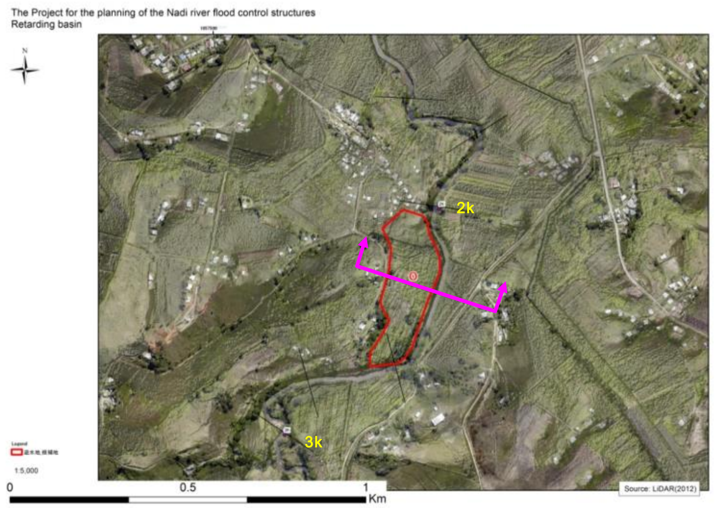
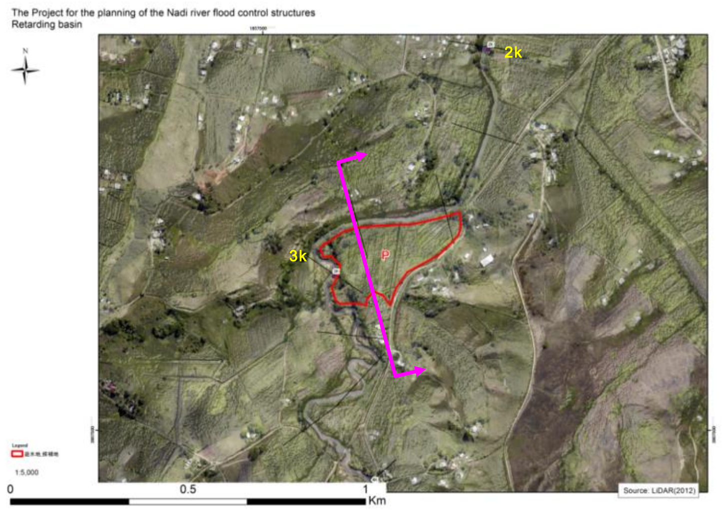
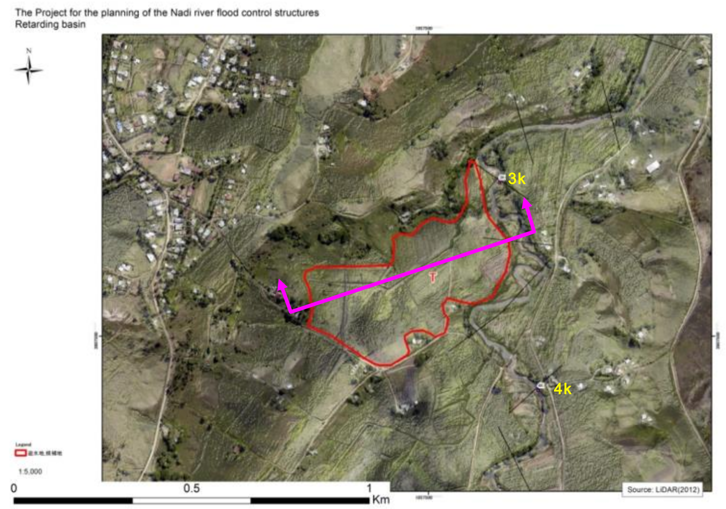
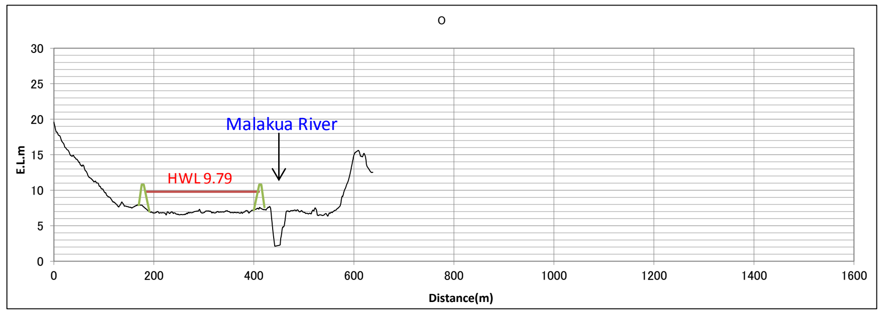
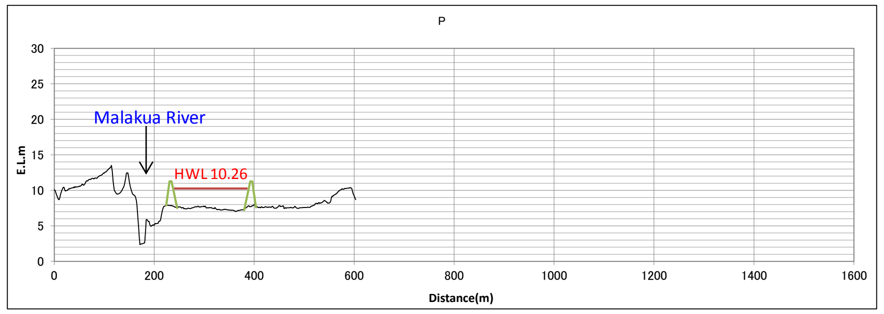
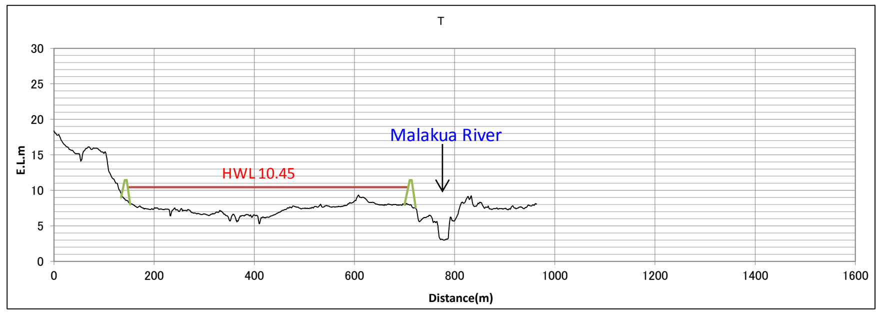
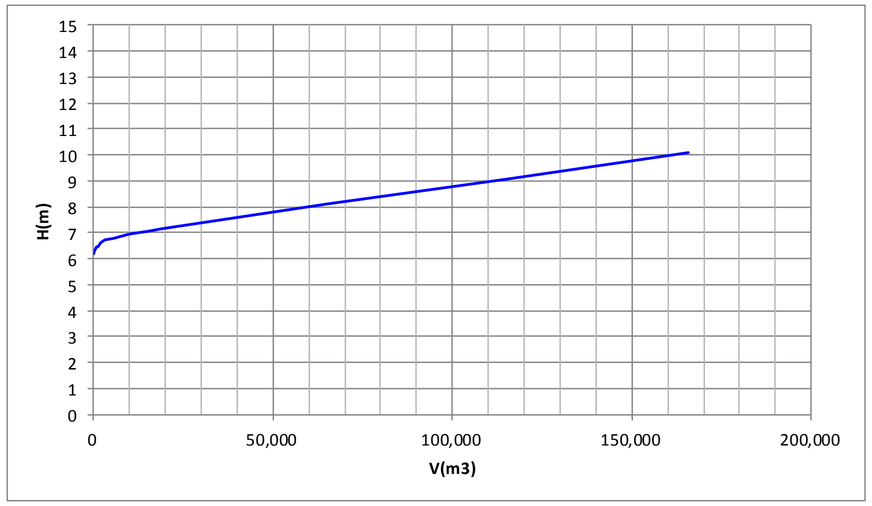
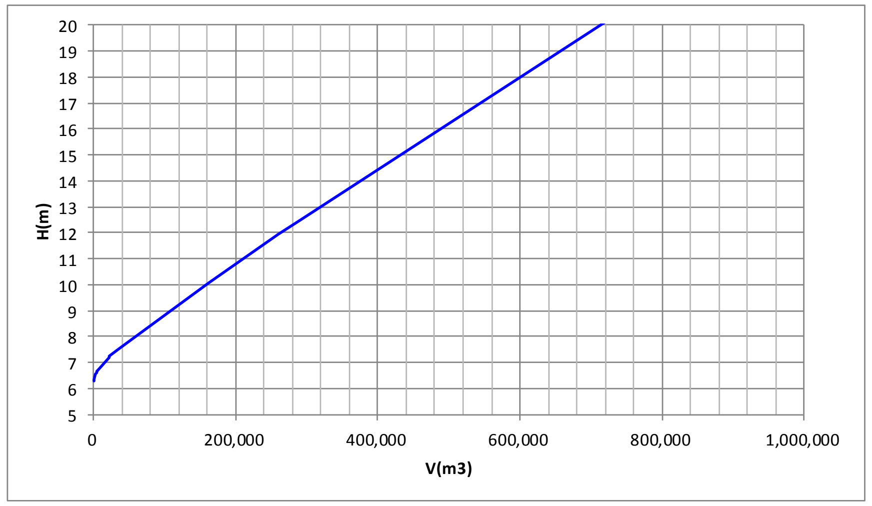
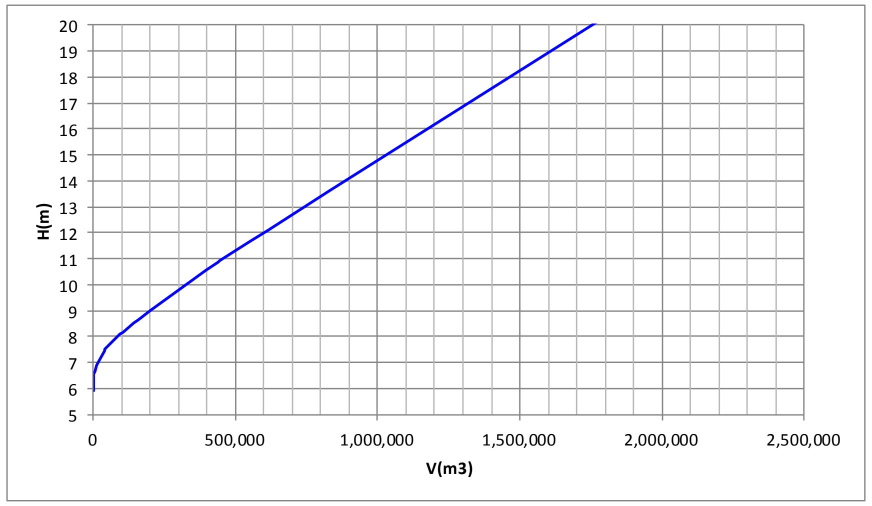
	Retarding Basin O **Malakua River (2k～2.5k)**	Retarding Basin P **Malakua River (2.5k～3.25k)**	Retarding Basin T **Malakua River (3.25k～3.5k)**
Plane Figure			
Cross Section			
H-V Curve			

Figure 6-30 (6) Cross section and H-V Curve

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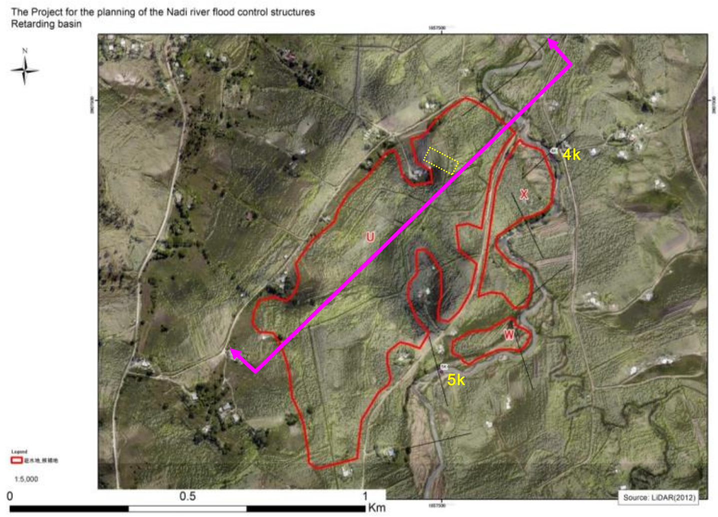
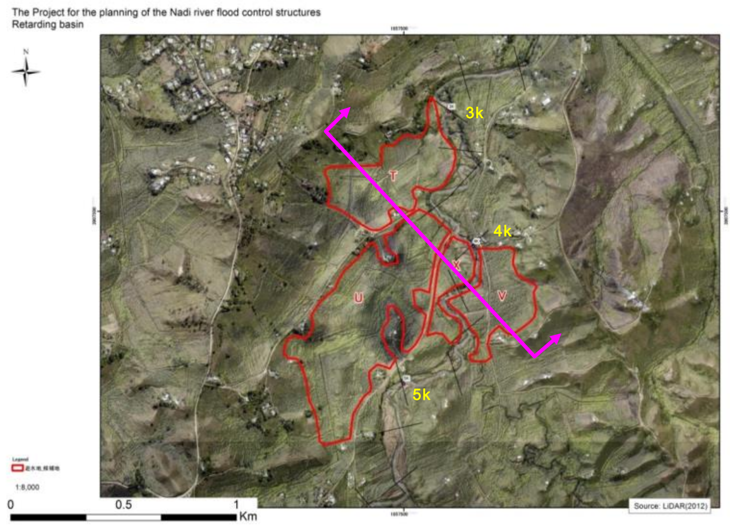
<tr><td>平面 Plane Figure</td><td>
</td><td>
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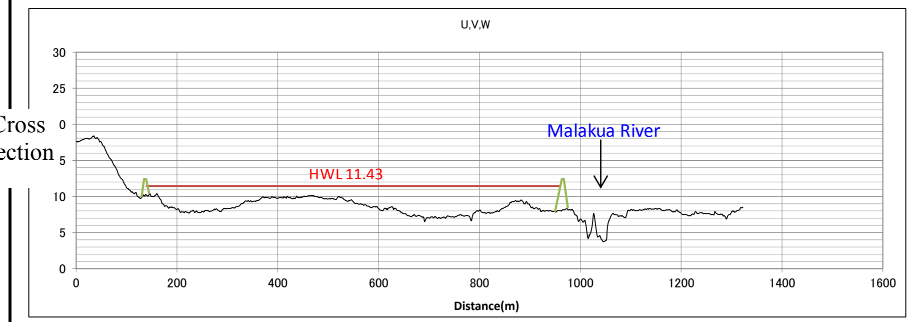
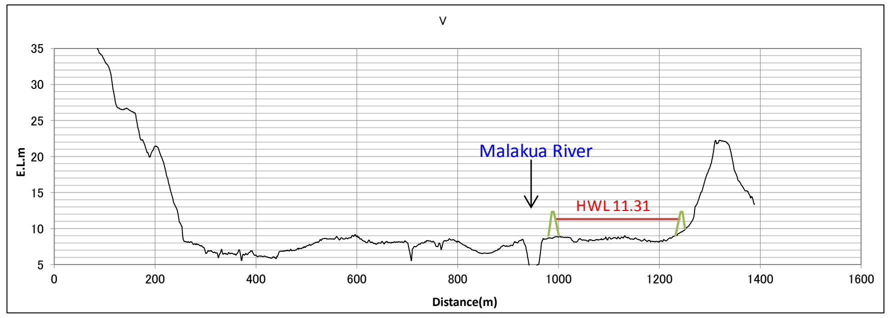
<tr><td>横断 Cross Section</td><td>
</td><td>
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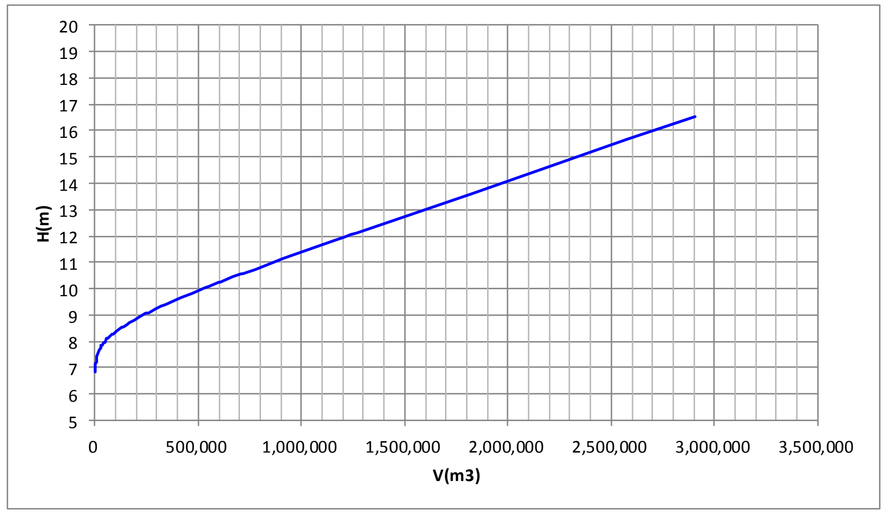
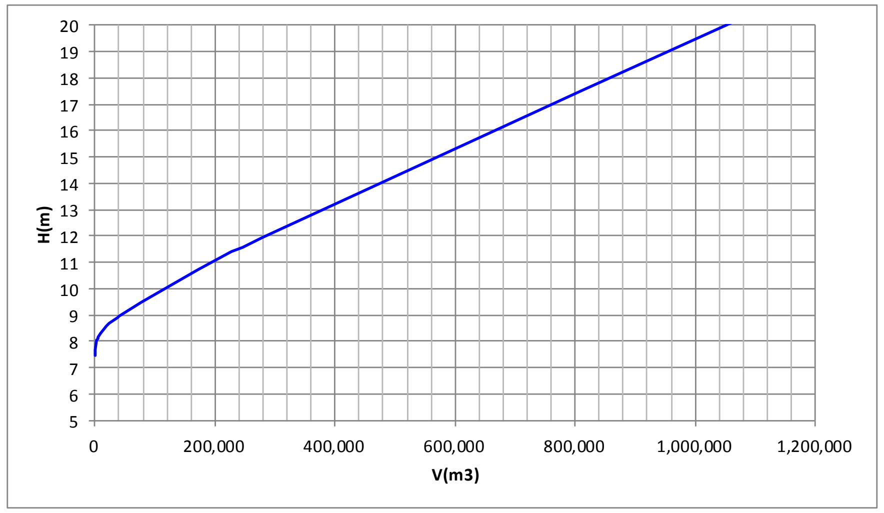
<tr><td>H-V Curve</td><td>
</td><td>
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Figure 6-30 (7) Cross section and H-V Curve

b) Examination of Flood Control Effect by Retarding Basin

I) Nadi River: Upstream

The scale of retarding basins was examined in order to reduce the flood discharge to 1,400m^3/s at Back Road Bridge.

A group of retarding basins (8 sites, 384.5 ha, V= 22,884,000m^3) can reduce the flood discharge from 2,430m^3/s to 1,400m^3/s .

In case of only embankment in retarding basins, flood control volume would be 1,640m^3/s at Back Road Bridge so that A, B and C retarding basins were necessary to be excavated by 1,280,000m^3, 5,100,000m^3 and1,739,000m^3 respectively to meet the requirement of 1,400m^3/s.

H retarding basin wasn't expected flood control effect so that it was excluded from candidate.

Table 6-10 Flood Control Effect by Retarding Basins (at Back Road Bridge)

Objective Flood	Number of Site	Area (ha)	Volume (1,000m^3)	Average Depth (m)	Before Control (m^3/s)	After Control (m^3/s)	**Effect (m^3/s)**
Flood of March 2012	8	382.3	22,807	6～11	2,430	1,400	**1,050**

2 sites among 8 sites were natural retarding basin so that the embankment wasn't needed.

Table 6-11 Flood Control Effect by Each Retarding Basin

Site		River	Bank Side	Outflow Point (K)	Design depth (m)	Area (ha)	Design Volume	Before Control (m^3/s)	After Control (m^3/s)	Retarding Volume (m^3/s)	Flood Control Volume (1000m^3)	Required volume per unit control discharge (1m3/s)	Remarks
A		Nadi	Left	20.50	6.9	44.1	2,867	1,499	1,399	100	2,615	26.2	Excavation 2-5m (1,280,000m^3)
B		Nadi	Right	23.00	8.6	153.1	11,508	1,923	1,451	472	10,286	21.8	Excavation 1-4m (5,100,000m^3)
C	C1	Nadi	Left	24.50	8.9	34.2	3,727	2,235	1,924	311	3,441	11.1	Excavation 1-5m (1,730,000m^3)
	C2	Nadi	Left		6.0	34.4							Jointed with C1
EDF	D	Nadi	Right	25.00	9.4	4.4	1,049	2,300	2,235	65	1,048	16.1	Jointed with E
	E	Nadi	Right		7.7	12.5							Jointed with D and F
	F	Nadi	Right		7.7	7.3							Jointed with E
G		Nadi	Left	25.75	7.8	23.4	683	1,656	1,585	71	606	8.5	
NRB1		Nadi	Both	25.75	4.3	26.0	1,100	1,823	1,643	180	1,100		NAD-L10, R6, R7, R8, R9
Subtotal						339.4	20,934				19,097		
H		Namosi	Left		4.5	2.2	78	-	-	-	-		No Effect
I		Namosi	Right		11.1	14.9	1,125	781	732	49	1,118		
NRB2		Namosi	Both		2.7	28.0	748	850	777	73	748		NAM-L2, L3, L4, L5, R2, R3, R4
Subtotal						42.9	1,873				1,866		

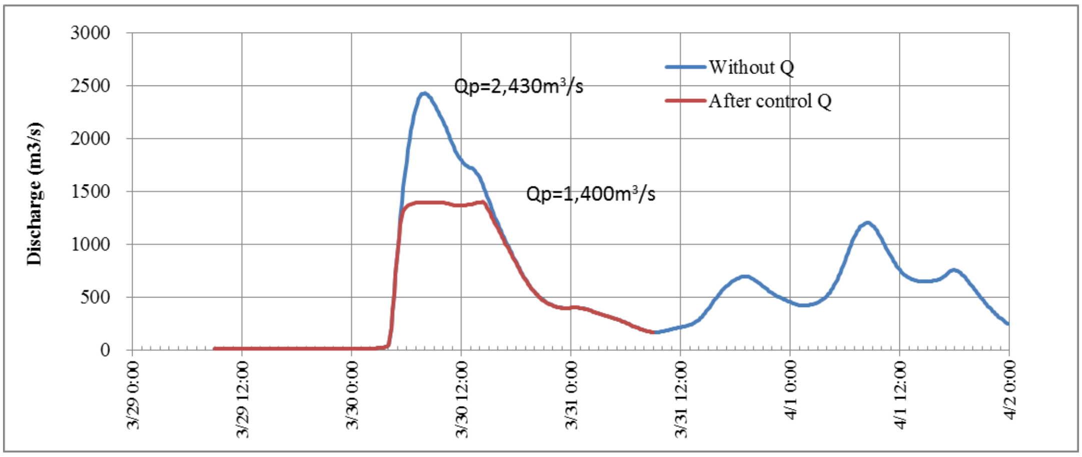


Figure 6-31 Hydrograph at Back Road Bridge (Flood of March 2012)

II) Nawaka/ Malukua River

The scale of retarding basins was examined for the candidate of retarding basins in order to reduce the flood discharge to 1000m^3/s at the point before the confluence of Nadi and Nawaka River.

A group of retarding basins (10 sites, 382.6 ha, V= 11,363,000 m^3) can reduce the flood discharge from 1,450m^3/s to 960m^3/s .

R and S retarding basin in Nawaka River and O, P and Q basin in Malakua River have small capacity and not much effect so that they were excluded from candidate.

Table 6-12 Flood Control Effect by Retarding Basins
(at the point before the confluence of Nadi and Nawaka River)

Objective Flood	Number of Site	Area (ha)	Volume (1,000m^3)	Average Depth (m)	Before Control (m^3/s)	After Control (m^3/s)	**Effect (m^3/s)**
Flood of March 2012	10	386.2	11,363	3.5～6.5	1,450	960	**490**

2 sites among 10 sites were natural retarding basin so that the embankment wasn't needed.

Table 6-13 Flood Control Effect by Each Retarding Basin

Site		River	Bank Side	Outflow Point (K)	Design depth (m)	Area (ha)	Design Volume	Before Control (m^3/s)	After Control (m^3/s)	Retarding Effect (m^3/s)	Flood Control Volume ($1000m^3$)	Required volume per unit control discharge (1m3/s)	Remarks
AA		Nawaka	Left	0.75	3.9	47.0	683	991	962	29	683	23.5	Confluence with Nadi River
N		Nawaka	Left	1.75	6.3	48.5	1,859	731	689	42	1,324	31.5	
MLK	M	Nawaka	Left	3.50	6.6	36.2	2,489	833	733	100	2,489	24.9	Jointed with M
	L	Nawaka	Left		5.1	14.6							Jointed with M
	K	Nawaka	Left		3.8	10.0							
J		Nawaka	Left	4.50	5.6	39.4	1,334	646	588	58	1,334	23.0	
Q		Nawaka	Right	5.25	5.1	52.3	2,220	742	646	96	2,220	23.1	Nawaka Lake, Connection at 5.25K
NRB3		Nawaka	Left	7.00	1.4	25.0	349	759	736	23	3,334		NAW-L4, L5, R2
Subtotal						273.0					7,368		
Z		Nawaka	Right	1.75	4.8	9.5		313	300	13	315	24.2	
T		Nawaka	Left	3.25	4.5	14.5		327	312	15	370	24.7	
UXW	U	Nawaka	Left	4.50	4.6	4.5		368	327	41	1,107	24.8	Jointed with U
	X	Nawaka	Left		4.0	1.5							Jointed with U
	W	Nawaka	Left		4.3	33.2							
NRB4		Nawaka	Both	5.00	1.4	50.0		335	302	33	691	20.9	MAL-L4, R2, LR1
Subtotal						113.2					1,701		

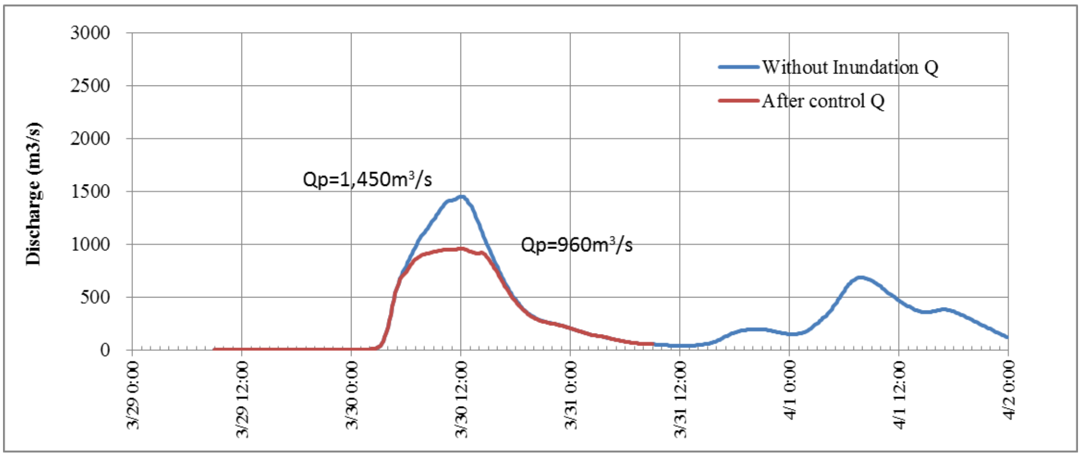


Figure 6-32 Hydrograph at the point before Confluence of Nadi and Nawaka River (Flood of March 2012)

Discharge distribution by retarding basins located in Nadi upstream, Nawaka River and Malakuwa River is shown in Figure 6-33.

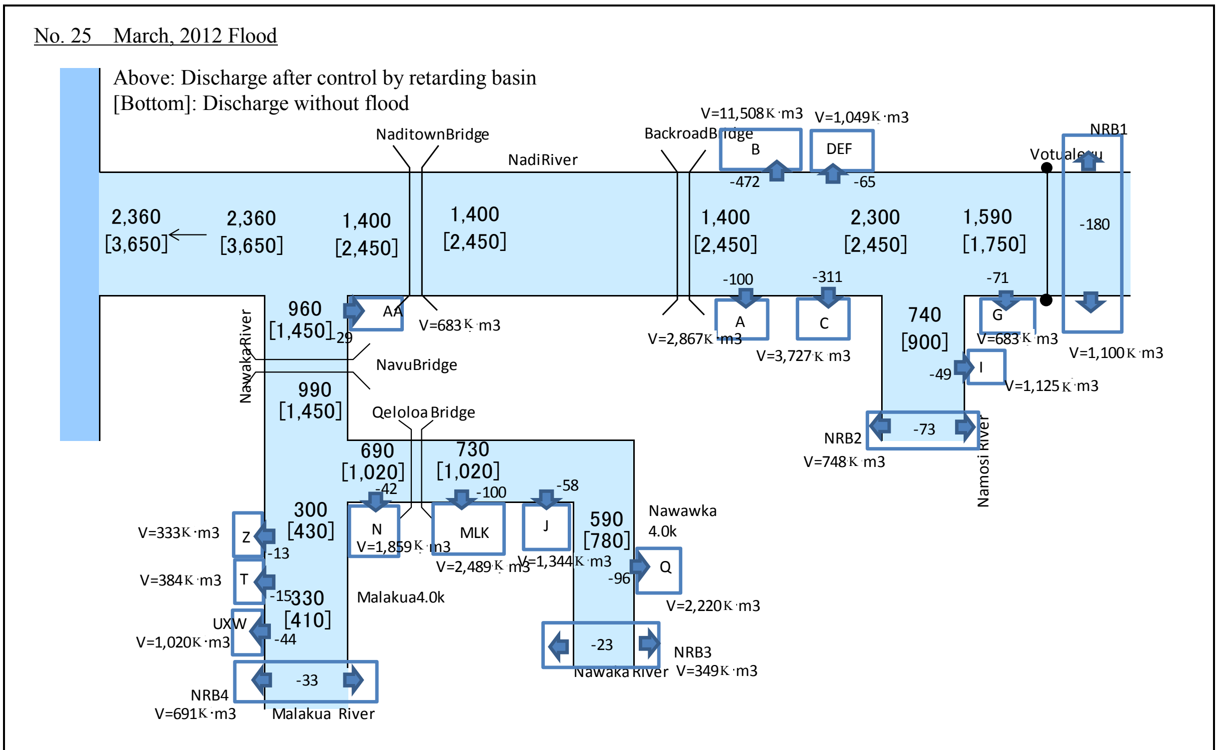


Figure 6-33 Discharge Distribution

(by retarding basin located in Nadi upstream, Nawaka River and Malakuwa River)

c) Examination of Flood Control Effect by Dam + Retarding Basin

I) Nadi River: Upstream

The scale of retarding basins was examined in order to reduce the flood discharge to 1,400m^3/s at Nadi Back Road Bridge after controlled discharge by NAD-3 dam.

Reterding basin B (1 site, 153.1 ha, V= 4,005,000 m^3) can reduce the flood discharge from 1,600m^3/s to 1,400m^3/s . (Refer Table 6-14)

Table 6-14 Flood Control Effect by Dam + Retarding Basins
(at the point back Road Bridge)

Objective Flood	Number of Site	Area (ha)	Volume (1,000m^3)	Average Depth (m)	Before Control (m^3/s)	After Control (m^3/s)	**Effect (m^3/s)**
Flood of March 2012	1	153.1	4,005	7.6	1,600	1,400	**200**

Table 6-15 Flood Control Effect by Each Retarding Basin

Site	River	Bank Side	Outflow Point (K)	Basin HWL (EL m)	Free Board (m)	Design Bank Elevation (EL m)	Basin Bottom Elevation (EL m)
B	Nadi	Right	23.00	16.60	1.00	17.6	9.03

Site	River	Bank Side	Design depth (m)	Area (ha)	Design Volume (1000m^3)	Before Control (m^3/s)	After Control (m^3/s)	Retarding Effect (m^3/s)	Flood Control Volume (1000m^3)	Required volume per unit control discharge (1m3/s)	Remarks
B	Nadi	Right	7.6	153.1	4,882	1,617	1,365	252	4,005	15.9	20% allowance is included in Design Volume

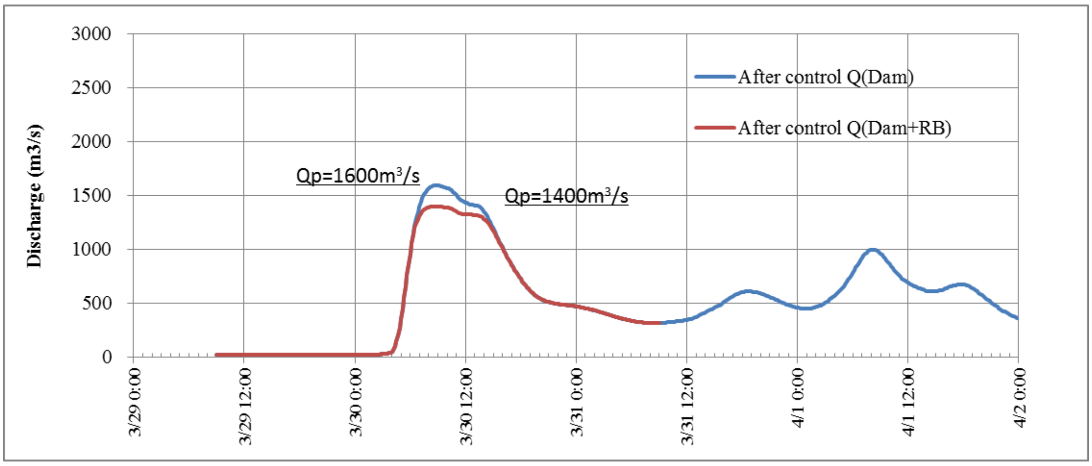


Figure 6-34 Hydrograph at the point Back Road Bridge (Flood of March 2012)

No. 25 March, 2012 Flood

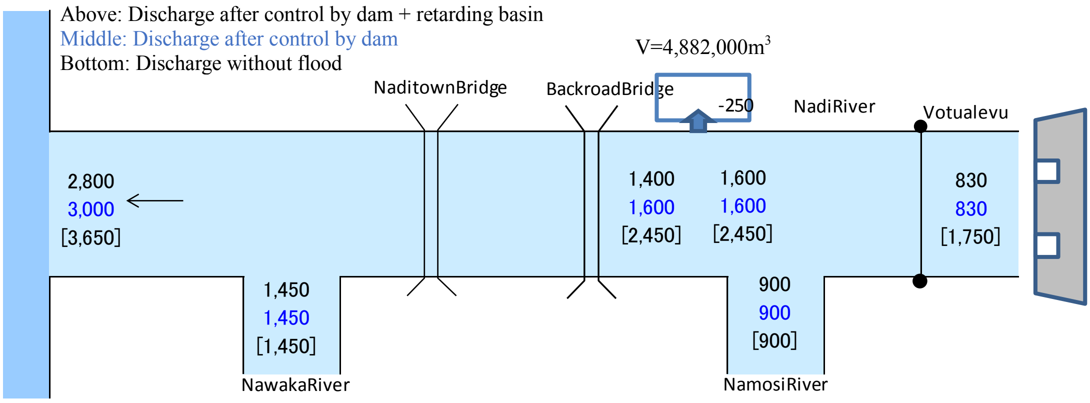


Figure 6-35 Discharge Distribution

(by retarding basin located in Nadi upstream, Upstream of Nadi River)

2) Downstream

In Nadi downstream, retarding basin was considered to meet following discharge distribution shown in Figure 6-36. The targeted retarding area was on left bank because there is Denarau area, which includes existing developed area and developing Fantasy Island (shown in Figure 6-38 and Figure 6-39). The houses located near the over flow section are subjected to be transferred and other houses and community are protected from inundation by surrounding ring dike.

a) Discharge before and after Flood Control Measure

Since the discharge before flood control is to be 2,400m^3/s and 1,400m^3/s depending on the flood control measures in the middle stream, in order to make the discharge after control 1,000 m^3/s, which is discharge capacity of river channel after normalization of the channel, the following 2 cases of discharge conditions are to be studied (refer to Figure 6-30).

Before control: 2,400m^3/s ⇒ After control: 1,400m^3/s by retarding basin so that discharge at river mouth would be 1,000m^3/s.

Before control: 1,400m^3/s ⇒ After control: 700m^3/s by retarding basin so that discharge at river mouth would be 1,000m^3/s.

■Discharge Distribution

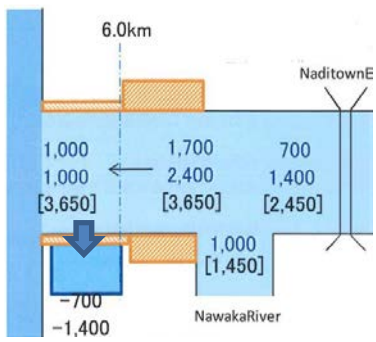


Figure 6-36 Discharge Distribution after before and after Flood Control

b) Outline of Retarding Basin

The outline of retarding basin designed in downstream is shown in Table 6-12. And the ring dike protecting scattered houses and along main road is outlined in Table 6-14.

Table 6-16 Introduction about Retarding Basin

■Parameters about Retarding Basin

Items	Parameters	
Area	807 ha	
Filling volume	10,263 Km^3	
Ave. filling depth	1.27 m	
Land use	Area (ha)	Ratio
Mangrove	640.52	79.4%
Sugar Cane	40.92	5.1%
Firm Land (without sugar cane)*	0.04	0.0%
Other	125.52	15.6%
Overflow area	Q=1,400m^3/s	Q=700m3/s
Length	L=600m	L=300m
Section	Nadi left bank 5.15-5.75k	Nadi left bank 5.45-5.75k
Overflow depth	1.0m	
Glound level at overflow	River HWL -1.0m	
Emankment area		
Length	7,128m	
Bank height	1.2～3.1m (Ave. 2.0m)	
Slope gradient	Landside: 1:2.0, Waterside: 1:2.0	
Site area	41 ha	
Removal house	12 houses	

* Idle former cane areas, Grazing Mixed Vegetable, Roots Crops
**Sand, Water surfece, Grazing, Others

Table 6-17 Outline of Ring Dike

Name	Crown Height (EL.m)	Gound Level (EL.m)	Crown Width (m)	Bank Height (m)	Slope Gradient (landside/ 1:m)	Slope Gradient (waterside/ 1:m)	Length (m)
①	4.32	1.82	4.0	2.5	2.0	2.0	1,534
②	4.35	2.45	4.0	1.9	2.0	2.0	90
③	4.30	2.70	4.0	1.6	2.0	2.0	340
④	6.28	4.28	4.0	2.0	2.0	2.0	320
⑤-1	6.17	3.07	4.0	3.1	2.0	2.0	730
⑤-2	4.20	2.10	4.0	2.1	2.0	2.0	1,097
⑤-3	4.40	2.20	4.0	2.2	2.0	2.0	500
⑥	4.37	1.87	4.0	2.5	2.0	2.0	942
⑦	3.82	2.32	4.0	1.5	2.0	2.0	1,210
⑧	3.41	2.21	4.0	1.2	2.0	2.0	310
⑨	3.38	1.98	4.0	1.4	2.0	2.0	55
SUM							7,128

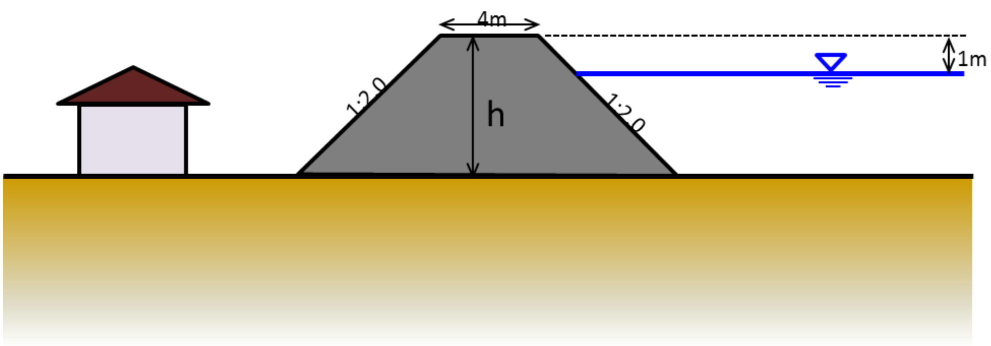


Figure 6-37 Image Map of Ring Dike

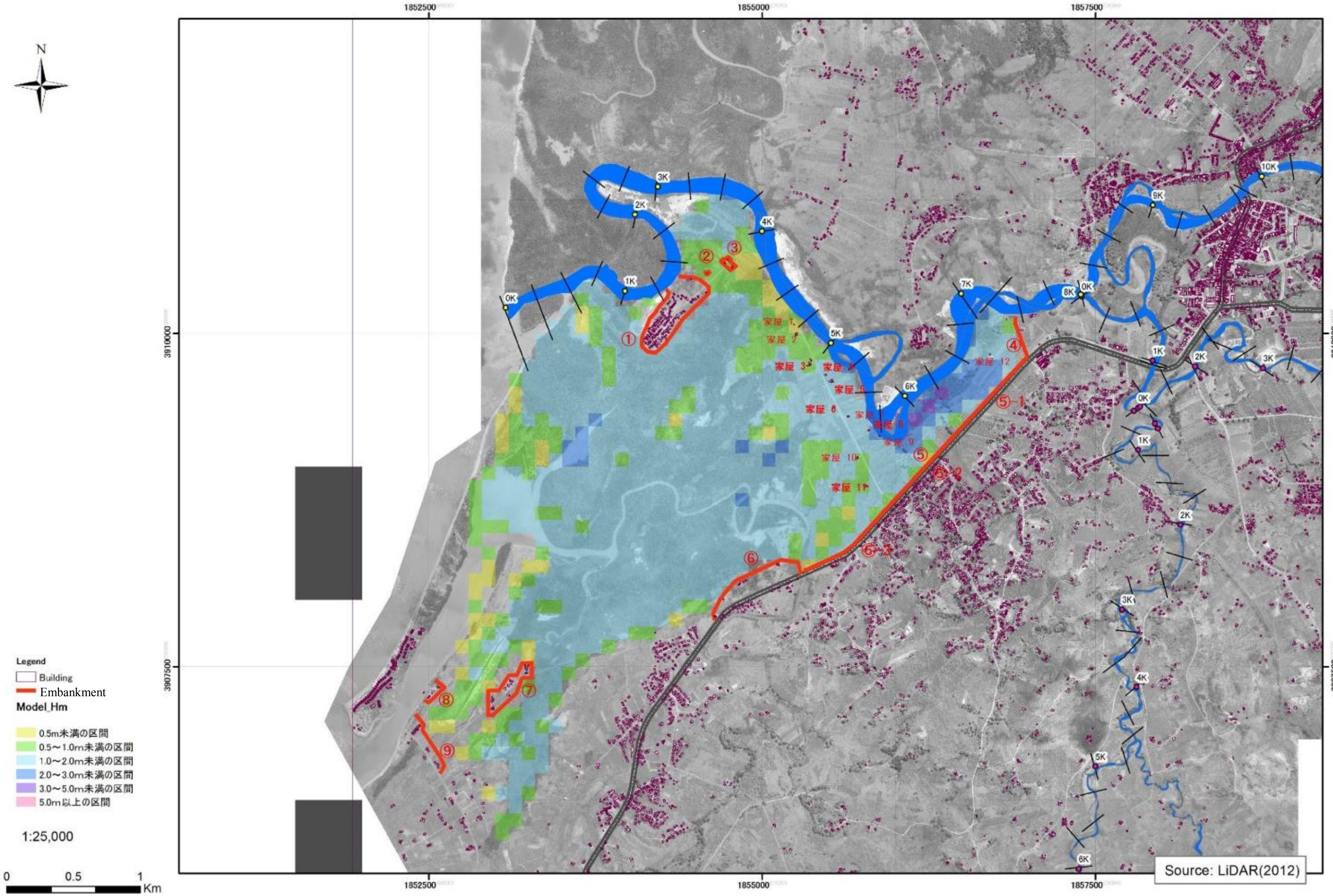


Figure 6-38 Location of Retarding Basin and Ring Dike

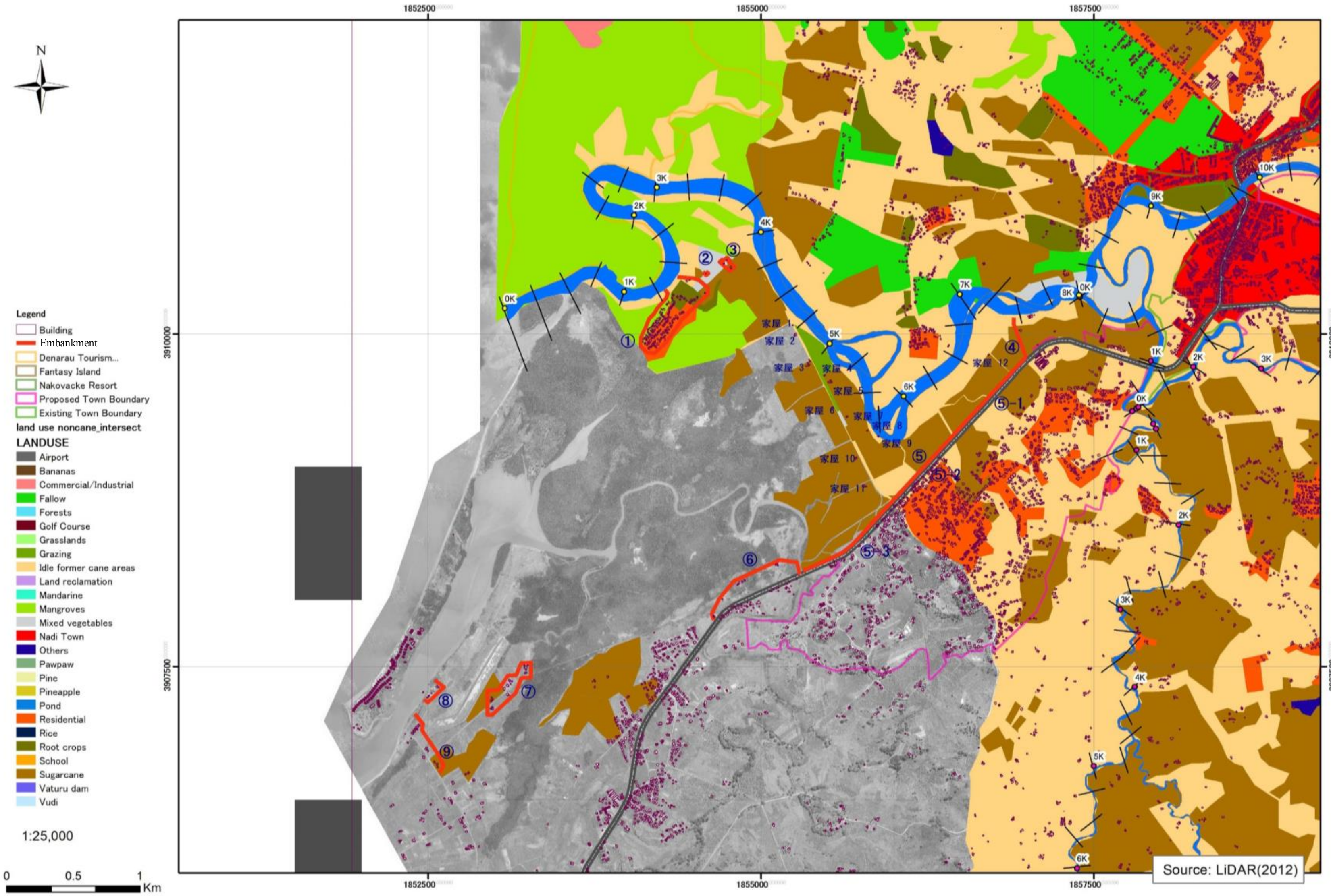


Figure 6-39 Land Use Map near Retarding Basin

6.3.3 River Improvement

The river improvement is examined for the target flood discharge as follows:

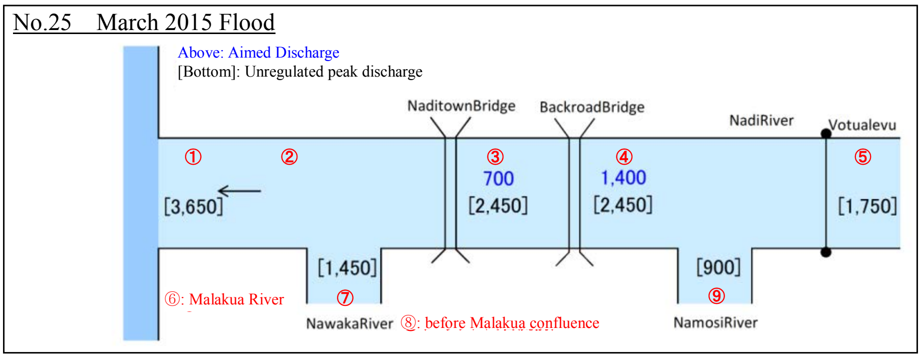


Figure 6-40 Target Flood Discharge

The river improvement is planned according to the following considerations..

- Design water depth: average depth in section is determined considering depth to top of bank d.
- Slope gradient of excavation: 1:2.0
- Design roughness coefficient: average integrated roughness coefficient in the section considering depth to top of bank and plantation condition after improvement.
- Design river slope: present river slope considering river bed stability

The standard cross sections are as shown in Figure 6-41.

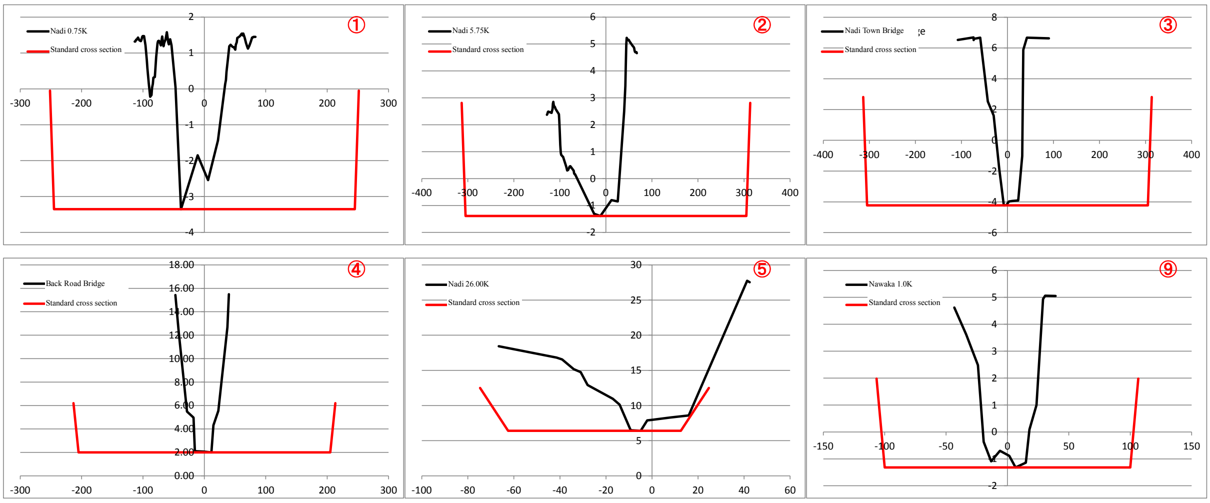


Figure 6-41 Standard Cross Section of River Improvement and Present Cross Section

As shown in Figure 6-41, the cross section area after improvement is required 2 to 5 times bigger than the present cross section so that the large scale enlargement is required accompanying large land acquisition, many houses transfer, rebuilding present bridges which affects so much to social environment. Therefore the river improvement only has no reality as flood control measure, it is desirable to combine with other flood control measures.

6.3.4 Diversion Channel

The trial calculation was conducted to find out how much discharge could be branched by diversion channel supposing various standard cross sections.

(1) Selection of Diversion Channel Route

Table 6-18 and Figure 6-42 are shown 5 candidate routes for diversion channel.

Table 6-18 Candidate Route for Diversion Channel

Route	Length (km)	Distance mark of Nadi river
1	4.809	19.10k
2	3.800	13.75k
3	4.111	9.00k
4	4.301	8.30k
5	2.680	5.75k

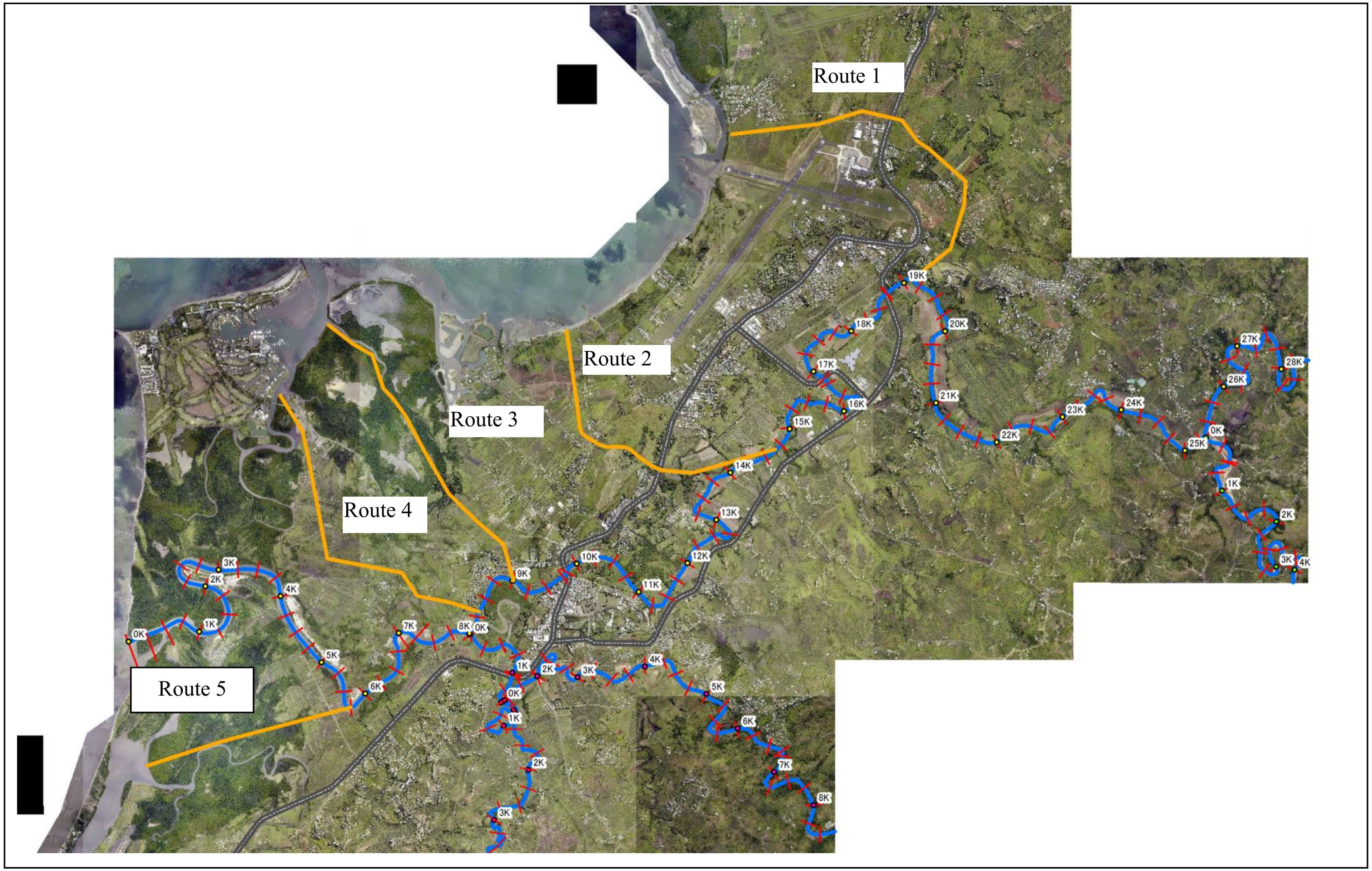


Figure 6-42 Candidate Route Map of Diversion Channel

(2) Introduction about Cross Section of Diversion Channel

Hydrological calculation at each diversion channel was conducted to find out discharge capacity which could be flown out by diversion channel based on following assumed cross section. The cross section of diversion channel route-1~4 is shown in Figure 6-43 and the cross section of diversion channel route-5 is shown in Figure 6-44.

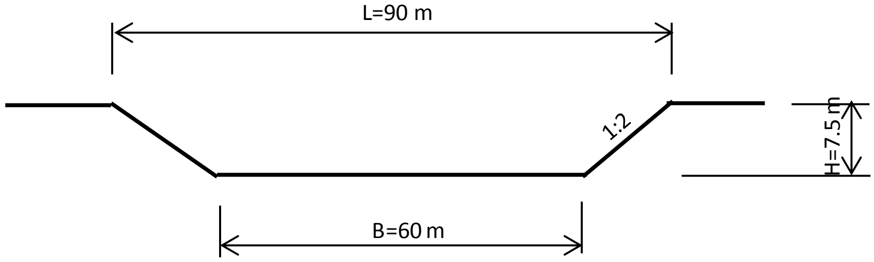


Figure 6-43 Cross Section about Diversion Channel Route-1~4

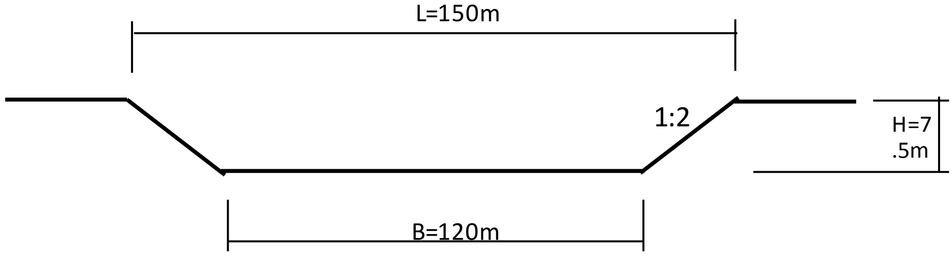


Figure 6-44 Cross Section about Diversion Channel Route-5

(3) Profile of Diversion Channel

The inflow elevation was set with river bed elevation of Nadi River and the outflow elevation is shoreline elevation. As additional case, the case of 2m higher inflow elevation than Nadi River was examined.

Table 6-19 shows diversion channel profile of each route. The outflow elevation of candidate route-3 and -4 were lower than Nadi River bed of inflow so that only the case of 2m higher inflow than Nadi River was considered. Design profile of diversion channel at each route is shown in Figure 6-39～Figure 6-45.

Table 6-19 Longitudinal Status of Diversion Channel

Route	Length (km)	Inflow Elevation	Outflow Elevation	Slope	Notes
1	4.809	2 m	-1.0 m	1/1,601	Case-1
		4 m		1/961	Case-2
2	3.800	0 m	-1.0 m	1/3,800	Case-1
		2 m		1/1,270	Case-2
3	4.111	0 m	1.0 m	1/4,090	Case-1
4	4.301	0 m	1.0 m	1/4,267	Case-1
5	2.590	1 m	0 m	1/2,590	Case-1

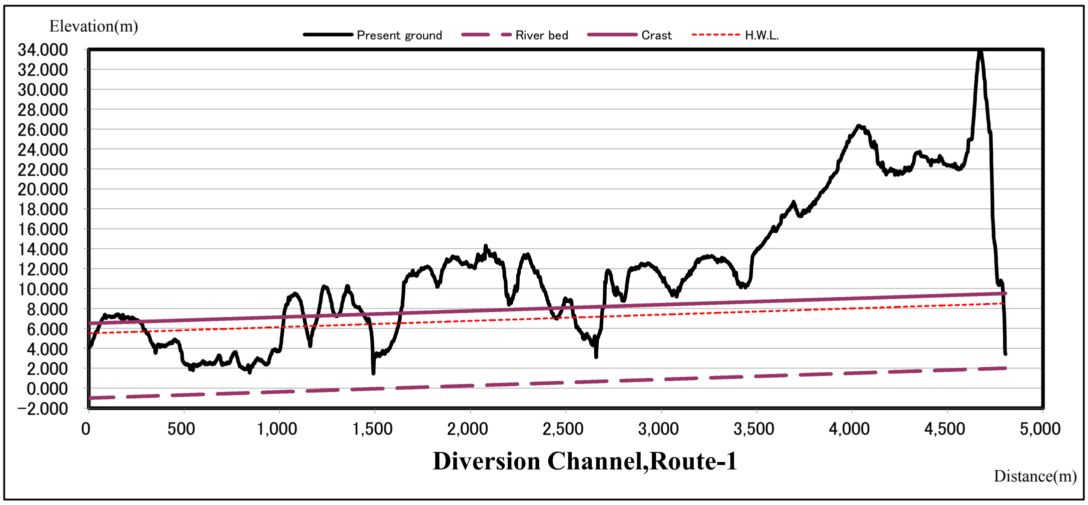


Figure 6-45 Diversion Channel Route-1 (Case-1)

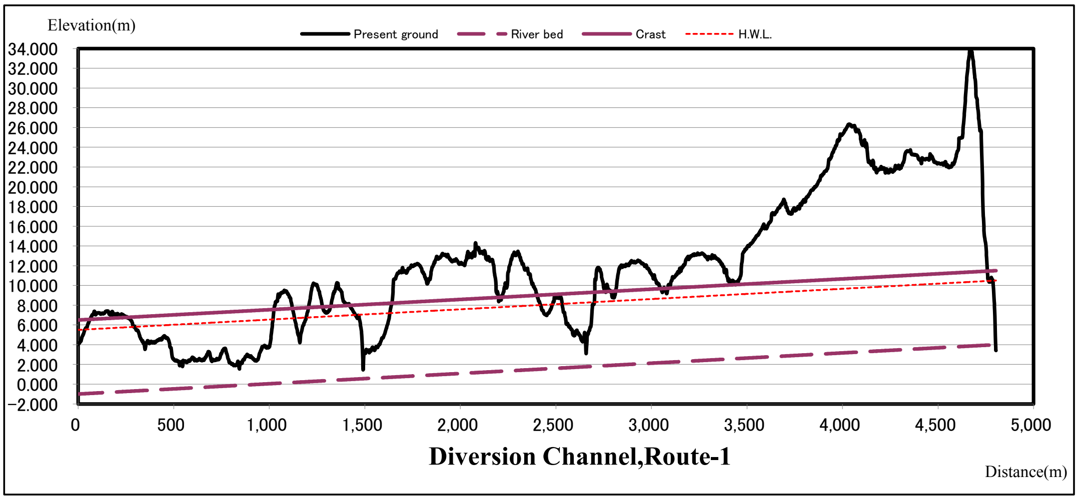


Figure 6-46 Diversion Channel Route-1 (Case-2)

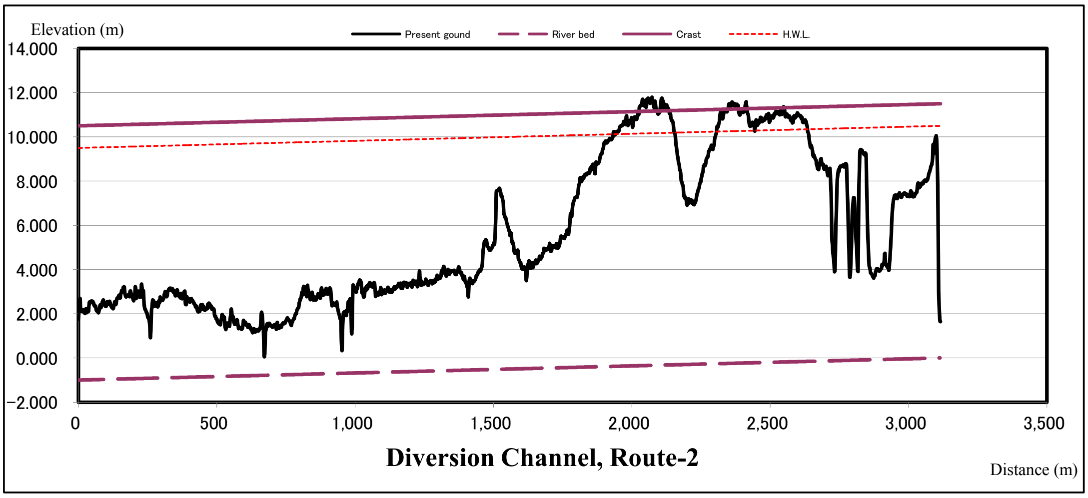


Figure 6-47 Diversion Channel Route-2 (Case-1)

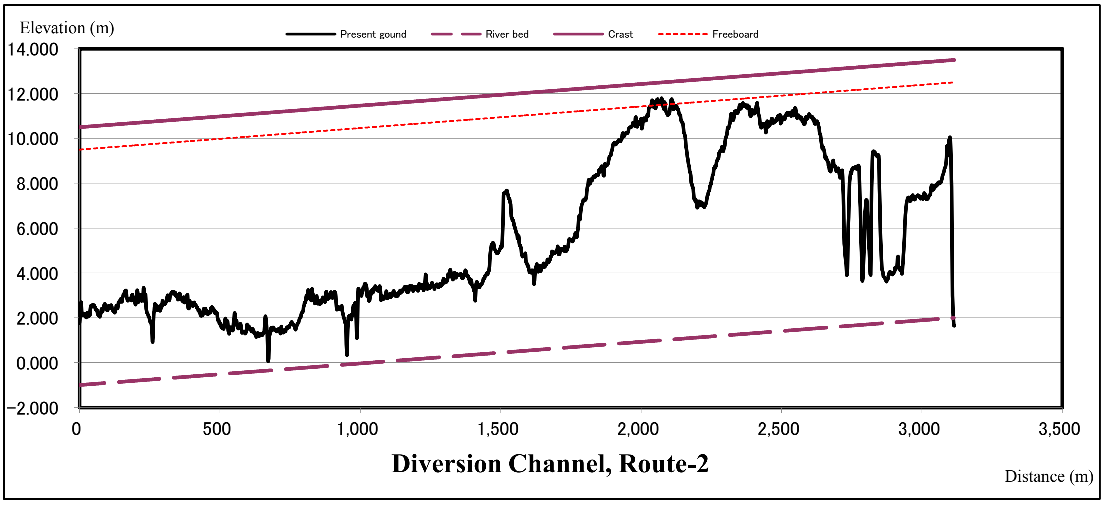


Figure 6-48 Diversion Channel Route-2 (Case-2)

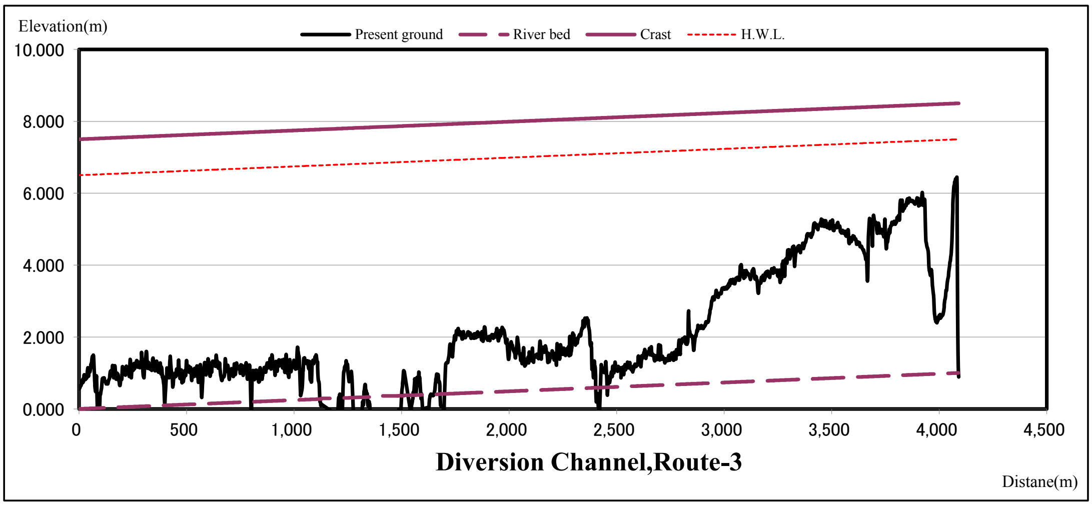


Figure 6-49 Diversion Channel Route-3 (Case-1)

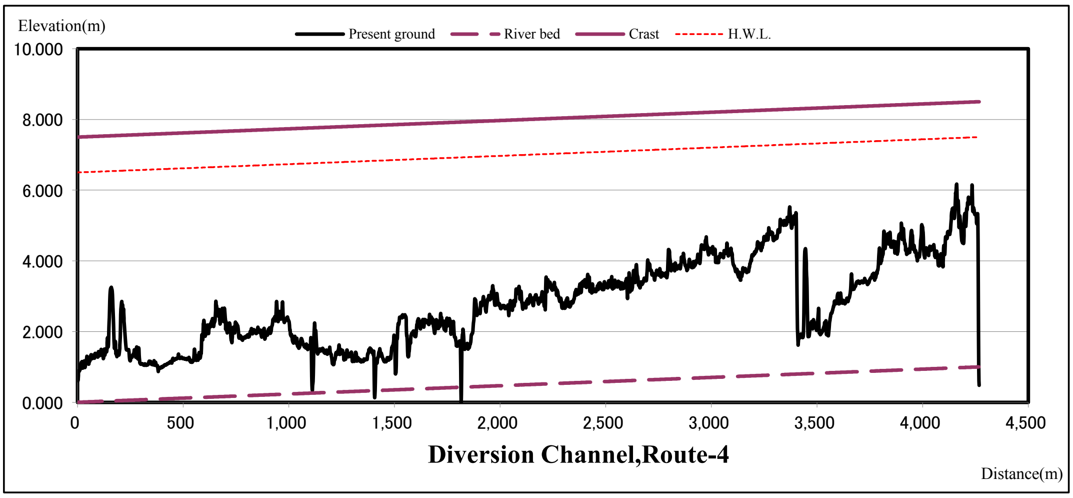


Figure 6-50 Diversion Channel Route-4 (Case-1)

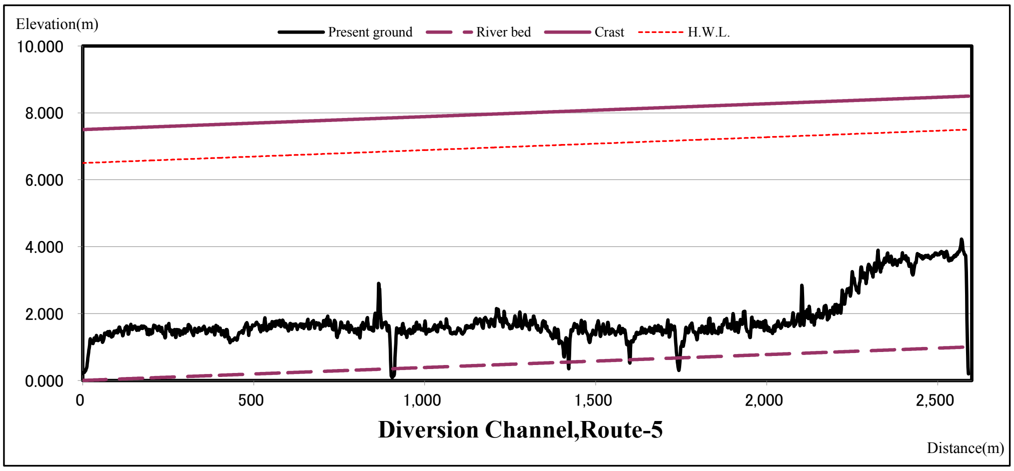


Figure 6-51 Diversion Channel Route-5 (Case-1)

(4) Non-Uniform Flow Calculation

The non-uniform flow calculation was conducted to find out discharge capacity of each candidate diversion channel. Calculation conditions are as shown below.

1) Calculation water level at starting point: EL. 1.188m which is average high water springs in Nadi Bay
2) Roughness coefficient: 2 case of 0.030 and 0.035

Calculation result is shown in Table 6-20.

The discharge capacity of each diversion route is summarized as follows:

Route 1: 500~1,000 m^3/s

Route 2: 1,000 m^3/s

Route 3: 500 m^3/s

Route 4: 500 m^3/s

Route 5: 2,000m^3/s

Table 6-20 Result of Non-Uniform Flow Calculation

Route	Case	Roughness coefficient	500 m^3/s	1,000 m^3/s	1,500 m^3/s	2,000 m^3/s
1	Case-1	0.030	○	○	×	×
		0.035	○	○	×	×
	Case-2	0.030	○	○	○	×
		0.035	○	×	×	×
2	Case-1	0.030	○	○	×	×
		0.035	○	○	×	×
	Case-2	0.030	○	○	○	×
		0.035	○	○	×	×
3	Case-1	0.030	○	○	×	×
		0.035	○	×	×	×
4	Case-1	0.030	○	○	×	×
		0.035	○	×	×	×
5	Case-1	0.030	○	○	○	○
		0.035	○	○	○	○

6.3.5 Ring Dike

Ring dike is the method that the specific area such as community and houses are protected by surrounding dike (ring dike) in inundated area so that the method would not contribute to increase of discharge capacity and discharge regulation. Therefore the ring dike is applied to the community or houses left unprotected in the inundated area or in the retarding basin in the Priority Project.

Chapter 7 Flood Control Plan and Channel Improvement Plan

7.1 The Best Combination of Measure Facility for Flood Control

7.1.1 Consideration of Measure Facility for Flood Control at Each Section

As mentioned 6.1.3, the studied area for flood control plan was divided following 3 sections considering the middle section which was the most important area. The combination of measure facility for flood control at each section was as provided below.

(1) Middle Section (5.75km～Back road Bridge)

1) M-1: River Improvement

2) M-2: River Improvement + Diversion Channel (Route-1) (700m^3/s)*

3) M-3: River Improvement + Diversion Channel (Route-2) (700m^3/s)

*Route-1 proposed here is located in the Upper Stream Section with regulation of 700m^3/s.

(2) Downstream Section (Estuary～5.75km)

1) D-1: River Improvement

2) D-2: River Channel Normalization + Retarding Basin

3) D-3: River Channel Normalization + Diversion Channel (Route-5) (700m^3/s or 1400m^3/s)

(3) Upper Stream Section (Back road Bridge～Upper Stream)

1) U-1: River Improvement + Retarding Basin

2) U-2: River Improvement + Retarding Basin (one) + Dam (NAD-3)

3) U-3: River Improvement + Dams (NAD-3&NAM-1)

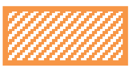
4) U-3: River Improvement + Diversion Channel (Route-1) (1,050m^3/s)*

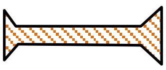
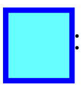
*Route-1 proposed here is located in the Upper Stream Section with regulation of 700m^3/s.

Each counter measure plan was evaluated by following items and the result would be shown in following figures.

- Safety Level
- Feasibility
- Stability
- Flexibility to Climate Change
- Social Influence
- Environmental Influence
- Economic Efficiency

Furthermore, the legend shown in following comparison table is as shown below:.

: Large-scale River Improvement : Channel Normalization

 : Rebuilding Bridge : Planned Retarding Basin  : Diversion Channel

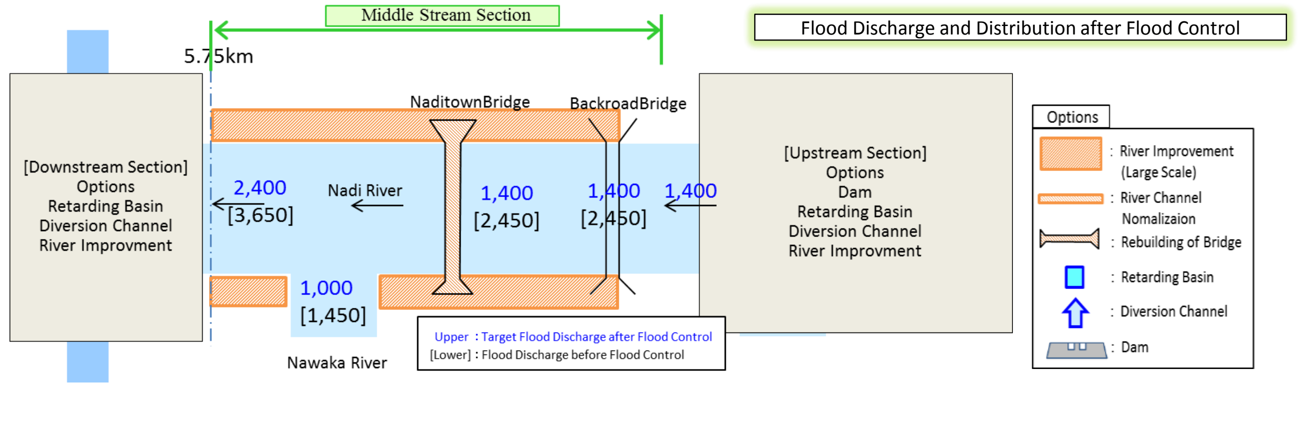
7.1.2 Facility Layout for Flood Control at Middle Section

※The number of moving house, area of land acquisition and economic efficiency are rough estimation and they will be examined in detail in the Feasibility Study.

Options for Flood Control in Middle Stream Section

M-1: River Improvement

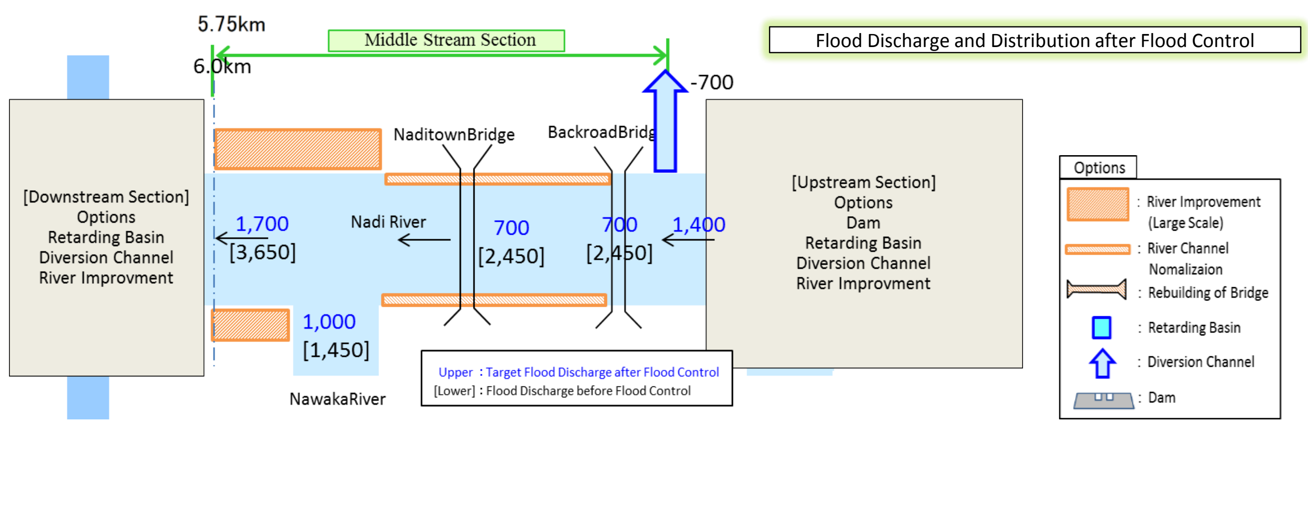
Basic Concept: To conduct only River Improvement to develop discharge ability by expanding present cross section. (following flood control standard)



Evaluation		
Established Items		Alignment improvement, Channel expansion, Some dykes, Rebuilding 2 bridges (Nadi Town Bridge and Old Queens Road Bridge)
Security Level		Security Level is relatively high because design discharge can run down under HWL which is equivalent height of ground level on landside. Safety against flood is improved in stage by establishment of river improvement in stage.
Feasibility		Number of :moved house: 7, Land Acquisition Area: 0.99km^2 Moving houses and land acquisition is needed but feasibility is high. This scheme takes 4~5 years depending on investment scale and construction ability.
Stability		Stability can be assured by adequate operation and maintenance river channel
Flexibility to Climate Change		It is needed to repair banks.
Social Influence		Moving houses and land acquisition is needed but social influence is relatively small because construction site and benefitting section basically accord.
Environmental Influence		Environmental recovery is expected by sectional shape and shore protection after improvement.
Economic Efficiency		Estimated project cost: 1.00 (Ratio)
Comprehensive Evaluation	○	Construction site and benefitting section basically accord and it is expected to develop security level against flood by river improvement in stage.

M-2: River Improvement + Diversion Channel (Route-1)

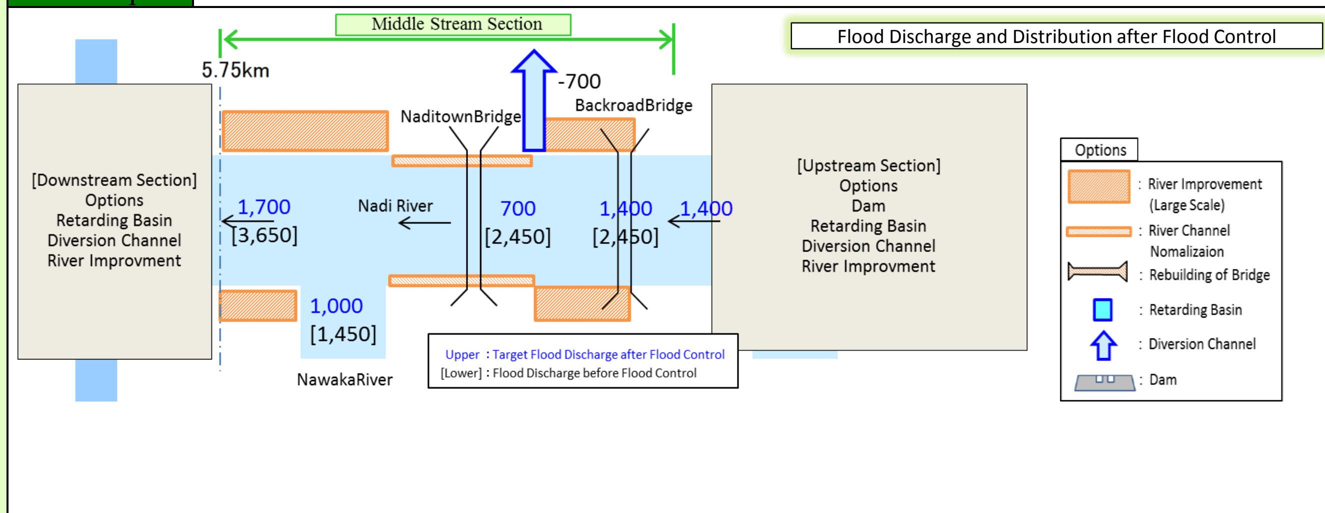
Basic Concept: To decline inundation risk by keeping flood at a distance from Airport ~ Downtown setting up Diversion Channel on hill country on upper stream of airport. (comparatively small of flood risk)



Evaluation		
Established Items		Channel expansion, Some dykes, Arrangement of river course, Rebuilding Old Queens Road Bridge, Building 4 New Bridges, Diversion Channel
Security Level		To be sure of security level at the moment when Diversion Channel complete
Feasibility		Number of :moved house: 27, Land Acquisition Area: 0.79km^2 Feasibility is low because large-scale cut or diversion channel having tunnel structure is needed to evacuate high-level hinterland of diversion channel. This scheme takes 4~5 years depending on investment scale and construction ability.
Stability		Stability can be assured by adequate operation and maintenance river channel and diversion channel.
Flexibility to Climate Change		It is needed to redevelop diversion channel
Social Influence		Moving houses and land acquisition is needed. Construction site and benefitting section don't accord. Nasoso resort locates on exit of diversion channel so there is some possibility that value for sightseeing declines.
Environmental Influence		Sediment flowing down Nadi River Estuary is divided in main stream and diversion channel so topography change and sediment deposits are concerned. In case of forming water stop condition in normal time, alga occurrence and environmental degradation by water quality deterioration is concerned. Salt water go up by establishing diversion channel and salt damage to neighboring farm land is concerned.
Economic Efficiency		Estimated project cost: 1.10 (Ratio)
Comprehensive Evaluation	△	Feasibility of diversion channel is low and project cost is more expensive compared to another scheme.

M-3: River Improvement + Diversion Channel (Route-2)

Basic Concept: To decline inundation risk in downtown mainly setting up Diversion Channel not on hill country but on plain area (raising feasibility of diversion channel)



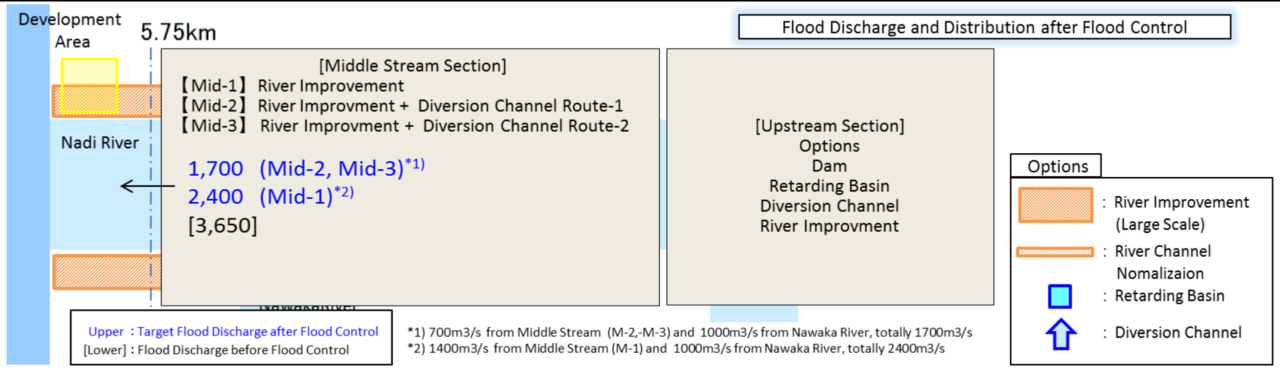
Evaluation		
Established Items		Channel expansion, Some dykes, Arrangement of river course, Rebuilding Old Queens Road Bridge, Building 3 New Bridges, Diversion Channel
Security Level		To be sure of security level at the moment when Diversion Channel complete
Feasibility		Number of :moved house:19, Land Acquisition Area: 0.91km^2 Moving houses and land acquisition is needed but feasibility is relatively high. This scheme takes 3~4 years depending on investment scale and construction ability.
Stability		Stability can be assured by adequate operation and maintenance river channel and diversion channel.
Flexibility to Climate Change		It is needed to redevelop diversion channel
Social Influence		Moving houses and land acquisition is needed. Construction site and benefitting section don't accord. Nadi Bay locates on exit of diversion channel so there is some possibility of impacting on value of sightseeing and fishery
Environmental Influence		Sediment flowing down Nadi River Estuary is divided in main stream and diversion channel so topography change and sediment deposits are concerned. In case of forming water stop condition in normal time, alga occurrence and environmental degradation by water quality deterioration is concerned. Salt water go up by establishing diversion channel and salt damage to neighboring farm land is concerned.
Economic Efficiency		Estimated project cost: 0.98 (Ratio)
Comprehensive Evaluation	○	Project cost is the same degree of M-1 and influence to downstream section is small. On the other hand, impact on exit of diversion channel is concerned.

7.1.3 Facility Layout for Flood Control at Downstream Section

Options for Flood Control in Down Stream Section

D-1: River Improvement

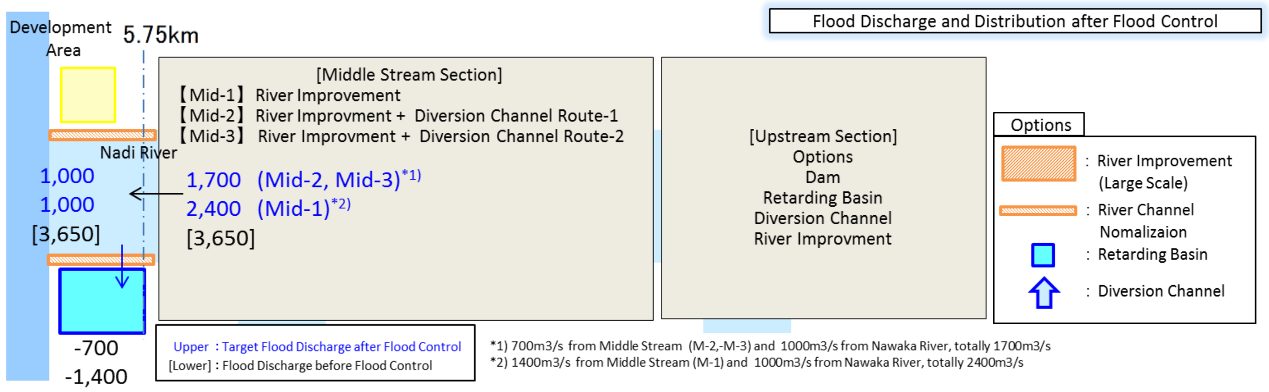
Basic Concept: To conduct only River Improvement to flow down discharge from middle stream. (following flood control standard)



Evaluation		
Established Items	River Improvement (Channel expansion, Some dykes, Alignment improvement)	
Security Level	Security Level is relatively high because design discharge can run down under HWL which is equivalent height of ground level on landside. More improvement makes progress, more safety against flood in stages.	
Feasibility	In case of 1,700m^3/s: Number of moved houses is 0, Land Acquisition Area is 0.20km^2. In case of 2,400m^3/s: Number of moved houses is 0, Land Acquisition Area is 0.39km^2 Land acquisition for area planned development and farm land but feasibility is relatively high.	
Stability	Stability can be assured by adequate operation and maintenance river channel	
Flexibility to Climate Change	It is needed to repair banks.	
Social Influence	Land acquisition is needed including part of area planned development. Construction site and benefiting section basically accord.	
Environmental Influence	Environment around river is changed by river improvement but environmental recovery is expected by sectional shape and shore protection after improvement.	
Economic Efficiency	1,700m^3/s: 1.00 (Ratio) 2,400m^3/s: 1.00 (Ratio)	
Comprehensive Evaluation	△	Project cost is higher than other schemes and land acquisition is needed.

D-2: River Channel Normalization + Retarding Basin

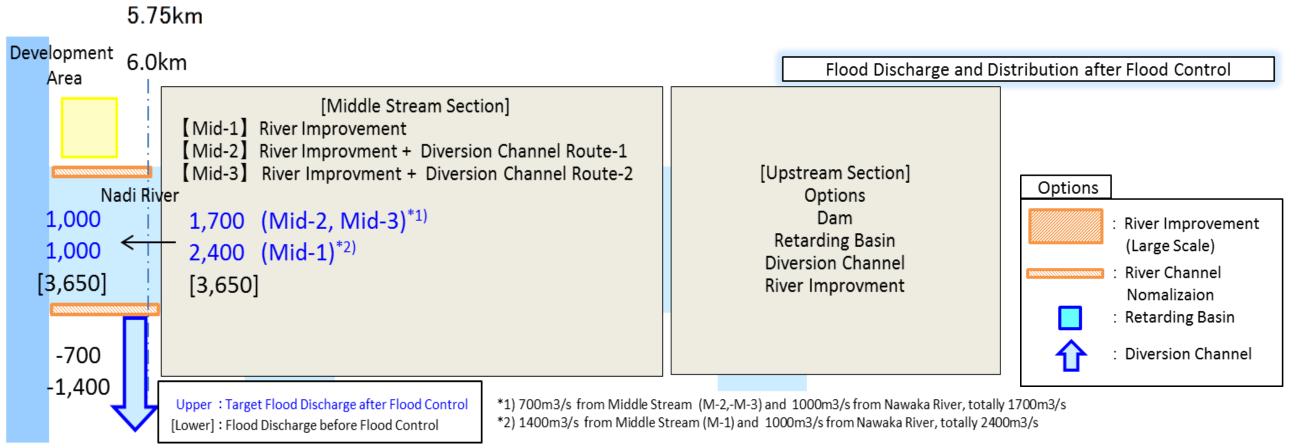
Basic Concept: To improve flood damage by planned Retarding Basin declining River Improvement section. (application of present flood inundation specific)



Evaluation		
Established Items	Some dykes, Alignment improvement, 1 site of Retarding basin	
Security Level	For houses in retarding basin, inundation measure is needed by move or ring dike.	
Feasibility	In case of 1,700m^3/s: Number of moved houses is 12, Land Acquisition Area is 0.50km^2. In case of 2,400m^3/s: Number of moved houses is 12, Land Acquisition Area is 0.50km^2 Land acquisition for area planned development and farm land but feasibility is relatively high.	
Stability	Stability can be assured by adequate operation and maintenance channel and retarding basin.	
Flexibility to Climate Change	This scheme has room to adjust volume so flexibility is high.	
Social Influence	Firm land and mangrove forest in downstream is mainly used as retarding basin so social influence is relatively small.	
Environmental Influence	Environment around river is changed by river improvement but environmental recovery is expected by sectional shape and structural materials after improvement.	
Economic Efficiency	1,700m^3/s: 0.25 (Ratio) 2,400m^3/s: 0.20 (Ratio)	
Comprehensive Evaluation	○	Land acquisition of area planned development isn't needed because retarding basin is set up on left side downstream

D-3: River Channel Normalization + Diversion Channel (Route-5)*

Basic Concept: To decline inundation risk in downtown mainly setting up Diversion Channel not on hill country but on plain area (raising feasibility of diversion channel)



*Diversion Channel Root-5 is to be referred to 6.3.4

Evaluation		
Established Items	Some dykes, Alignment improvement, Building new 1 bridge, Diversion Channel	
Security Level	Exit of diversion channel (Sonaisali Resort) is formed by sand spit at river mouth so there is possibility of closing by diversion channel.	
Feasibility	In case of 1,700m^3/s: Number of moved houses is 2, Land Acquisition Area is 0.37km^2. In case of 2,400m^3/s: Number of moved houses is 2, Land Acquisition Area is 0.48km^2 Land acquisition for area planned development and farm land but feasibility is relatively high.	
Stability	Stability can be assured by adequate operation and maintenance channel and diversion channel.	
Flexibility to Climate Change	It is needed to redevelop diversion channel.	
Social Influence	Moving houses and land acquisition is needed on new channel side. Sonaisali is located in planned exit of diversion channel so sightseeing value go down.	
Environmental Influence	Sediment flowing down Nadi River Estuary is divided in main stream and diversion channel so topography change and sediment deposits are concerned. In case of forming water stop condition in normal time, alga occurrence and environmental degradation by water quality deterioration is concerned. Salt water go up by establishing diversion channel and salt damage to neighboring farm land is concerned.	
Economic Efficiency	1,700m^3/s: 0.20 (Ratio) 2,400m^3/s: 0.12 (Ratio)	
Comprehensive Evaluation	△	Project cost is more economic than other schemes but Exit of diversion channel (Sonaisali Resort) is formed by sand spit at river mouth so there is possibility of closing by diversion channel.

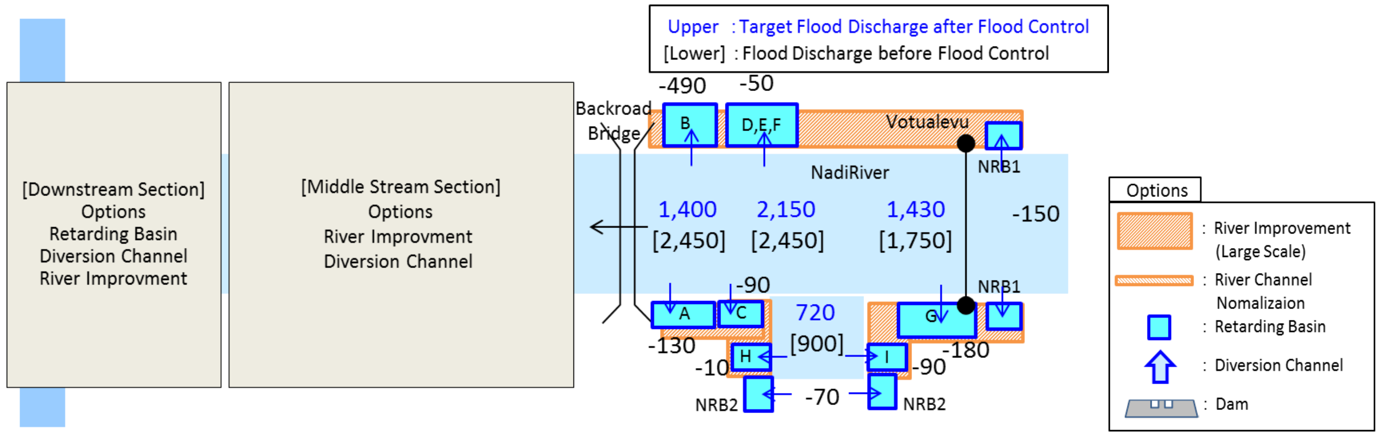
7.1.4 Facility Layout for Flood Control at Upper Stream Section

Options for Flood Control in Upstream Section

U-1: River Improvement + Retarding Basins

Basic Concept

- **To cut flooding flow economically by Retarding Basin applying present flood inundation specific. (Scheme by group of Retarding Basin applying present flood inundation specific)**

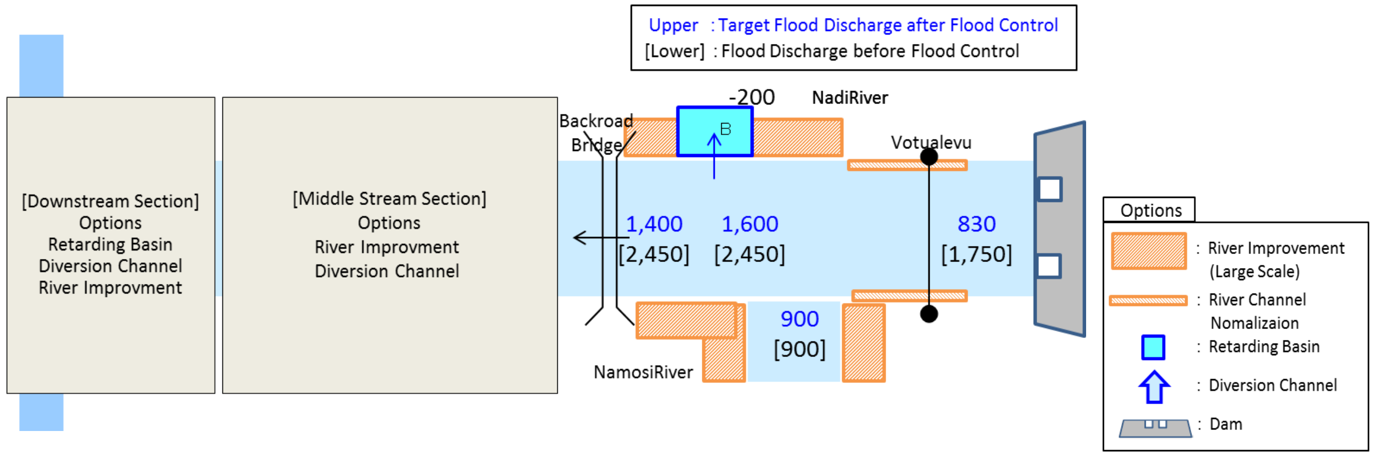


Evaluation		
Established Items		Channel expansion, Some dykes, Alignment improvement, 11 sites of Retarding basin
Security Level		In case of retention in retarding basin, control of sluice is needed so there is some possibility of not being effective. Safety against flood is improved in stage by establishment of retarding basin in stage.
Feasibility		Number of moved houses is 9, Land Acquisition Area is 3.5km^2. Land acquisition of firm land is needed.
Stability		Stability can be assured by adequate operation and maintenance channel and retarding basin.
Flexibility to Climate Change		This scheme has room to adjust volume so flexibility is high.
Social Influence		Impact on social is huge because retarding basin regulates land development in future.
Environmental Influence		Environment around river is changed by river improvement but environmental recovery is expected by sectional shape and structural materials after improvement.
Economic Efficiency		Estimated project cost: 1.00 (Ratio)
Comprehensive Evaluation	○	It is necessary to operation/maintenance of retarding basins and to maintenance of project area to be effective. This scheme is the lowest than in all schemes.

U-2: River Improvement + Retarding Basin (One) + Dam (One)

Basic Concept

- **To cut flooding flow by 1 dam at the maximum not to utilize retarding basin stubbornly because retarding basin leave inundation area. (Scheme of maximum cut off flooding flow by main stream dam)**

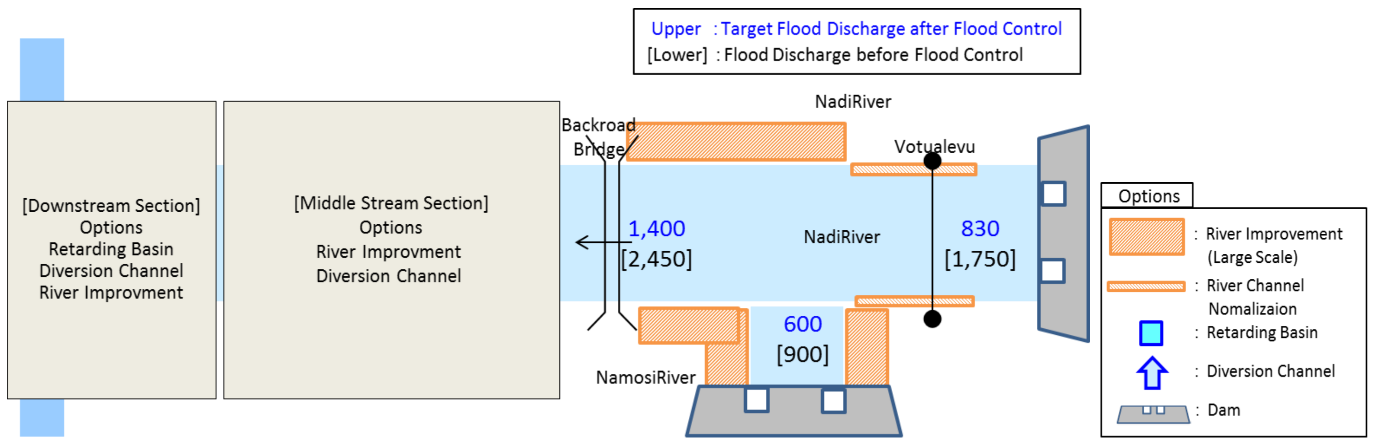


Evaluation		
Established Items		Channel expansion, Some dykes, Alignment improvement, 11 site of Retarding basin, 1 dam (running water dam)
Security Level		To be sure of security level at the moment when dam complete.
Feasibility		Number of moved houses is 25, Land Acquisition Area is 2.55km^2. Project cost is huge so feasibility is low level. However, large community isn't located around planned area for dam.
Stability		Stability can be assured by adequate operation and maintenance channel and Dam.
Flexibility to Climate Change		Running water dam doesn't have any room to adjust volume so redevelopment of dam is needed.
Social Influence		Large community isn't located around planned area for dam so impact on social is small.
Environmental Influence		Impact by filling and change of sediment transfer in downstream like degradation of river bed are avoidable. Environment around river is changed by river improvement but environmental recovery is expected by sectional shape and structural materials after improvement.
Economic Efficiency		Estimated project cost: 1.25 (Ratio)
Comprehensive Evaluation	○	Effect is expected absolutely. Operation/maintenance is relatively easy because dam type is water running and dam control isn't needed.

Options for Flood Control in Upstream Section / Evaluation

U-3: River Improvement + Dams (Two)

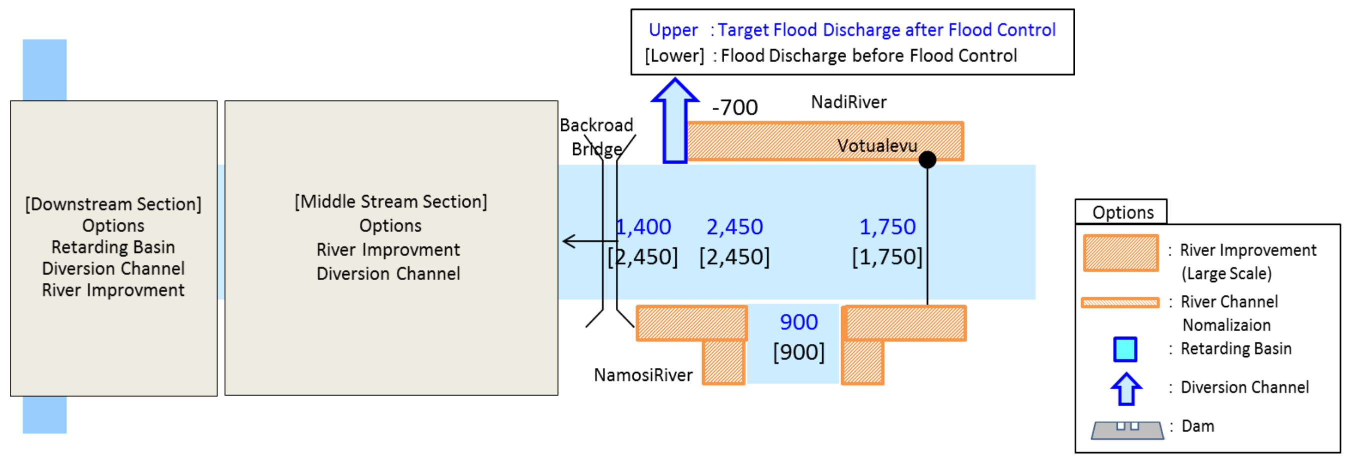
Basic Concept: **To cut flooding flow by 2 dams at the maximum not to utilize retarding basin stubbornly because retarding basin leave inundation area. (Scheme of maximum cut off flooding flow by group of dam)**



Evaluation	
Established Items	Channel expansion, Some dykes, Alignment improvement, 2 Dams (running water dam)
Security Level	To be sure of security level at the moment when dam complete.
Feasibility	Number of moved houses is 20, Land Acquisition Area is 3.31km^2. Project cost is huge so feasibility is low level. However, large community isn't located around planned area for dam.
Stability	Stability can be assured by adequate operation and maintenance channel and Dam.
Flexibility to Climate Change	Running water dam doesn't have any room to adjust volume so redevelopment of dam is needed.
Social Influence	Large community isn't located around planned area for dam so impact on social is small.
Environmental Influence	Impact by filling and change of sediment transfer in downstream like degradation of river bed are avoidable. Environment around river is changed by river improvement but environmental recovery is expected by sectional shape and structural materials after improvement.
Economic Efficiency	Estimated project cost: 1.93 (Ratio)
Comprehensive Evaluation △	Project cost is huge compared to other schemes.

U-4: River Improvement + Diversion Channel (One)

Basic Concept: **To cut flooding flow by River Improvement and Diversion Channel (Scheme of River Improvement and Diversion Channel)**



Evaluation	
Established Items	Channel expansion, Some dykes, Alignment improvement, Diversion channel
Security Level	To be sure of security level at the moment when diversion channel complete.
Feasibility	Number of moved houses is 27, Land Acquisition Area is 0.67km^2 Feasibility is low because large-scale river improvement is needed and large-scale cut or diversion channel having tunnel structure is needed to evacuate high-level hinterland of diversion channel
Stability	Stability can be assured by adequate operation and maintenance channel and diversion channel.
Flexibility to Climate Change	It is needed to redevelop diversion channel.
Social Influence	Moving house and land acquisition is needed. Construction site and benefitting section accord. Nadi Bay locates on exit of diversion channel so there is some possibility of impacting on value of sightseeing and fishery
Environmental Influence	Sediment flowing down Nadi River Estuary is divided in main stream and diversion channel so topography change and sediment deposits are concerned. In case of forming water stop condition in normal time, alga occurrence and environmental degradation by water quality deterioration is concerned. Salt water go up by establishing diversion channel and salt damage to neighboring farm land is concerned.
Economic Efficiency	Estimated project cost: 1.49 (Ratio)
Comprehensive Evaluation △	Large-scale river improvement is needed in upper stream and feasibility of diversion channel is low.

7.2 Determine of Alternative Plan for Flood Control

7.2.1 Evaluation of Alternative Plan for Flood Control

4 optimal combinations were considered by combination of flood control measures at each section and the alternative plan for flood control was evaluated.

Result of evaluation (refer to Table 7-1 and Table 7-2), Combination-1 [Down Stream: Retarding Basin (D-2) + Middle Stream: River Improvement (M-1) + Upstream: Dam (U-2)] and Combination-2 [Down Stream: Retarding Basin (D-2) + Middle Stream: Diversion Route-2 (M-3) + Upstream: Dam (U-2)] were selected as proposed scheme of M/P in initial consideration for flood control plan. .

The inundation simulation in March 2012 as targeted flood at present and after implementation of M/P is shown in Figure 7-1 and inundating would be completely prevented after completion of M/P.

The final solution of 2 of alternative plans of M/P would be determined after the conference with Fiji government.

Table 7-1 Comparison Consideration of M/P

Evaluation	C-1	C-2	C-3	C-4
Main Items	･Retarding Basin (D-2) ･River Improvement (M-1) ･Dam(U-2)	･Retarding Basin (D-2) ･Diversion Route-2(M-3) ･Dam(U-2)	･Retarding Basin (D-2) ･River Improvement (M-1) ･Retarding Basins(U-1)	･Retarding Basin (D-2) ･Diversion Route-2(M-3) ･Retarding Basins(U-1)
Merit	□ Simple and certainly effective to flood. □ Less operation before and during flood	□ Simple and certainly effective to flood except of diversion	□ Low project cost and Low social and environmental impact	□ Lowest project cost.
Demerit	■ Relatively higher Project Cost ■ Longer Construction Period	■ Difficulty and Uncertainty of divert ■ Negotiation with developer at diversion route ■ Large Impact to society and environment	■ **Difficulty and Uncertainty of retarding flood water at retarding basins(11)**	■ **Difficulty and Uncertainty of diverting and retarding flood water.**
Cost (Ratio in case that cost of C-1 is 1.0)	1.0	0.98	0.90	0.87
House Relocation	44 houses	56 houses	28 houses	40 houses
Land Acquisition	**4.04 km^2**	**4.16 km^2**	4.99 km^2	5.11 km^2
Comprehensive Evaluation	○	○	△(*)	△(*)

* Retarding basins (C-3 and C-4) in upstream might be possible to be applied if conditions are improved in the future.

Table 7-2(1) Combination scheme for flood control (1)

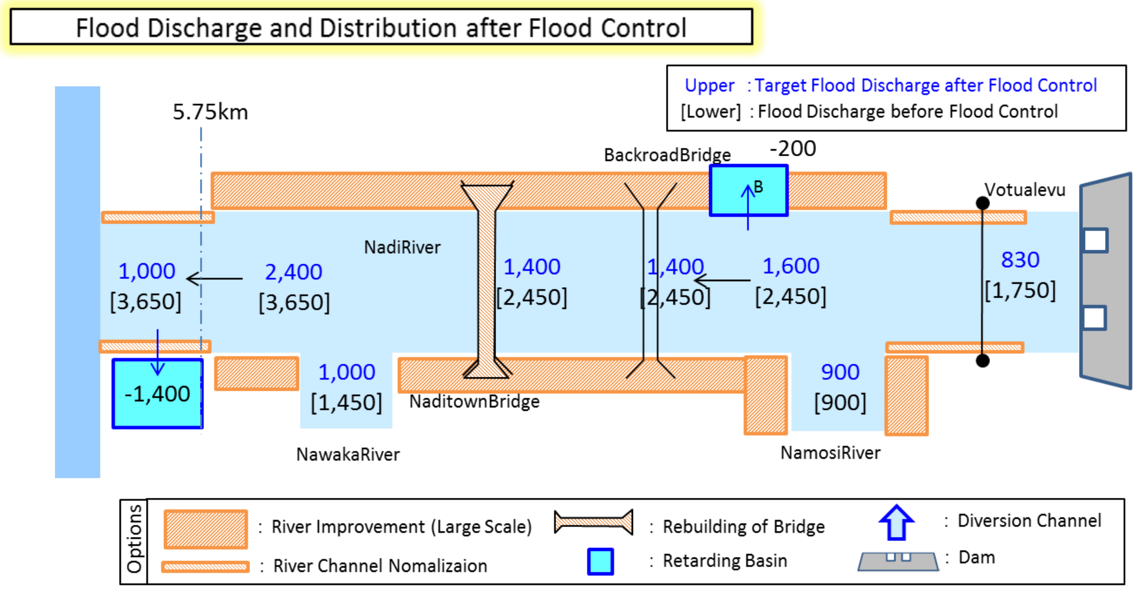
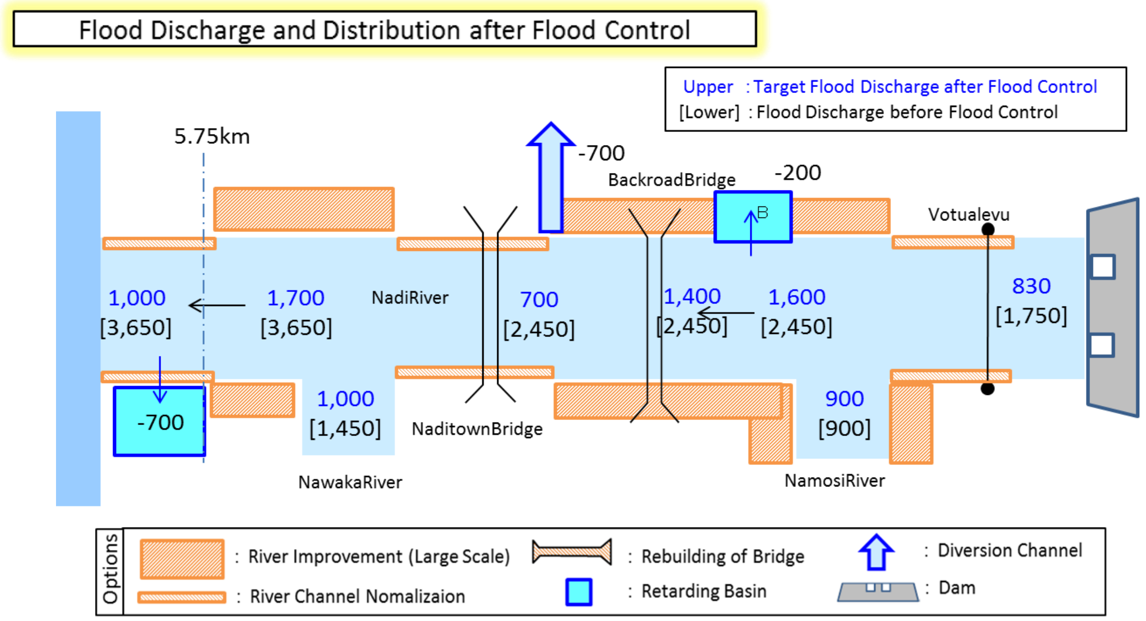
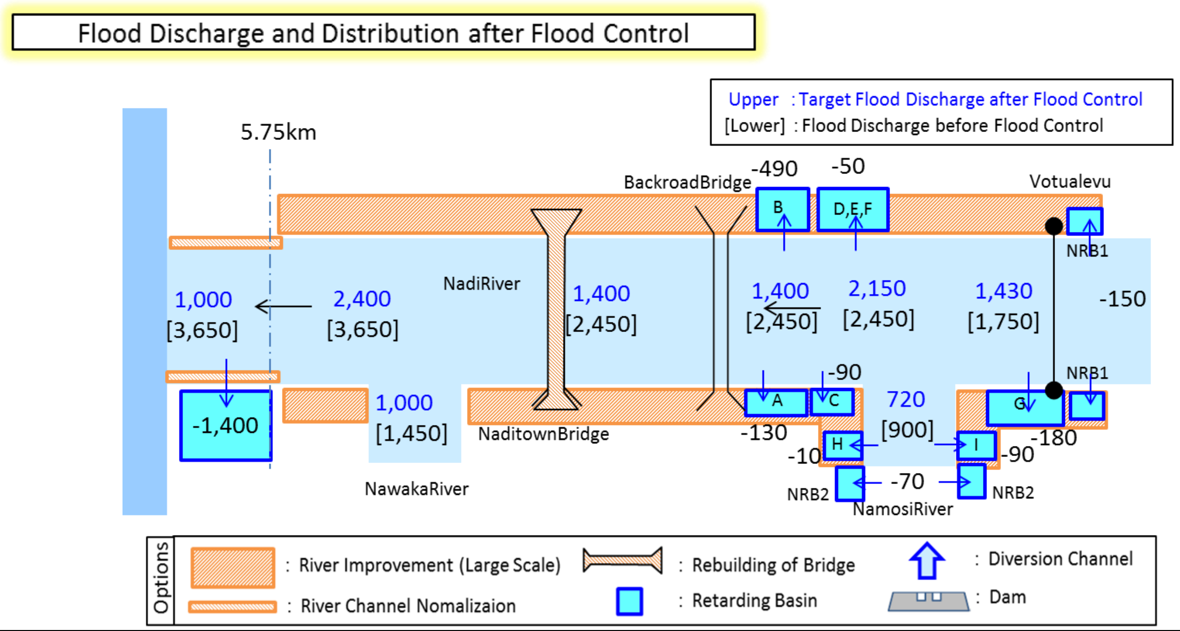
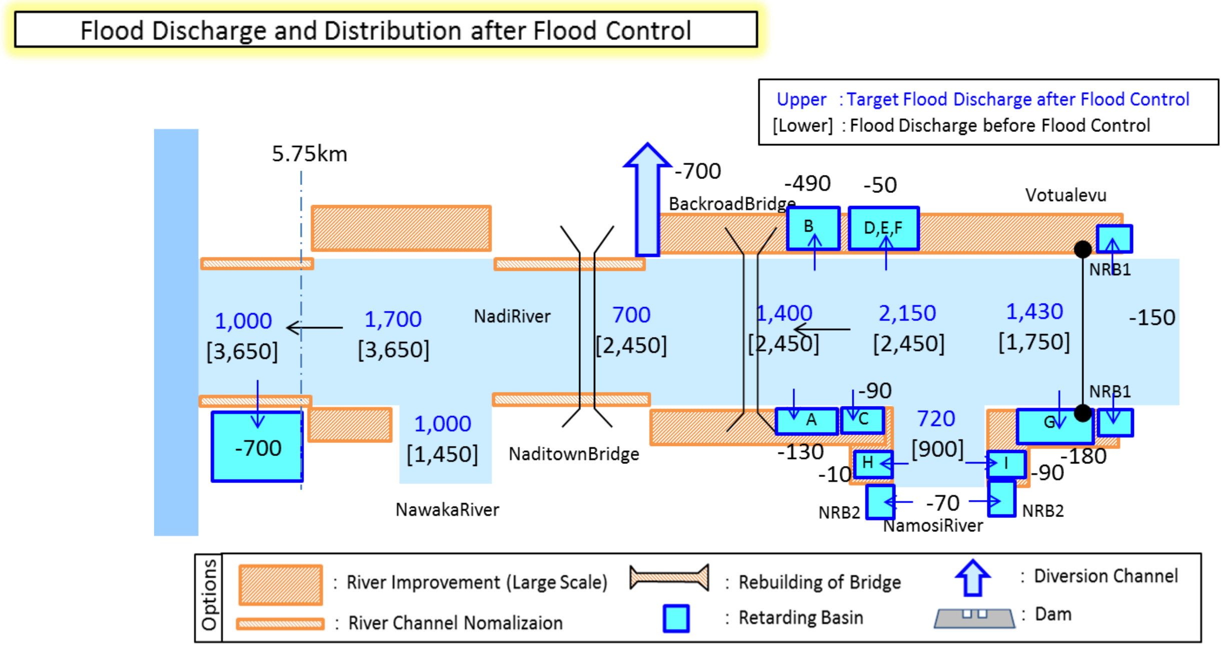
Options for Flood Control in Nadi River Basin		Evaluation			
Combination-1	Down Stream: Retarding Basin (D-2) + Middle Stream: River Improvement (M-1) + Upstream: Dam (U-2)	Estimated Project Cost	1.00 (Ratio)	Comprehensive Evaluation	○
Basic Concept	A combination of simple flood control measures as a whole, flood is controlled relatively surely in comparison with other combinations	Number of House Relocation	44 (houses)	Area of Land Acquisition	4.04km^2
		Merit		Demerit	
		■Down stream ・Less construction modification volume by utilizing river course and inundation characteristics ・Unnecessary land acquisition at right bank development site		■Down stream ・Ring dike for village located in retarding basin at right bank side is required.	
		■Middle Stream ・River channel improvement is certainly effective against flood ・Less number of houses relocation		■Middle stream ・Rebuilding of Nadi Town Bridge and houses relocation is required ・Relatively long construction period	
		■Upstream ・Less construction modification volume in the section between downstream of dam and confluence point with Namosi. ・Dam is certainly effective against flood		■Upstream ・Long construction period for Dam so long period is required for flood control ・Flood control dam cannot be used as multipurpose dam (multiplepurpose dam is required to control dam gate and operation/management.)	
Combination-2	Down Stream: Retarding Basin (D-2) + Middle Stream: Diversion Route-2 (M-3) + Upstream: Dam (U-2)	Estimated Project Cost	0.98 (Ratio)	Comprehensive Evaluation	○
Basic Concept	A combination of simple flood control measures as a whole, and a diversion channel is adopted in middle stream	Number of House Relocation	56 (houses)	Area of Land Acquisition	3.96km^2
		Merit		Demerit	
		■Down stream ・Less construction modification volume by utilizing river course and inundation characteristics ・Unnecessary land acquisition at right bank development site		■Down stream ・Ring dike for village located in retarding basin at right bank side is required.	
		■Middle Stream ・Less construction modification volume near town area so impact on downtown is small. ・Unnecessary rebuilding of Nadi Town Bridge ・Load of flow quantity in downstream is relatively small. ・Relatively short construction period because diversion channel and river improvement are conducted simultaneously.		■Middle Stream ・Construction area and benefitting section don't accord and flood risk is newly increased near diversion channel. In case of breaking diversion channel, airport may be inundated too. ・Monitoring of Nadi Bay is required because traffic pattern of sediment is changed. ・Impact and monitoring of salt damage by diversion channel	
		■Upstream ・Less construction modification volume in the section between downstream of dam and confluence point with Namosi. ・Dam is certainly effective against flood		■Upstream ・Long construction period for Dam so long period is required for flood control ・Flood control dam cannot be used as multipurpose dam (multiplepurpose dam is required to control dam gate and operation/management.)	

Table 7-2(2) Combination scheme for flood control (2)

Options for Flood Control in Nadi River Basin		Evaluation			
Combination-3	Down Stream: Retarding Basin (D-2) + Middle Stream: River Improvement (M-1) + Upstream: Retarding Basin (U-1)	Estimated Project Cost	0.90 (Ratio)	Comprehensive Evaluation	△
Basic Concept	A combination of simple flood control measures in middle stream and downstream section, and a group of retarding basins is adopted in upstream section	Number of House Relocation	28 (houses)	Area of Land Acquisition	4.99km^2
		Merit		Demerit	
		■Down stream ・Less construction modification volume by utilizing river course and inundation characteristics ・Unnecessary land acquisition at right bank development site		■Down stream ・Ring dike for village located in retarding basin at right bank side is required.	
		■Middle Stream ・River channel improvement is certainly effective against flood ・Less number of houses relocation		■Middle stream ・Rebuilding of Nadi Town Bridge and houses relocation is required ・Relatively long construction period	
		■Upstream ・Improvement of flood control safety degree by stage development of retarding basins		■Upstream ・Gate operation to be effective at retarding basin is required at flood ・Land development in future is regulated in retarding basins ・Consultation for Land acquisition, easement and compensation are required. ・To remove sediment after flood and operation/management of retarding basin is needed.	
Combination-4	Down Stream: Retarding Basin (D-2) + Middle Stream: Diversion Route-2 (M-3) + Upstream: Retarding Basin (U-1)	Estimated Project Cost	0.87 (Ratio)	Comprehensive Evaluation	△
Basic Concept	A combination of diversion channel in middle stream and a group of retarding basins is adopted in upstream section	Number of House Relocation	40 (houses)	Area of Land Acquisition	4.91km^2
		Merit		Demerit	
		■Down stream ・Less construction modification volume by utilizing river course and inundation characteristics ・Unnecessary land acquisition at right bank development site		■Down stream ・Ring dike for village located in retarding basin at right bank side is required.	
		■Middle Stream ・Less construction modification volume near town area so impact on downtown is small. ・Unnecessary rebuilding of Nadi Town Bridge ・Load of flow quantity in downstream is relatively small. ・Relatively short construction period because diversion channel and river improvement are conducted simultaneously.		■Middle Stream ・Construction area and benefitting section don't accord and flood risk is newly increased near diversion channel. In case of breaking diversion channel, airport may be inundated too. ・Monitoring of Nadi Bay is required because traffic pattern of sediment is changed. ・Impact and monitoring of salt damage by diversion channel	
		■Upstream ・Improvement of flood control safety degree by stage development of retarding basins		■Upstream ・Gate operation to be effective at retarding basin is required at flood ・Land development in future is regulated in retarding basins ・Consultation for Land acquisition, easement and compensation are required. ・To remove sediment after flood and operation/management of retarding basin is needed.	

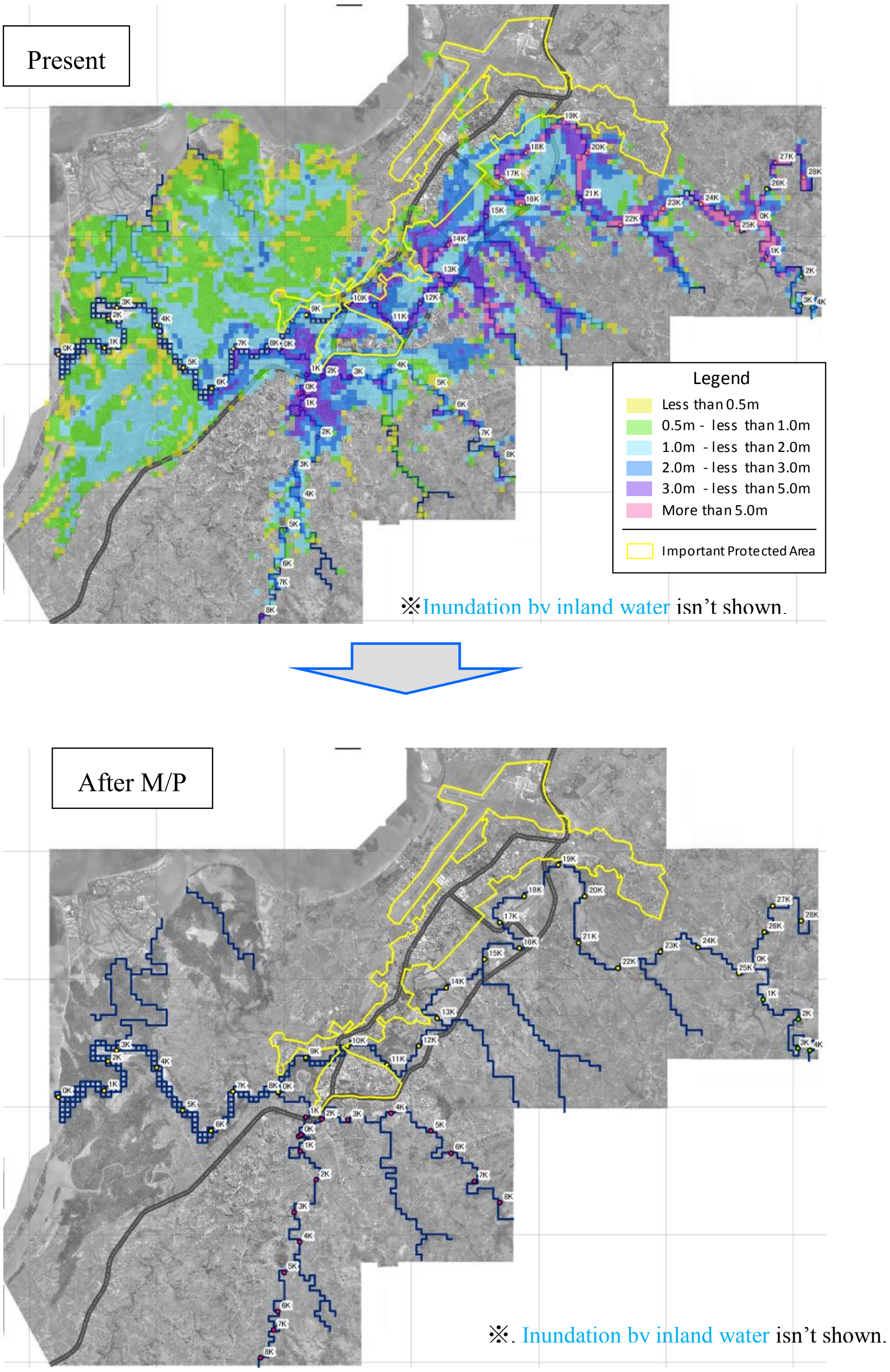


Figure 7-1 Flooding Condition at present and after M/P

7.2.2 Establishment of Design Flood before Regulation

Design flood discharge of combination-1 [Down Stream: Retarding Basin (D-2) + Middle Stream: River Improvement (M-1) + Upstream: Dam (U-2)] is shown in Figure 7-2 and combination-2 [Down Stream: Retarding Basin (D-2) + Middle Stream: Diversion Route-2 (M-3) + Upstream: Dam (U-2)] is shown in Figure 7-3.

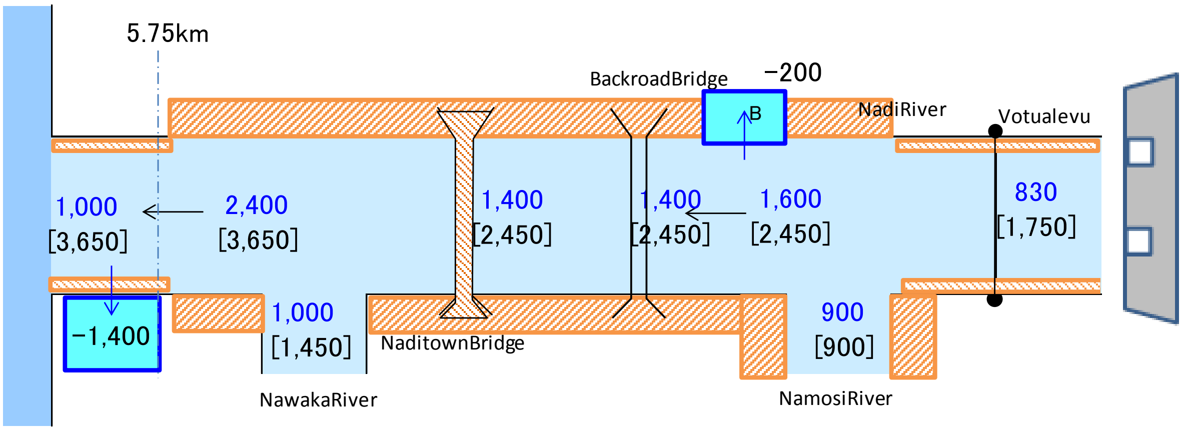


Figure 7-2 Design flood discharge of Combination-1

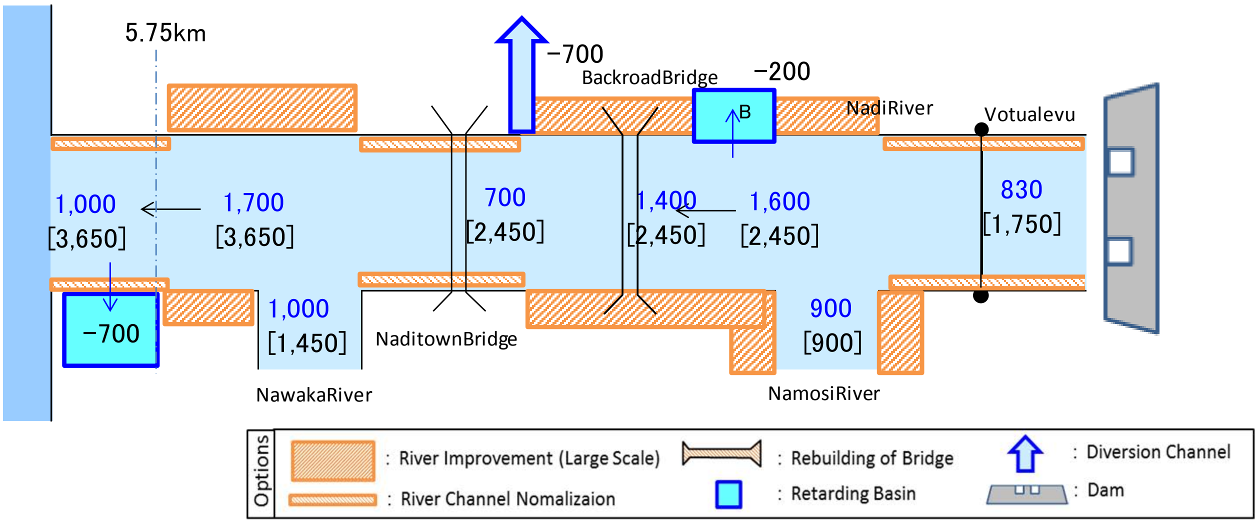


Figure 7-3 Design flood discharge of Combination-2

In the selected two (2) alternatives of M/P, the major countermeasure in the most important middle stream section is the river improvement in the Combination-1 and the diversion channel in the Combination-2. These major flood control facilities are studied preliminary as shown below.