5.3 Current Discharge Capacity Analysis

5.3.1 Setting of the Conditions for the Analysis

The current discharge capacity of the Nadi River, including those of the Namosi, Nawaka and Malakua Rivers, was estimated with the non-uniform flow calculation.

The conditions used in the calculation are mentioned below.

(1) Setting of the Dike Heights for the Calculation

The dike heights to be used in the calculation of the discharge capacities were set by drawing the cross-sections of the river created from the surveying data (surveying cross-sections) and LiDAR data (LiDAR cross-sections) on the same diagrams.

Figure 5.3-1 to Figure 5.3-4 show the typical examples of the overlaid surveying and LiDAR cross-sections. As it is impossible to measure the elevation of water-covered areas with LiDAR, all those areas are shown with horizontal straight lines on the LiDAR cross-sections to maintain the continuity of the cross-sections.

As seen in those figures, there are approx. 1m differences between the dike heights on the surveying cross-sections and LiDAR cross-sections. It is assumed that the LiDAR data gave elevation values somewhat higher than the actual values because the dense growth of weeds and sugar cane along the rivers interfered with the filtering of trees, a function of LiDAR. Meanwhile, as shown in Table 5.3-1, the use of a ground level of a protected area on a LiDAR cross-section as the dike height for the calculation was considered where the ground level of the protected area was not measured in the surveying, with the land use in the area taken into consideration.

As there is no significant difference observed in the shapes of the two types of the cross-sections, it was concluded that the surveying results were appropriate to be used for the hydraulic analyses. Field surveys were conducted to confirm the cross-sections at the locations where significant localized difference in the dike heights was observed when the cross-sections at the locations were compared with those just upstream or downstream of the locations and at the confluences of tributaries and channels.

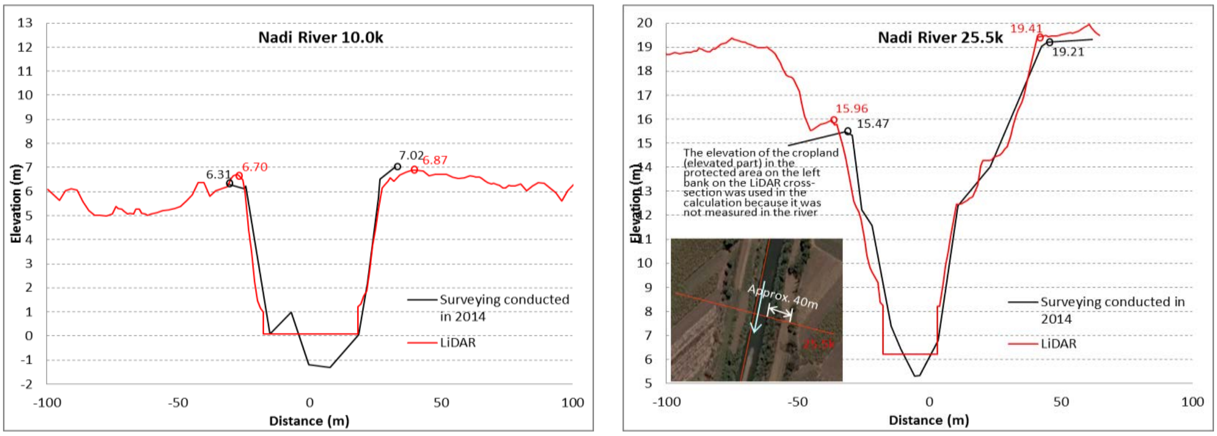


Figure 5.3-1 Example of Overlaid Cross-sections (Nadi River)

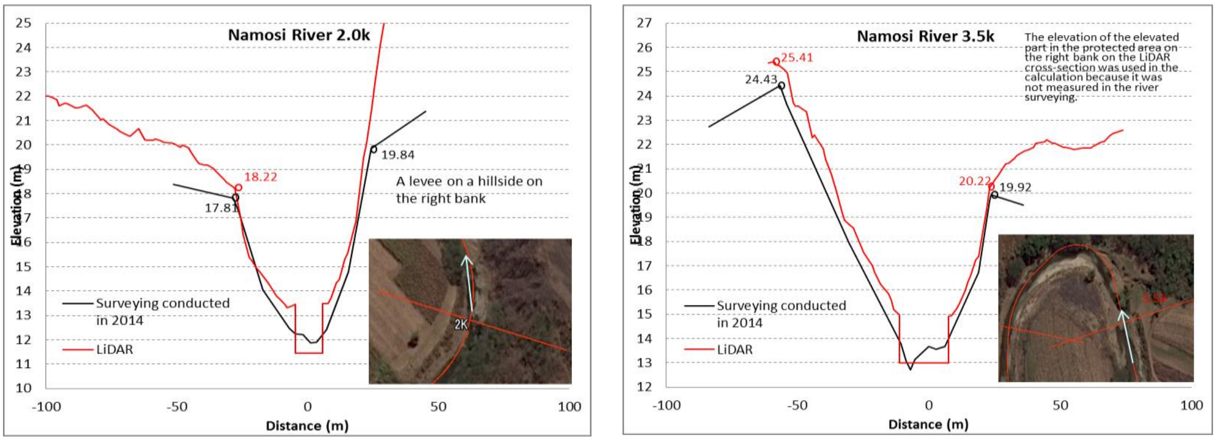


Figure 5.3-2 Example of Overlaid Cross-sections (Namosi River)

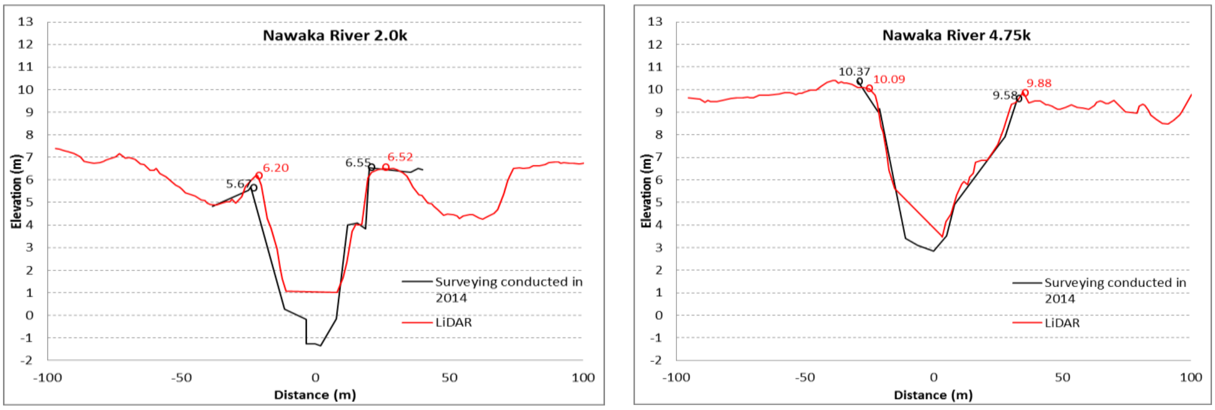


Figure 5.3-3 Example of Overlaid Cross-sections (Nawaka River)

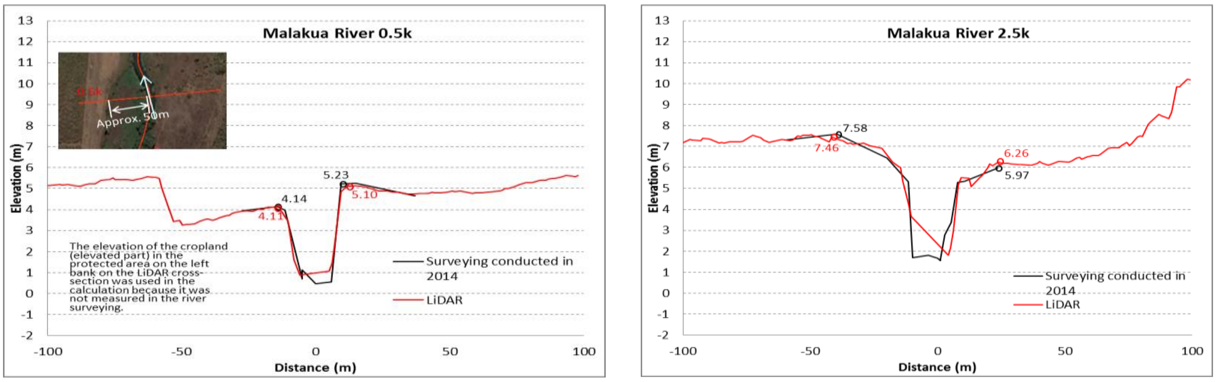
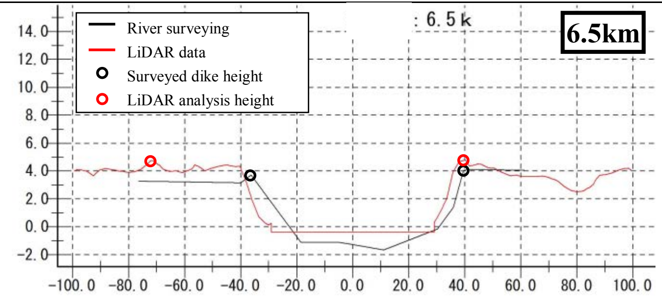
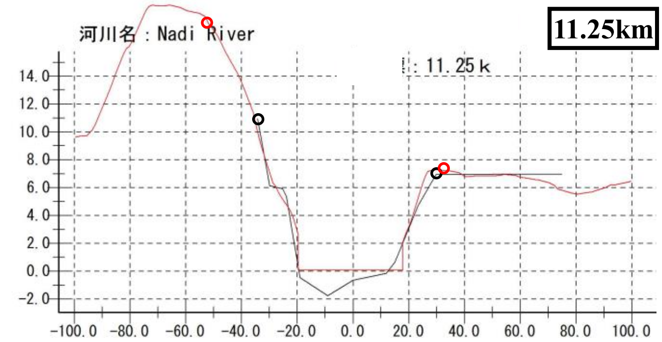
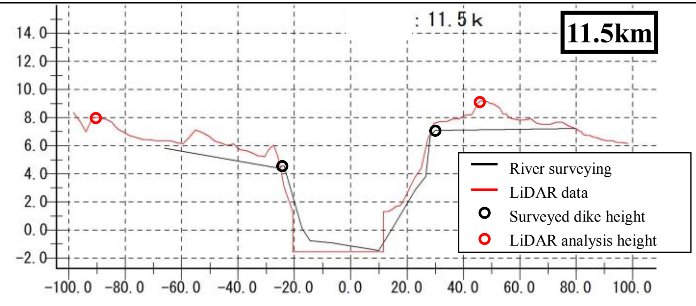
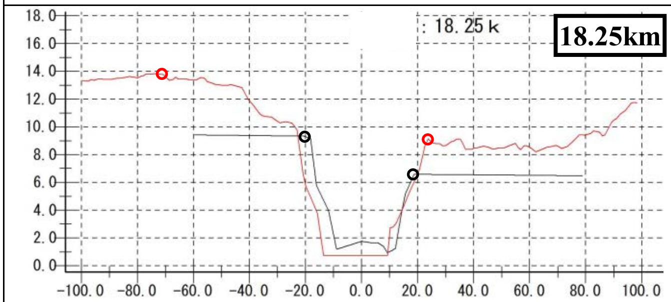
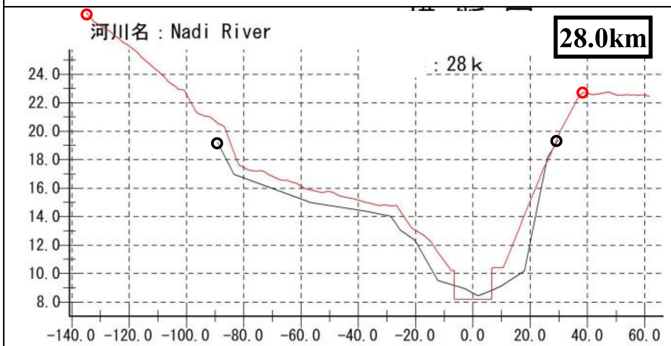


Figure 5.3-4 Example of Overlaid Cross-sections (Malakua River)

Table 5.3-1 Examples of Dike Height Evaluation of Surveying Data and LiDAR Data

<table>
<tr><td rowspan="2">
</td><td><u>Surveyed dike height (m)</u>
Left bank: 3.72
Right bank: 4.12</td><td><u>LiDAR analysis height (m)</u>
Left bank: 4.75
Right bank: 4.79</td></tr>
<tr><td colspan="2"><Note>
Empty land and cropland occupy the protected area on the left bank.</td></tr>
<tr><td rowspan="2">
</td><td><u>Surveyed dike height (m)</u>
Left bank: 10.93
Right bank: 6.95</td><td><u>LiDAR analysis height (m)</u>
Left bank: 17.83
Right bank: 7.35</td></tr>
<tr><td colspan="2"><Note>
There are buildings on a hill on the left bank. The height of the dike on the left bank at 11.00km in the lower reaches is approx. 10m.</td></tr>
<tr><td rowspan="2">
</td><td><u>Surveyed dike height (m)</u>
Left bank: 4.60
Right bank: 7.09</td><td><u>LiDAR analysis height (m)</u>
Left bank: 8.00
Right bank: 9.20</td></tr>
<tr><td colspan="2"><Note>
The location at the LiDAR analysis height on the left bank is on a road. The area between the road and the riverbank is occupied by empty land and cropland. The protected area on the right bank is used as cropland.</td></tr>
<tr><td rowspan="2">
</td><td><u>Surveyed dike height (m)</u>
Left bank: 9.34
Right bank: 6.59</td><td><u>LiDAR analysis height (m)</u>
Left bank: 13.83
Right bank: 9.13</td></tr>
<tr><td colspan="2"><Note>
Cropland occupied the left bank. The location at the LiDAR analysis height is near the edge of the cropland.</td></tr>
<tr><td rowspan="2">
</td><td><u>Surveyed dike height (m)</u>
Left bank: 19.22
Right bank: 19.35</td><td><u>LiDAR analysis height (m)</u>
Left bank: 28.30
Right bank: 22.74</td></tr>
<tr><td colspan="2"><Note>
Cropland occupies the left bank. There are buildings on a hill on the right bank and the rest is occupied by cropland.</td></tr>
</table>

(2) Setting of the Water Level at the Downstream End

The water level at the estuary of the Nadi River (0.0km) was used as the water level at the downstream end of the water level calculation. The average maximum sea level in the five-year period between 2010 and 2014 was used as the water level at the estuary. However, as the sea level has been measured only at the two stations at Lautoka and Suva in Fiji, the data of the sea level observed with the tide gauge installed closest to the project area, *i.e.* the gauge at the Lautoka Station, were used as the base data and corrected with the reference data obtained with the pressure water level gauge installed near the estuary of the Nadi River (on the left bank approx. 1.3km from the estuary) in this project. As the data of the observed water level near the estuary of the Nadi River is being analyzed, the average maximum sea level in the five-year period between 2010 and 2014 was used as the primary water level at the estuary in the following.

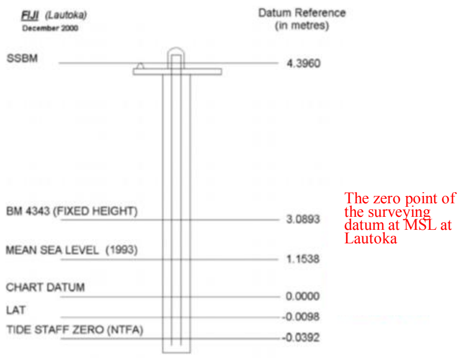
As the datum (zero elevation) of the river surveying was established at "MSL at Lautoka = 1.1538m," the water level at the downstream end at the estuary of the Nadi River was set at "1.188m (= water level at the estuary: 2.342m – 1.1538m)."

Table 5.3-2 Observed Sea Levels in Five-year Period and Set Water Level at Downstream End

(m)

Month	Year	Gaps	Good	Minimum Sea Level	Maximum Sea Level	Mean Sea Level	St Devn
1	2010	0	7440	0.169	2.437	1.335	0.498
2	2010	0	6720	0.184	2.421	1.307	0.474
3	2010	0	7440	0.237	2.419	1.258	0.492
4	2010	0	7200	0.259	2.391	1.266	0.471
5	2010	0	7440	0.283	2.154	1.237	0.469
6	2010	0	7200	0.199	2.127	1.226	0.471
7	2010	1840	5600	0.149	2.104	1.203	0.447
8	2010	0	7440	0.066	2.200	1.191	0.476
9	2010	0	7200	0.135	2.291	1.211	0.479
10	2010	0	7440	0.201	2.348	1.259	0.475
11	2010	2126	5074	0.221	2.245	1.256	0.492
12	2010	0	7440	0.240	2.203	1.258	0.489
1	2011	0	7440	0.239	2.312	1.287	0.488
2	2011	0	6720	0.184	2.335	1.295	0.494
3	2011	0	7440	0.253	2.388	1.312	0.487
4	2011	0	7200	0.218	2.398	1.293	0.483
5	2011	0	7440	0.263	2.364	1.319	0.469
6	2011	519	6681	0.295	2.271	1.307	0.466
7	2011	0	7440	0.330	2.273	1.319	0.488
8	2011	0	7440	0.317	2.358	1.323	0.506
9	2011	0	7200	0.313	2.478	1.333	0.506
10	2011	0	7440	0.243	2.479	1.357	0.500
11	2011	0	7200	0.179	2.364	1.320	0.484
12	2011	0	7440	0.266	2.415	1.317	0.478
1	2012	0	7440	0.322	2.324	1.359	0.471
2	2012	0	6960	0.338	2.235	1.341	0.486
3	2012	0	7440	0.390	2.393	1.427	0.477
4	2012	0	7200	0.348	2.494	1.413	0.487
5	2012	0	7440	0.275	2.487	1.348	0.491
6	2012	0	7200	0.195	2.343	1.319	0.489
7	2012	0	7440	0.287	2.414	1.370	0.496
8	2012	0	7440	0.319	2.357	1.356	0.503
9	2012	0	7200	0.406	2.348	1.373	0.501
10	2012	0	7440	0.295	2.424	1.359	0.491
11	2012	0	7200	0.184	2.414	1.346	0.491
12	2012	0	7440	0.241	2.529	1.376	0.492
1	2013	0	7440	0.225	2.515	1.383	0.500
2	2013	0	6720	0.198	2.303	1.307	0.499
3	2013	0	7440	0.365	2.256	1.293	0.492
4	2013	0	7200	0.280	2.337	1.305	0.495
5	2013	0	7440	0.186	2.387	1.277	0.498
6	2013	0	7200	0.079	2.318	1.270	0.498
7	2013	0	7440	0.096	2.308	1.241	0.487
8	2013	0	7440	0.193	2.315	1.236	0.484
9	2013	0	7200	0.310	2.272	1.279	0.488
10	2013	0	7440	0.375	2.227	1.299	0.483
11	2013	0	7200	0.276	2.272	1.336	0.489
12	2013	0	7440	0.239	2.403	1.353	0.498
1	2014	0	7440	0.138	2.522	1.367	0.514
2	2014	0	6720	0.192	2.423	1.340	0.490
3	2014	1	7439	0.209	2.377	1.310	0.514
4	2014	0	7200	0.329	2.253	1.320	0.495
5	2014	60	7380	0.293	2.274	1.258	0.492
6	2014	0	7200	0.183	2.277	1.271	0.491
7	2014	0	7440	0.151	2.380	1.256	0.494
8	2014	524	6916	0.079	2.308	1.206	0.492
9	2014	0	7200	0.135	2.309	1.235	0.500
10	2014	0	7440	0.254	2.346	1.256	0.495
11	2014	0	7200	0.276	2.262	1.238	0.496

5-year average maximum sea level
2.342m
Datum (zero elevation) of the river surveying
1.1538m
Water level at the downstream end
1.188m



Relationship between the surveying datum and MSL

[Source: Pacific Country Report pp.19-20, 2002, National Tidal Facility Australia]

[Source: http://www.bom.gov.au/oceanography/projects/spslcmp/data/monthly.shtml#table]

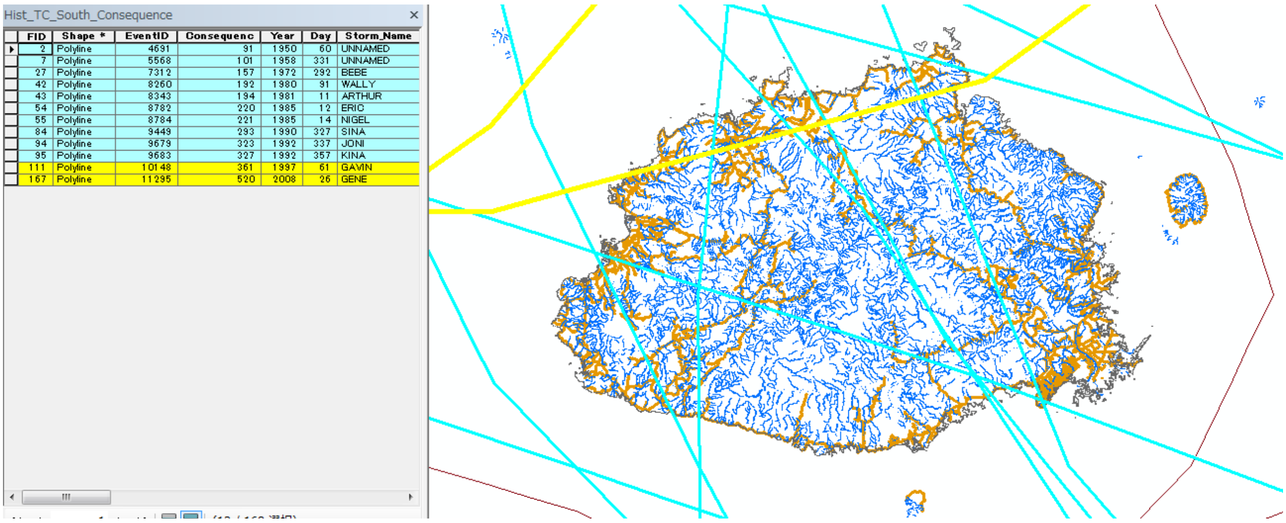
Table 5.3-3 shows the tropical cyclones (which are supposed to have had influence on the western Viti Levu Island) for which the sea level observation data is available.

The tropical cyclone (T/C) Gavin which affected Fiji in 1997 is supposed to have had caused a storm surge as the highest water level in the period between 1992 and 2014 was recorded. The fact that March 9th was the day of the new moon, as well as the low pressure caused by the cyclone, is considered to have caused the surge. Meanwhile, as the T/C Gene made landfall on Fiji on a day which was not close to either the new moon or full moon, it is assumed that the cyclone did not cause a storm surge exceeding the maximum sea level. The T/C Mick approached Nadi in 2009 days after the full moon (around December 2nd) and the T/C Evan reached the point closest to the western Viti Levu Island around December 17th, 2012, days after the new moon (around December 13th). Therefore, it is assumed that neither of them caused a storm surge exceeding the water level higher than the maximum sea level.

The discussion mentioned above indicates that storm surges had little influence on the maximum sea level in the five-year period between 2010 and 2014.

Table 5.3-3 Major Tropical Cyclones and Maximum Sea Levels Recorded

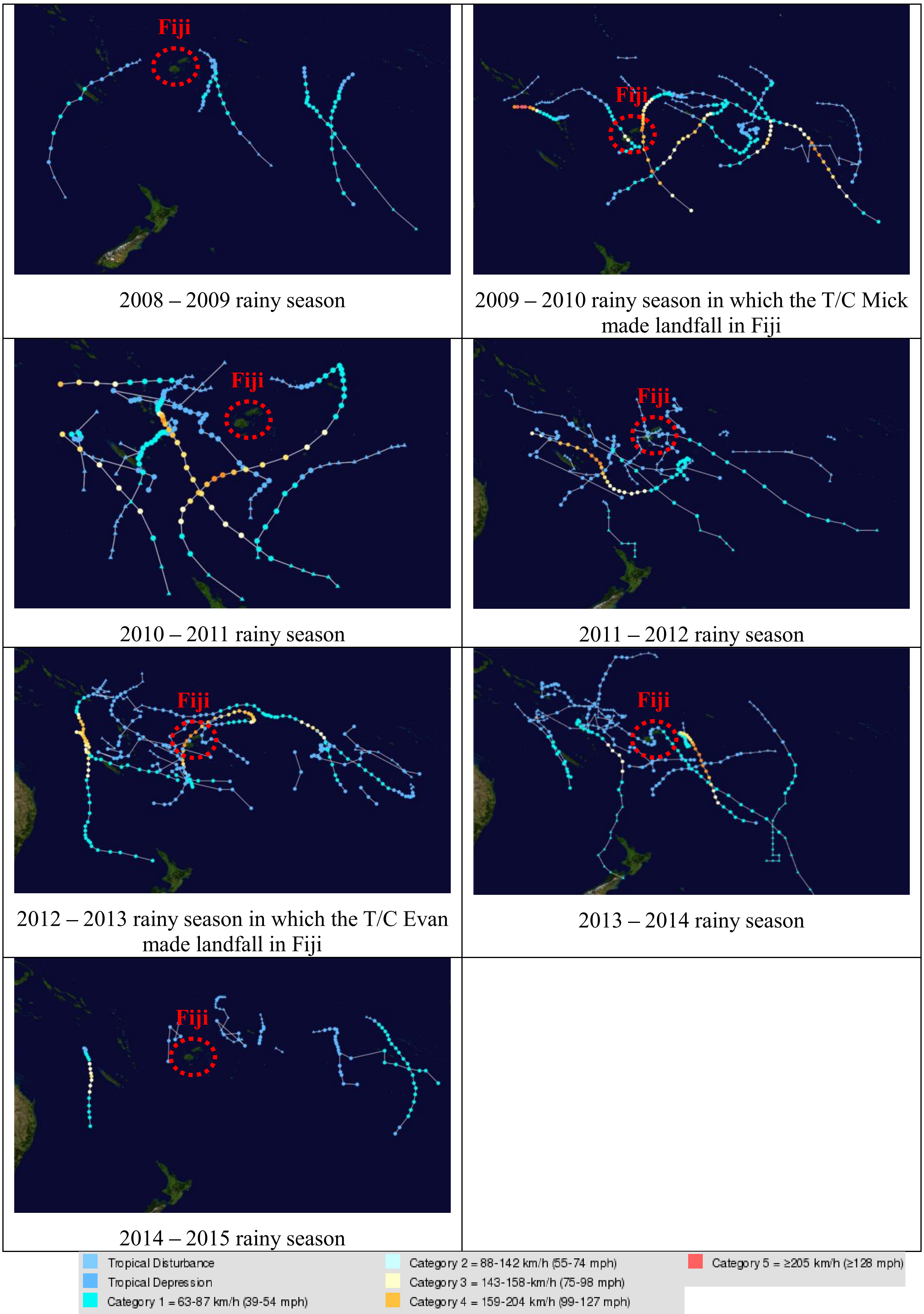
Date (Formed - Dissipated)	Name of T/C	Maximum Sea Level on the hour during T/C (m)	Maximum Sea Level in Month (m)
Mar 7th, 1997 (Mar 2nd – 11th)	T/C Gavin	2.777	2.777 (Mar 8th 5:42) *Maximum recorded level
Jan 28th, 2008 (Jan 25th – Feb 9th)	T/C Gene	2.114	2.266 (Jan 22nd) 2.263 (Feb 20th)
Dec 14th, 2009 (Dec 3rd – 15th)	T/C Mick	2.277	2.309 (Dec 3rd)
Dec 17th, 2012 (Dec 9th – 27th)	T/C Evan	2.521	2.529 (Dec 13th)


Hist_TC_South_Consequence

FID	Shape *	EventID	Consequenc	Year	Day	Storm_Name
2	Polyline	4691	91	1950	60	UNNAMED
7	Polyline	5568	101	1958	331	UNNAMED
27	Polyline	7312	157	1972	292	BEBE
42	Polyline	8260	192	1980	91	WALLY
43	Polyline	8343	194	1981	11	ARTHUR
54	Polyline	8782	220	1985	12	ERIC
55	Polyline	8784	221	1985	14	NIGEL
84	Polyline	9449	293	1990	327	SINA
94	Polyline	9679	323	1992	337	JONI
95	Polyline	9683	327	1992	357	KINA
111	Polyline	10148	361	1997	61	GAVIN
167	Polyline	11295	520	2008	26	GENE

Figure 5.3-5 Paths of Cyclones (the lines in yellow and light blue) in Past (between 1948 and 2008)

[Source: GIS data provided by SOPAC, PCRAFI/Component_1-Hazards/Historical Events]



2008 – 2009 rainy season

2009 – 2010 rainy season in which the T/C Mick made landfall in Fiji

2010 – 2011 rainy season

2011 – 2012 rainy season

2012 – 2013 rainy season in which the T/C Evan made landfall in Fiji

2013 – 2014 rainy season

2014 – 2015 rainy season

Figure 5.3-6 Paths of Cyclones in Past (between 2008 and 2015)

[Source: http://en.wikipedia.org/wiki/2009%E2%80%9310_South_Pacific_cyclone_season#, etc.]

(3) Characteristics of the River Channels (Segmentation)

It is important to understand various characteristics of existing river channels in the river channel planning. In this project, the channels in the Nadi River were classified into segments, or "parts with shared channel characteristics." The segments are defined as mentioned in the box below (p.60, Handbook for the Study for River Channel Planning, Japan Institute of Country-ology and Engineering, ed.). In principle, longitudinal gradient of riverbed and composition of riverbed material are used as the criteria for the classification. Accordingly, the channels in the Nadi River and its tributaries were classified into the segments mentioned in Table 5.3-5 by longitudinal gradient of the riverbed and composition of the riverbed material.

■ Segment

A longitudinal section of a river, including its part in a mountainous area, can be regarded as being composed of several sections, each of which has an almost uniform gradient. Similarity in various characteristics is observed in the riverbed material and river channels throughout each section with an almost identical gradient. Such a section is called a segment.

A segment means a section of river channel with similar characteristics. In principle, the entire channel of a river is divided into segments by longitudinal gradient of riverbed and composition of riverbed material. The division of a river channel into section with similar river channel characteristics is referred to as "segmentation." The use of segments as spatial units in a study and analysis of river channel characteristics is referred to as "the segment-based approach."

In Japan, a section of a river in a mountainous area where rocks are found on the riverbed and riverbanks and gravel is provided from collapsing slopes to the river channel is classified as Segment M. A river channel coming out of a mountainous area and heading to the sea is generally classified into three sections, which are called Segment 1 (channel in an alluvial fan), Segment 2 (channel in the intermediate area, a natural dike zone, etc.) and Segment 3 (channel in a delta) from upstream to downstream. Segment 2 is further divided into Segment 2-1 in the upstream and Segment 2-2 in the downstream by composition of the riverbed material and occurrence of sand waves.

Table 5.3-4 Segmentation and Characteristics in Each Segment

	Segment M	Segment 1	Segment 2		Segment 3
			2-1	2-2	
Classification by topography	← Mountainous area →	← Alluvial fan → ← Valley plain	Valley plain → ← Natural levee zone	Natural levee zone →	← Delta →
Representative grain size of riverbed	Varies widely	2cm and above	3cm – 1cm	1cm – 0.3mm	0.3mm and below
Riverbank composite materials	Rocks exposed on the riverbed and riverbanks at many locations	Same as the riverbed material with occasional thin layer of sand and silt on the surface	Mixture of fine sand, silt and clay With the same material as the riverbed material at the bottom		Silt and clay
Standard range of the gradient	Varies widely	1/60 – 1/400	1/400 – 1/5,000		1/5,000 – level
Meander	Varies widely	Few meanders	Many sharp meanders: formation of braided channels and bars where the depth ratio is large		Both large and small meanders
Erosion on the riverbanks	Very severe	Very severe	Moderate (the larger the riverbed material, the more frequently channels change routes)		Little (Most of the channels do not change routes.)
Average depth of the low-water channel	Varies widely	0.5m – 3m	2m – 8m		3m – 8m
Corresponding sections in the Nadi River and its tributaries	–	Upper reaches of the Nadi River	Nadi River: 25.25k – (28.75k) Nawaka and Namosi Rivers	Nadi River: 4.00k – 25.25k (downstream of the confluence of the Namosi River Malakua River	Nadi River: 0.00k – 4.00k (Dense growth of Mangrove)

(1) Segmentation by Longitudinal Gradient of Riverbed

Figure 5.3-15 and Figure 5.3-16 show the longitudinal sections of the rivers. The longitudinal gradient of the mean riverbed elevation changes at 17.0km and 25.25km in the calculation section of the Nadi River (0.0km – 28.75km). These points were assumed as the boundaries of the river channel sections. Meanwhile, although the riverbed gradient in the most downstream section appeared almost the same throughout its length, the condition of the river banks of the area near the estuary (0.0km – 4.0km) in particular (the dense growth of mangrove) differed from that of the rest of the section and the composition of the riverbed material was expected to be different from that of the rest of the section. Therefore, this section was divided into the segments as shown in the table below. The three tributaries, the Malakua, Nawaka and Namosi Rivers in the calculation section, were classified into the same segment as there was no point at which riverbed gradient changes clearly in their channels.

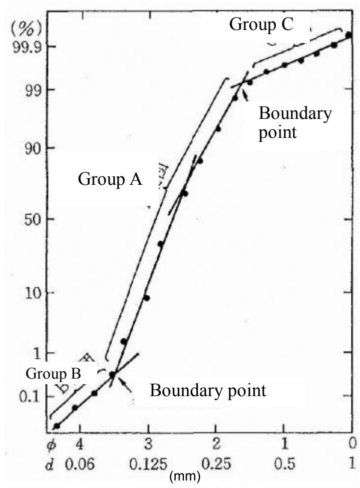
Table 5.3-5 Segmentation of Nadi River by Longitudinal Gradient of Riverbed

Section	Gradient of the mean riverbed elevation	Segment
Nadi River: Estuary – 17.0km	1/4,200	2 – 3
Nadi River: 17.0km – confluence of the Namosi River	1/1,350	2
Nadi River: Confluence of the Namosi River – the upstream end of the calculation section	1/630	2
Nadi River: Upper reaches of the Nadi River, *: outside the calculation section	–	1
Malakua River: 0.0km – 7.0km	1/780	2
Nawaka River: 0.0km – 10.0km	1/860	2
Namosi River: 0.0km – 5.0km	1/480	2

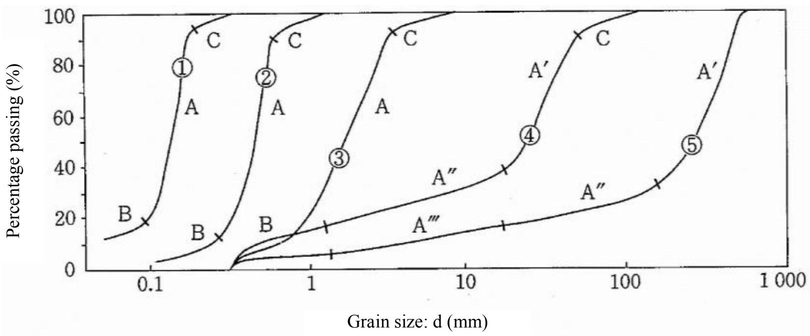
(2) Segmentation by Representative Grain Size

Before the segmentation of the river channels by representative grain size, a representative grain size was set for each segment with the method mentioned below, which was provided in pp.57 – 60 of the Handbook for the Study for River Channel Planning, Japan Institute of Country-ology and Engineering, ed.

Although grain size distribution of riverbed material is believed to follow a logarithmic normal distribution closely, it usually consists of three or more groups of components with different characteristics in reality. In the sedimentology, a group of particles which forms the main mode of riverbed material is called Group A and groups of the finer and coarser particles are called Groups B and C, respectively, as shown in the conceptual diagram in Figure 5.3-7. The grain sizes at the points on the grain size accumulation curve where the gradient of the curve changed sharply were used as the boundaries between different groups as shown in Figure 5.3-7.



Conceptual diagram of a composition of riverbed material



Classification by grain size group on various grain size distributions

Figure 5.3-7 Classification of River Bed Material by Grain Size Group

The riverbed material below the surface layer in alluvial fans consists of particles with mixed grain sizes including large-sized and small-sized particles. Among them, the small-sized particles contribute little to the riverbed variation. Mainly the particles in Groups C and A' contribute to riverbed variation and they also define the mobility of the riverbed material.

When the percentage of the particles in Group A" and those with smaller grain sizes account for 20% or less of the riverbed material, the mean grain size, d_m, or the 60% passing grain size, d_{60}, is not significantly different from the representative grain size of Groups C and A' (mean grain size of the particles in Groups C and A'). However, when the percentage of the smaller particles increases to approx. 30%, the difference between d_m or d_{60} and the representative grain size of Groups C and A' becomes too large for the latter to be an appropriate indicator of the mobility. Therefore, in such a case, the mean grain size or 60% passing grain size obtained from the grain size distribution of the riverbed material consisting only of the particles of Group C and A' is used as the representative grain size, d_R, which influences the mobility of the riverbed and riverbed variation.

It was decided to use the 60% passing grain size, d_{60}, as the representative grain size in this calculation. Table 5.3-6 shows the method of setting the representative grain sizes.

Table 5.3-6 Setting of Representative Grain Sizes

d_{60} of the riverbed material	Representative grain size, d_R
1cm or below	Use d_{60} as d_R.
1cm or above	If the percentage of the particles in Group A" and those of the smaller sizes account for 30% or less of the riverbed material, use d_{60} as d_R.
	If the percentage of the particles in Group A" and those of the smaller sizes account for 30% or more of the riverbed material, draw a new grain size distribution curve only with the particles in Groups A' and C and use d_{60} obtained from this new curve as d_R.

The result of the riverbed material survey conducted in this project (Figure 5.3-8) was used for drawing the grain size accumulation curves (Figure 5.3-9 and Figure 5.3-10), which were used for setting the

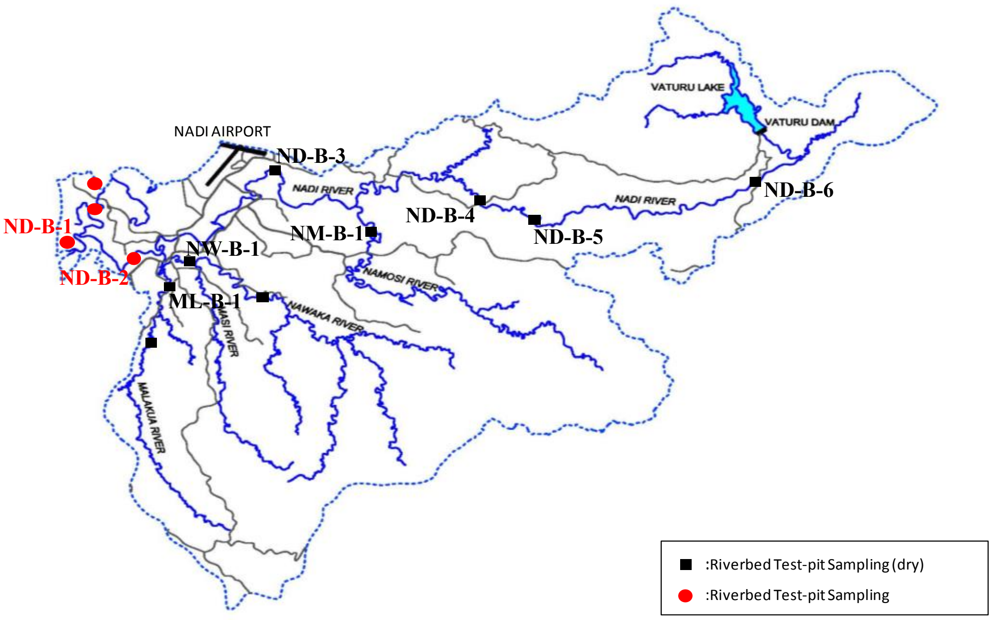


Figure 5.3-8 Sampling Sites of Riverbed Material Survey

Table 5.3-7 Scenes in Riverbed Material Survey

ND-B-1 (Nadi River), Segment 3, representative grain size - d_R = 0.02mm 	ND-B-2 (Nadi River), Segment 2-2, representative grain size - d_R = 2.0mm 	ND-B-3 (Nadi River), Segment 2-2, representative grain size - d_R = 2.7mm 
ND-B-4 (Nadi River), Segment 2-1, representative grain size - d_R = 45.0mm 	ND-B-5 (Nadi River), Segment 2-1, representative grain size - d_R = 31.0mm 	ND-B-6 (Nadi River), Segment 1, representative grain size - d_R = 38.0mm 
ML-B-1 (Malakua River), Segment 2-2, representative grain size - d_R = 2.2mm 	NW-B-1 (Nawaka River), Segment 2-1, representative grain size - d_R = 40.0mm 	NM-B-1 (Namosi River), Segment 2-1, representative grain size - d_R = 44.0mm 

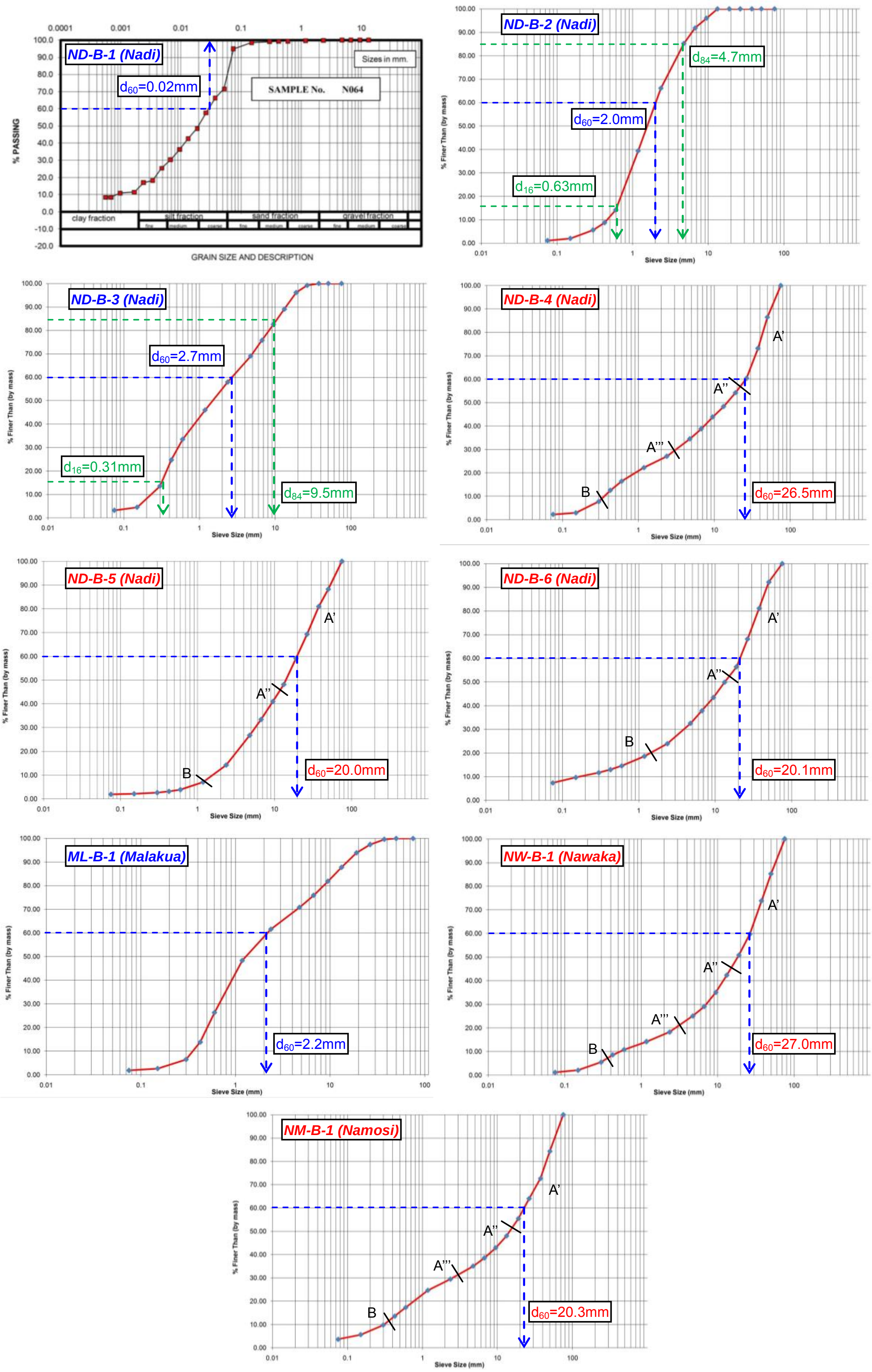


Figure 5.3-9 Grain Size Accumulation Curves

(Blue letters: Use d_{60} as the representative grain size, red letters: Create a new grain size distribution)

When the range of grain sizes is so wide that it is difficult to find the points where the gradient of the accumulation curve changes, the procedures to set the boundary grain sizes between the groups mentioned below were used.

① Draw a grain size accumulation curve of riverbed material of each segment.
② The boundary between a group of large grain particles, Group C, and the major component of the riverbed material, Group A', usually appear on a grain size accumulation curve as a point where the gradient of the curve changes sharply. Use the grain size at this point as the boundary grain sizes.
③ Regard the sand component as Group B. If a point where the gradient changes sharply is found on a grain size accumulation curve, use the grain size at the point as the boundary grain size of Group B. Such a point is usually found in the range of grain size between 1.0mm and 2.0mm. If a point where the gradient of the curve changes sharply is not found, use 2.0mm as the boundary grain size.
④ The boundary grain size between Groups A' and A'' often appears as a point on a grain size accumulation curve where the gradient of the curve changes sharply. If such a point is not found on the curve, use the grain size approx. one-eighth of the boundary grain size between Groups C and A' as the boundary grain size between Groups A' and A'' because a mixed-grain-size riverbed material is transported as a group of particles with the same grain size, when it is composed of coarse sand and the larger particles and the ratio of the largest particles to the smallest particles in the material is around 7 or 8.
⑤ If the ratio of the boundary grain size between Groups A' and A'' to the size of the largest particles in Group B is around 8 to 10, the particles with the grain sizes between the two are considered to belong to Group A''. If this ratio is larger than 15, particles with the grain size between the boundary grain size between Groups A' and A'' and the largest grain size in Group B are to be divided into groups so that the ratio between the largest and smallest particles within each group is approx. 8 and the groups thus formed are named Groups A'', A''', A'''', etc. in the descending order in the grain size.

The analysis of the riverbed materials sampled at ND-B-4, 5 and 6 (Nadi), NW-B-1 (Nawaka) and NM-B-1 (Namosi) revealed that the 60% passing grain sizes of these materials were 1cm or above and the proportion of the material belonging to Groups A'' to B accounted for more than 30% of the material. Therefore, new grain size accumulation curves shown in Figure 5.3-10 were drawn using the materials belonging to Group A' and C and d_{60}'s obtained from the new curves were used as the representative grain sizes in accordance with the procedures mentioned above.

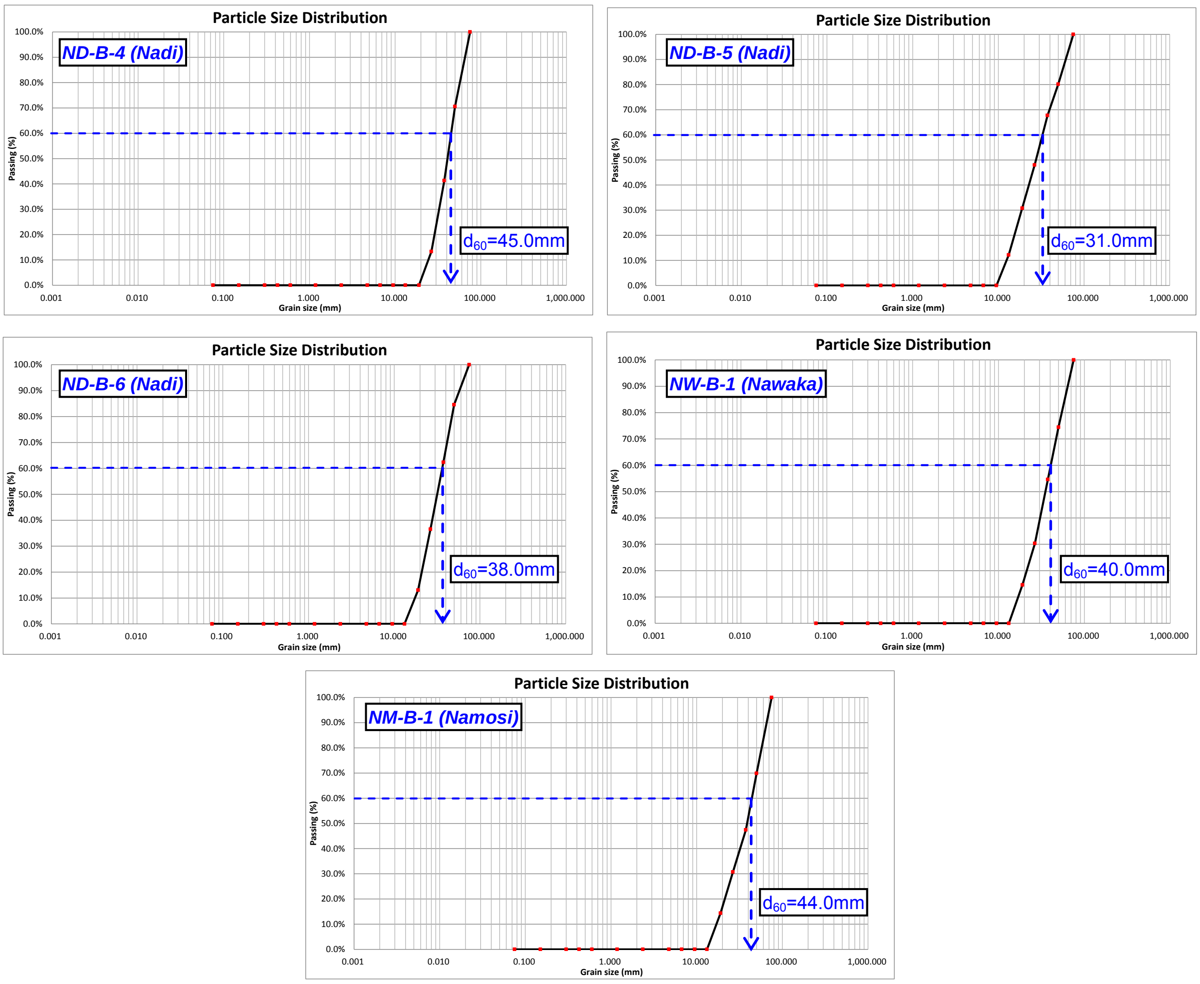


Figure 5.3-10 Grain Size Accumulation Curves of Materials Belonging to Group A

From the above-mentioned analysis, the representative grain sizes mentioned in the table below were obtained.

Table 5.3-8 Representative Grain Sizes at Survey Points in Nadi River and its Tributaries

Survey point	Representative grain size (mm)	Segment
ND-B-1 (at the estuary of the Nadi River)	0.02	3
ND-B-2 (near 7.0k on the Nadi River)	2.0	2-2
ND-B-3 (near 17.0k on the Nadi River)	2.7	2-2
ND-B-4 (Upstream of the confluence of the Namosi River)	45.0	2-1
ND-B-5 (Upstream of the confluence of the Namosi River)	31.0	2-1
ND-B-6 (Upper reaches of the Nadi River)	38.0	1
ML-B-1	2.2	2-2
NW-B-1	40.0	2-1
NM-B-1	44.0	2-1

Table 5.3-9 summarizes the segmentation of the Nadi River and its tributaries based on the results obtained in (1) and (2) above.

Table 5.3-9 Segmentation of Nadi River and its Tributaries

Section	Mean riverbed gradient	Representative grain size (mm)	Segment
Nadi River - River channel section 1 (Estuary – 4.0km)	1/4,200	0.02	3
Nadi River - River channel section 2 (4.0km – confluence of the Namosi River, 25.25km)	1/4,200, 1/1,350	2.0, 2.7	2-2
Nadi River - River channel section 3 (25.25km – upstream end of the calculation section, 28.75km)	1/630	45.0, 31.0	2-1
Nadi River (Upper reaches of the Nadi River) *Outside the calculation section	–	38.0	1
Malakua River (0.0km – 7.0km)	1/780	2.2	2-2
Nawaka River (0.0km – 10.0km)	1/860	40.0	2-1
Namosi River (0.0km – 5.0km)	1/480	44.0	2-1

(4) Estimation of the Roughness Coefficients

It was decided to estimate roughness coefficients in each segment section mentioned above in this study. The roughness coefficients of low-water channel and high-water channel were estimated from the roughness of the riverbed and riverbanks (growth of vegetation), respectively, on the representative cross-section of each segment.

1) Roughness Coefficients of Low-water Channel

The flowchart provided in the Handbook for the Study for River Channel Planning (p.109) (Figure 5.3-12) was used for the estimation of the roughness coefficient of low-water channel in Segment 3. As the representative grain size (d_R) of Segment 3 in this study was smaller than 0.1mm, the smallest coefficient in the chart, 0.015, was used for the estimation.

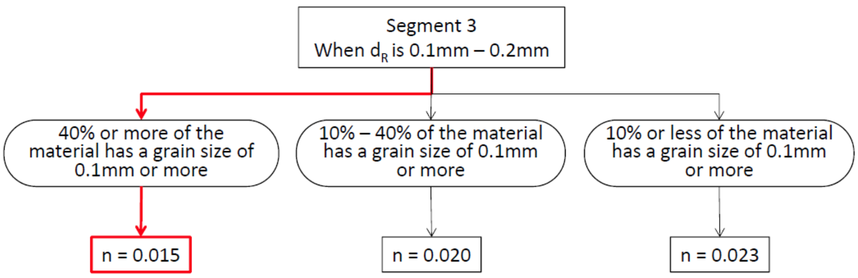


Figure 5.3-11 Flowchart for Estimation of Standard Roughness Coefficient of Low-water Channel in Segment 3

The flowchart shown below (Handbook for the Study for River Channel Planning, p.106) was used for the estimation of the roughness coefficients of low-water channel in Segment 2-2.

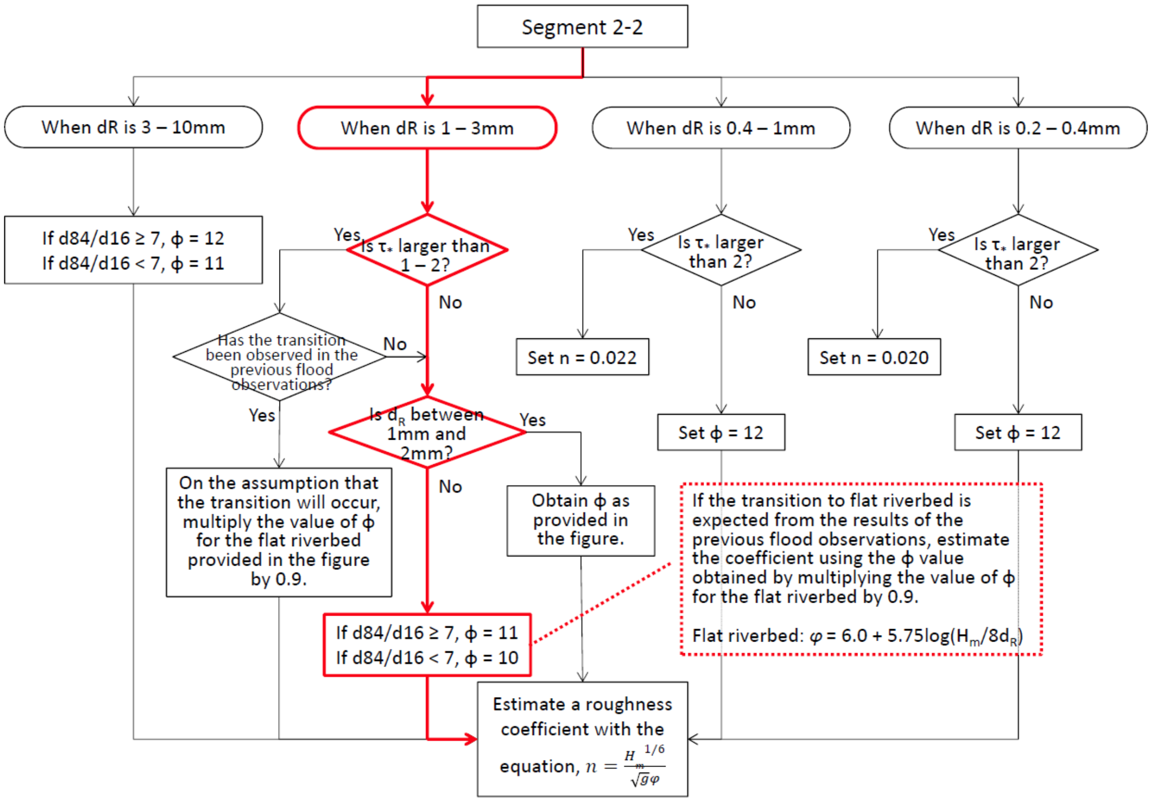


Figure 5.3-12 Flowchart for Estimation of Standard Roughness Coefficients of Low-water Channel in Segment 2-2

As the representative grain size in the Segment 2-2 sections was between 2.0mm and 2.7mm (d_R = 2.0mm – 2.7mm), the path marked in red in the above-mentioned estimation flowchart was used.

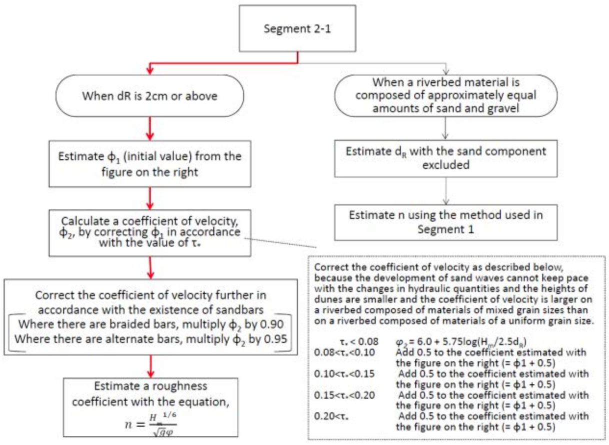
Coefficients of velocity, φ_1 (initial value) and φ_2, were estimated using the dimensionless tractive force, τ_*, and depth/grain-size ratio, H/d_R, obtained under the condition of water up to the design high-water level. Then the coefficients of velocity thus obtained were used to estimate the roughness coefficients of low-water channel (Table 5.3-10).

Table 5.3-10 Hydraulic Quantities and Roughness Coefficients of Low-water Channel in Segment 2-2 under Condition of Water up to Design High-water Level

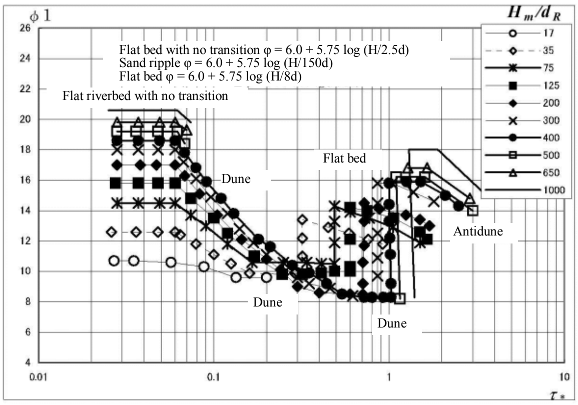
River channel section	Mean water depth	Friction velocity u_* (m/s)	Representative grain size d_R (mm)	Depth/grain size ratio H/d	Dimensionless tractive force, τ_*	Coefficient of velocity φ_1	Coefficient of velocity φ_2	**Roughness coefficient of low-water channel**
Nadi River, River channel section 2 4.00km – 25.25km	9.18	0.18	2.4 (2.0, 2.7)	3,905	0.84	19.91*	–	**0.023**
Malakua River 0.0km – 7.0km	5.33	0.16	2.2	2,421	0.76	18.84*	–	**0.022**

* The value obtained by multiplying the φ value for the flat riverbed by 0.9

The flowchart shown below (p.104, Handbook for the Study for River Channel Planning) was used for the estimation of roughness coefficients of low-water channel in Segment 2-1.



Flowchart for the estimation of the standard roughness coefficients of low-water channel



Relationship between τ_* and φ_1 (when d is 0.4 cm or above)

Figure 5.3-13 Flowchart for Estimation of Standard Roughness Coefficients of Low-water Channels in Segment 2-1

As the representative grain size of the riverbed material in Segment 2-1 sections was between 31mm and 45mm (d_R = 31mm – 45mm), the path on the left side of the flowchart shown in the figure above was used in the estimation.

As in Segment 2-2, the coefficients of velocity, φ_1 (initial value) and φ_2, were estimated using the dimensionless tractive force, τ_*, and the depth/grain-size ratio, H/d_R. Then the roughness coefficients were estimated using those hydraulic quantities (Table 5.3-11).

Table 5.3-11 Hydraulic Quantities and Roughness Coefficients of Low-water Channel in Segment 2-1 under Condition of Water up to Design High Water Level

River channel section	Mean water depth	Friction velocity u_* (m/s)	Representative grain size d_R (mm)	Depth/ grain size ratio H/d	Dimensionless tractive force, τ_*	Coefficient of velocity φ_1	Coefficient of velocity φ_2	**Roughness coefficient of low-water channel**
Nadi River River channel section 3 25.25km – 28.75km	8.71	0.20	45	194	0.05	–	16.86	**0.027**
Nawaka River 0.0km – 10.0km	5.13	0.10	40	128	0.01	–	15.83	**0.026**
Namosi River 0.0km – 5.0km	6.19	0.11	44	141	0.02	–	16.07	**0.027**

2) Roughness Coefficients of High-Water Channel

The roughness coefficients of high-water channel (riverbanks) were estimated from the results of the field study on the growth of vegetation and with the Handbook for the Study for River Channel Planning (Japan Institute of Country-ology and Engineering, 2002) used as reference.

Table 5.3-12 Vegetation in High-water Channels

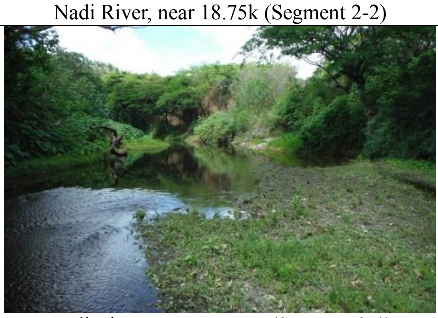
 Nadi River, near 1.25k (Segment 3)	 Nadi River, near 9.50k (Segment 2-2)
 Nadi River, near 18.75k (Segment 2-2)	 Nadi River, near ND-B-4 (Segment 2-1)
 Nadi River, near ND-B-5 (Segment 2-1)	 Malakua River, near ML-B-1 (Segment 2-2)
 Nawaka River, near NW-B-1 (Segment 2-1)	 Namosi River, near NM-B-1 (Segment 2-1)

Figure 5.3-14, which gave the relationships between the roughness coefficient of vegetation and the ratio of the expected water depths of herbaceous plants during the design flood to their heights for three different plant postures.

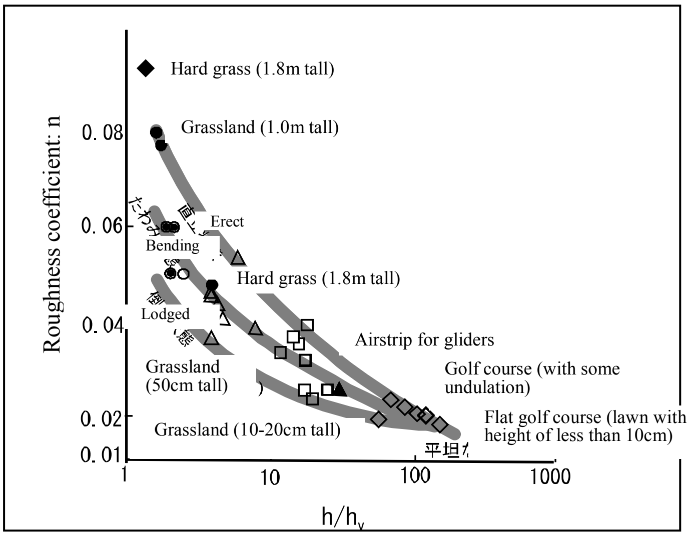


Figure 5.3-14 Relationship between Condition of Water Depth to Vegetation in High-water Channel and Roughness Coefficient (h: grass height, h_V:water depth)

<Thick growth of hard grass>

Hard grass means grass with a one- to three-meter-tall, erect and hard stalk, including reeds, silver grass and Canada goldenrods. The table below gives the friction velocities in flowing water, u*, of the hard grass in different postures.

Erect	Bending	Lodged
u* ≤ 12cm/s	12cm/s < u* ≤ 22cm/s	22cm/s < u*

< Thick growth of soft grass>

Soft grass means grass with many leaves near the ground surface and a relatively flexible stalk, including green foxtails, barnyard grass and annual ryegrass. The table below gives the friction velocities in flowing water, u*, of the soft grass in different postures.

Erect	Bending	Lodged
u* ≤ 7cm/s	7cm/s < u* ≤ 15cm/s	15cm/s < u*

The cross-sections of the Namosi River and the Nadi River near 18.50k were selected as the representative cross-sections of Segments 2-1 and 2-2, respectively, for the estimation of the roughness coefficients. The table below shows the roughness coefficients of the high-water channel at the two locations estimated from the existing vegetation. Roughness coefficient in Segment 3 was not estimated, because, practically, there is no plant other than mangrove in the high-water channel in the segment.

Table 5.3-13 Vegetation and Roughness Coefficients in High-water Channel

(Segment 2-1: Namosi River, Segment 2-2: near 18.50k on the Nadi River)

Predominant plants	Grass height hv (cm)	Hard/soft grass	Flow rate (m^3/s)	Water depth h (cm)	h/hv	Friction velocity u* (cm/s)	Posture	**Roughness coefficient n**
Grass family plants (Segment 2-1)	150	Hard grass	63	Approx. 200	1.3	Approx. 15	Bending	**0.060**
Grass family plants (Segment 2-2)	250	Hard grass	540	Approx. 350	1.4	Approx. 20	Bending	**0.060**

Table 5.3-14 the roughness coefficients in each river channel section estimated as mentioned above.

Table 5.3-14 Estimated Roughness Coefficients

Section (Segmentation)	Roughness coefficient [Low-water channel]	Roughness coefficient [High-water channel]
Nadi River, River channel section 1 (0.00km – 4.00km, Segment 3)	0.015	– (Thick growth of only mangrove [dead water zone]))
Nadi River, River channel section 2 (4.00km – 25.25km, Segment 2-2)	0.023	0.060
Nadi River, River channel section 3 (25.25km –, Segment 2-1)	0.027	0.060
Malakua River (0.0km – 7.0km, Segment 2-2)	0.022	0.060
Nawaka River (0.0km – 10.0km, Segment 2-1)	0.026	0.060
Namosi River (0.0km – 5.0km, Segment 2-1)	0.027	0.060

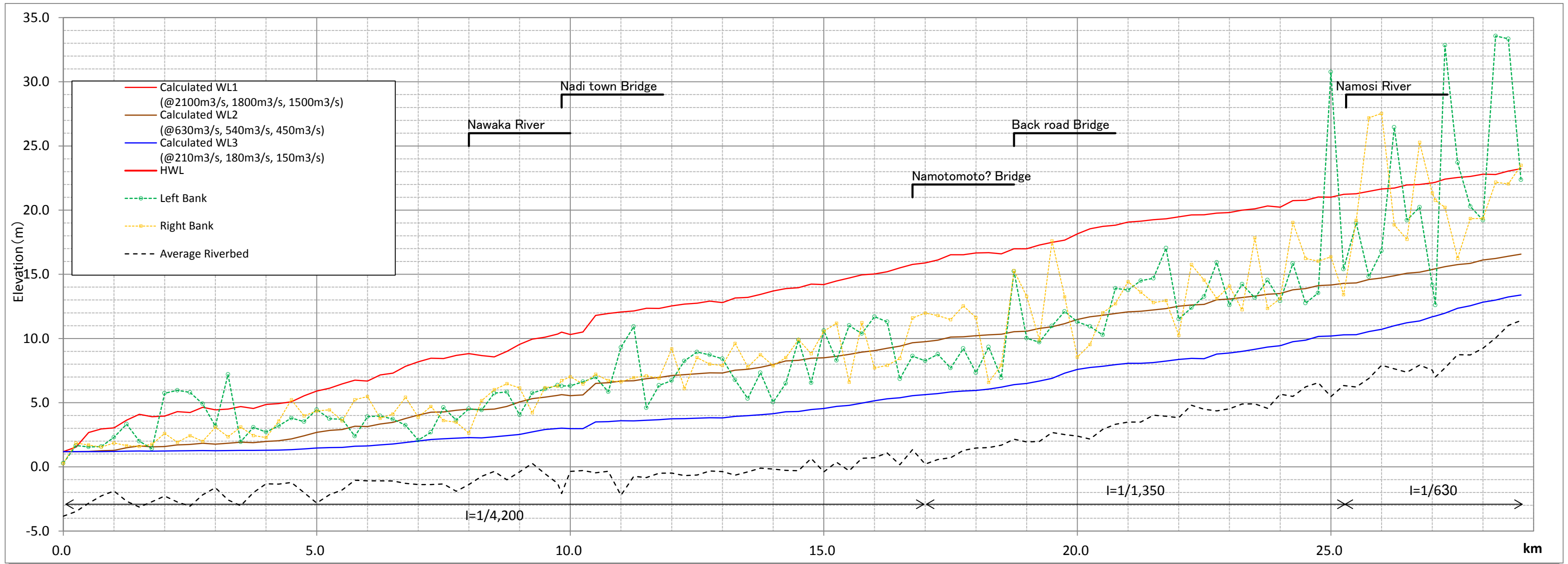
5.3.2 Result of the Study

The longitudinal sections and the tables and diagrams of the estimated discharge capacities of the Nadi River and its tributaries are shown in Figure 5.3-15~Figure 5.3-20 and Table 5.3-16 and Table 5.3-17. The flow rates and the water levels at the downstream end used in the estimation of the discharge capacities are described in Table 5.3-15. The discharge capacities estimated with the dike heights obtained from the results of the river surveying partly supplemented by LiDAR data are shown in Table 5.3-16 and Table 5.3-17.

Table 5.3-15 Flow Rate and Water Level at Downstream End Used in Estimation of Discharge Capacities

Flow rate used in the estimation		Nadi				Malakua		Nawaka			Namosi	
		Water level at the downstream end	Estimated flow rate (m^3/s)			Water level at the downstream end Nawaka 1.50k Estimated water level	Estimated flow rate (m^3/s)	Water level at the downstream end Nadi 8.00k Estimated water level	Estimated flow rate (m^3/s)		Water level at the downstream end Nadi 25.25k Estimated water level	Estimated flow rate (m^3/s)
			– 8.00k	– 25.25k	25.50k –		– 7.75k		0.00 – 1.50k	1.75 – 10.00k		– 5.00k
①	⑥×0.05	1.188	105.0	90.0	75.0	1.611	6.5	1.586	15.5	9.0	8.754	10.5
②	⑥×0.10	1.188	210.0	180.0	150.0	2.309	13.0	2.275	31.0	18.0	10.283	21.0
③	⑥×0.30	1.188	630.0	540.0	450.0	4.537	39.0	4.504	93.0	54.0	14.296	63.0
④	⑥×0.50	1.188	1,050.0	900.0	750.0	6.235	65.0	6.208	155.0	90.0	16.817	105.0
⑤	⑥×0.70	1.188	1,470.0	1,260.0	1,050.0	7.408	91.0	7.379	217.0	126.0	18.735	147.0
⑥	Equivalent to the 20 year return period flood obtained in the study in 1998	1.188	2,100.0	1,800.0	1,500.0	8.848	130.0	8.817	310.0	180.0	21.237	210.0
⑦	⑥×0.90	1.188	1,890.0	1,620.0	1,350.0	8.395	117.0	8.365	279.0	162.0	20.438	189.0
⑧	⑥×0.95	1.188	1,995.0	1,710.0	1,425.0	8.625	123.5	8.594	294.5	171.0	20.841	199.5

The smallest discharge capacities in the Nadi River, those between $200m^3/s$ – $300m^3/s$, were observed on the left bank at 1.75k and 7.00k and on the right bank at 8.00k. The discharge capacities in the lower reaches of the Nawaka and Malakua Rivers were particularly small: The minimum capacities observed in these tributaries were between $20m^3/s$ and $30m^3/s$. In Namosi River the river channel is narrowed by hillside slopes at some places so that the minimum discharge capacity in this tributary was $70m^3/s$.



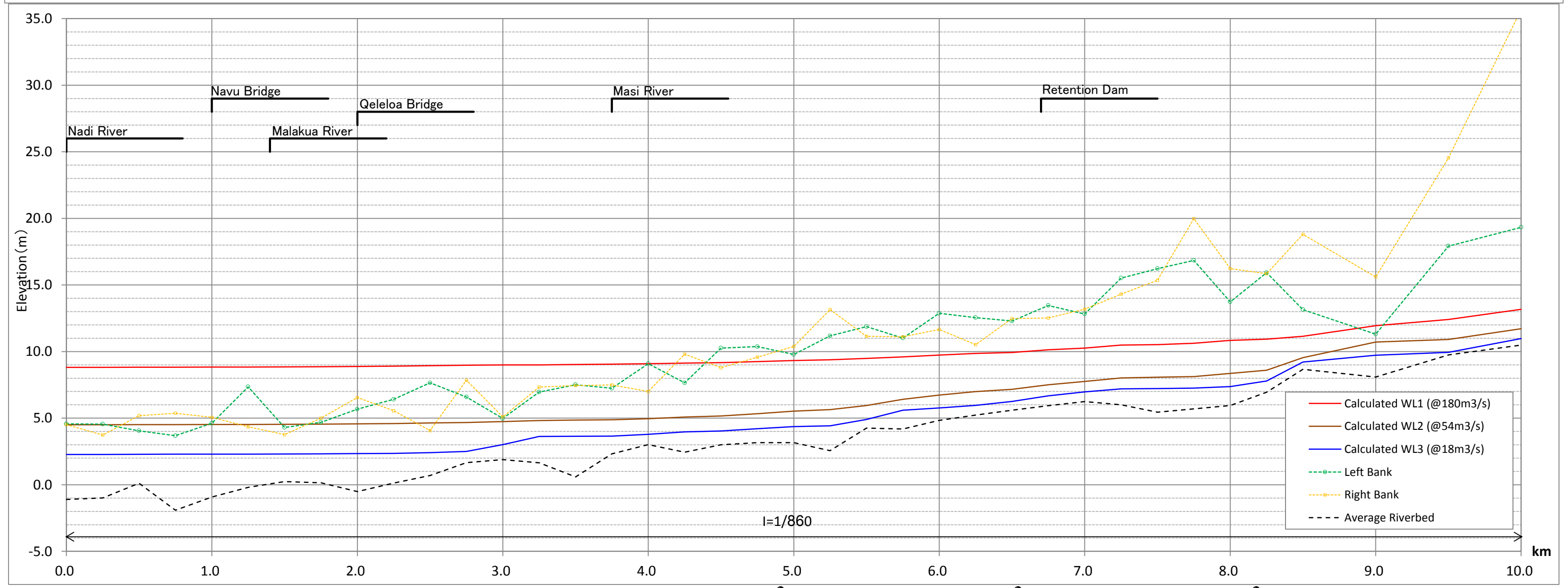


Figure 5.3-15 Longitudinal Profile (1/2) (Above: Nadi River[~8.00k: 2,100m^3/s, ~25.25k: 1,800m^3/s, 25.50k~: 1,500m^3/s and so on], Below: Nawaka River)

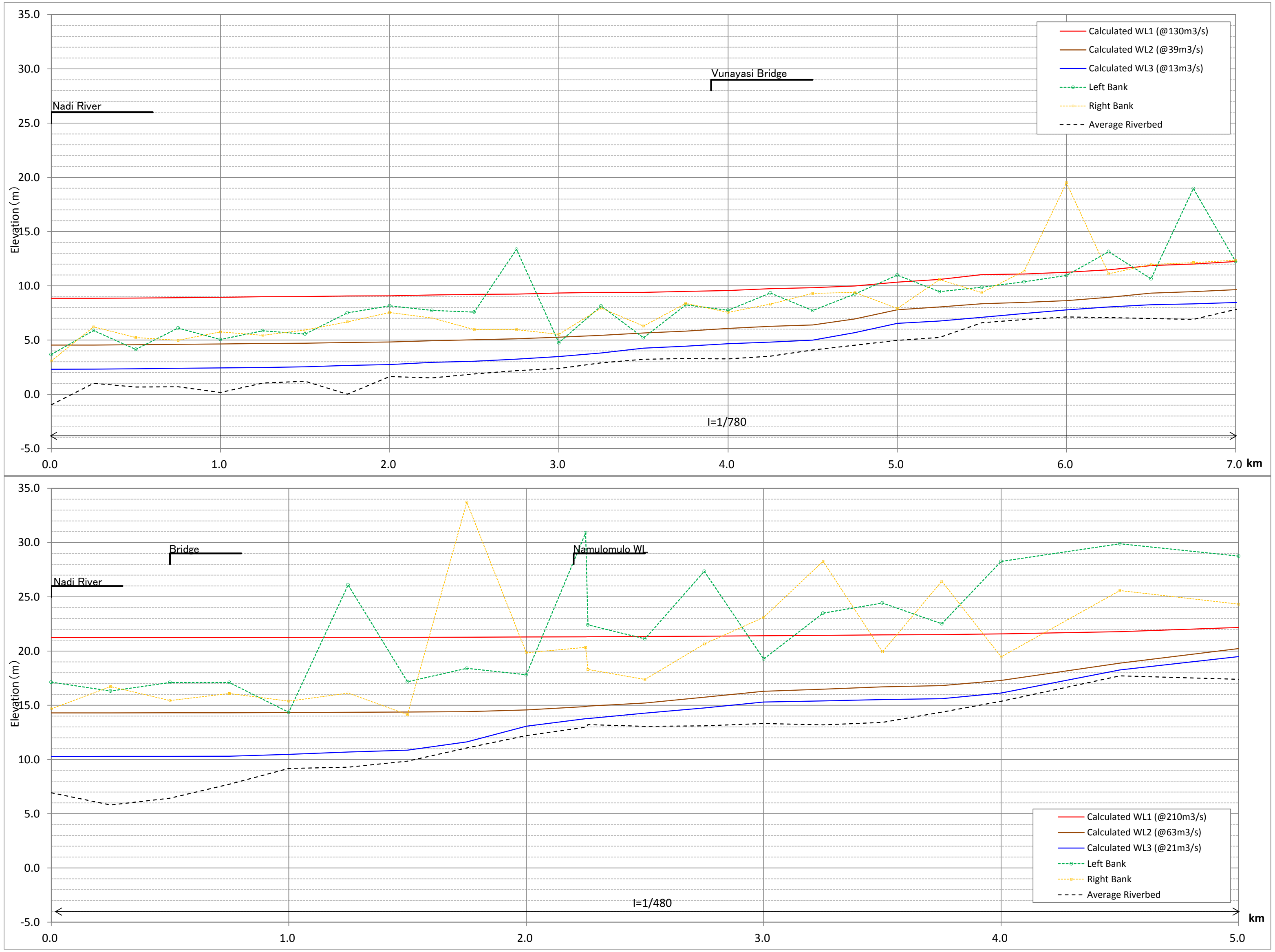


Figure 5.3-16 Longitudinal Profile (2/2) **(Above: Malakua River, Below: Namosi River)**

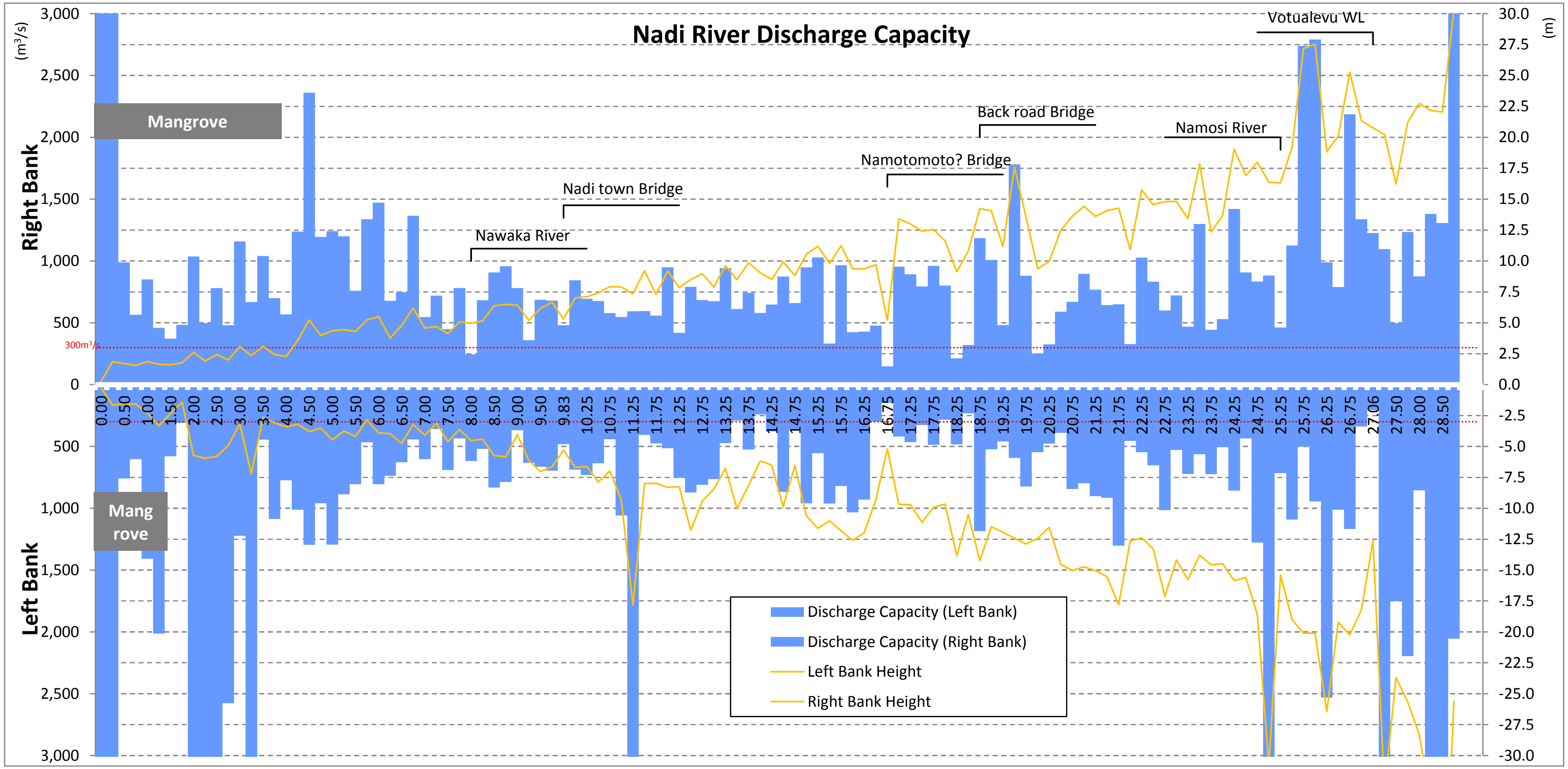


Figure 5.3-17 Discharge Capacity (Nadi River)

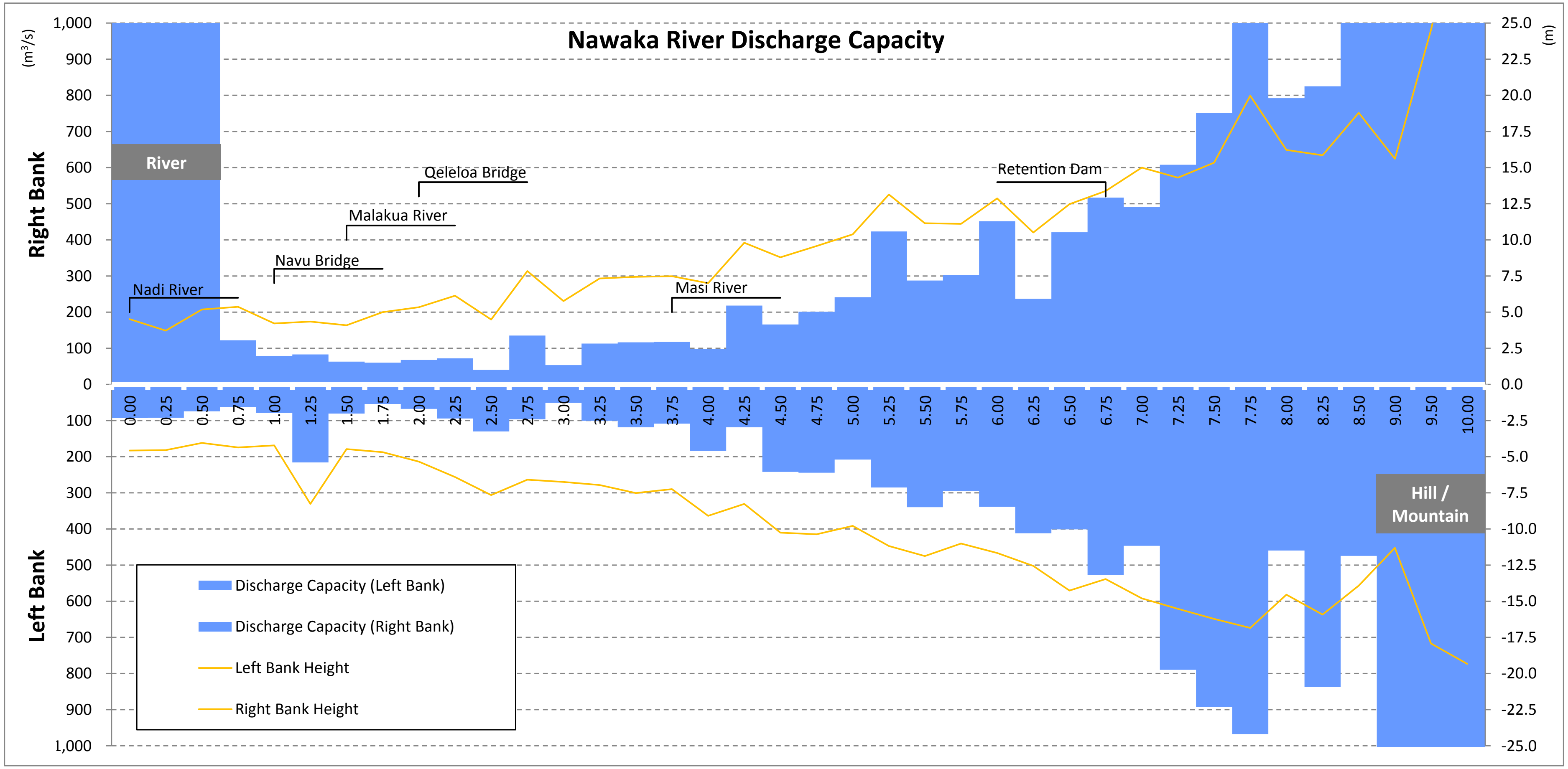


Figure 5.3-18 Discharge Capacity (Nawaka River)

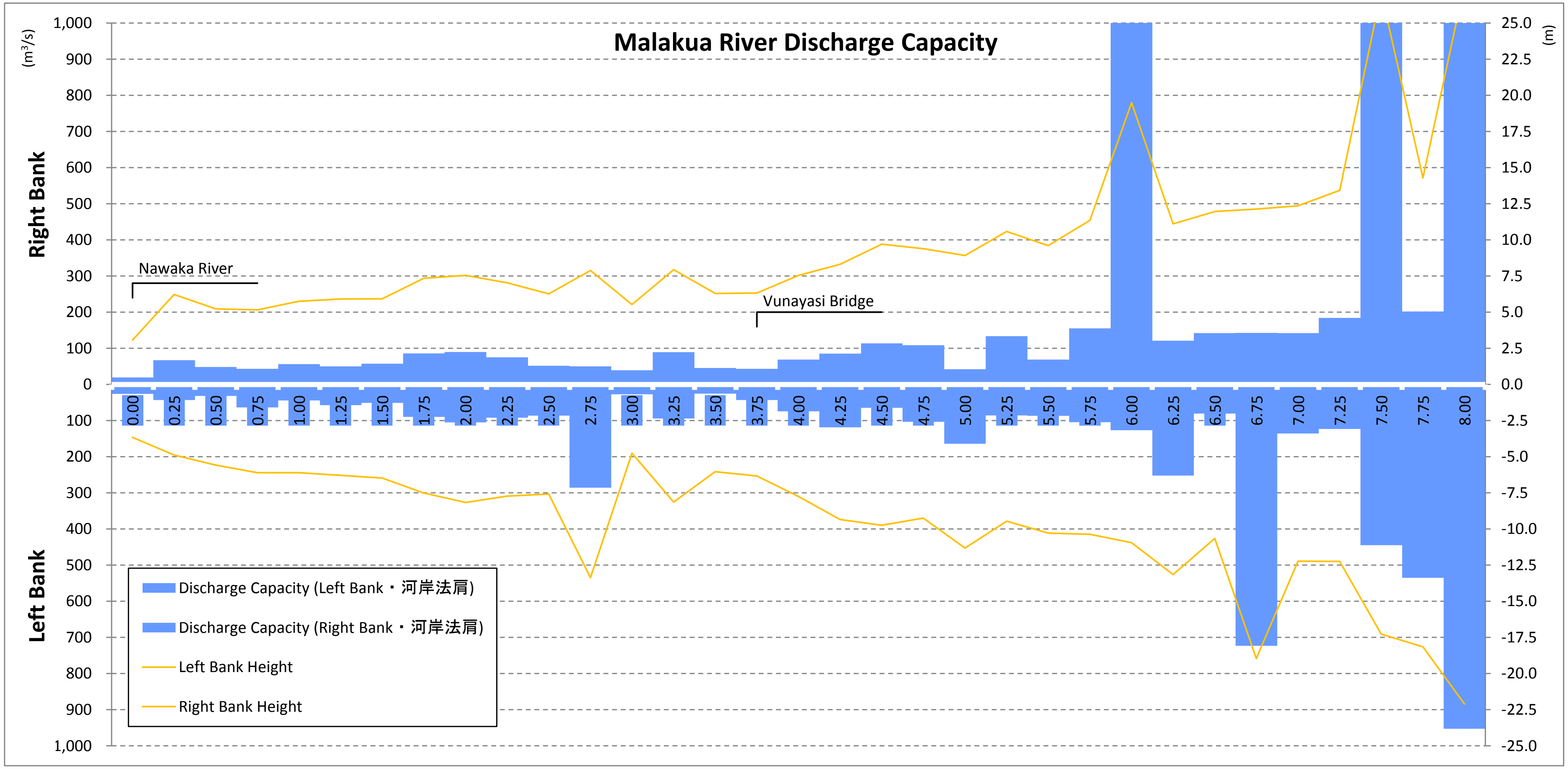


Figure 5.3-19 Discharge Capacity (Malakua River)

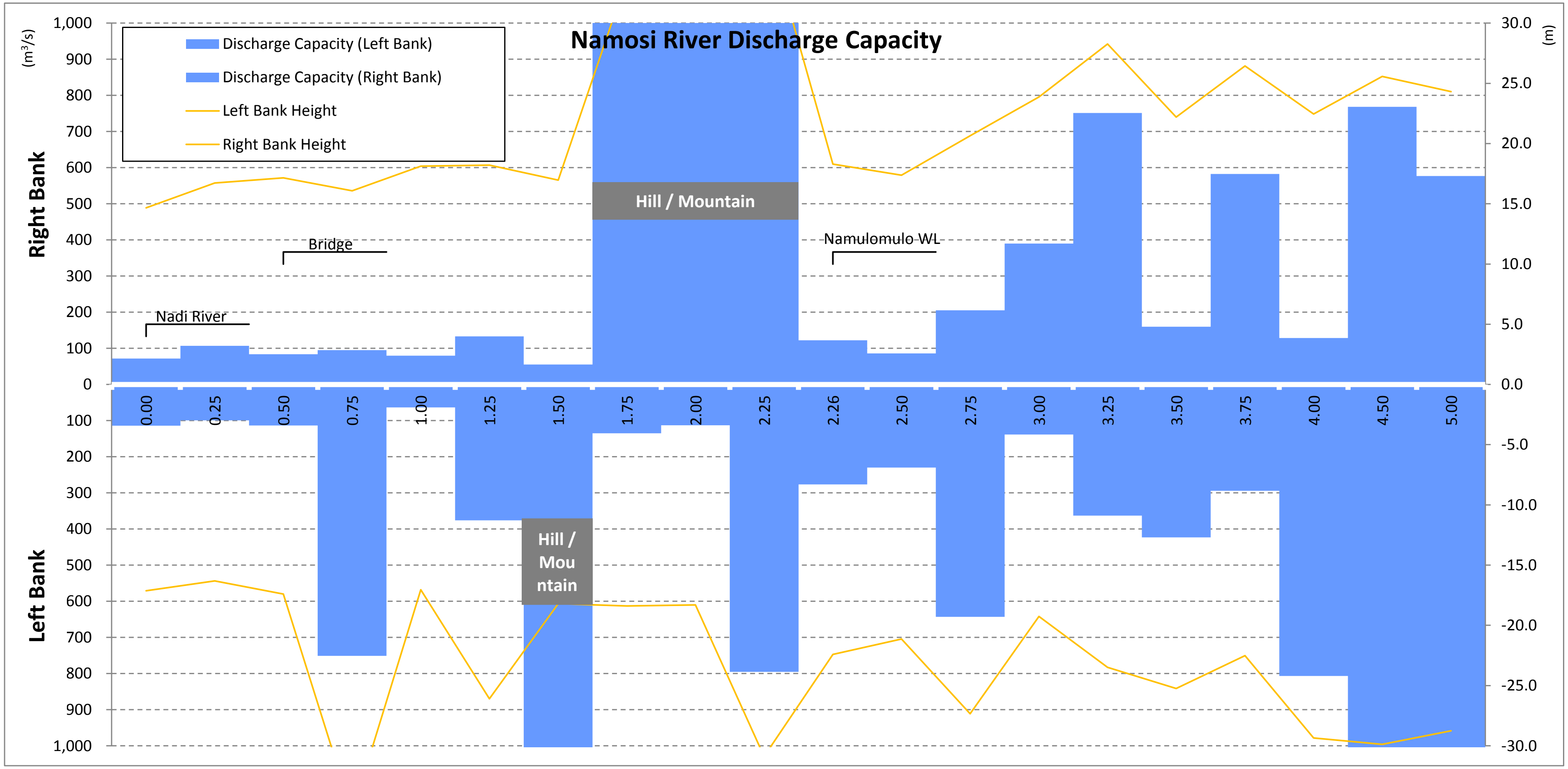


Figure 5.3-20 Discharge Capacity (Namosi River)

Table 5.3-16 List of Discharge Capacity (Nadi River)

■: LiDAR survey data is used for Bank height
■: LiDAR survey data is used for River channel (No River survey data)

Nadi River

Cross Section	Remarks	Interval	Cumulative Distance	①Bank Height		Land Use @ 50–100m from the bank		Discharge Capacity at Bank Height ①		H-Q Formula $Q=a\times(h+b)^2$		Cross Section
		(m)	(m)	Left Bank	Right Bank	Left Bank	Right Bank	Left Bank	Right Bank	a	b	
0.00		0	0	0.28	0.27	Sea	Sea	9999	9999	0.00	0.00	0.00
0.25		250	250	1.66	1.86	Mangrove	Mangrove	10085	18149	29399.41	-1.07	0.25
0.50		250	500	1.55	1.70	Mangrove	Mangrove	759	988	671.05	-0.49	0.50
0.75		250	750	1.58	1.54	Mangrove	Mangrove	603	564	400.08	-0.35	0.75
1.00		250	1000	2.30	1.86	Mangrove	Mangrove	1408	851	359.94	-0.32	1.00
1.25		250	1250	3.33	1.65	Resident	Mangrove	2013	460	194.49	-0.11	1.25
1.50		250	1500	2.00	1.59	Empty/Crop	Mangrove	580	373	137.65	0.05	1.50
1.75		250	1750	1.41	1.76	Empty Land	Mangrove	309	484	158.58	-0.01	1.75
2.00		250	2000	5.74	2.61	Empty Land	Mangrove	5032	1038	152.94	0.00	2.00
2.25		250	2250	5.96	1.92	Empty Land	Mangrove	4408	496	119.23	0.12	2.25
2.50		250	2500	5.80	2.43	Empty Land	Mangrove	4302	780	124.84	0.07	2.50
2.75		250	2750	4.91	1.99	Empty Land	Empty Land	2577	480	97.66	0.23	2.75
3.00		250	3000	3.17	3.08	Empty Land	Empty Land	1222	1159	110.18	0.16	3.00
3.25		250	3250	7.20	2.35	Empty Land	Empty Land	5743	668	106.01	0.16	3.25
3.50		250	3500	1.95	3.10	Empty Land	Empty Land	445	1040	94.76	0.22	3.50
3.75		250	3750	3.08	2.44	Empty Land	Empty Land	1086	700	103.29	0.16	3.75
4.00		250	4000	2.71	2.29	Empty/Crop	Crop	773	568	86.53	0.28	4.00
4.25		250	4250	3.20	3.57	Empty/Crop	Empty/Crop	1011	1238	83.58	0.28	4.25
4.50		250	4500	3.80	5.23	Crop	Empty/Crop	1295	2361	77.71	0.28	4.50
4.75		250	4750	3.52	3.97	Crop	Empty/Crop	961	1195	63.14	0.38	4.75
5.00		250	5000	4.46	4.36	Crop	Empty/Crop	1294	1242	54.09	0.43	5.00
5.25		250	5250	3.75	4.44	Crop	Empty Land	887	1201	49.88	0.47	5.25
5.50		250	5500	3.71	3.59	Crop	Empty Land	806	759	43.47	0.59	5.50
5.75		250	5750	2.85	5.23	Crop	Empty Land	466	1338	39.70	0.58	5.75
6.00		250	6000	3.91	5.48	Empty/Crop	Empty Land	805	1473	40.66	0.54	6.00
6.25		250	6250	3.97	3.78	Empty/Crop	Empty/Resident	737	678	34.73	0.64	6.25
6.50		250	6500	3.72	4.12	Empty/Crop	Empty/Resident	627	747	33.55	0.60	6.50
6.75		250	6750	3.24	6.20	Empty Land	Empty/Resident	443	1367	28.89	0.68	6.75
7.00		250	7000	4.09	3.87	Empty Land	Empty/Crop	603	548	26.63	0.67	7.00
7.25		250	7250	3.13	4.70	Empty Land	Empty/Crop	359	719	25.12	0.65	7.25
7.50		250	7500	4.62	3.61	Crop	Empty Land	691	448	25.65	0.57	7.50
7.75		250	7750	3.64	5.08	Crop	Empty Land	435	780	24.12	0.61	7.75
8.00	Confluence	250	8000	4.53	2.62	Malakua+Nawaka	Empty/Resident	618	245	23.39	0.61	8.00
8.25		250	8250	4.42	5.16	Empty/Old river	Empty/Resident	519	683	20.87	0.56	8.25
8.50		250	8500	5.74	6.01	Empty/Old river	Resident	833	908	21.98	0.41	8.50
8.75		250	8750	5.84	6.48	Empty/Old river	Resident	788	957	19.81	0.47	8.75
9.00		250	9000	4.05	6.15	Empty/Old river	Resident	368	781	17.41	0.55	9.00
9.25		250	9250	5.75	4.22	Empty/Old river	Empty/Crop	633	360	16.36	0.47	9.25
9.50		250	9500	6.06	6.17	Town	Empty/Crop	664	687	16.54	0.27	9.50
9.75		250	9750	6.36	6.29	Town	Crop/Resident	695	681	15.76	0.28	9.75
9.83	Nadi Town Bridge / WL	80	9830	5.30	5.30	Town	Crop/Resident	481	481	15.26	0.31	9.83
10.00		170	10000	6.31	7.02	Town	Resident	688	844	15.81	0.28	10.00
10.25		250	10250	6.63	6.46	Empty/Town	Resident	730	695	15.03	0.34	10.25
10.50		250	10500	6.99	7.21	Empty/Town	Empty/Resident	636	676	12.21	0.23	10.50
10.75		250	10750	5.85	6.73	Empty/Town	Empty/Resident	441	578	11.85	0.25	10.75
11.00		250	11000	9.31	6.63	Town	Empty/Crop	1058	546	11.67	0.21	11.00
11.25		250	11250	17.83	6.95	Town	Empty/Crop	3745	594	11.46	0.25	11.25
11.50		250	11500	5.82	7.09	Resident	Empty/Crop	407	595	11.03	0.26	11.50
11.75		250	11750	6.35	6.90	Crop/Resident	Empty/Crop	476	559	11.16	0.18	11.75
12.00		250	12000	6.72	9.19	Crop/Resident	Empty/Crop	514	949	10.83	0.17	12.00
12.25		250	12250	8.25	6.10	Empty/Crop	Empty/Crop	754	419	10.56	0.20	12.25
12.50		250	12500	8.95	8.51	Empty/Resident	Empty/Crop	873	791	10.47	0.18	12.50
12.75		250	12750	8.72	8.00	Empty/Resident	Empty	810	685	10.17	0.21	12.75
13.00		250	13000	8.42	7.90	Empty/Crop	Empty	764	674	10.37	0.16	13.00
13.25		250	13250	6.77	9.62	Empty/Crop	Resident	473	942	9.82	0.17	13.25
13.50		250	13500	5.32	7.78	Crop	Empty	290	612	9.80	0.12	13.50
13.75		250	13750	7.33	8.74	Crop	Crop	525	743	9.49	0.11	13.75
14.00		250	14000	5.04	7.88	Crop	Crop	241	580	9.13	0.09	14.00
14.25		250	14250	6.51	8.51	Crop	Crop/Resident	378	649	9.05	-0.04	14.25
14.50		250	14500	9.88	9.92	Resident	Crop	866	873	8.97	-0.05	14.50
14.75		250	14750	6.55	8.82	Crop	Crop	360	660	8.72	-0.12	14.75
15.00		250	15000	10.62	10.56	Empty/Crop	Crop	959	948	8.90	-0.24	15.00
15.25		250	15250	8.29	11.19	Empty/Crop	Crop	554	1029	8.64	-0.28	15.25
15.50		250	15500	11.01	6.60	Crop	Empty/Crop	962	333	8.39	-0.30	15.50
15.75		250	15750	10.38	11.23	Crop	Resident	821	966	8.21	-0.38	15.75
16.00		250	16000	11.70	7.71	Resident	Empty	1033	424	8.39	-0.60	16.00
16.25		250	16250	11.30	7.91	Resident	Empty	929	428	8.35	-0.75	16.25
16.50		250	16500	6.85	8.45	Empty/Crop	Empty	299	476	8.03	-0.75	16.50
16.75	Namotomoto? Bridge	250	16750	5.20	5.20	Resident	Resident	148	148	7.85	-0.85	16.75
17.00		250	17000	8.26	11.98	Crop	Crop	419	953	7.81	-0.93	17.00
17.25		250	17250	8.77	11.79	Crop	Crop	464	892	7.58	-0.94	17.25
17.50		250	17500	7.70	11.47	Crop	Crop	327	795	7.18	-0.94	17.50
17.75		250	17750	9.22	12.54	Crop	Resident	487	961	7.24	-1.01	17.75
18.00		250	18000	7.33	11.63	Crop	Resident	283	801	7.11	-1.02	18.00
18.25		250	18250	9.34	6.59	Crop/Resident	Empty/Crop	484	213	7.22	-1.15	18.25
18.50		250	18500	6.94	7.92	Empty/Crop	Empty/Crop	232	322	7.52	-1.38	18.50
18.75	Back Road Bridge	250	18750	14.24	14.24	Crop	Crop	1184	1184	7.28	-1.48	18.75
19.00		250	19000	10.02	13.29	Crop	Resident	523	1009	7.40	-1.61	19.00
19.25		250	19250	9.71	9.90	Crop	Empty/Resident	460	482	7.24	-1.74	19.25
19.50		250	19500	10.98	17.60	Crop	Crop/Resident	592	1781	7.29	-1.96	19.50
19.75		250	19750	12.89	13.24	Crop	Crop	825	881	7.69	-2.54	19.75
20.00		250	20000	11.30	8.55	Crop	Crop	546	252	7.40	-2.71	20.00
20.25		250	20250	10.94	9.53	Crop	Empty/Crop	476	326	7.08	-2.74	20.25
20.50		250	20500	10.28	12.00	Crop	Empty/Crop	391	591	6.96	-2.79	20.50
20.75		250	20750	13.91	12.71	Crop/Resident	Empty/Crop	844	670	7.00	-2.92	20.75
21.00		250	21000	13.77	14.42	Crop/Resident	Empty/Crop	798	897	6.81	-2.95	21.00
21.25		250	21250	14.50	13.61	Crop/Resident	Crop	902	768	6.75	-2.94	21.25
21.50		250	21500	14.69	12.80	Crop/Resident	Crop	915	644	6.68	-2.98	21.50
21.75		250	21750	17.04	12.95	Resident	Crop	1303	649	6.74	-3.13	21.75
22.00		250	22000	11.51	10.25	Resident	Crop	455	327	6.70	-3.26	22.00
22.25		250	22250	12.39	15.76	Empty/Resident	Crop	546	1027	6.62	-3.31	22.25
22.50		250	22500	13.27	14.55	Empty/Resident	Crop	653	833	6.65	-3.36	22.50
22.75		250	22750	15.93	13.12	Empty/Crop	Crop	1015	599	6.91	-3.81	22.75
23.00		250	23000	12.60	14.08	Empty/Crop	Crop	527	722	6.94	-3.88	23.00
23.25		250	23250	14.23	12.24	Empty/Crop	Crop/Resident	722	469	6.86	-3.97	23.25
23.50		250	23500	13.17	17.84	Empty	Resident	563	1299	6.96	-4.18	23.50
23.75		250	23750	14.56	12.35	Empty	Crop	724	444	6.94	-4.35	23.75
24.00		250	24000	12.92	13.11	Empty/Resident	Crop	506	530	7.15	-4.51	24.00
24.25		250	24250	15.85	19.04	Crop	Crop	858	1420	6.93	-4.73	24.25
24.50		250	24500	12.75	16.24	Crop	Crop/Resident	436	908	7.05	-4.89	24.50
24.75		250	24750	18.60	16.03	Crop/Resident	Crop	1278	834	7.13	-5.22	24.75
25.00		250	25000	30.76	16.36	Hill	Crop/Resident	4673	883	7.20	-5.29	25.00
25.25	Confluence	250	25250	15.40	13.42	Namosi	Crop/Resident	715	462	7.01	-5.30	25.25
25.50		250	25500	19.00	19.21	Crop	Crop/Resident	1091	1125	5.83	-5.32	25.50
25.75		250	25750	14.82	27.19	Crop	Crop/Resident	502	2739	5.86	-5.57	25.75
26.00		250	26000	18.43	27.54	Crop	Resident	945	2792	5.89	-5.76	26.00
26.25		250	26250	26.45	18.85	Crop/Resident	Crop	2532	988	6.17	-6.20	26.25
26.50		250	26500	19.22	17.73	Crop	Crop	1011	790	6.14	-6.38	26.50
26.75		250	26750	20.23	25.28	Crop	Crop/Resident	1168	2187	6.22	-6.53	26.75
27.00		250	27000	14.16	21.33	Crop/Resident	Empty/Resident	339	1338	6.42	-6.89	27.00
27.06	Votualevu WL	60	27060	12.60	20.77	Crop/Resident	Empty/Resident	205	1227	6.42	-6.94	27.06
27.25		190	27250	32.84	20.22	Crop/Resident	Crop/Resident	4243	1097	6.44	-7.17	27.25
27.50		250	27500	23.71	16.23	Crop/Resident	Crop/Resident	1750	497	6.82	-7.69	27.50
27.75		250	27750	25.66	21.22	Crop/Resident	Crop/Resident	2197	1235	6.98	-7.92	27.75
28.00		250	28000	19.22	19.35	Crop	Crop/Resident	856	876	7.07	-8.22	28.00
28.25		250	28250	33.57	22.18	Crop	Empty/Crop	4622	1380	7.33	-8.45	28.25
28.50		250	28500	46.71	22.05	Empty Land	Empty/Crop	10611	1308	7.35	-8.71	28.50
28.75		250	28750	25.62	30.30	Empty Land	Crop/Resident	2055	3366	7.35	-8.90	28.75

Table 5.3-17 List of Discharge Capacity (Nawaka River, Malakua River, and Namosi River)

■: LiDAR survey data is used for Bank height
■: LiDAR survey data is used for River channel (No River survey data)

Cross Section	Remarks	Interval	Cumulative Distance	①Bank Height		Land Use @ 50-100m from the bank		Discharge Capacity at Bank Height ①		H-Q Formula $Q=a\times(h+b)^2$		Cross Section
		(m)	(m)	Left Bank	Right Bank	Left Bank	Right Bank	Left Bank	Right Bank	a	b	
Nawaka River												
0.00		0	0	4.57	4.52	Empty Land	Empty Land	93	9999	3.45	0.61	0.00
0.25		250	250	4.55	3.73	Crop	Empty Land	92	9999	3.46	0.61	0.25
0.50		250	500	4.05	5.19	Crop	Empty Land	75	9999	3.45	0.60	0.50
0.75		250	750	3.68	5.37	Crop	Resident	63	122	3.48	0.56	0.75
1.00	Navu Bridge	250	1000	4.22	4.22	Crop	Empty Land	79	79	3.45	0.57	1.00
1.25		250	1250	7.35	4.35	Resident	Empty Land	216	83	3.45	0.56	1.25
1.50	Confluence	250	1500	4.30	3.76	Empty Land	Empty Land	80	63	3.45	0.53	1.50
1.75		250	1750	4.69	5.00	Empty/Crop	Empty Land	54	60	1.99	0.50	1.75
2.00	Qeleloa Bridge	250	2000	5.34	5.34	Resident	Resident	68	68	1.98	0.50	2.00
2.25		250	2250	6.41	5.56	Empty Land	Resident	94	72	1.98	0.49	2.25
2.50		250	2500	7.65	4.07	Empty Land	Empty Land	130	40	1.99	0.43	2.50
2.75		250	2750	6.59	7.85	Empty Land	Crop	97	135	2.06	0.26	2.75
3.00		250	3000	4.98	5.10	Crop	Empty/Crop	51	53	2.42	-0.39	3.00
3.25		250	3250	6.96	7.33	Crop	Resident	100	113	2.91	-1.08	3.25
3.50		250	3500	7.51	7.45	Crop	Crop	119	117	2.89	-1.10	3.50
3.75		250	3750	7.24	7.49	Crop	Empty/Crop	108	117	2.89	-1.11	3.75
4.00		250	4000	9.09	7.00	Crop	Crop	183	98	3.03	-1.32	4.00
4.25		250	4250	7.65	9.80	Resident	Resident	119	218	3.25	-1.60	4.25
4.50		250	4500	10.26	8.79	Crop/Resident	Crop/Resident	242	166	3.28	-1.68	4.50
4.75		250	4750	10.37	9.58	Crop	Crop/Resident	244	201	3.38	-1.87	4.75
5.00		250	5000	9.78	10.38	Crop	Resident	208	242	3.49	-2.06	5.00
5.25		250	5250	11.18	13.15	Crop	Resident	285	423	3.51	-2.16	5.25
5.50		250	5500	11.87	11.15	Crop	Crop	340	288	4.16	-2.83	5.50
5.75		250	5750	11.01	11.11	Crop	Crop	295	303	5.52	-3.70	5.75
6.00		250	6000	11.66	12.87	Empty/Crop	Empty/Crop	339	452	5.56	-3.86	6.00
6.25		250	6250	12.55	10.52	Empty/Crop	Resident	412	237	5.82	-4.14	6.25
6.50		250	6500	12.29	12.48	Empty/Crop	Resident	401	421	6.76	-4.58	6.50
6.75	6.70k Retention Dam	250	6750	13.46	13.38	Empty/Crop	Empty/Crop	527	517	7.49	-5.07	6.75
7.00		250	7000	12.82	13.18	Empty/Crop	Resident	447	491	8.13	-5.41	7.00
7.25		250	7250	15.52	14.31	Empty/Crop	Resident	790	608	8.08	-5.63	7.25
7.50		250	7500	16.22	15.35	Empty/Crop	Resident	892	752	7.99	-5.65	7.50
7.75		250	7750	16.85	19.98	Empty/Crop	Empty/Crop	968	1585	7.72	-5.65	7.75
8.00		250	8000	13.73	16.23	Crop	Empty Land	460	792	7.18	-5.73	8.00
8.25		250	8250	15.92	15.85	Empty/Crop	Resident	837	825	9.11	-6.33	8.25
8.50		250	8500	13.15	18.80	Empty/Crop	Resident	474	1771	12.91	-7.09	8.50
9.00		500	9000	11.31	15.61	Empty/Crop	Empty/Crop	9999	1405	26.36	-8.31	9.00
9.50		500	9500	17.92	24.54	Empty/Crop	Empty/Crop	1433	4248	17.03	-8.75	9.50
10.00		500	10000	19.33	35.68	Empty/Crop	Empty/Crop	1513	9861	13.65	-8.80	10.00
										17.49	-9.95	
Malakua River												
0.00		0	0	3.67	3.07	Crop	Empty Land	26	19	1.45	0.58	0.00
0.25		250	250	4.88	6.22	Empty Land	Crop	43	67	1.46	0.56	0.25
0.50		250	500	4.14	5.23	Empty/Crop	Empty/Crop	32	48	1.47	0.49	0.50
0.75		250	750	6.11	4.98	Resident	Empty/Crop	63	43	1.48	0.45	0.75
1.00		250	1000	5.05	5.75	Crop	Empty/Crop	44	56	1.47	0.42	1.00
1.25		250	1250	5.86	5.44	Crop	Crop	57	50	1.46	0.40	1.25
1.50		250	1500	5.55	5.92	Empty/Crop	Crop	51	58	1.49	0.31	1.50
1.75		250	1750	7.51	7.34	Crop	Crop	90	86	1.53	0.16	1.75
2.00		250	2000	8.16	7.54	Resident	Crop	105	90	1.57	0.01	2.00
2.25		250	2250	7.73	7.03	Empty/Crop	Empty/Crop	92	75	1.66	-0.28	2.25
2.50		250	2500	7.58	5.97	Crop/Resident	Crop/Resident	86	52	1.67	-0.39	2.50
2.75		250	2750	13.36	5.96	Resident	Empty/Crop	286	50	1.77	-0.65	2.75
3.00		250	3000	4.75	5.53	Empty/Crop	Empty/Resident	27	39	1.87	-0.95	3.00
3.25		250	3250	8.14	7.95	Crop	Empty/Resident	94	89	2.07	-1.38	3.25
3.50		250	3500	5.21	6.29	Empty/Crop	Empty/Crop	25	45	2.46	-2.00	3.50
3.75	3.87k Vunayasi Bridge	250	3750	6.33	6.33	Crop	Empty/Crop	43	43	2.53	-2.19	3.75
4.00		250	4000	7.75	7.55	Crop	Resident	74	69	2.64	-2.45	4.00
4.25		250	4250	9.34	8.31	Crop	Crop	119	85	2.61	-2.59	4.25
4.50		250	4500	7.72	9.30	Crop	Crop	65	113	2.72	-2.84	4.50
4.75		250	4750	9.25	9.39	Empty/Crop	Crop	103	109	3.40	-3.74	4.75
5.00		250	5000	10.99	7.90	Crop/Resident	Crop	164	42	4.19	-4.73	5.00
5.25		250	5250	9.46	10.58	Crop/Resident	Crop/Resident	86	134	4.27	-4.98	5.25
5.50		250	5500	9.87	9.37	Crop	Crop	87	69	4.20	-5.32	5.50
5.75		250	5750	10.37	11.36	Crop/Resident	Crop	104	155	5.16	-5.88	5.75
6.00		250	6000	10.95	19.50	Crop	Crop/Resident	127	1023	5.88	-6.31	6.00
6.25		250	6250	13.15	11.11	Crop/Resident	Empty/Crop	252	121	5.74	-6.52	6.25
6.50		250	6500	10.65	11.97	Empty Land	Empty Land	81	142	4.99	-6.63	6.50
6.75		250	6750	18.97	12.14	Empty Land	Empty Land	724	142	4.80	-6.69	6.75
7.00		250	7000	12.23	12.36	Empty Land	Empty/Crop	136	142	4.59	-6.79	7.00
7.25		250	7250	12.25	13.42	Resident	Empty/Crop	123	184	4.46	-6.99	7.25
7.50		250	7500	17.28	27.15	Resident	Empty/Crop	445	1784	4.59	-7.44	7.50
7.75		250	7750	18.15	14.30	Empty/Crop	Empty/Crop	535	202	5.37	-8.16	7.75
8.00		250	8000	22.10	27.66	Empty Land	Empty Land	953	1886	5.11	-8.44	8.00
Namosi River												
0.00		0	0	17.13	14.67	Empty/Crop	Crop	114	72	0.82	-5.30	0.00
0.25		250	250	16.31	16.72	Crop	Crop	99	107	0.82	-5.30	0.25
0.50	Bridge	250	500	17.10	15.43	Crop	Crop	114	84	0.82	-5.31	0.50
0.75		250	750	35.58	16.08	Resident	Crop	751	95	0.82	-5.33	0.75
1.00		250	1000	14.35	15.38	Crop/Resident	Crop	63	80	0.89	-5.92	1.00
1.25		250	1250	26.10	18.21	Hill	Crop	376	133	0.99	-6.61	1.25
1.50		250	1500	17.16	14.14	Crop/Resident	Empty/Crop	9999	55	1.01	-6.76	1.50
1.75		250	1750	18.40	33.73	Crop	Hill	135	9999	1.17	-7.67	1.75
2.00		250	2000	17.81	19.84	Crop	Hill	113	9999	1.63	-9.49	2.00
2.25		250	2250	30.89	38.56	Resident	Empty/Crop	795	1494	1.85	-10.18	2.25
2.26	Mulomulo WL	10	2260	22.41	18.30	Resident	Empty/Crop	277	122	1.85	-10.17	2.26
2.50		240	2500	21.13	17.38	Crop	Crop	230	86	2.48	-11.51	2.50
2.75		250	2750	27.35	20.65	Crop	Crop	643	205	2.72	-11.96	2.75
3.00		250	3000	19.26	23.87	Crop	Crop	139	390	3.00	-12.46	3.00
3.25		250	3250	23.49	28.27	Crop	Crop	363	751	3.06	-12.59	3.25
3.50		250	3500	24.43	19.92	Crop	Crop	423	160	3.10	-12.74	3.50
3.75		250	3750	22.51	26.44	Crop	Resident	294	583	3.16	-12.85	3.75
4.00		250	4000	28.26	19.46	Crop/Resident	Resident	807	129	3.76	-13.61	4.00
4.50		500	4500	29.89	25.58	Crop	Empty Land	1685	768	9.57	-16.62	4.50
5.00		500	5000	28.75	24.32	Crop/Resident	Empty Land	1739	577	15.93	-18.30	5.00

5.4 Setting of Design Scale

5.4.1 Setting of Design Scale

(1) Basic Concept

Design scale determines the magnitude of safety against flood in the area. Based on the degree of importance of the rivers, it is preferable to secure the balance between upstream and downstream, and main river and tributaries. Also, it should be maintained in the same quality in the national level.

Importance of a river shall be set based on the purpose of protection plan, size of basin, social and economic importance of basin, envisioned disaster damages in magnitude and quality, historical record of disaster and so on.

Especially in an area experienced severe damage in the past, it is not recommendable to set a design scale without consideration of historical flood event conditions. In generally, the design scale should be determined basically to prevent from disaster of which scale is equal to the experienced disaster.

The basic concept is indicated above, but in Fiji, there is no experience of flood control project with adequate design scale determination. Therefore, setting of design scale in this Project is to be based on the evaluation of historical flood scale.

(2) Occurrence Probability of Past Flood

Table 5.4-1 shows occurrence probability at the Nadi Town Bridge point of top five (5) floods. The occurrence probability of these floods is approximately 1/20 to 1/50 (meaning once in 20 years to 50 years)

The occurrence probability of the biggest flood which occurred in March, 2012 is approximately 1/50. The occurrence probability of second largest flood which occurred in January, 2009 is 1/30.

Table 5.4-1 Occurrence Probability of Major Flood (at Upstream of Nadi Town Bridge)

Date	Rainfall Depth	Return Period
2012/3/29	483 mm/2day	approximately 1/50
2009/1/9	442 mm/2day	approximately 1/30
1972/10/23	405 mm/2day	approximately 1/20
1999/1/18	404 mm/2day	approximately 1/20
1993/2/26	400 mm/2day	approximately 1/20

(3) Setting of Design Scale

It is important for the public security to set the flood in March, 2012 which caused historical maximum damage to the basin as target flood. Therefore, the design scale for the Master Plan is to be set to the flood scale equivalent to historical maximum flood. The scale is approximate 1/50 in occurrence probability, equivalent to the flood in March, 2012.

(4) Comparison with the Design Scale in 1998 Study

1) Comparison with the Evaluation Indicator in 1998 Study

In the JICA Study in 1998, catchment area, inundation area, and population, residential area, value of property in potential inundation area, are set to be indicators for evaluation of the importance of basin. In the study in 1998, design scale for long term plan was decided as 1/50 (refer to Table 5.4-2).

Table 5.4-2 Design Scale in the 1998 Study

Item		Nadi Index Value
Catchment Area (km2)		516
Inundation Area (ha)		3,050
Inundation Area	Residential Area (ha)	120
	Population (1,000 persons)	11.1
	*Property (10^3)	59
	*Industrial Product (10^3)	3.5
Return Period of Determined Design Flood		1/50

*Value devided by GDP per capita

The indicators of the importance of basin for 2014 are as shown in Table 5.4-3. According to the Table, population become four (4) times, residential area become 5.5 times in the potential inundation area compared to the value in 1998.

From the point of view of the importance of basin decided in 1998, it is desirable to secure more than 1/50 in design scale even at present.

Table 5.4-3 Evaluation Indicators in Nadi River Basin

Item		Nadi (1998)		Nadi (2014)	
		Index Value	Return Period	Index Value	Return Period
Catchment Area (km2)		516	1/70	516	1/70
**Inundation Area (ha)		3,050	1/70	4,550	1/70
Inundation Area	Residential Area (ha)	120	1/50	660	1/50
	Population (1,000 persons)	11.1	1/30	41.2	1/50
	*Property (10^3)	59	1/50	324	1/70
	*Industrial Product (10^3)	3.5	1/30	19.2	1/50

*Value devided by GDP per capita
**Based on the record of flood in March, 2012
Value converted based on the residential area ratio between 1998 and 2014

5.4.2 Setting of Design Control Point

(1) Basic Concept

Design control point is the point to determine the design scale which the most important indicator for flood protection plan. It should be set at the place which can obtain enough hydro meteorological records and which is to be the base point in consideration of hydro meteorological analysis.

The design control point is suitable at points such as “Upstream of flood protection area such as urban area near a river mouth”, “a point or branch river which have water level gauge for a basis of the plan” and “a point of flood control facilities such as dam” . In case of set a design control point in a tributary, it is require to select a point of without influence from back water of Main River.

In the integrated planning of flood control in the basin, it is desirable to select important points in planning besides design control point.

1 Design Control Point

Design Control Point is a point of determining a design scale for the most important flood protection area. In the basin, one (1) design flood control point is to be determined considering distribution of population and property, topographic characteristics and inundation condition. It is desirable to be selected at just upstream or near from flood protection area such as important urban area. Also, it is required to be selected at the point where enough records of water level and discharge can be obtained.

2 Important Point

Important Point is suitable point for development of distribution of design high-water discharge. Also, it is to be a point of confluence of tributaries or a point of change in discharge distribution for diversion.

In a plan for main river, a dam point is treated as same as important point. However in case of the dam, the point is treated as design control point.

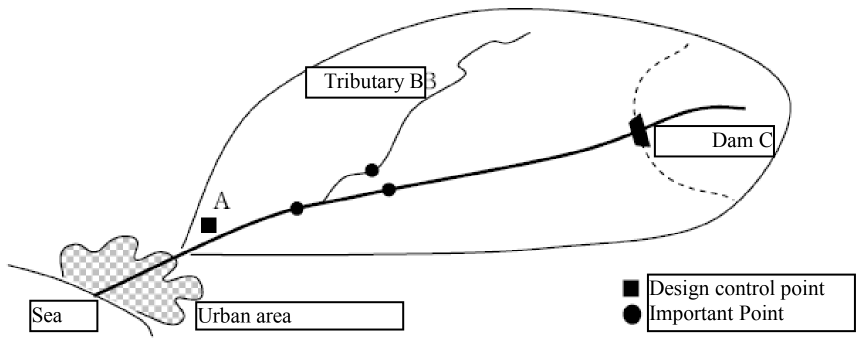


Figure5.4-1 Setting of Design Control Point and Important Point

(2) Setting of Design Control Point

1) Candidate Control Point and its Evaluation

a) Target area of flood protection

The following areas are designated as flood protection area in the potential inundation area

- Nadi Town where the center for sightseeing and commerce
- Nadi Airport and its access roads which are important facilities

The Nadi Town Council has a plan to expand the area of Nadi Town. In the future, the Nadi Town will develop more.

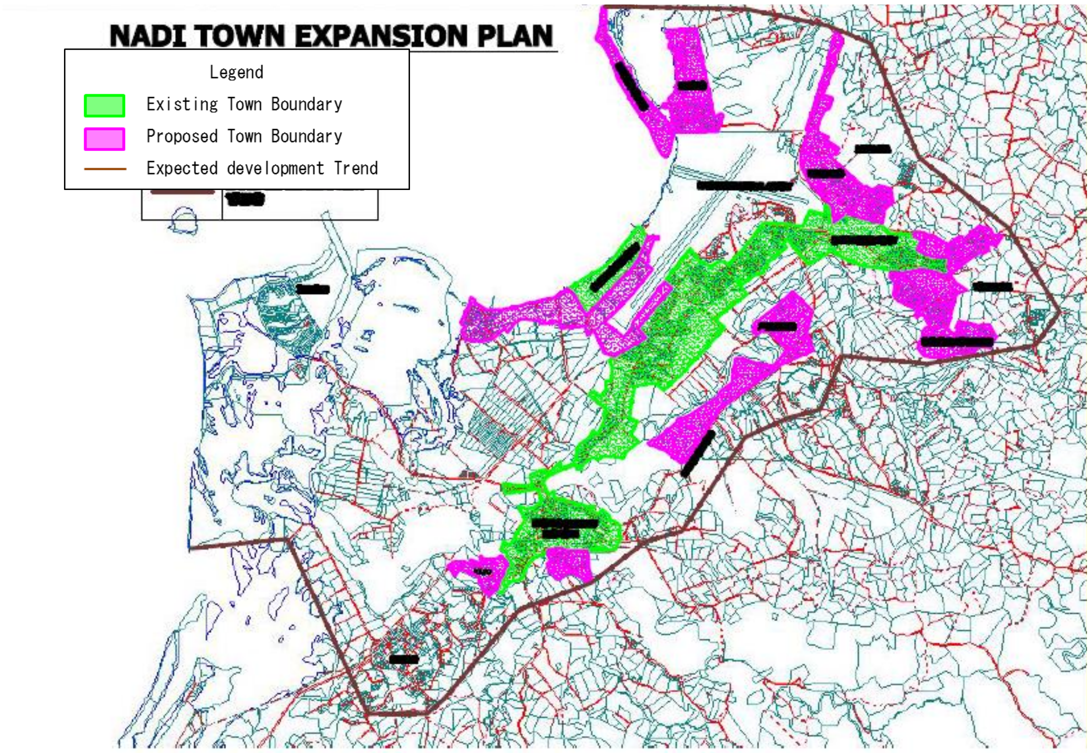


Figure5.4-2 Expansion Plan of Nadi Town

2) Candidate control point

The following four (4) points are considered as candidates for the design control points of Nadi River.

a) Criteria of control point

- A point at upstream of short distance from or near flood protection area.
- A point or tributary with water level gauge for basis of the planning
- A point for main area of hydro meteorological analysis

a) Candidate control point

・Nadi Town Bridge: the point at water level station

・Back Road Bridge: the point at the bridge, the downstream of confluence of Namosi River

・Votualevu: the point at water level station, the upstream of confluence of Namosi River

・Namulomulo: the point at water level station, in Namosi River

The Nawaka tributary meets Nadi River at the downstream of Nadi Town; therefore, the point in the Nawaka River is excluded from the candidate control point of main stream.

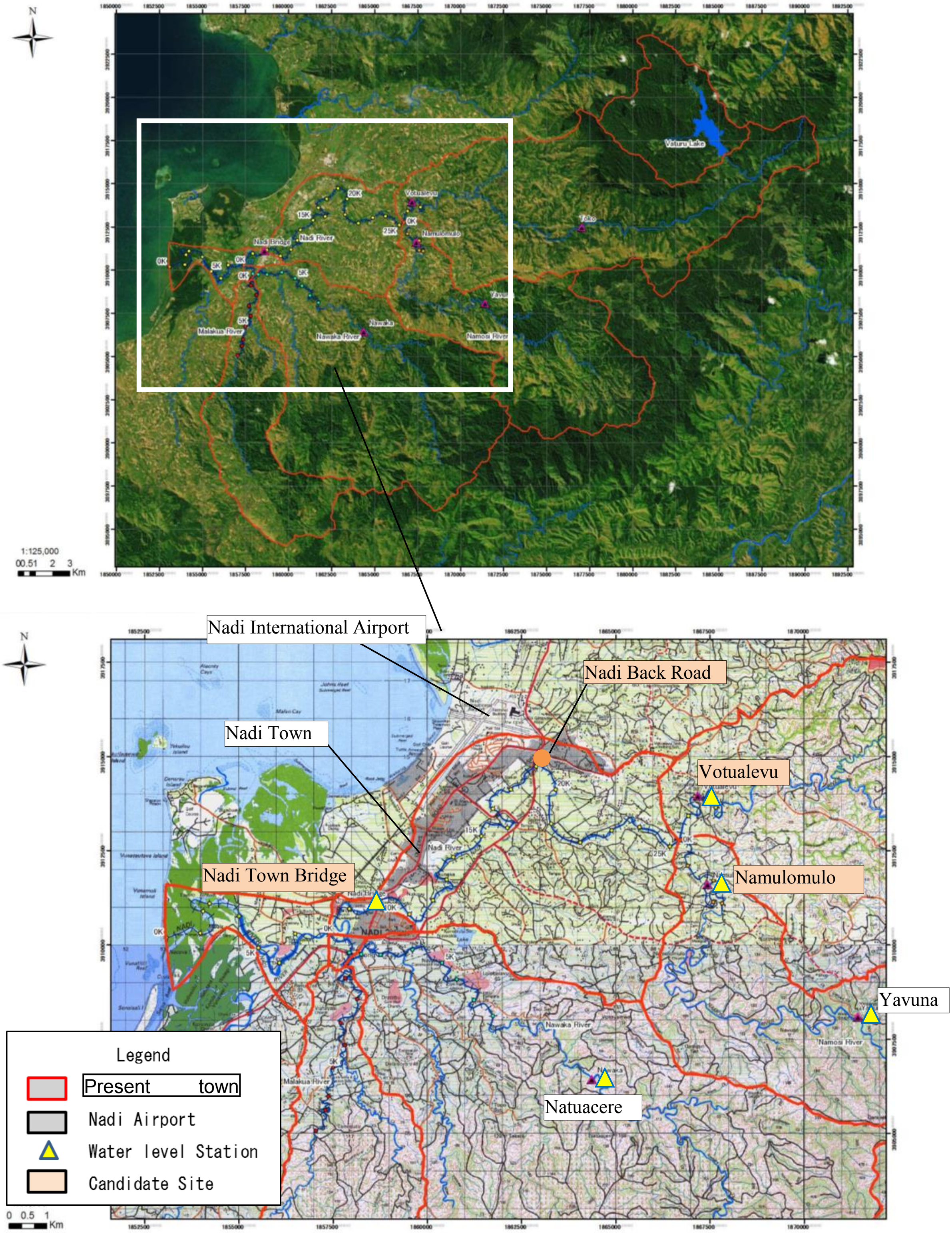


Figure5.4-3 Flood Protection Area and Candidate site of Design Control Point

b) Evaluation of candidate point

The candidate sites of design control point are evaluated based on the relationship among topographic characteristics, inundation characteristics and flood protection area, and accumulation of records of water level and discharge. And also adequacy of the measurement point of water level and discharge, and future continuity of observation are evaluated.

The result of evaluation is shown in Table 5.4-4.

For the design control pint, the point of Back Road Bridge is suitable, however the accumulation of water level records is not enough, and therefore the Nadi Town Bridge point is to be selected as design control point in the Project, because of enough records of water level.

It is desirable to install the water level station and accumulate the water level record at the Back Road Bridge point which will be changed to the design control point in the future.

Design Control Point : Nadi Town Bridge, water level station

Important Point : Back Road Bridge

Votualevu: water level station, upstream of Namosi River confluence

Namulomulo water level station, Namosi River

Table 5.4-4 Comparison of Design Control Point

Candidate point	Nadi town Bridge	Back road Bridge	Votualevu	Namulomulo
Name of River	Nadi River	Nadi River	Nadi River	Namosi River
Watershed Area	316	290	184	92
Percentage of own catchment area in the Nadi River Basin	61%	56%	36%	18%
Physical feature	Low-lying land	Low-lying land	Hilly area	Hilly area
	This point is located downstream of the confluence of Namosi River and the percentage of own catchment area is approximately 60%	This point is located downstream of the confluence of Namosi River and the percentage of own catchment area is approximately 60%	This point is located upstream of the confluence of Namosi River and the percentage of own catchment area is approximately 30%	This point is located upstream of the confluence of Nadi River and the percentage of own catchment area is approximately 20%
	○	○	△	△
Flood feature	Flow along the river / Wide spread	Flow along the river	Flow along the river	Flow along the river
	Impact of flood occurred in upstream is relatively high than the candidate point at Back Road Bridge	Impact of flood occurred in upstream is relatively high than the candidate point at Votualevu	Impact of flood occurred in upstream will be along the river and an affected area will be narrow	Impact of flood occurred in upstream will be along the river and an affected area will be narrow
	△	△	○	○
Upstream or near the target protection area	Upstream of Nadi Town and downstream of the Nadi Airport	Upstream of the Nadi Town and the Nadi Airport	Upstream of the Nadi Town and the Nadi Airport	Upstream of the Nadi Town and the Nadi Airport
	○	◎	◎	◎
Compiled hydrological data	There are compiled water level data approximately for 11 years since 1997	No existing water level data Water level is now observed with simplified water level gauge	There are compiled water level data approximately for 25 years since 1978	There are compiled water level data approximately for 4 years since 2011
	○	△	○	△
Appropriateness of the observation station for water level and flow discharge	- Appropriate flow discharge cannot be observed since this point is located in the tidal area - Flow discharge survey is possible at a bridge using rotameter	- This point is located upstream of tidal area - Flow discharge survey is possible at a bridge using rotameter	- This point is located upstream of tidal area - Contactless flowmeter such as ultrasonic flowmeter is preferable since flow discharge survey using rotameter is unsuitable	- This point is located upstream of tidal area - Contactless flowmeter such as ultrasonic flowmeter is preferable since flow discharge survey using rotameter is unsuitable
	×	○	△	△
Sustainability of observation	Sustainability is secured since this point is used as a control point of issuing of flood warning. Temporal relocation is required if river improvement is implemented.	Sustainability of observation is secured since there is no plan for reconstruction of bridge. Even though, installation of new equipment is required.	Sustainability is secured since this point is used as a control point of issuing of flood warning. Temporal relocation is required if river improvement is implemented.	Sustainability is secured. Temporal relocation is required if river improvement is implemented.
	○	○	○	○
Control point of issuing of flood warning	Yes	No	Yes	No
	○	△ Location is considered as preferable since its location is upstream of tidal area and downstream of the Namosi River	○	△
Evaluation	- Hydrological data has been accumulated for long term - It is located near or upstream of target protection area - Its catchment area is approximately 60% Considering above conditions, this point is considered as a "Design Control Point".	- Hydrological observation has not been observed - It is located upstream of tidal area and target protection area - Its catchment area is approximately 60% Considering above conditions, this point is considered as an "Important Point". This point can be preferable for control point in the future after the accumulation of hydrological data for long term.	- Hydrological data has been accumulated for long term - It is located far upstream of target protection area - Its catchment area is approximately 30% Considering above conditions, this point is not preferable for control point but considered as an "Important Point".	- Hydrological data has been accumulated for 4 years - It is located far upstream of target protection area - Its catchment area is approximately 20% Considering above conditions, this point is not preferable for control point but considered as an "Important Point".

◎: Preferable, ○: Good, △: Fair, ×: Not preferable

3) Setting of Design Control Point

Location of the Design Control Point of Nadi River Basin is "the point of Nadi Town Bridge (Nadi Town Bridge Water Level Station" in Nadi Main River. The reasons of selection are shown below.

The point is located in the tidal area, so that it is better to reconsider the handling of this point after accumulation of hydrological data in the upper points.

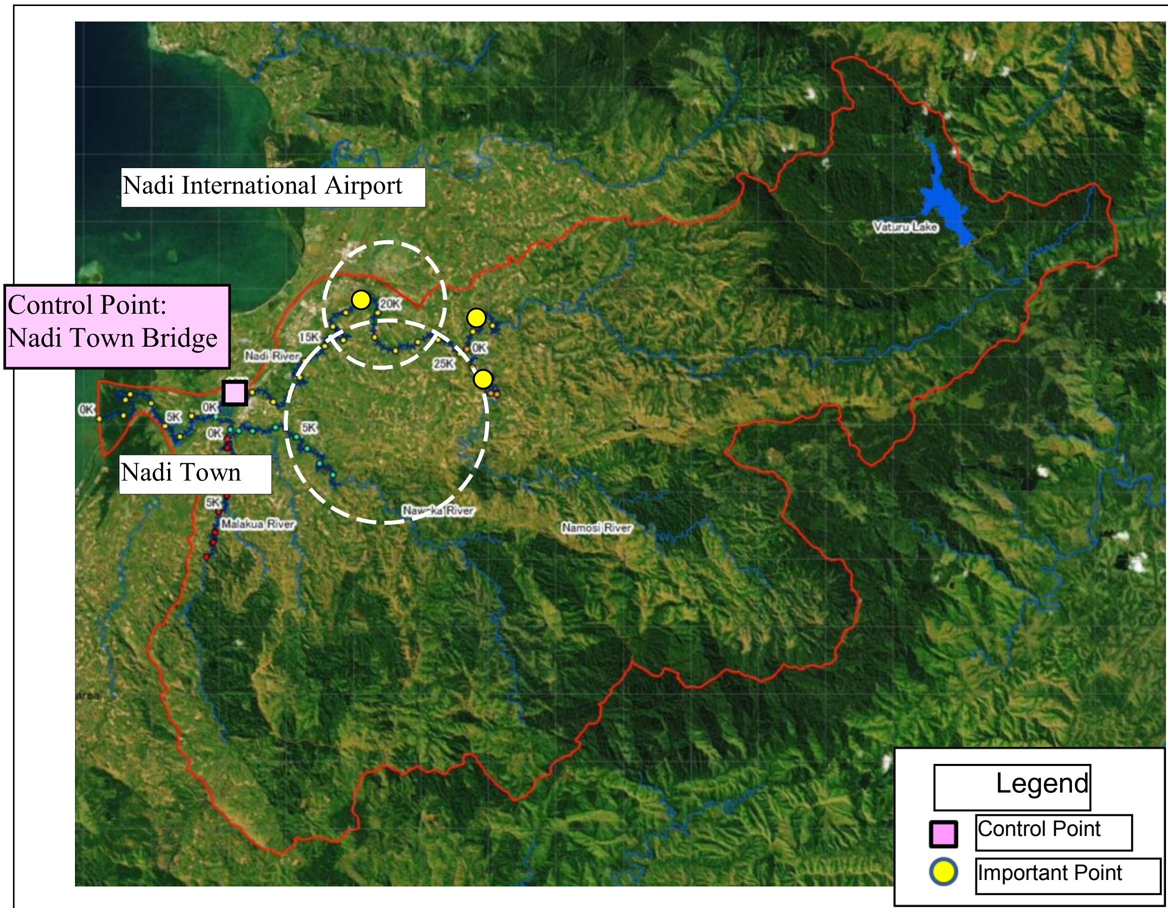
0 The point locates upstream of urban area (Nadi Town) where is the area with concentration of population and property in inundation area.

1 The point locates near the important facility(Nadi International Airport)

2 The point is control point for flood fighting warnings.

3 The point has enough hydrological records and secured the future observation continuity

4 The basin area at Nadi Town Bridge is approximate 316km^2, 60 % of the Nadi River Basin.



Source: JICA Study Team

Figure 5.4-4 Locations of Design Control Point and Important Point

5.5 Setting of Design Hyetograph

The design hydrograph is selected from hydrographs which are stretched from actual rainfall to design rainfall. At the selection of hydrograph, the too much extended cases in short term rainfall (focus on the extended rate) and local distribution of rainfall are rejected.

The groups of design hydrographs are selected as follows.

5.5.1 Primary Selection of Group of Design Hyetograph

As to the primary selection for design hydrograph, major 26 floods with enough hourly rainfall data after 1991 are selected (refer to Table 5.5-5).

5.5.2 Secondary Selection of Group of Design Hyetograph

From the two (2) points of view, secondary selection had been conducted to select design hyetograph.

Rejection Criteria 1: Rejection by stretch rate to the design scale

The scale of the deign flood is determined as same as the historical maximum flood in March, 2012 of which occurrence probability is approximately 1/50, and the hyetographs of which stretch rate is more than two times of design rainfall which is 483.1mm of two (2) days rainfall are rejected.

Rejection Criteria 2: Rejection by local distribution of rainfall

In case that the rainfall during design continuity of two (2) days extends the Jackknife upper limit after stretching, the hyetographs is rejected. Jackknife upper limit and estimated value are as shown below.

Table 5.5-4 Jackknife Upper Limit and Estimated Value

Basin	Design scale of occurrence probability	Design rainfall duration	Adopted probability distribution	Jackknife estimated values (mm)		
				① Estimated	2 Margin of error	①+② Upper Limit
Nadi River Basin (upstream of Namosi River Confluence)	1/50	2days	GEV	582.6	45.1	627.7
Namosi River Basin	1/50	2days	LP3Rs	501.0	41.5	542.7

Rejection Criteria

5.5.3 Selection of Design Hyetograph

According to the rejection criteria shown above, six (6) floods 7th March, 1997, 18th January, 1999, 9th January, 2009, 13th January, 2009, 23rd January, 2012, 29th March, 2012 were selected.

The result of selection of design hyetograph is shown in Table 5.5-5, the design hyetographs are shown in Figure 5.5-1.

Table 5.5-5 List of Design Hydrograph

Date time (dd/mmm/yy)	Cause	Rejection Criteria 1			Rejection Criteria 2						Final Evaluation
		Precipitation in 2 days @ Catchment of Nadi Town Bridge	Stretch Rate	Evaluation	Precipitation in 2 days @ Catchment of Confluence of the Nawaka River	Precipitation after stretch	Evaluation	Precipitation in 2 days @ Catchment of the Namosi River	Precipitation after stretch	Evaluation	
24-Jan-97	T.C Evan	137.9	3.504	Rejection	108.1	379.0		186.5	653.6	Rejection	
30-Jan-97	T.D	123.3	3.920	Rejection	112.4	440.5		135.1	529.4		
7-Mar-97	T.C Gavin	373.8	1.292		479.0	619.0		181.9	235.1		○
18-Jan-99	T.D	404.2	1.195		373.6	446.5		435.2	520.1		○
3-May-00	L.P	77.9	6.204	Rejection	58.2	361.3		108.1	670.5	Rejection	
6-Dec-00	T.D	140.8	3.430	Rejection	166.3	570.4		110.4	378.8		
11-Dec-00	T.D	140.9	3.430	Rejection	147.9	507.4		122.3	419.4		
14-Mar-01	N/R	117.1	4.124	Rejection	121.7	502.0		131.5	542.3		
21-Oct-01	L.P	166.7	2.898	Rejection	158.7	460.0		169.0	489.8		
23-Feb-02	T.D	209.4	2.307	Rejection	248.3	572.8		151.0	348.3		
11-Mar-03	T.C Eseta	217.9	2.217	Rejection	246.0	545.4		187.2	415.1		
18-Apr-05	L.P-Monsoonal Trough	202.2	2.389	Rejection	199.1	475.5		226.6	541.2		
11-Feb-07	L.P	191.5	2.522	Rejection	155.4	391.9		294.0	741.6	Rejection	
24-Mar-07	T.D	183.8	2.628	Rejection	233.7	614.1		126.7	333.0		
28-Jan-08	T.C Gene	343.7	1.406		465.9	654.9	Rejection	162.1	227.9		
24-Feb-08	SPCZ	70.0	6.898	Rejection	20.7	142.7		147.5	1017.8	Rejection	
28-Mar-08	N/R	69.0	7.003	Rejection	60.3	422.4		79.3	555.4	Rejection	
28-Nov-08	L.P	119.1	4.057	Rejection	132.9	539.2		111.3	451.3		
9-Jan-09	T.D	442.0	1.093		460.5	503.4		429.9	469.8		○
13-Jan-09	T.D	245.9	1.965		266.9	524.4		222.9	438.0		○
18-Feb-11	N/R	157.5	3.068	Rejection	151.6	465.2		157.7	483.8		
5-Jan-12	N/R	136.1	3.549	Rejection	107.5	381.4		182.8	648.9	Rejection	
23-Jan-12	T.D	309.6	1.560		330.2	515.2		222.5	347.1		○
29-Mar-12	TD	483.1	1.000		481.6	481.7		512.9	512.9		○
29-Jan-14	L.P	191.1	2.528	Rejection	180.4	456.1		205.7	520.1		

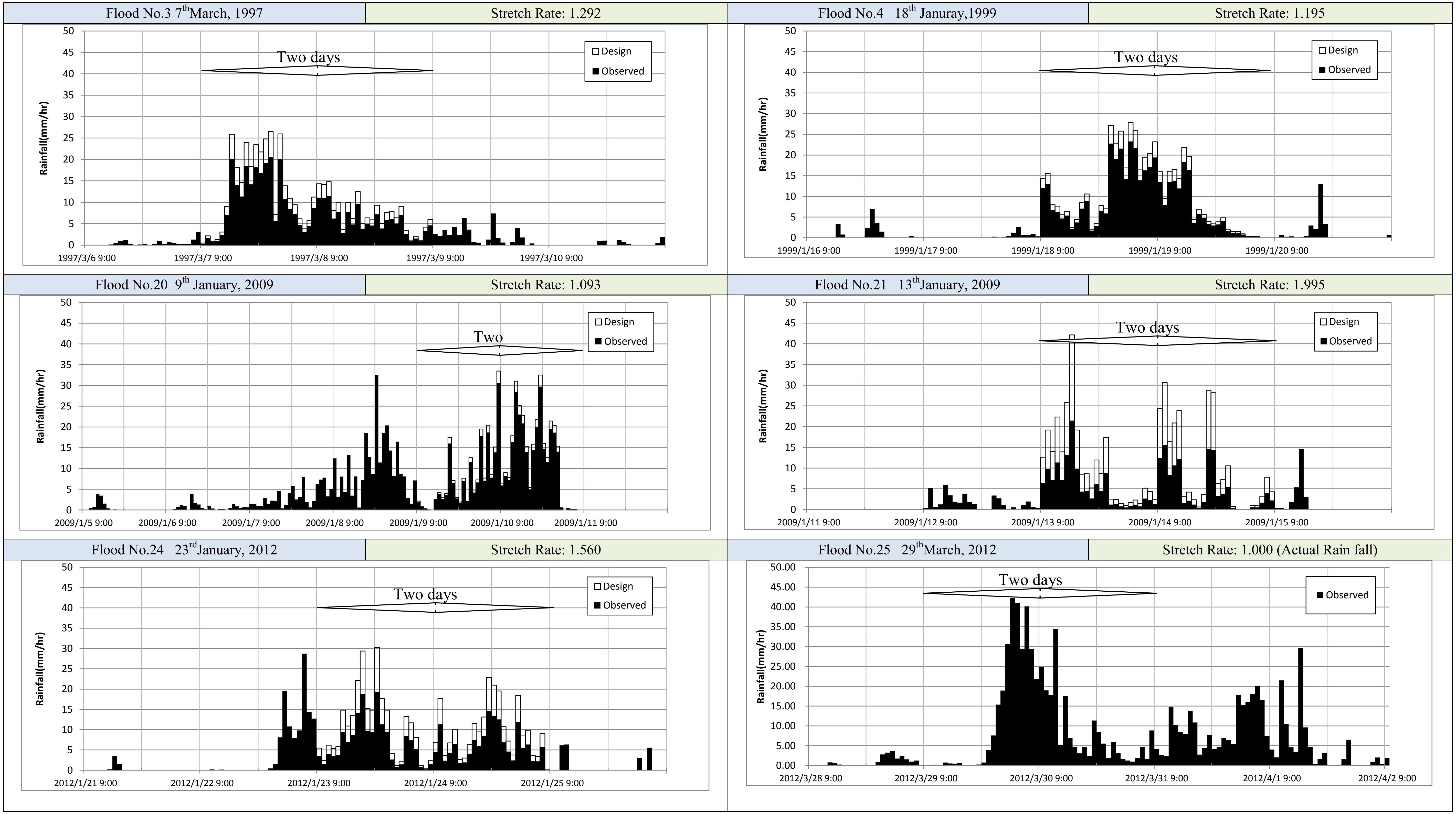


Figure 5.5-1 Hyetographs of Design Rainfalls

5.5.4 Estimation of Probable Rainfall Considering the Effect of Climate Change

(1) Valuation of Precipitation by Climate Change

Intergovernmental Panel on Climate Change (IPCC) evaluates the climate changes form scientific and social economic aspects and issues Assessment Report every 5-7 years. In 2014, 5th Assessment Report (AR5) have been approved and published.

In the AR5, island countries including Fiji, visions and challenges for adaptation against major risks are described as follows;

- ✓ The interaction between mean sea level rising and high water phenomenon in the 21 century intimidates lowland area along sea shore. (high in certainty)
- ✓ If a coastal area is large compared with inland area, measures for adaptation are major issues in financial and resources aspects for island countries.
- ✓ Alternatives for adaptation, maintain and recreation of coastal topography and ecosystem, improvement of fresh water resources, and appropriate building standards and pattern for habitat, are selectable.

Official opinions and documents based on AR5 are not issued form Fiji and its organizations. The results of climate change variation in AR4 are shown in Table 5.5-6, Figure 5.5-2 and Figure 5.5-3. According to the results, it is predicted that the occurrence probability of more than 200mm/day precipitation is increasing and occurrence of sea level rise is decreasing. Regarding annual rainfall, it is predicted that will be increasing 21% by 2055 and decreasing 16% by 2090.

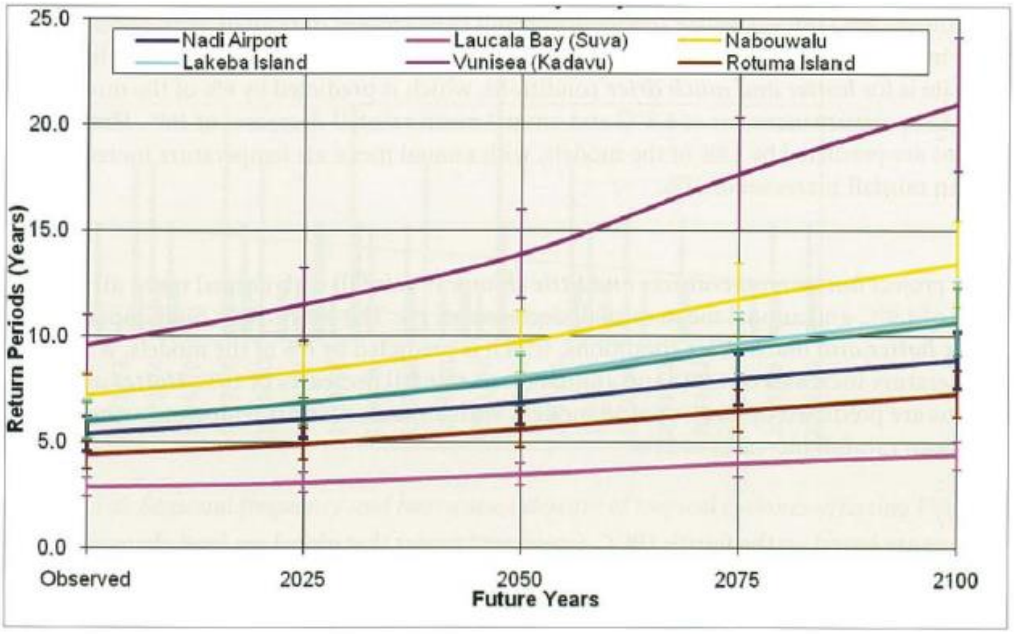
Table 5.5-6Climate Projections (Global Climate Models)

By 2030	The most likely projected change for Fiji is for warmer temperatures and little change in rainfall with annual mean temperature increases of 0.7℃ and negligible (-1%) change in mean annual rainfall, which is predicted by 69% of the models. Warmer and drier change in projected climate is predicted by 6% of the models with annual mean air temperature increases of 0.6℃ and annual mean rainfall decreases of 6%. Warmer and wetter conditions are represented by 13% of the models with annual mean air temperature increases of 0.8℃ and annual mean rainfall increases of7%.
By 2055	The majority of the models (569.) project hotter temperatures and little change in rain fall, with annual mean air temperature increases of 1.9℃ and annual mean rainfall decreases of 1%. The other likely high impact projected climate is for hotter and much drier conditions, which is predicted by 6% of the models, with annual mean air temperature increases of 1.8℃ and annual mean rainfall decreases of 16%. Hotter and much wetter conditions are predicted by 13% of the models, with annual mean air temperature increases of 2.3℃ and annual mean rainfall increases of 21%.
By 2090	Nine out of 16 models project hotter temperatures and little change in rainfall with annual mean air temperature increases of 1.9℃ and annual mean rainfall decreases of 1%. The other likely high impact projected climate is for hotter and much drier conditions, which is predicted by 6% of the models, with annual mean air temperature increases of 1.8℃ and annual mean rainfall decreases of 16%. Hotter and much wetter conditions are predicted by two out of 18 models, with annual mean air temperature increases of2.3℃and annual mean rainfall increases of 21%.
By 2100	The sea level projections are based on the fourth IPCC assessment report that global sea level changes are expected to be ranging from 0.21 to 0.48 meters by end of the century (IPCC 2007a). However, there is significant uncertainty surrounding ice-sheet contributions to sea level rise and a larger rise than that projected cannot be excluded.

出典:Republic of Fiji, National Climate Change Policy 2012

Maximum rainfall

The maximum daily rainfall of 200 mm is projected to become less frequent by 2100 at various locations in Fiji (Figure A1-7).

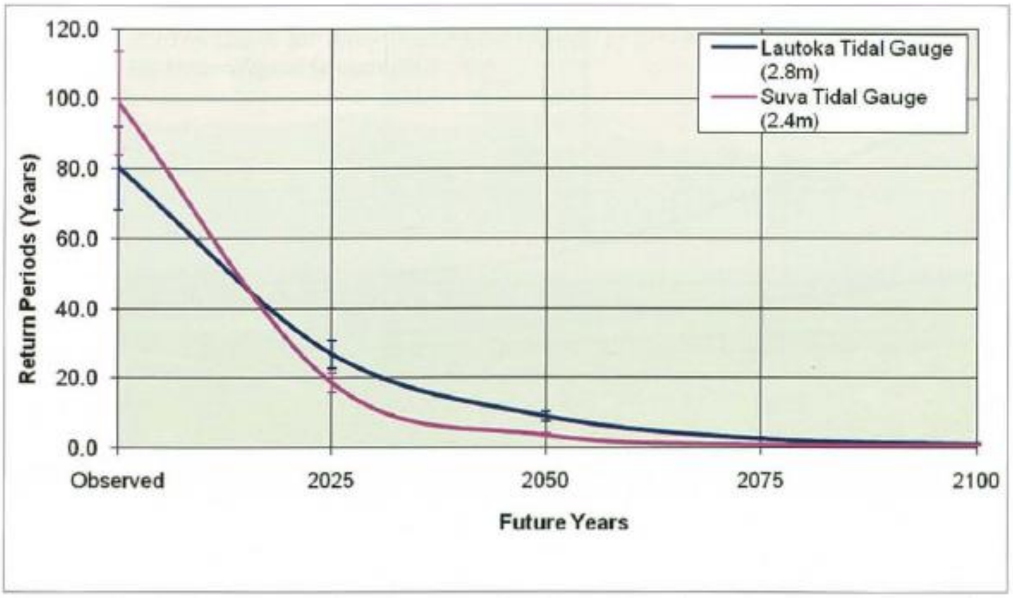


Source: Data source: Fiji Meteorological Services 2011, Republic of Fiji, and and National Climate Change Policy 2012

Figure 5.5-2 Projections for Daily Maximum Rainfall of200 mm in Fiji Projected to 2100

Maximum sea levels

Maximum sea level currently observed at Lautoka and Suva tide gauges are expected to become more frequent by at least by 2050 and become a normal occurrence by 2100 (Figure A1-11).



Source: Data source: Fiji Meteorological Services 2011, Republic of Fiji, and and National Climate Change Policy 2012

Figure 5.5-3 Climate Risk of Maximum Sea Level at Various Locations in Fiji Projected to 2100

(2) Changes of Design Scale by Climate Change

Based on the prediction of climate change from 4th Assessment Report (AR4), changes of design scale are exanimated with the case of 21% increasing and 16% decreasing of precipitation.

The results of examinations are shown in Table 5.5-7. In case of 21% increasing of precipitation, current design scale changes from approximate 1/50 to 1/15. On the other hand, in case of 16% decreasing of precipitation, the design scale changes into approximate 1/200.

Table 5.5-7 Changes of Design Scale by Climate Change

Basin	Rainfall	Present		Future (Rainfall increases of 21%)		Future (Rainfall decreases of 16%)	
		Probability	Model	Probability	Model	Probability	Model
Nadi town Bridge Basin	483.1 mm/2 days	Approx. 1/50	IshiTaka	Approx. 1/15	IshiTaka	Approx. 1/200	IshiTaka

Table 5.5-8 Maximum Annual Rainfall by Climate Change

Catchment of Nadi Town Bridge					
Hydrological Year		Precipitation during design continuous rain in 2 days			
		Date	Present	Future (rainfall increases of 21%)	Future (rainfall decreases of 16%)
1	1967	20-Mar-68	136.09	164.67	114.32
2	1968	01-Feb-69	146.24	176.95	122.84
3	1969	12-Feb-70	217.67	263.38	182.84
4	1970	06-Mar-71	155.03	187.59	130.23
5	1971	19-Jan-72	155.15	187.74	130.33
6	1972	23-Oct-72	404.82	489.83	340.05
7	1973	24-Apr-74	319.41	386.49	268.31
8	1974	08-Dec-74	144.94	175.38	121.75
9	1975	28-Oct-75	190.11	230.03	159.69
10	1976	04-Sep-76	192.41	232.82	161.63
11	1977	24-Jan-78	91.11	110.25	76.53
12	1978	27-Mar-79	230.16	278.49	193.34
13	1979	26-Jan-80	108.78	131.63	91.38
14	1980	27-Jan-81	249.17	301.49	209.30
15	1981	29-Jan-82	239.08	289.29	200.83
16	1982	28-Feb-83	394.38	477.19	331.28
17	1983	17-Mar-84	298.03	360.61	250.34
18	1984	04-Mar-85	261.95	316.96	220.04
19	1985	09-Apr-86	275.33	333.15	231.27
20	1986	05-Feb-87	77.07	93.25	64.74
21	1987	03-Mar-88	93.95	113.68	78.92
22	1988	10-Feb-89	238.61	288.72	200.43
23	1989	20-Mar-90	294.56	356.41	247.43
24	1990	27-Nov-90	210.10	254.22	176.48
25	1991	13-Sep-91	82.95	100.37	69.68
26	1992	26-Feb-93	400.24	484.29	336.20
27	1993	03-Jun-94	108.07	130.76	90.78
28	1994	16-Mar-95	96.14	116.33	80.76
29	1995	08-Mar-96	140.09	169.51	117.68
30	1996	07-Mar-97	373.78	452.28	313.98
31	1997	06-Aug-97	93.39	113.00	78.45
32	1998	18-Jan-99	404.23	489.12	339.56
33	1999	24-Jan-00	184.92	223.76	155.33
34	2000	11-Dec-00	140.86	170.44	118.32
35	2001	23-Feb-02	209.43	253.41	175.92
36	2002	11-Mar-03	217.91	263.68	183.05
37	2003	13-Feb-04	139.69	169.03	117.34
38	2004	18-Apr-05	202.25	244.72	169.89
39	2005	29-Jan-06	132.57	160.41	111.36
40	2006	11-Feb-07	191.53	231.75	160.89
41	2007	28-Jan-08	343.66	415.82	288.67
42	2008	09-Jan-09	441.99	534.80	371.27
43	2009	14-Dec-09	268.78	325.22	225.77
44	2010	18-Feb-11	157.47	190.53	132.27
45	2011	29-Mar-12	483.08	584.52	405.78
46	2012	16-Dec-12	134.79	163.10	113.22
47	2013	29-Jan-14	191.06	231.19	160.49

5.6 Examination of Design Flood before Regulation

The design flood is calculated by the run-off and inundation model inputting data of group of design hyetograph determined in 5.4.

Calculation conditions of run-off and inundation model are shown below;

River mouth water level: Mean sea level of spring tide 1.188m

(Actual tide level at the flood in March, 2012)

Effect of storage along the river: 2 cases (with inundation and without inundation)

5.6.1 Design Flood before Regulation

Peak discharges at the Nadi Town Bridge Point from design hyetograph are shown in Table 5.6-9. The hydrographs are also shown in Figure 5.6-2 to Figure 5.6-7. And peak discharges at important points are shown in Table 5.6-10 and Table 5.6-11.

As a result, the flood which records maximum discharge at Nadi Town Bridge point is the No.25 type occurred in March, 2012 flood in the both case of with and without inundation.

Therefore, design flood before regulation is to be determined by using No.25 type which occurred in March, 2012 flood. The discharge distribution diagram of design flood before regulation is as shown in Figure 5.6-1.

The gap between with and without inundation at the Nadi Town Bridge Point, is 1000m^3/s less, the former is less than the latter.

Table 5.6-9 Peak Discharge at Nadi Town Bridge Point

Flood		Nadi Town Bridge	
		Without Inundation	With Inundation
No.3	1997/3/7	1,530	1,135
No.4	1999/1/18	1,651	1,224
No.20	2009/1/9	1,548	1,202
No.21	2009/1/13	1,622	1,024
No.24	2012/1/23	1,534	1,135
No.25	2012/3/29	2,432	1,473

No.25, May, 2012 type flood

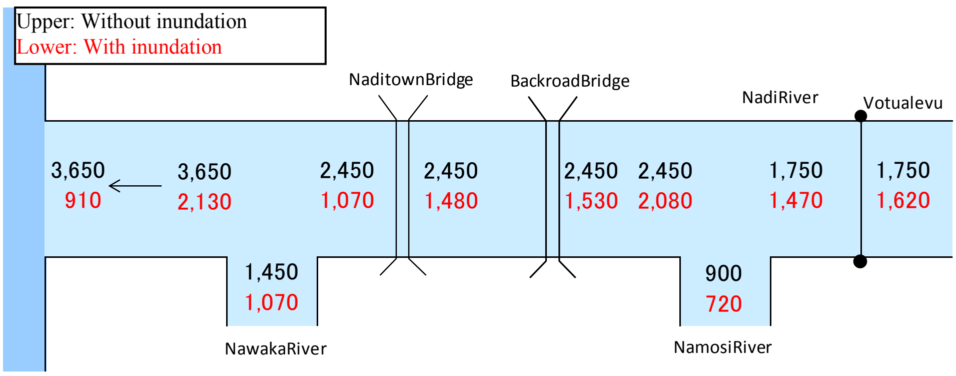


Figure 5.6-1 Discharge Distribution of Design Food before Regulation (No.25, March, 2012 type flood)

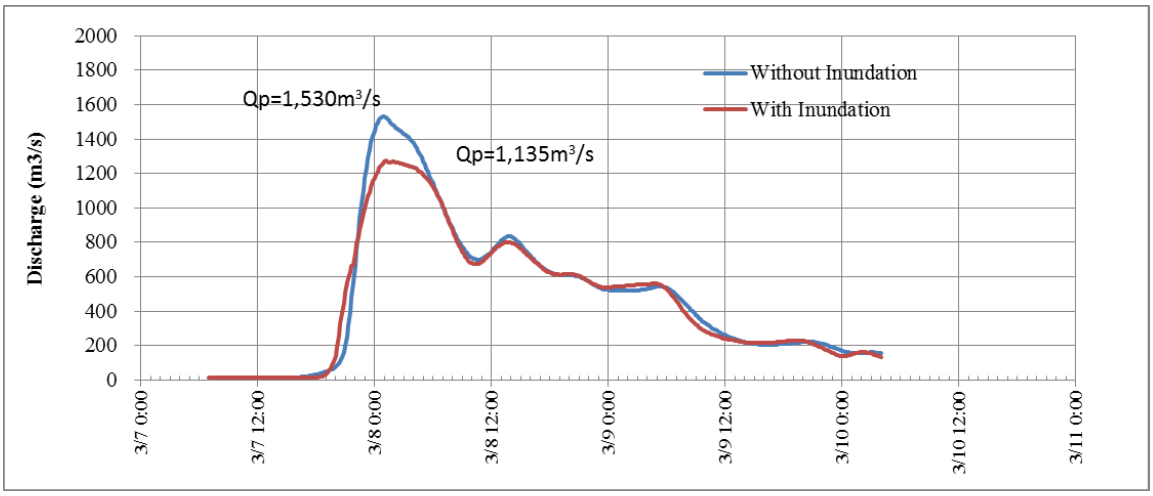


Figure 5.6-2 Hydrograph of No3 flood in March, 2007

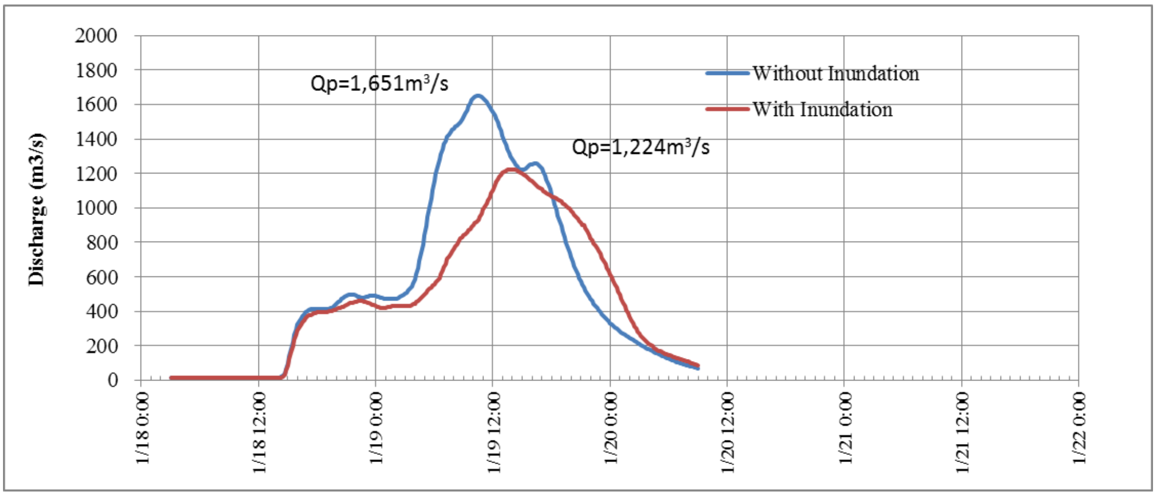


Figure 5.6-3 Hydrograph of No4 flood in January, 1999

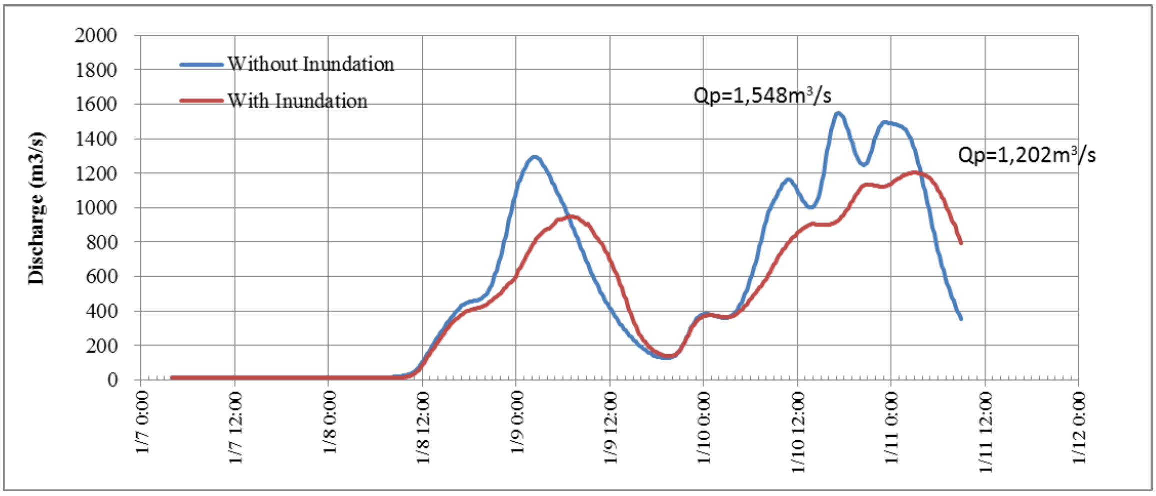


Figure 5.6-4 Hydrograph of No20 flood in 9th January, 2009

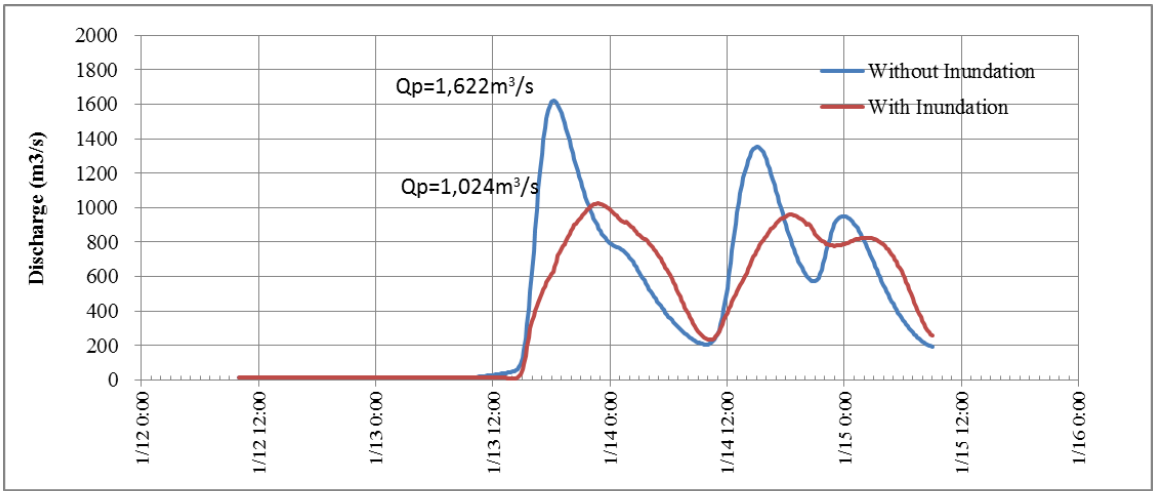


Figure 5.6-5 Hydrograph of No21 flood in 13th January, 2009

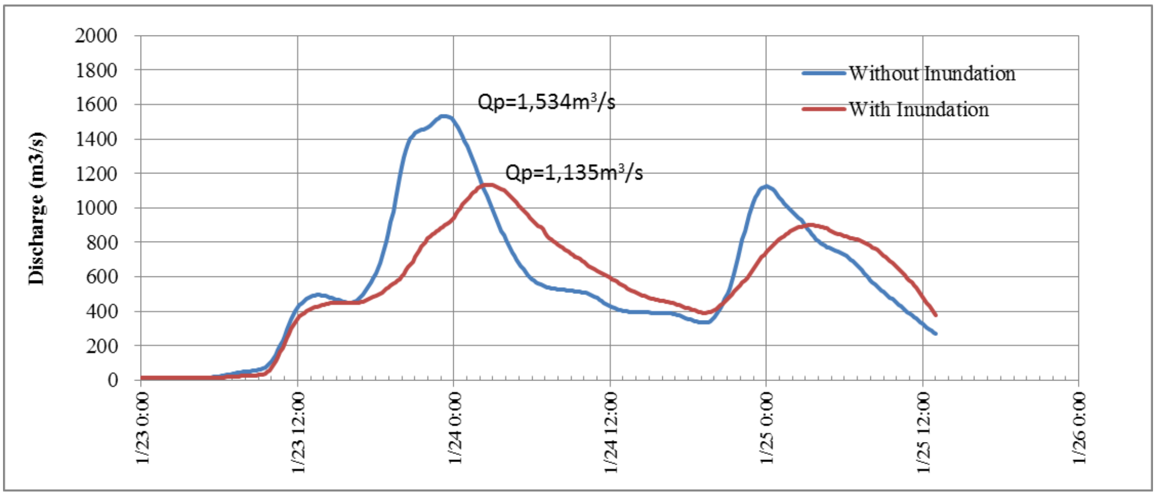


Figure 5.6-6 Hydrograph of No24 flood in January, 2012

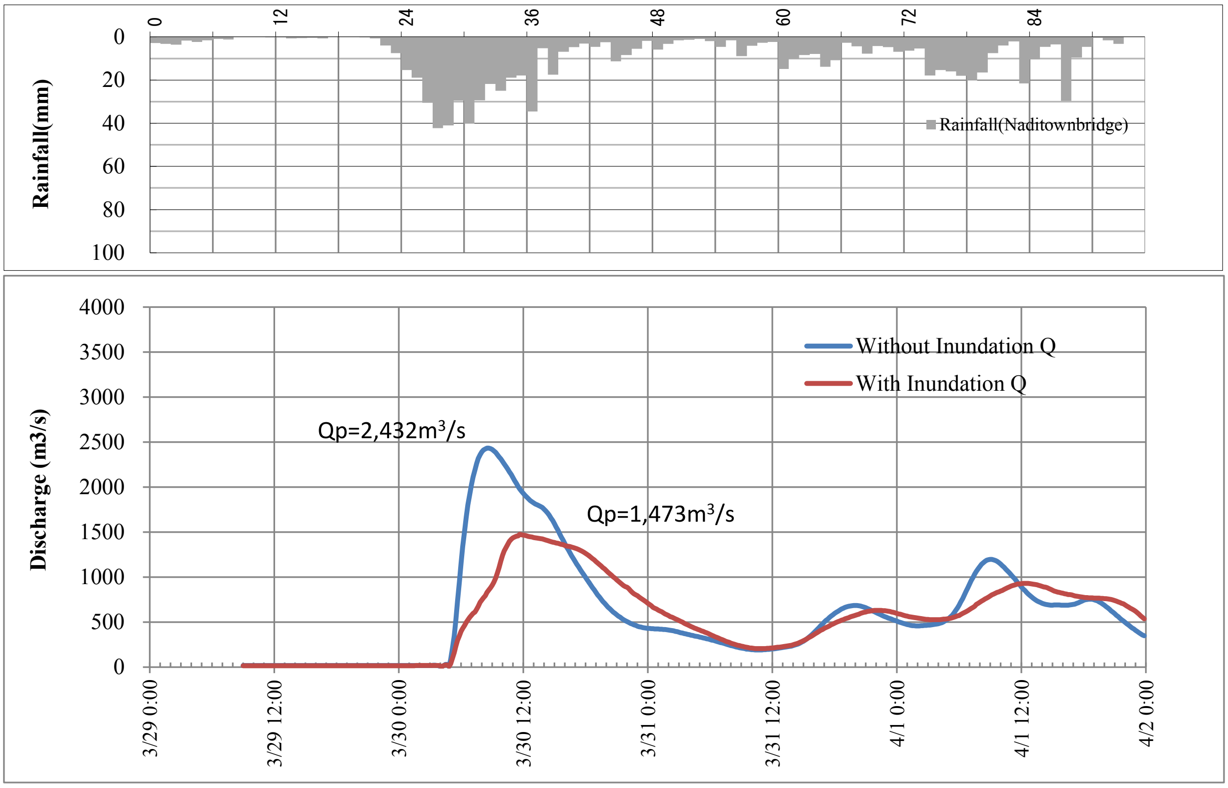


Figure 5.6-7 Hydrograph of No25 flood in March, 2012

Table 5.6-10 Peak Discharge of Important Point by Design Hyetograph (without inundation)

River	Distance	Point	No.3	No.4	No.20	No.21	No.24	No.25
	(km)		1997/3/7	1999/1/18	2009/1/9	2009/1/13	2012/1/23	2012/3/29
Nadi	0.00	Estuary	1,772	2,688	2,128	2,034	2,415	3,651
Nadi	8.00	After Nawaka confluence	1,774	2,695	2,144	2,072	2,430	3,656
Nadi	8.25	Before Nawaka confluence	1,524	1,645	1,550	1,612	1,534	2,423
Nadi	9.75	Nadi town Br.	1,530	1,651	1,548	1,622	1,534	2,432
Nadi	18.75	Back road Br.	1,546	1,606	1,561	1,681	1,505	2,429
Nadi	25.00	After Namosi confluence	1,556	1,571	1,597	1,754	1,477	2,440
Nadi	25.50	Before Namosi confluence	1,202	1,499	1,208	1,445	1,109	1,727
Nadi	27.00	Votualevu	1,209	1,506	1,223	1,472	1,152	1,762
Namosi	0.50	Before Nadi confluence	377	453	482	456	498	900
Namosi	2.26	Namulomulo	396	457	488	467	504	869
Nawaka	0.00	Before Nadi confluence	400	1,342	789	665	905	1,456
Nawaka	2.00	Qeleloa Br.	278	741	551	507	656	1,020
Nawaka	4.00	Nawka 4.0k	217	402	446	413	507	775
Malakua	0.00	Before Nawaka confluence	119	584	260	183	253	421
Malakua	4.00	Upstream of Vunayasi Br.	120	578	265	208	263	407

Table 5.6-11 Peak Discharge of Important Point by Design Hyetograph (with inundation)

River	Distance	Point	No.3	No.4	No.20	No.21	No.24	No.25
	(km)		1997/3/7	1999/1/18	2009/1/9	2009/1/13	2012/1/23	2012/3/29
Nadi	0.00	Estuary	657	788	712	650	723	905
Nadi	8.00	After Nawaka confluence	1,278	1,816	1,503	1,287	1,533	2,132
Nadi	8.25	Before Nawaka confluence	790	906	839	743	819	1,070
Nadi	9.75	Nadi town Br.	1,135	1,224	1,202	1,024	1,135	1,473
Nadi	18.75	Back road Br.	1,273	1,310	1,277	1,305	1,273	1,524
Nadi	25.00	After Namosi confluence	1,487	1,493	1,505	1,618	1,451	2,079
Nadi	25.50	Before Namosi confluence	1,173	1,450	1,187	1,394	1,118	1,466
Nadi	27.00	Votualevu	1,199	1,476	1,207	1,461	1,148	1,620
Namosi	0.50	Before Nadi confluence	320	453	472	401	407	720
Namosi	2.26	Namulomulo	410	457	491	474	509	860
Nawaka	0.00	Before Nadi confluence	489	911	724	615	747	1,063
Nawaka	2.00	Qeleloa Br.	232	303	325	320	309	362
Nawaka	4.00	Nawka 4.0k	215	339	403	388	408	486
Malakua	0.00	Before Nawaka confluence	63	255	160	123	169	289
Malakua	4.00	Upstream of Vunayasi Br.	107	293	138	135	141	215

5.6.2 Flow Discharge by Occurrence Probability

The peak discharges at important point by each return period are calculated by using No.25 flood in March, 2012. Table 5.6-125 shows peak discharges by return period at Nadi Town Bridge.Figure 5.6-8 to Figure 5.6-14 show hydrographs. Also in Table 5.6-13and Table 5.6-13, the peak discharges by return period in the important point are shown.

Table 5.6-12 Peak Discharge by Return Period at Nadi Town Bridge Point

Return Period	(A)Probable Rainfall	Ratio	Peak Discharge at Nadi Town Bridge(m^3/s)	
	(mm/2days)	(A)/(B)	Without Inundation	With Inundation
2-year	204.3	0.423	701	611
3-year	250.7	0.519	971	792
5-year	300.3	0.622	1,268	931
10-year	359.6	0.744	1,647	1,176
20-year	414.1	0.857	1,991	1,357
30-year	444.5	0.920	2,184	1,414
Design scale (approx. 50-year)	483.1	1.000	2,432	1,473

Note; Target Flood：No.25 2012/3/29 ((B) =2 days average rainfall depth:483.1mm)

Table 5.6-13 Peak Discharge at Important Point by Return Periods (No.25 flood in March, 2012, without inundation)

Unit:m3/s

River	Distance	Points	Probable Discherge for Each Return Period						
			2-year	3-year	5-year	10-year	20-year	30-year	Design scale (approx.50-year)
	(km)		Without Inundation	Without Inundation	Without Inundation	Without Inundation	Without Inundation	Without Inundation	Without Inundation
Nadi	0.00	Estuary	1,196	1,589	2,042	2,564	3,038	3,307	3,651
Nadi	8.00	After Nawaka confluence	1,210	1,597	2,045	2,576	3,046	3,312	3,656
Nadi	8.25	Before Nawaka confluence	702	964	1,259	1,636	1,982	2,174	2,423
Nadi	9.75	Nadi town Br.	701	971	1,268	1,647	1,991	2,184	2,432
Nadi	18.75	Back road Br.	707	985	1,283	1,659	1,996	2,184	2,429
Nadi	25.00	After Namosi confluence	710	990	1,303	1,682	2,008	2,192	2,440
Nadi	25.50	Before Namosi confluence	403	633	892	1,159	1,414	1,547	1,727
Nadi	27.00	Votualevu	418	656	922	1,195	1,450	1,583	1,762
Namosi	0.75	Before Nadi confluence	331	429	527	647	755	818	891
Namosi	2.26	Namulomulo	332	429	521	636	738	798	869
Nawaka	0.00	Before Nadi confluence	514	657	850	1,034	1,216	1,328	1,456
Nawaka	2.00	Qeleloa Br.	371	466	593	725	847	924	1,020
Nawaka	4.00	Nawka 4.0k	291	363	457	551	646	700	775
Malakua	0.00	Before Nawaka confluence	147	194	251	298	356	389	421
Malakua	4.00	Upstream of Vunayasi Br.	159	199	248	289	345	376	407

Notice: second peak discharge of 1/2 and 1/3 probability discharge are bigger than first peak, but only the first peak discharge which is target of stretch is shown in the table.

Table 5.6-14 Peak Discharge at Important Point by Return Periods (No.25 flood in March, 2012, with inundation)

Unit:m3/s

River	Distance	Points	Probable Discherge for Each Return Period						
			2-year	3-year	5-year	10-year	20-year	30-year	Design scale (approx.50-year)
	(km)		With Inundation	With Inundation	With Inundation	With Inundation	With Inundation	With Inundation	With Inundation
Nadi	0.00	Estuary	600	658	717	785	841	868	905
Nadi	8.00	After Nawaka confluence	1,020	1,216	1,441	1,703	1,904	2,006	2,132
Nadi	8.25	Before Nawaka confluence	550	626	725	868	975	1,017	1,070
Nadi	9.75	Nadi town Br.	611	792	931	1,176	1,357	1,414	1,473
Nadi	18.75	Back road Br.	673	884	1,137	1,330	1,424	1,462	1,524
Nadi	25.00	After Namosi confluence	711	999	1,299	1,568	1,750	1,872	2,079
Nadi	25.50	Before Namosi confluence	405	646	914	1,123	1,322	1,373	1,466
Nadi	27.00	Votualevu	420	663	936	1,168	1,433	1,500	1,620
Namosi	0.75	Before Nadi confluence	330	431	513	547	594	656	720
Namosi	2.26	Namulomulo	332	430	520	628	715	789	860
Nawaka	0.00	Before Nadi confluence	478	597	726	837	930	990	1,063
Nawaka	2.00	Qeleloa Br.	288	301	327	336	354	345	362
Nawaka	4.00	Nawka 4.0k	279	333	393	416	438	453	486
Malakua	0.00	Before Nawaka confluence	83	117	162	195	231	253	289
Malakua	4.00	Upstream of Vunayasi Br.	116	130	134	150	177	198	215

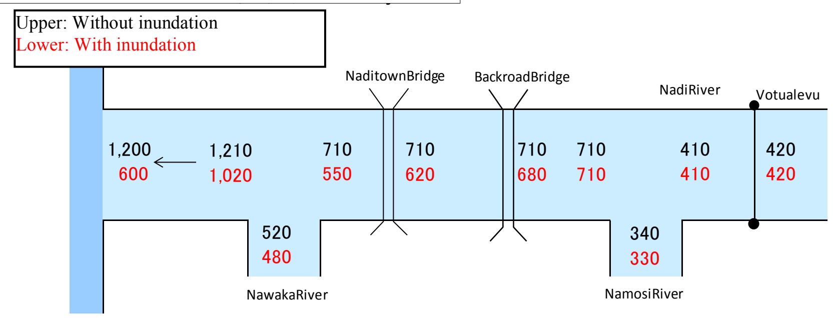
Notice: second peak discharge of 1/2 and 1/3 probability discharge are bigger than first peak, but only the first peak discharge which is target of stretch is shown in the table.

Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	1,196	600	597
Nadi	8.00	after Nawaka confluence	1,210	1,020	191
Nadi	8.25	before Nawaka confluence	702	550	152
Nadi	9.75	Nadi town Br.	701	611	90
Nadi	18.75	Back road Br.	707	673	34
Nadi	25.00	after Namosi confluence	710	711	−1
Nadi	25.50	before Namosi confluence	403	405	−3
Nadi	27.00	Votualevu	418	420	−2
Nawaka	0.00	before Nadi confluence	514	478	36
Namosi	0.75	before Nadi confluence	331	330	1

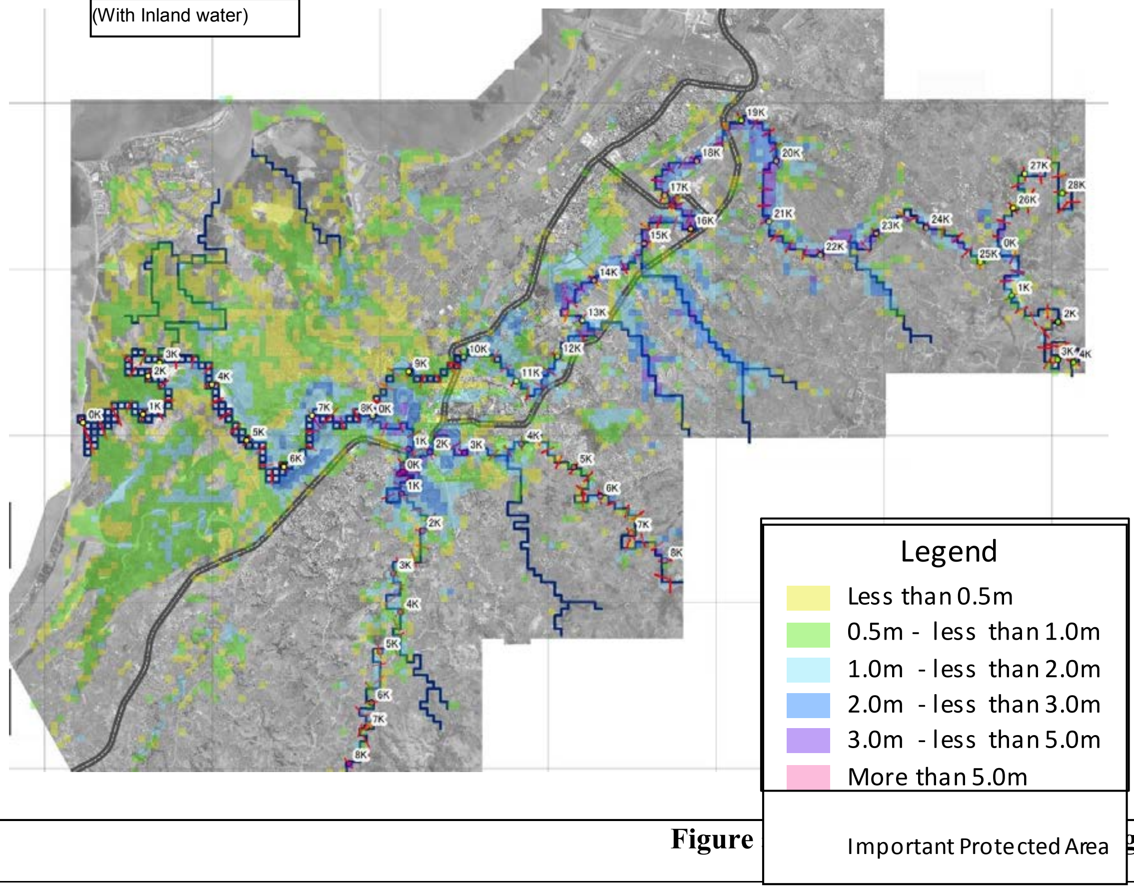
Discharge Distribution

No.25 Flood in March,2012 2-year probability



Maximum inundation Map

(With Inland water)



Hydrograph

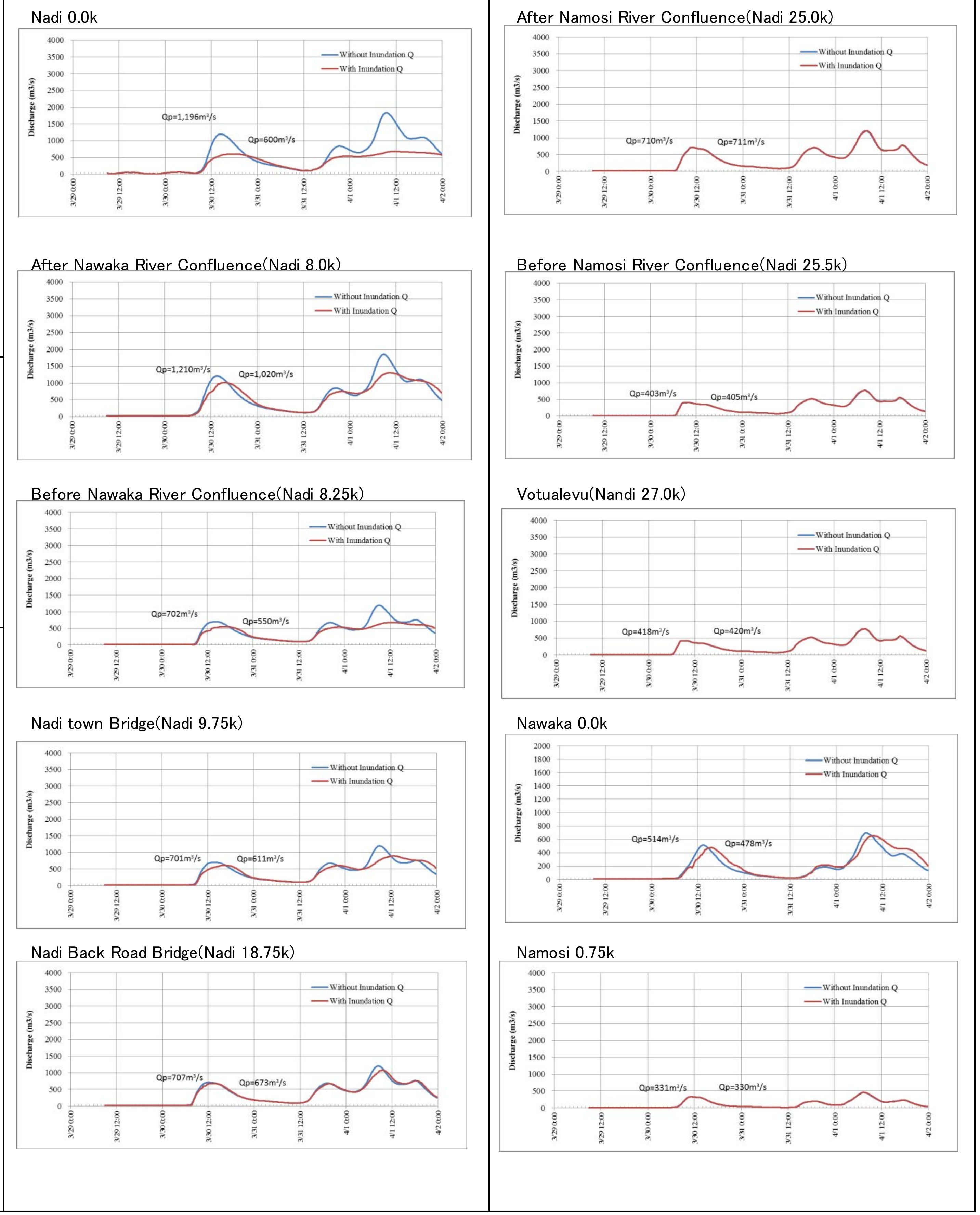


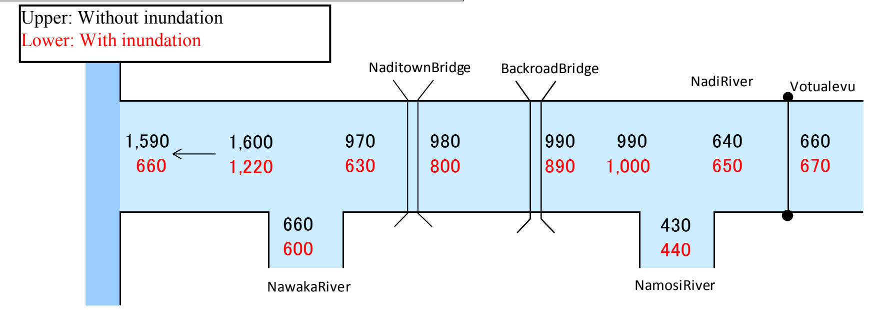
Figure ... graph and Maximum Inundation Map in 2-year probability

Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	1,589	658	931
Nadi	8.00	after Nawaka confluence	1,597	1,216	381
Nadi	8.25	before Nawaka confluence	964	626	338
Nadi	9.75	Nadi town Br.	971	792	179
Nadi	18.75	Back road Br.	985	884	101
Nadi	25.00	after Namosi confluence	990	999	-9
Nadi	25.50	before Namosi confluence	633	646	-13
Nadi	27.00	Votualevu	656	663	-7
Nawaka	0.00	before Nadi confluence	657	597	61
Namosi	0.75	before Nadi confluence	429	431	-2

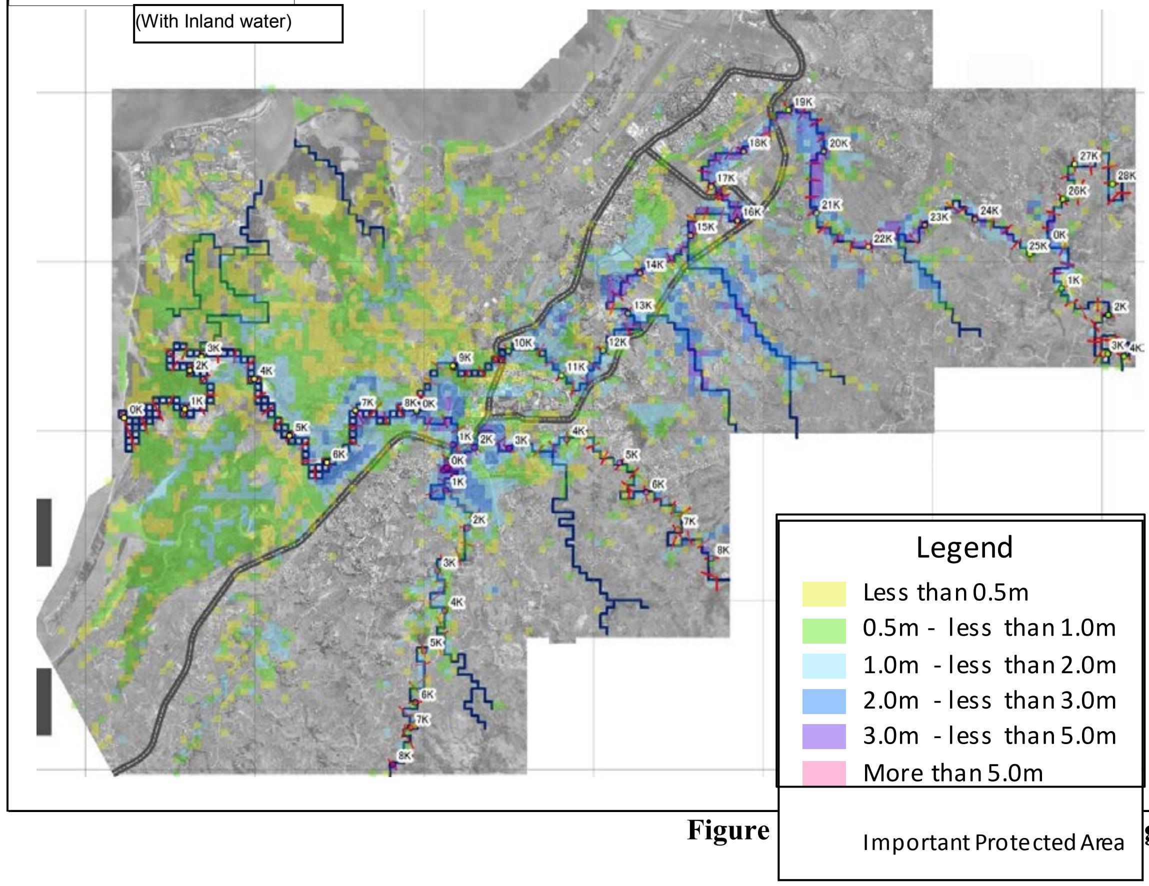
Discharge Distribution

No.25 Flood in March,2012 3-year probability



Maximum inundation Map

(With Inland water)



Hydrograph

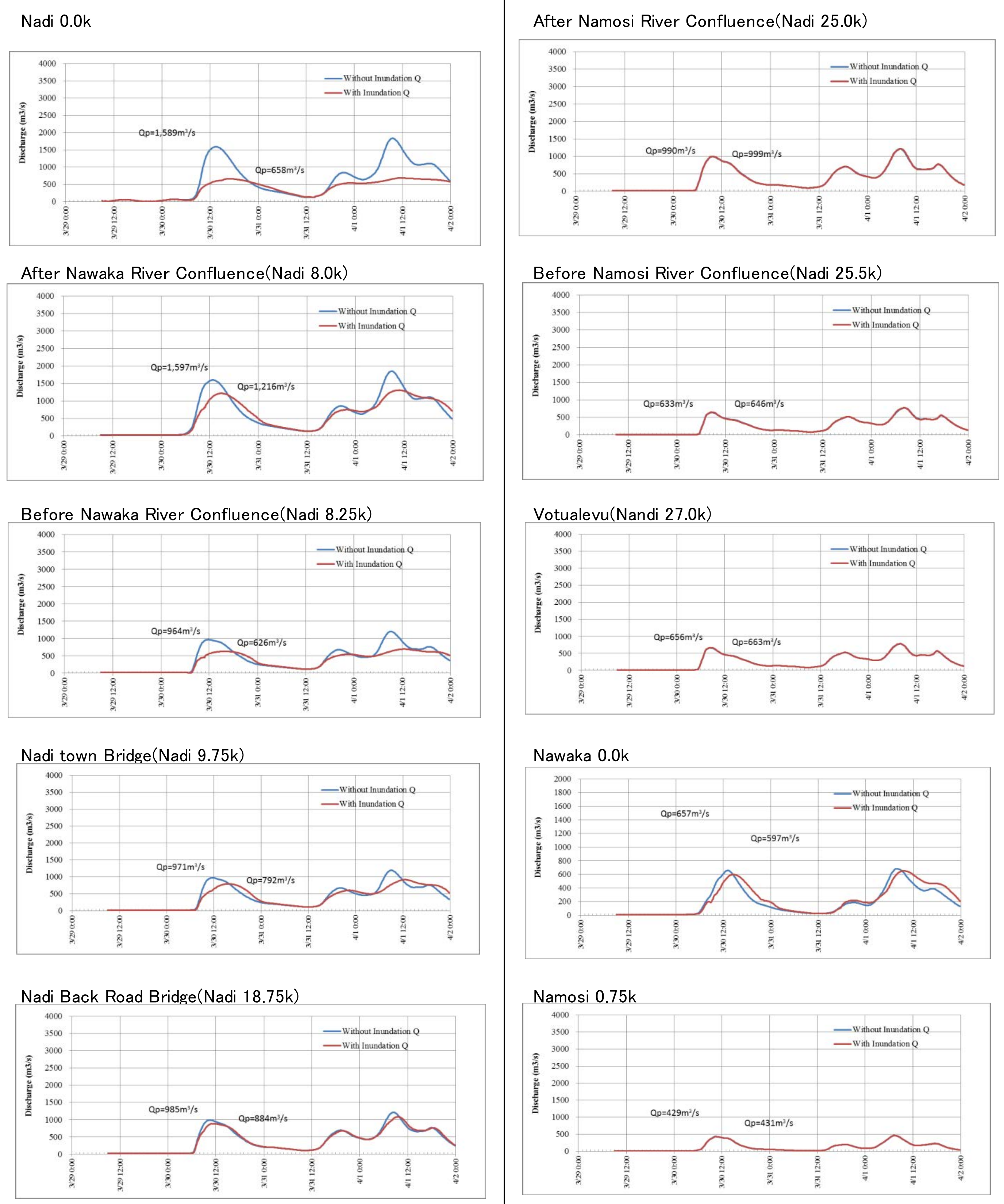


Figure ... graph and Maximum Inundation Map in 3-year probability

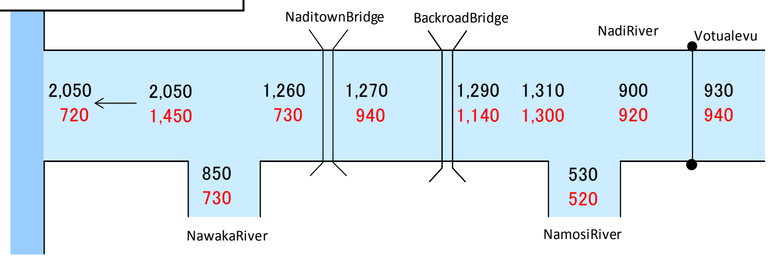
Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	2,042	717	1,324
Nadi	8.00	after Nawaka confluence	2,045	1,441	604
Nadi	8.25	before Nawaka confluence	1,259	725	534
Nadi	9.75	Nadi town Br.	1,268	931	336
Nadi	18.75	Back road Br.	1,283	1,137	147
Nadi	25.00	after Namosi confluence	1,303	1,299	4
Nadi	25.50	before Namosi confluence	892	914	−21
Nadi	27.00	Votualevu	922	936	−14
Nawaka	0.00	before Nadi confluence	850	726	124
Namosi	0.75	before Nadi confluence	527	513	14

Discharge Distribution

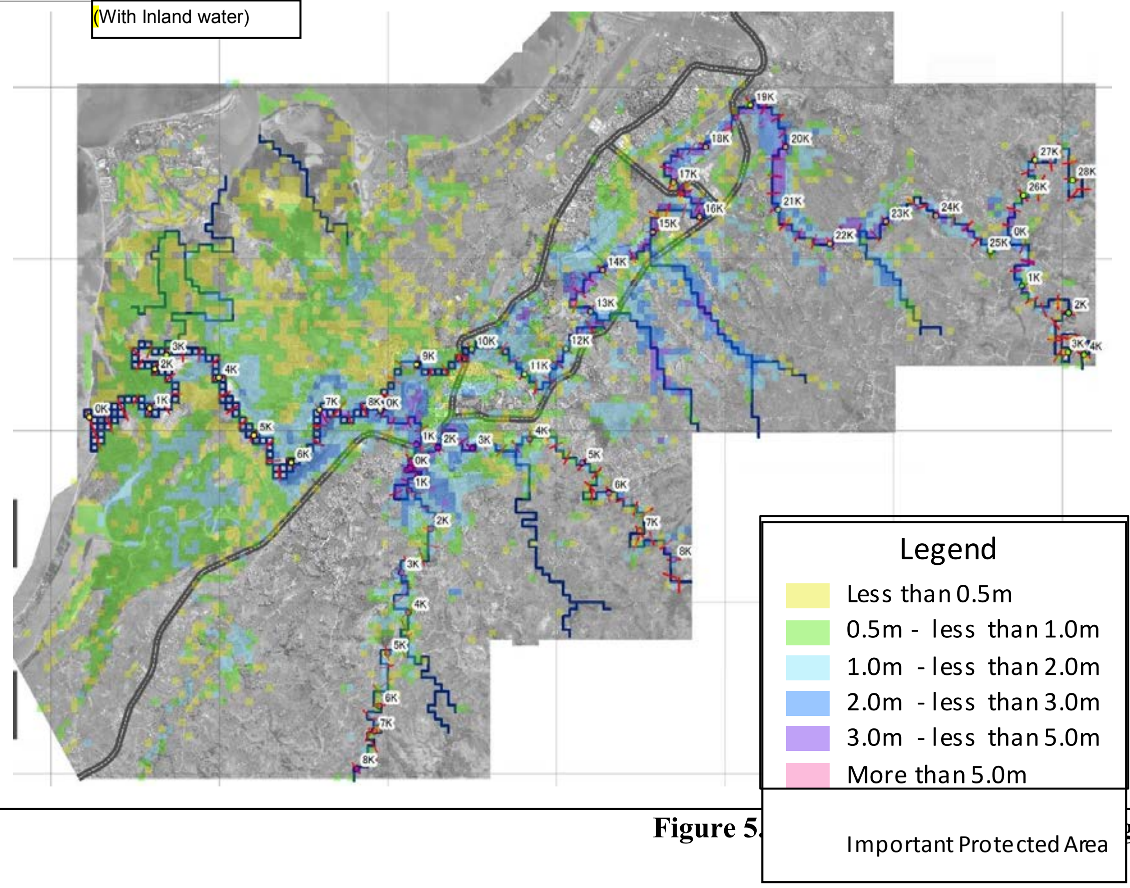
No.25 Flood in March,2012 5-year probability

Upper: Without inundation
Lower: With inundation



Maximum inundation Map

(With Inland water)



Hydrograph

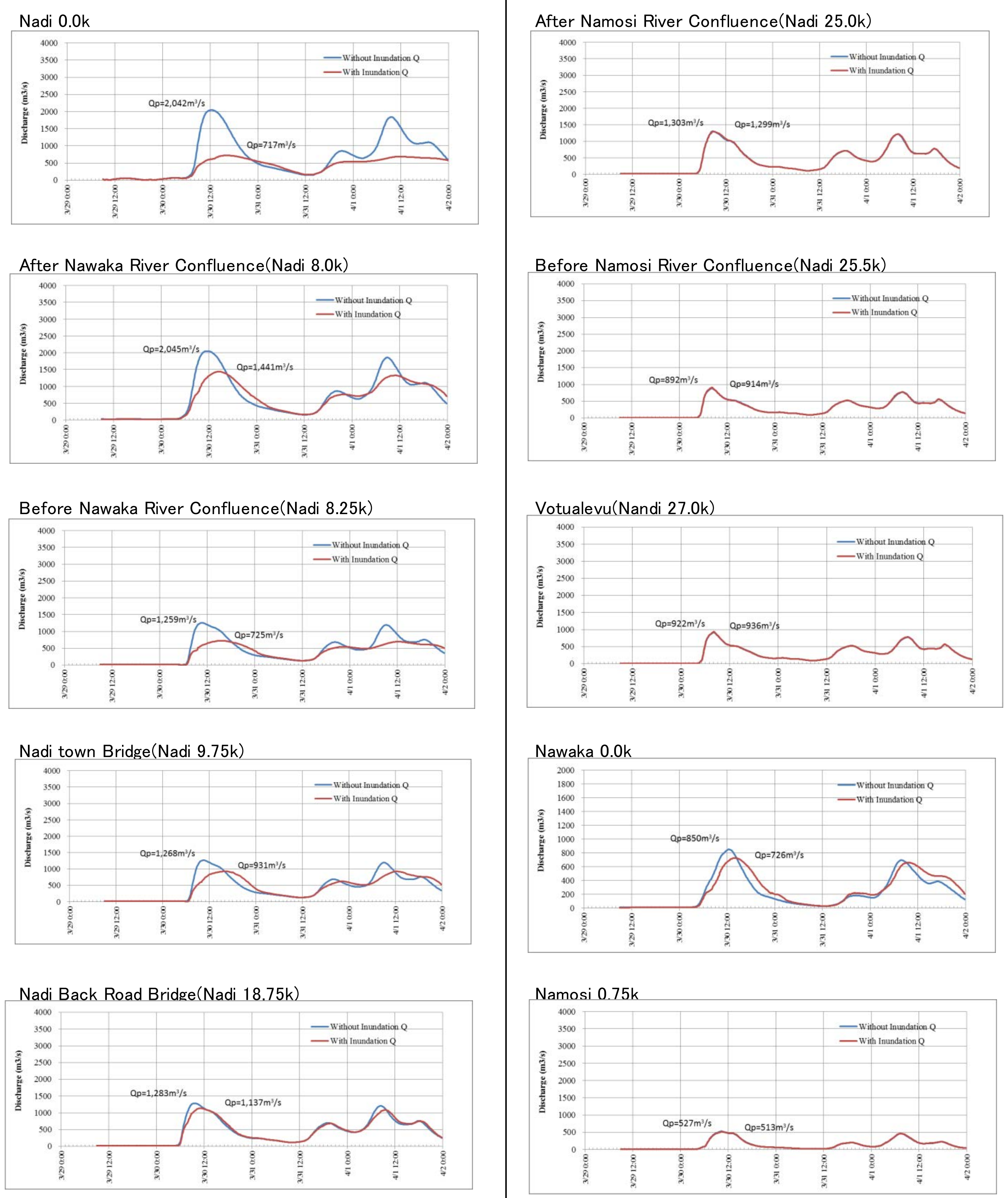
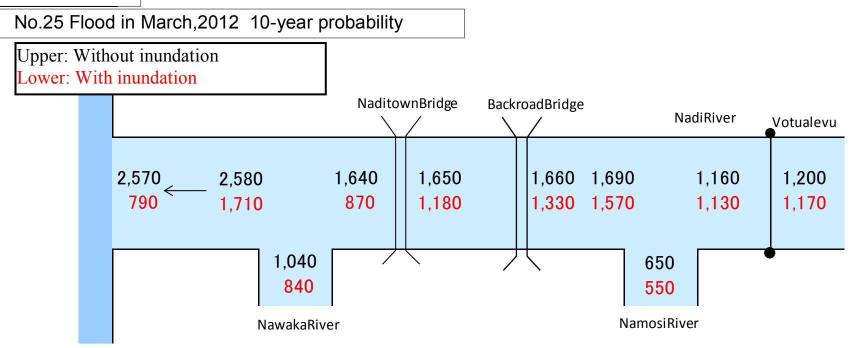


Figure 5. ... graph and Maximum inundation map in 5-year probability

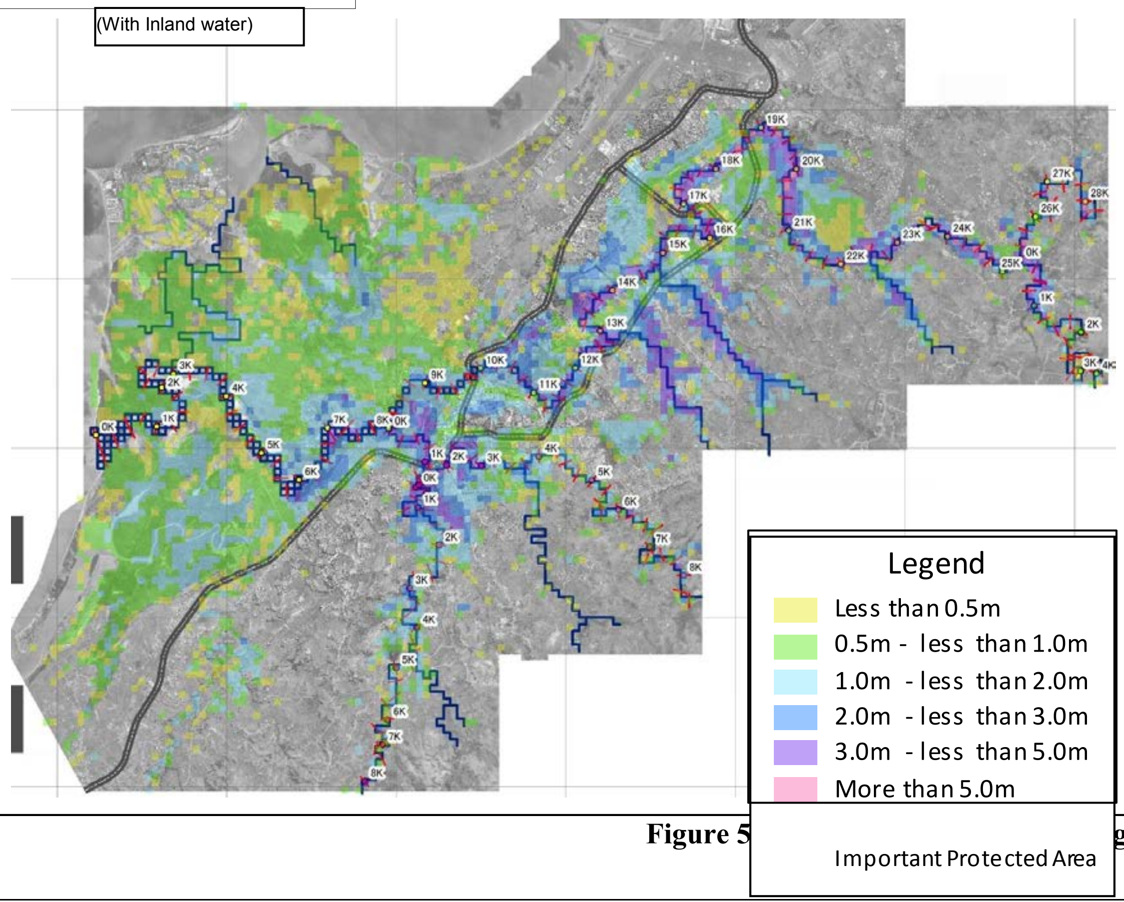
Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	2,564	785	1,778
Nadi	8.00	after Nawaka confluence	2,576	1,703	873
Nadi	8.25	before Nawaka confluence	1,636	868	768
Nadi	9.75	Nadi town Br.	1,647	1,176	470
Nadi	18.75	Back road Br.	1,659	1,330	329
Nadi	25.00	after Namosi confluence	1,682	1,568	114
Nadi	25.50	before Namosi confluence	1,159	1,123	37
Nadi	27.00	Votualevu	1,195	1,168	27
Nawaka	0.00	before Nadi confluence	1,034	837	197
Namosi	0.75	before Nadi confluence	647	547	100

Discharge Distribution



Maximum inundation Map



Hydrograph

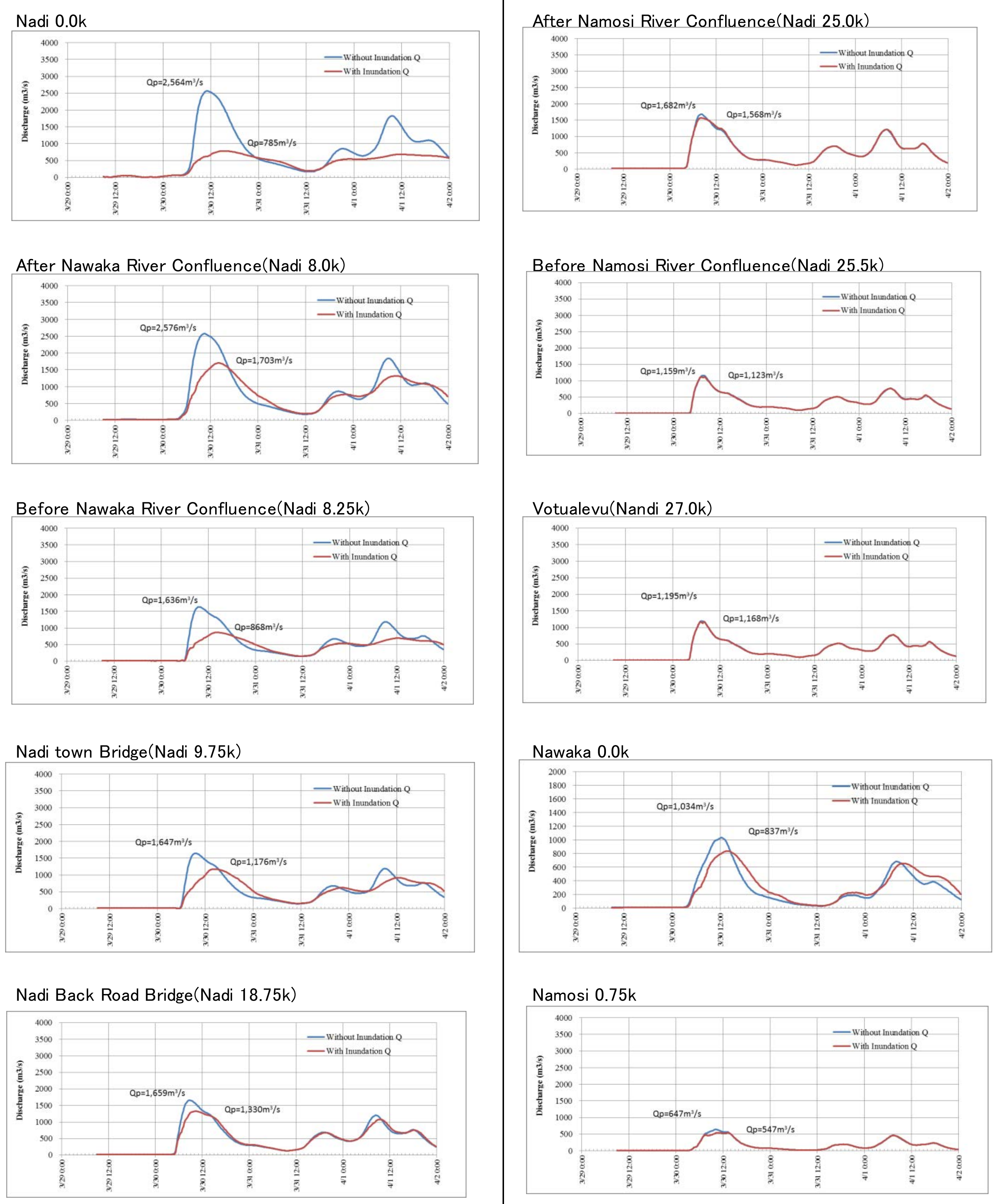


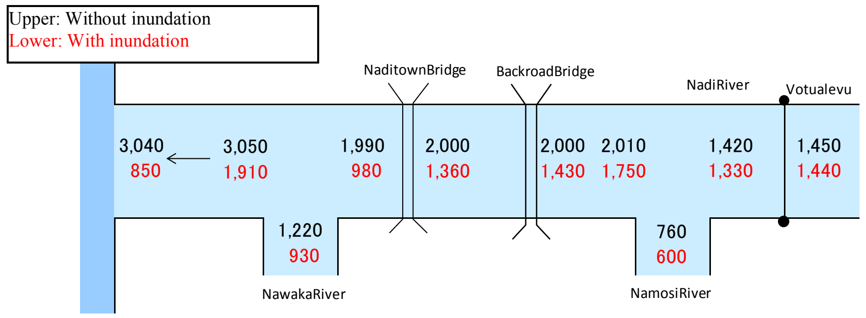
Figure 5 ... graph and Maximum inundation map in 10-year probability

Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	3,038	841	2,197
Nadi	8.00	after Nawaka confluence	3,046	1,904	1,142
Nadi	8.25	before Nawaka confluence	1,982	975	1,007
Nadi	9.75	Nadi town Br.	1,991	1,357	634
Nadi	18.75	Back road Br.	1,996	1,424	572
Nadi	25.00	after Namosi confluence	2,008	1,750	259
Nadi	25.50	before Namosi confluence	1,414	1,322	93
Nadi	27.00	Votualevu	1,450	1,433	17
Nawaka	0.00	before Nadi confluence	1,216	930	286
Namosi	0.75	before Nadi confluence	755	594	160

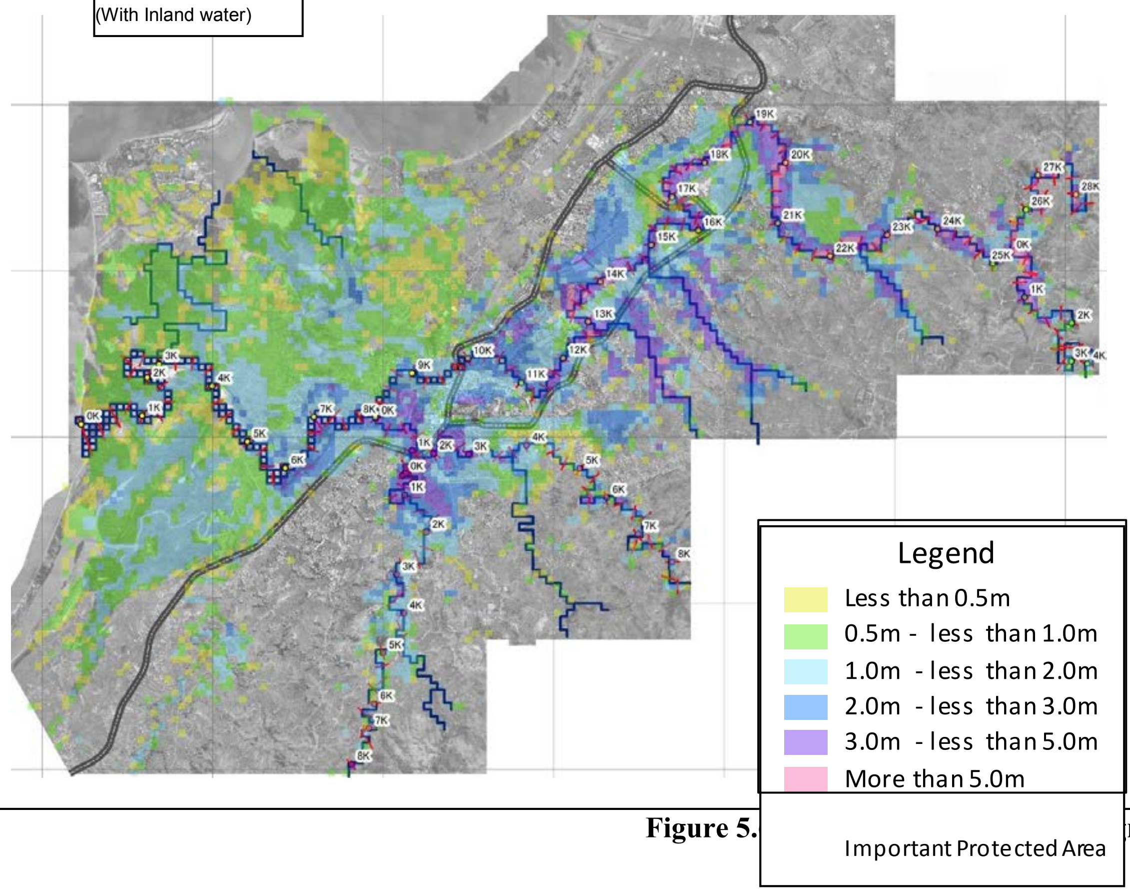
Discharge Distribution

No.25 Flood in March,2012 20-year probability



Maximum inundation Map

(With Inland water)



Hydrograph

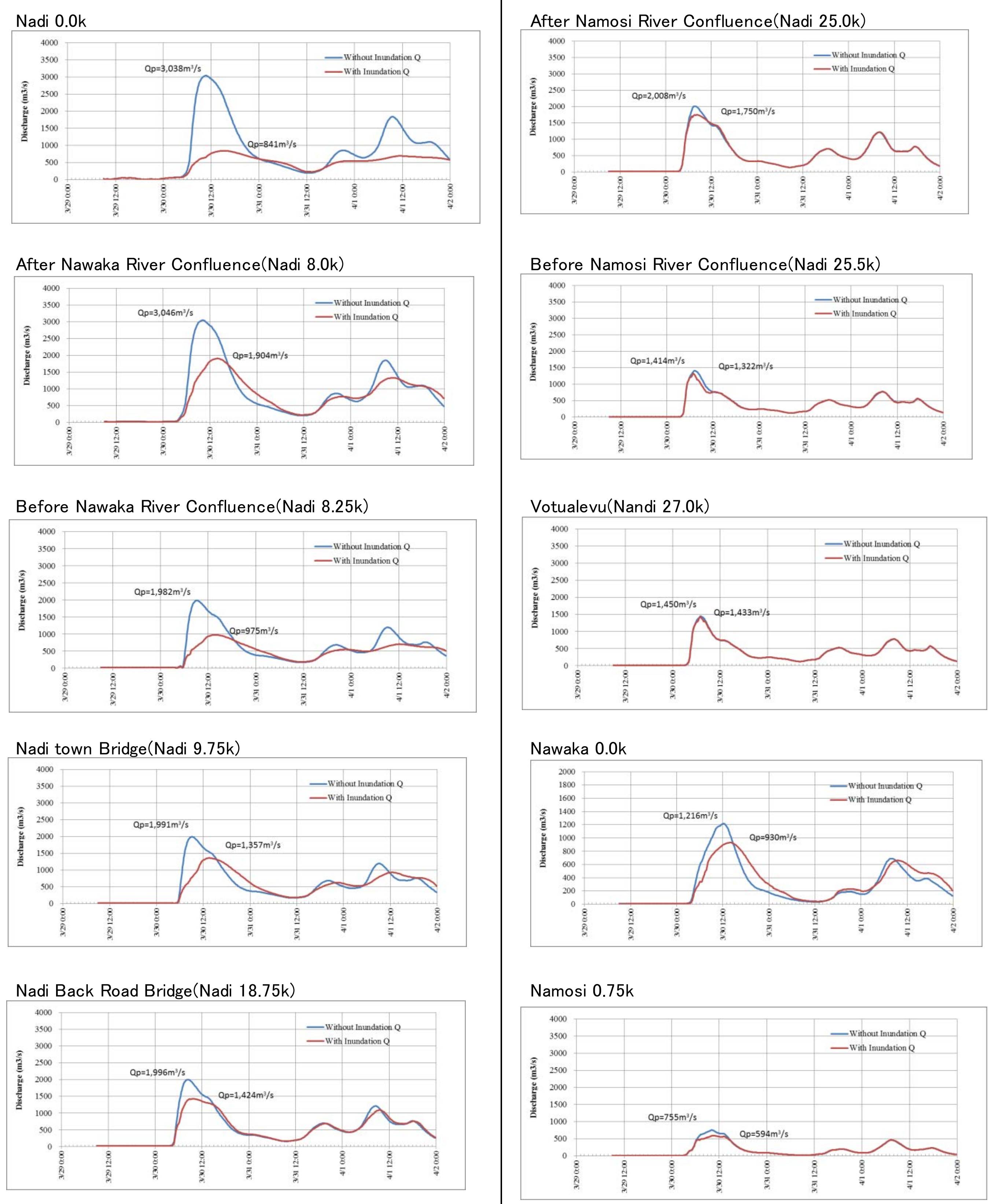
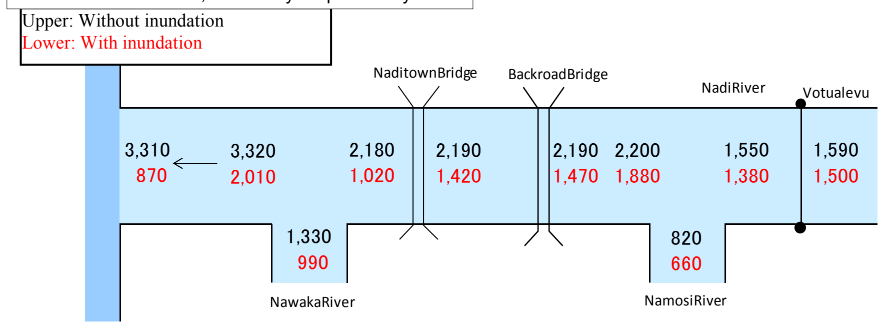


Figure 5. ... raph and Maximum inundation map in 20-year probability

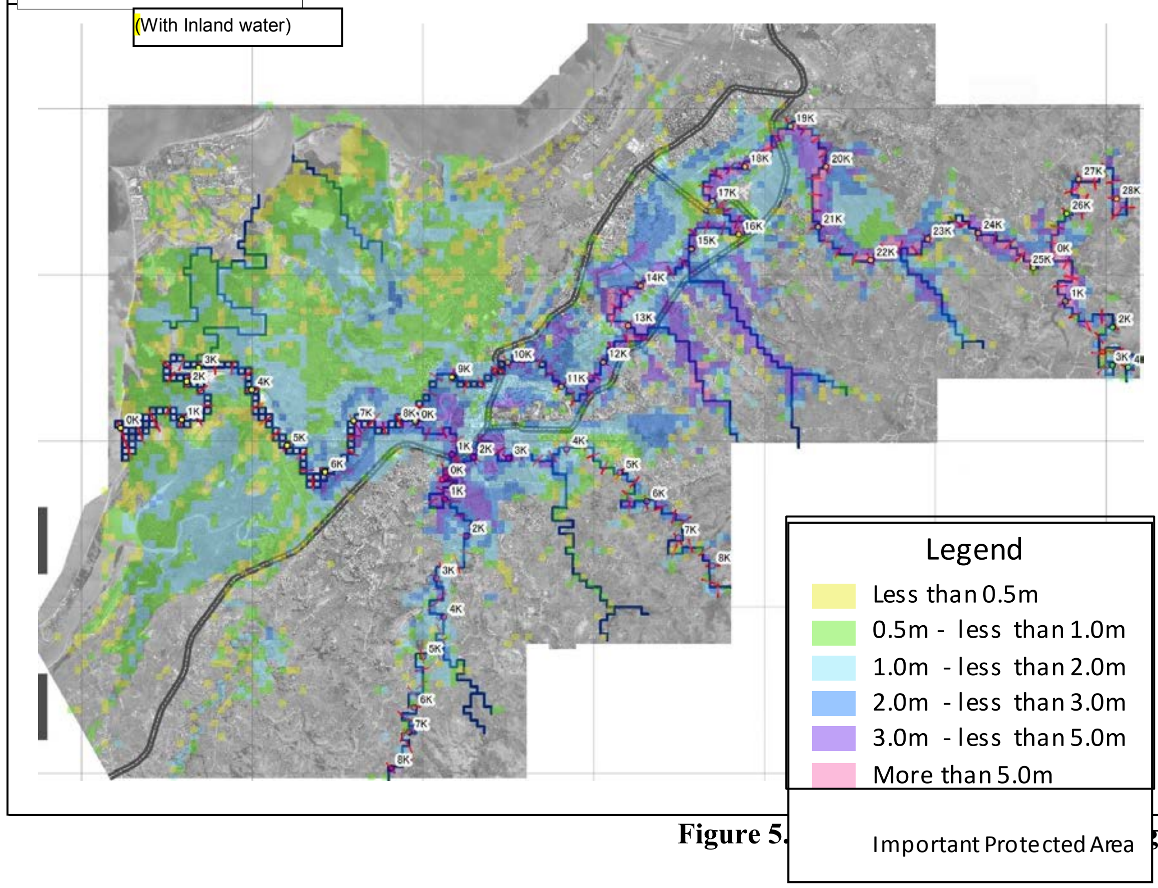
Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	3,307	868	2,439
Nadi	8.00	after Nawaka confluence	3,312	2,006	1,307
Nadi	8.25	before Nawaka confluence	2,174	1,017	1,156
Nadi	9.75	Nadi town Br.	2,184	1,414	769
Nadi	18.75	Back road Br.	2,184	1,462	722
Nadi	25.00	after Namosi confluence	2,192	1,872	320
Nadi	25.50	before Namosi confluence	1,547	1,373	174
Nadi	27.00	Votualevu	1,583	1,500	82
Nawaka	0.00	before Nadi confluence	1,328	990	338
Namosi	0.75	before Nadi confluence	818	656	162

Discharge Distribution



Maximum inundation Map



Hydrograph

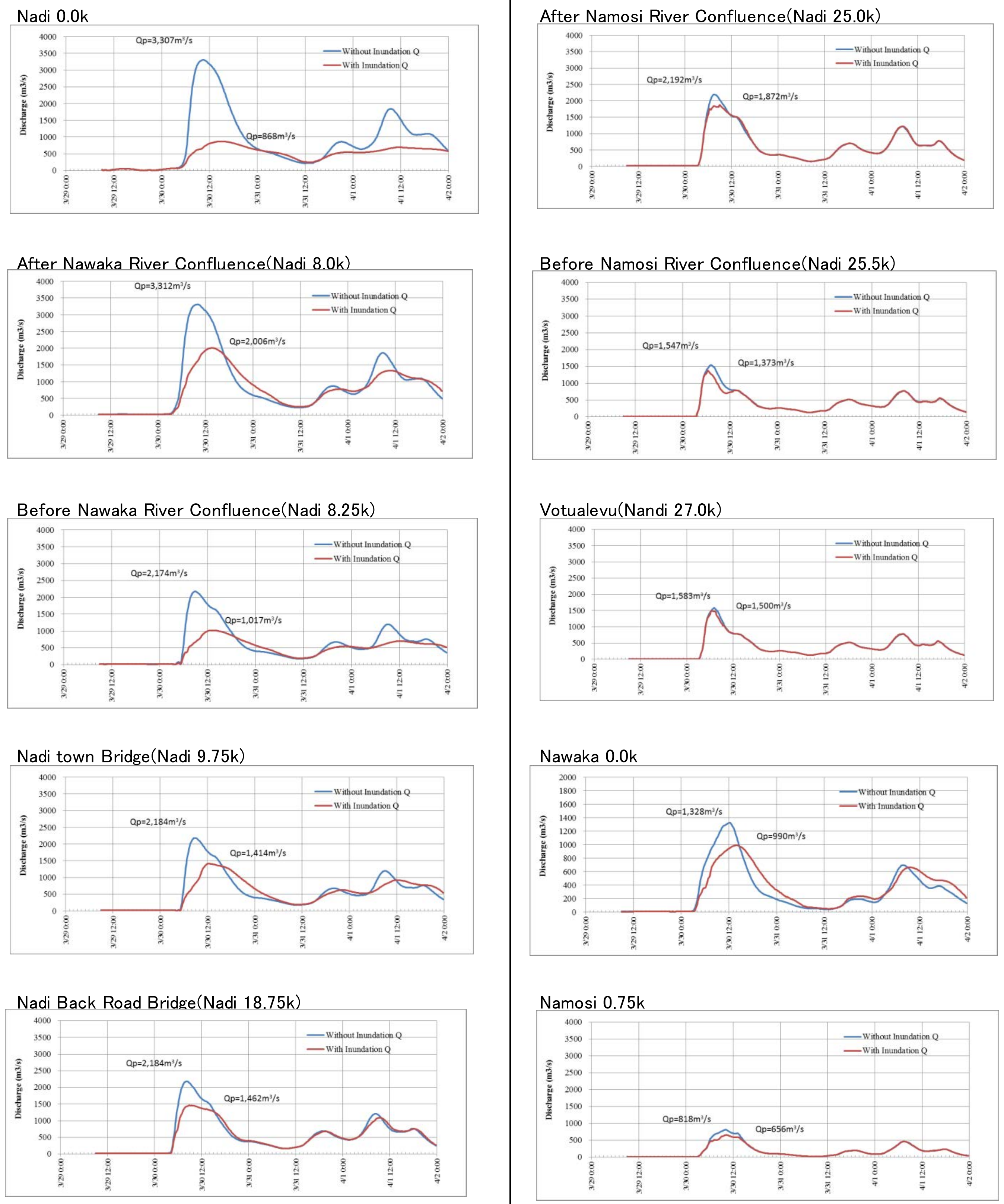


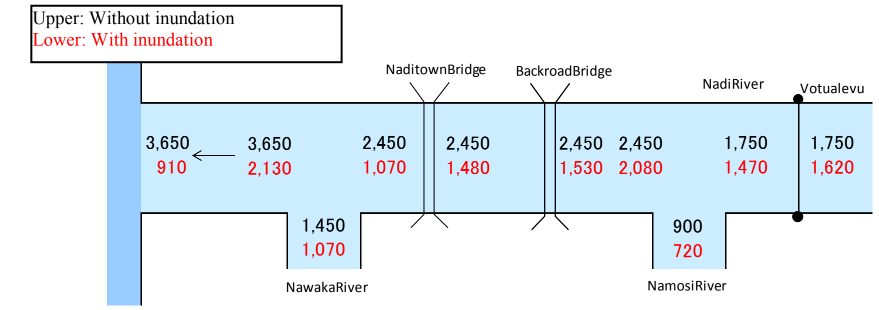
Figure 5. … graph and Maximum inundation map in 30-year probability

Peak discharge at important points (With and without inundation)

River	Distance km	Location	Maximum Q (a)Without Inundation	Maximum Q (b)With Inundation	(a)-(b)
Nadi	0.00	Estuary	3,651	905	2,746
Nadi	8.00	after Nawaka confluence	3,656	2,132	1,524
Nadi	8.25	before Nawaka confluence	2,423	1,070	1,353
Nadi	9.75	Nadi town Br.	2,432	1,473	959
Nadi	18.75	Back road Br.	2,429	1,524	905
Nadi	25.00	after Namosi confluence	2,440	2,079	361
Nadi	25.50	before Namosi confluence	1,727	1,466	262
Nadi	27.00	Votualevu	1,762	1,620	143
Nawaka	0.00	before Nadi confluence	1,456	1,063	393
Namosi	0.75	before Nadi confluence	891	720	171

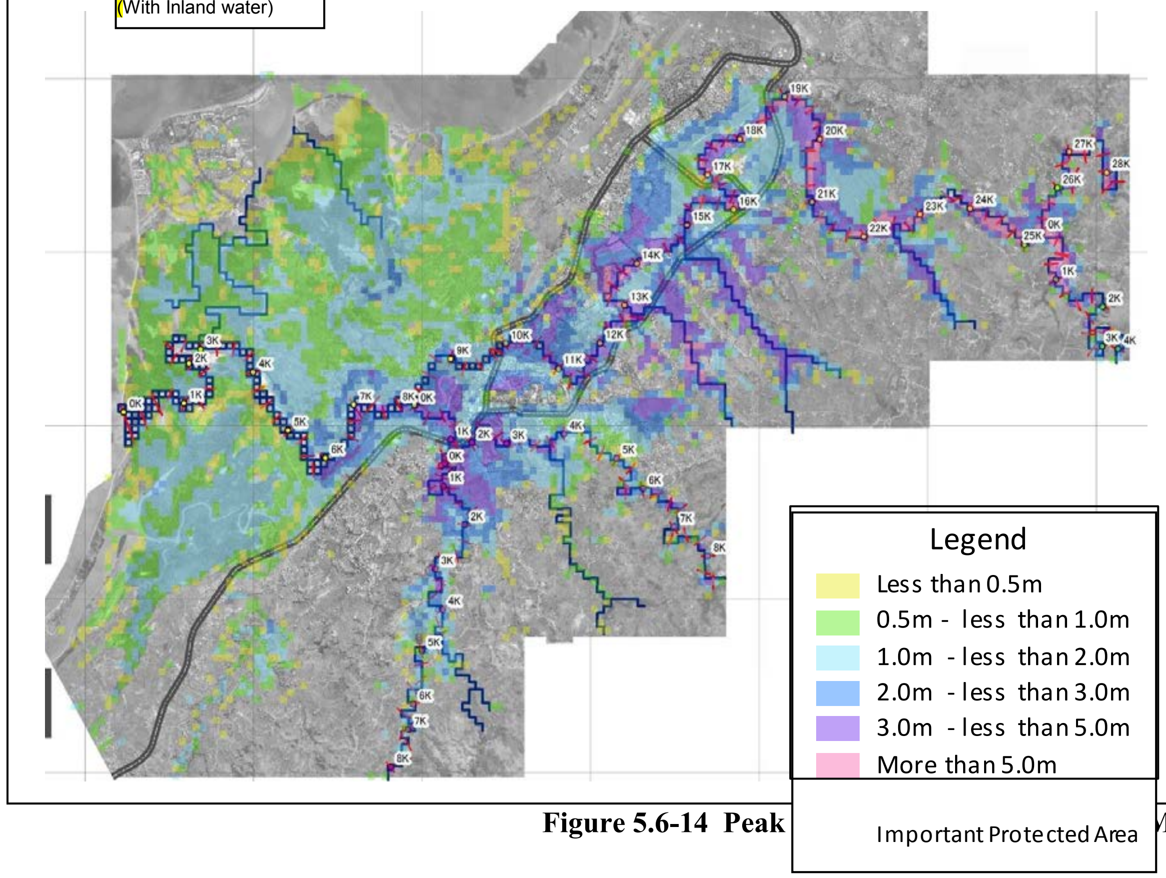
Discharge Distribution

No.25 Flood in March,2012 Design scale(approx. 50-year probability)



Maximum inundation Map

(With Inland water)



Hydrograph

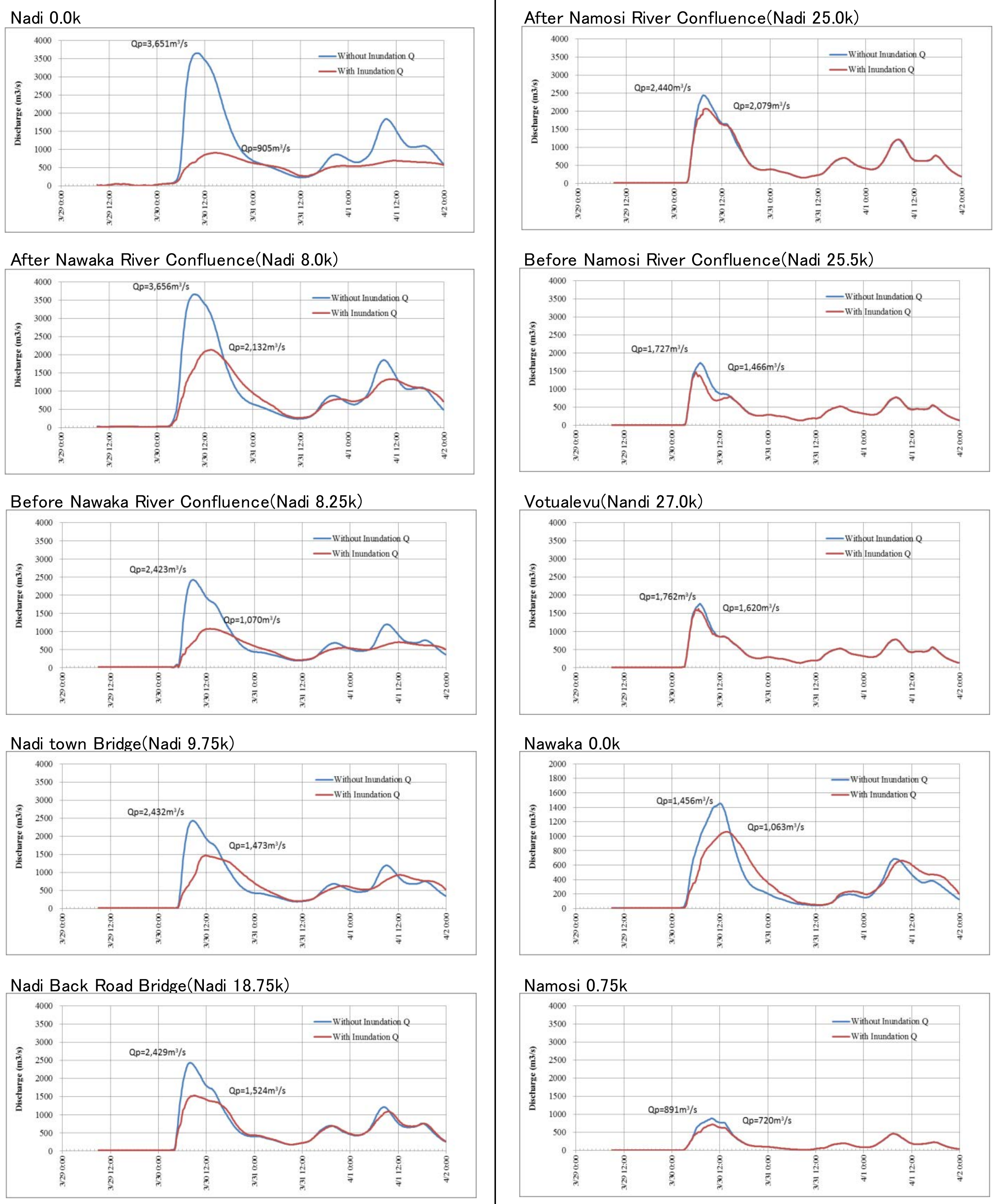


Figure 5.6-14 Peak ... Maximum inundation map in design scale (approx. 50-year probability)

Chapter 6 Consideration for Flood Control Measures

6.1 Basic Policy of Preliminary Flood Control Plan

6.1.1 Basic Consideration

The basic policy of preliminary flood control plan is established in the examination of combination of flood control measures as follows:

① The assets protected with top priority in planning flood control measures are to be “Nadi Town”, “Nadi Airport” and ”Queens Road” (refer to Figure 6-4). The plan should be examined not to cause the inundation damage to such assets.

② The rebuilding of Nadi Town Bridge and Back Road Bridge would be avoided as much as possible since these bridges are in main traffic route. However Nadi Town Bridge under which the discharge capacity of river channel is extremely low, will be examined to be rebuilt in case that the rebuilding is economical in cost and so on. Old Queens Road Bridge is to be rebuilt since it is too old to use hereafter.

6.1.2 Determination of Target Flood Discharge

Back Road Bridge and Nadi Town Bridge, between which the assets are concentrated, are established as control points.

The discharge capacity at Back Road Bridge and Nadi Town Bridge are as shown in Figure 6-1 and Figure 6-2 respectively in case that the river channel normalization is carried out in the present river.

The target discharge is determined as shown below depending on the possibility of large scale setting back of embankment and rebuilding of Nadi Town Bridge (refer to Figure 6-3).

In case of large scale setting back of embankment in the town area:

At Back Road Bridge: 1,400m3/s

At Nadi Town Bridge: 1,400m3/s

In case of normalization of present river channel in the town area:

At Back Road Bridge: 1,400m3/s

At Nadi Town Bridge: 700m3/s

The reasons are as follows:

At Back Road Bridge the possible discharge is 1,400m3/s even if the maximum flood control is carried out by flood control facilities such as dam and retarding basin and the improved discharge capacity is approximately 1,400 m3/s after river channel normalization.

At Nadi Town Bridge, the discharge capacity is 1,400m3/s in case that setting back of embankment and rebuilding of the bridge is possible in the town area; if not the discharge capacity is approximately 700m3/s after river channel normalization.

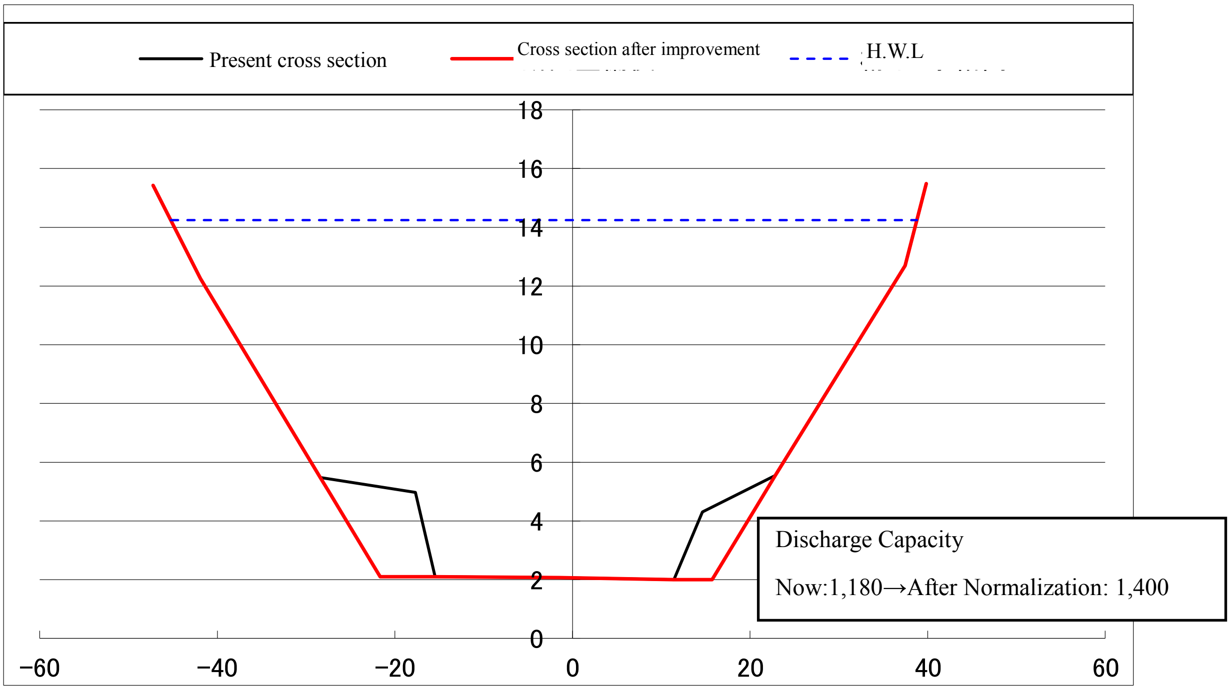


Figure 6-1 Cross Section before and after River Channel Normalization at Back Road Bridge

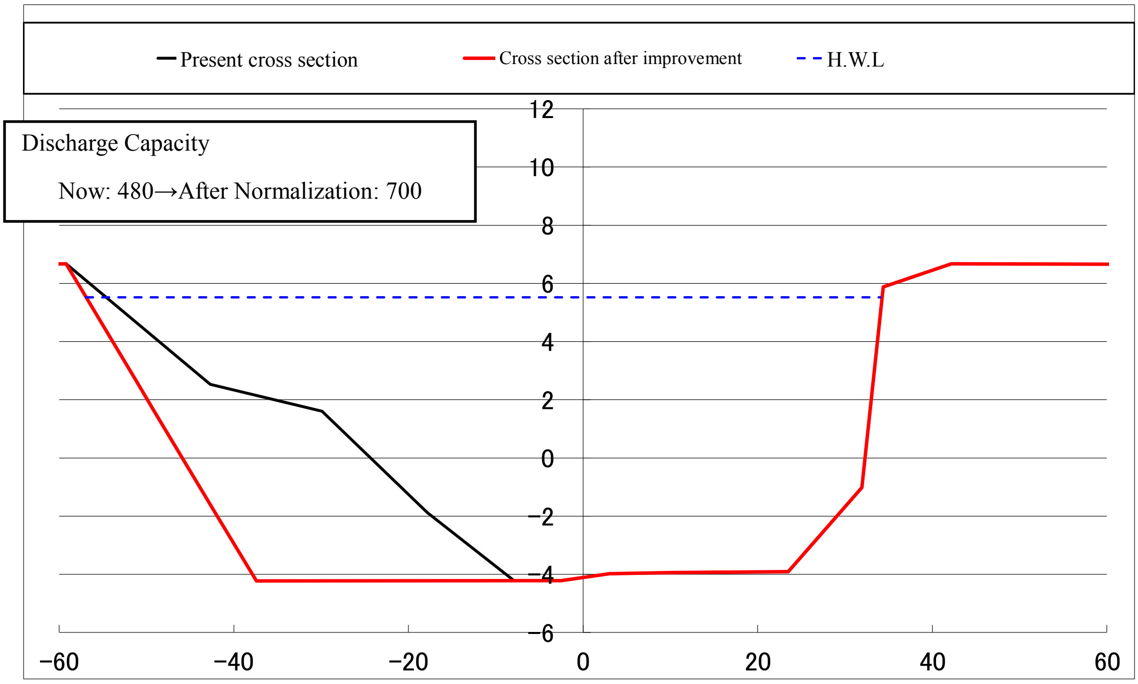


Figure 6-2 Cross Section before and after River Channel Normalization at Nadi Town Bridge

No.25 Flood in March, 2015

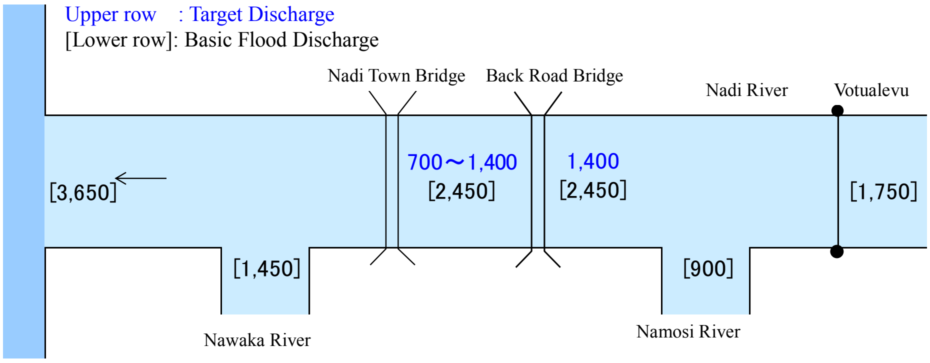


Figure 6-3 Determination of Target Discharge

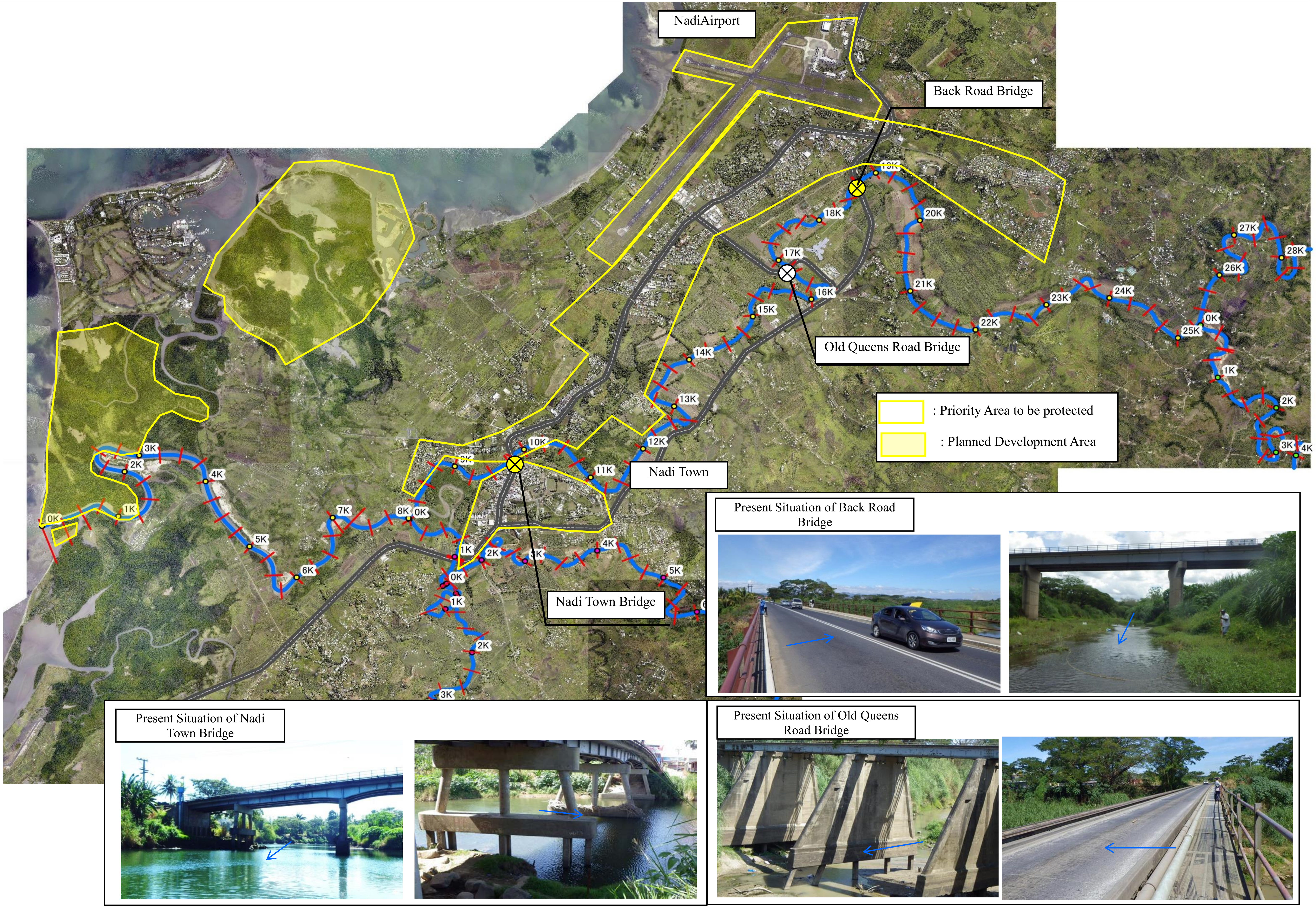


Figure 6-4 Priority Area to be Protected and Present Condition of Bridges

6.1.3 Division of River Section for Flood Control Plan

Nadi river is divided into three sections from view point of flood control planning regarding the middle stream section as the most important (refer to Figure 6-5). The combination of various flood control measures is studied based on the policy of each section.

① Middle Stream Section : 5.75km～Back Road Bridge

The middle stream section is defined from Back Road Bridge to approximately 6.0km in distance along river which is concentrated the town area. The flood control measures in the middle stream section are planned so that the design discharge at the Bridge is to be 1,400m^3 /s and the design discharge at Nadi Town Bridge is to be 1,400m^3 /s with rebuilding of Nadi Town Bridge or 700 m^3 /s without rebuilding.

Flood control measures to be studied are as follows:

- Diversion channel
- River improvement

② Downstream Section: River mouth～5.75km

In the downstream section there is a mangrove forest widely spread and less assets compared with the middle stream section and upstream section, however the area development is planned in the right bank of river mouth. The flood control measures in the downstream section are planned so that the influence to the development is minimized and water level rising caused by joining of Nawaka river dose not affect the upstream.

Flood control measures to be studied are as follows:

- Retarding basin
- Diversion Channel

③ Upstream Section: Back Road Bridge～Upstream

In the upstream section the flood control measures are planned so that the flood discharge is controlled to 1,400m3 /s

Flood control measures to be studied are as follows:

- Retarding basin
- Diversion channel
- River improvement
- Dam
- Flood control measures in Namosi river

6.1.4 First Selection of Flood Control Measures in each Section

The first selection of possible flood control measures is carried out in each section as shown in Table 6-1.

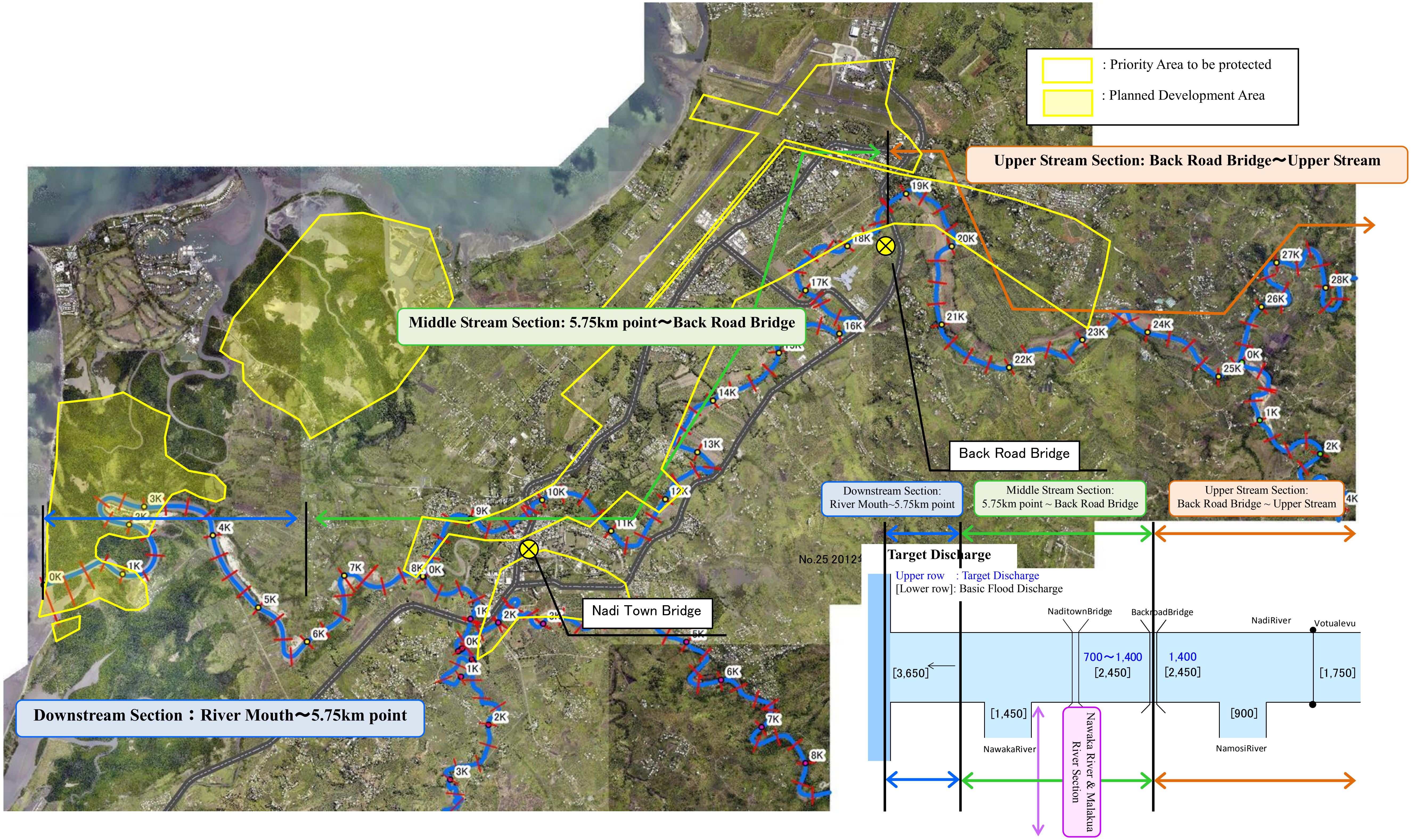


Figure 6-5 Division of River Section for Flood Control Plan

Table 6-1 Result of First Selection of Flood Control Measure

Flood Control Measures		Contents	Middle Stream Section		Downstream Section		Upper Stream Section	
			Selection Result	Conclusion	Selection Result	Conclusion	Selection Result	Conclusion
A	**Dam**	● Construction of new dam to reserve a part of flood discharge	●Dam scheme isn't considered in middle section because there is no candidate site for dam construction.	Not Selected	●Dam scheme isn't considered in downstream section because there is no candidate site for dam construction.	Not Selected	●Dam scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected
B	**Retarding Basin**	● Storage of a part of flood discharge in the retarding basin constructed along river channel.	●Retarding Basin scheme isn't considered in middle section because there is no candidate site for retarding basin.	Not Selected	●Retarding Basin scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected	●Retarding Basin scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected
C	**Diversion Channel**	● Excavation of new channel on upper stream of protection area and discharge toward the sea.	●Diversion Channel scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected	●Diversion Channel scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected	●Diversion Channel scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected
D	**River Improvement**	● Channel Excavation: Discharge capacity improvement by expanding sectional area ● Backward Displacement of Dyke: Discharge capacity improvement by constructing new dyke in landside ● Dyke: Discharge capacity improvement by constructing dyke.	●River Improvement scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected	●River Improvement scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected	●River Improvement scheme is selected because there is need of consideration, feasibility and prospect for comfortable flood control effect.	Selected
E	**Ring Dike**	● Inundation prevention by surrounding specific area locally	●River Dike scheme isn't selected because surrounding all protected area by bank isn't realistic	Not Selected	● River Dike scheme is selected to protect dotted communities.	Selected	●River Dike scheme isn't selected because there is no protected area.	Not Selected