CHAPTER 3 CONCLUSION

About the result of flood analysis for each river, the comparison without case and with case is shown below. As for the Chira River, since the fact that the discharge capacity is insufficient in all sections in the river, even if measures are carried out partially, the flood damage is not reduced.

On the other hand, about other rivers, it turns out that the flood damage has reduced sharply after implementation of works. In addition, in the Yauca River, since flood areas are limited along the river, the effects of measures work are small.

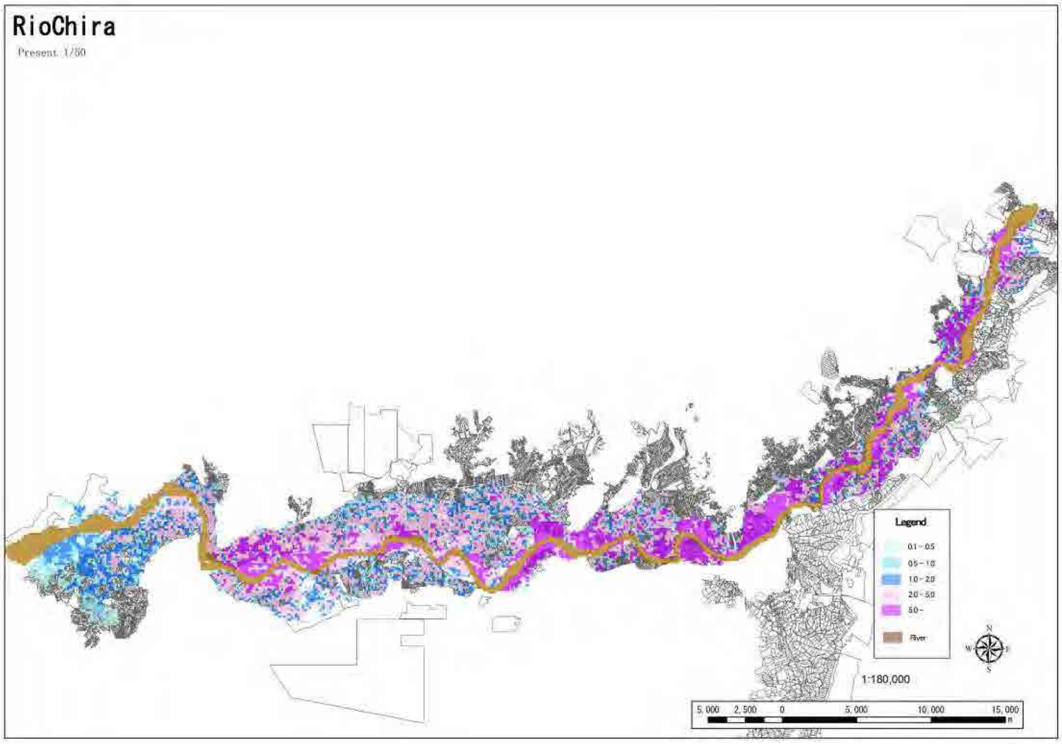
Table 3.1 **Comparison of Inundation Areas between Without Case and With Case**

Without Case		1/5		1/10		1/25		1/50	
		No, of Mesh	ha	No, of Mesh	ha	No, of Mesh	ha	No, of Mesh	ha
Chira		6,233	14,024.3	7,340	16,515.0	8,661	19,487.3	9,589	21,575.3
Canete		73	164.3	391	879.8	552	1,242.0	678	1,525.5
Chincha	①Chico	270	607.5	293	659.3	714	1,606.5	827	1,860.8
	②Matagente	249	560.3	265	596.3	498	1,120.5	587	1,320.8
	③No. of Overlap Mesh	0	0.0	0	0.0	249	560.3	256	576.0
	①+②-③	519	1,167.8	558	1,255.5	963	2,166.8	1,158	2,605.5
Pisco		251	564.8	344	774.0	438	985.5	517	1,163.3
Yauca		–	–	1	2.3	18	40.5	40	90.0
Majes-Camana		714	1,606.5	1,001	2,252.3	1,157	2,603.3	1,632	3,672.0

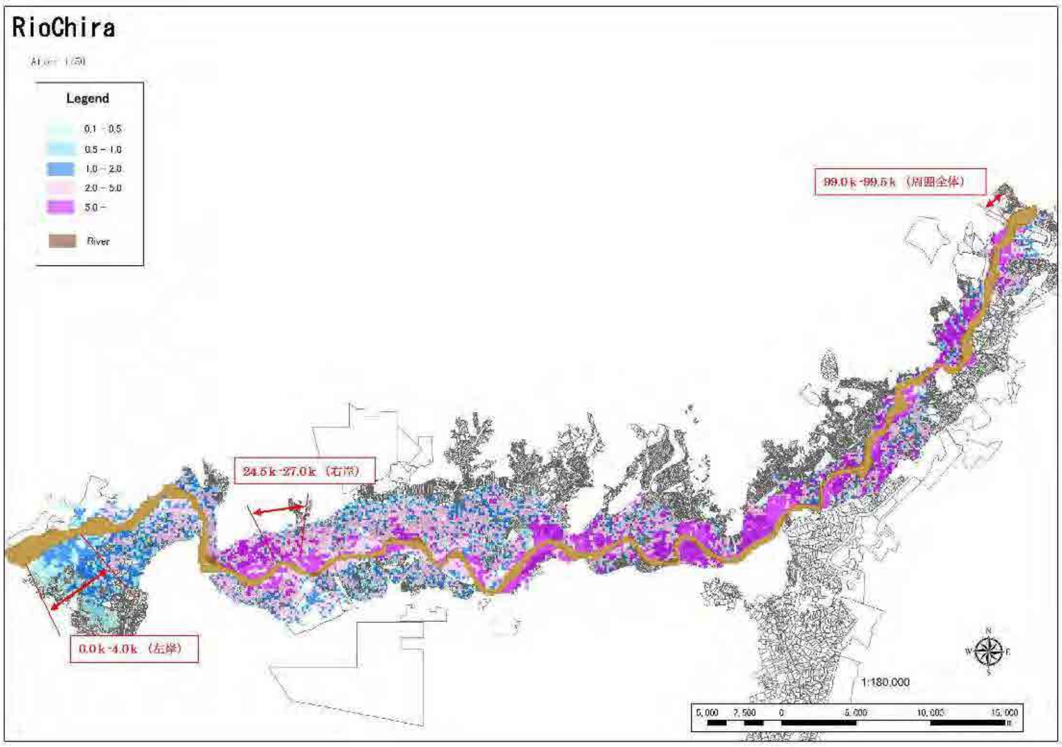
With Case		1/5		1/10		1/25		1/50	
		No, of Mesh	ha	No, of Mesh	ha	No, of Mesh	ha	No, of Mesh	ha
Chira		6,233	14,024.3	7,340	16,515.0	8,661	19,487.3	9,586	21,568.5
Canete		21	47.3	60	135.0	93	209.3	125	281.3
Chincha	①Chico	24	54.0	56	126.0	248	558.0	397	893.3
	②Matagente	–	–	–	–	148	333.0	245	551.3
	③No. of Overlap Mesh	–	–	–	–	76	171.0	140	315.0
	①+②-③	24	54.0	56	126.0	320	720.0	502	1,129.5
Pisco		18	40.5	69	155.3	140	315.0	193	434.3
Yauca		–	–	1	2.3	13	29.3	20	45.0
Majes-Camana		104	234.0	196	441.0	288	648.0	523	1,176.8

3.1 Chira River

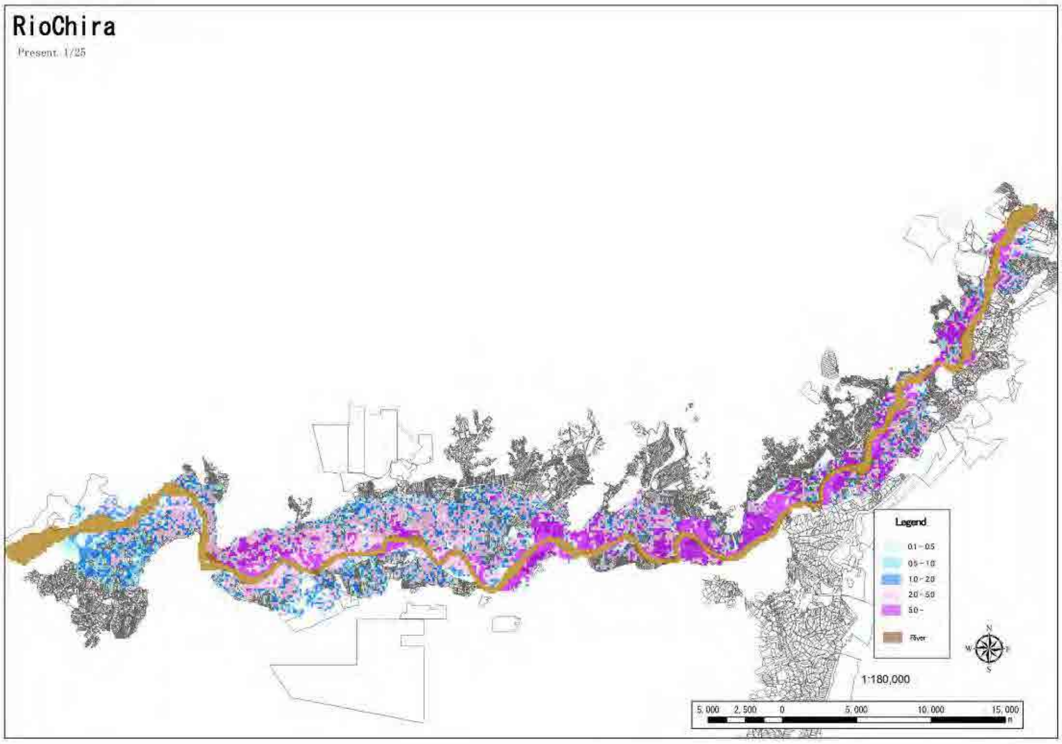
(1) Chira River (1/50 Year Probable Flood) Without Case



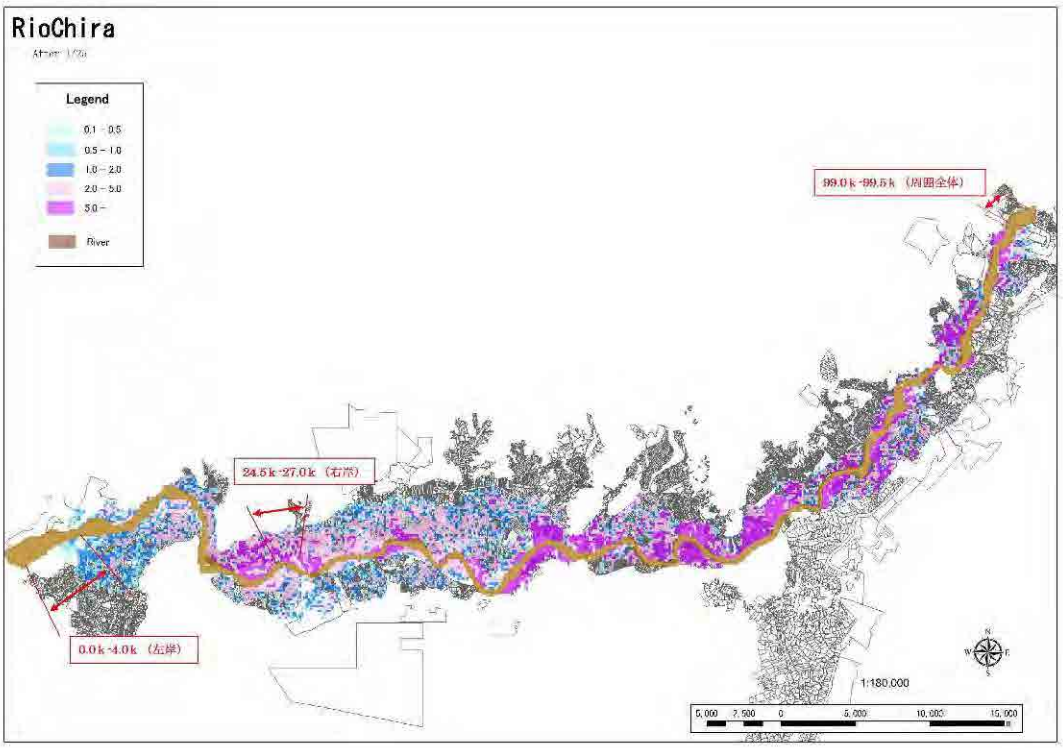
(2) Chira River (1/50 Year Probable Flood) With Case



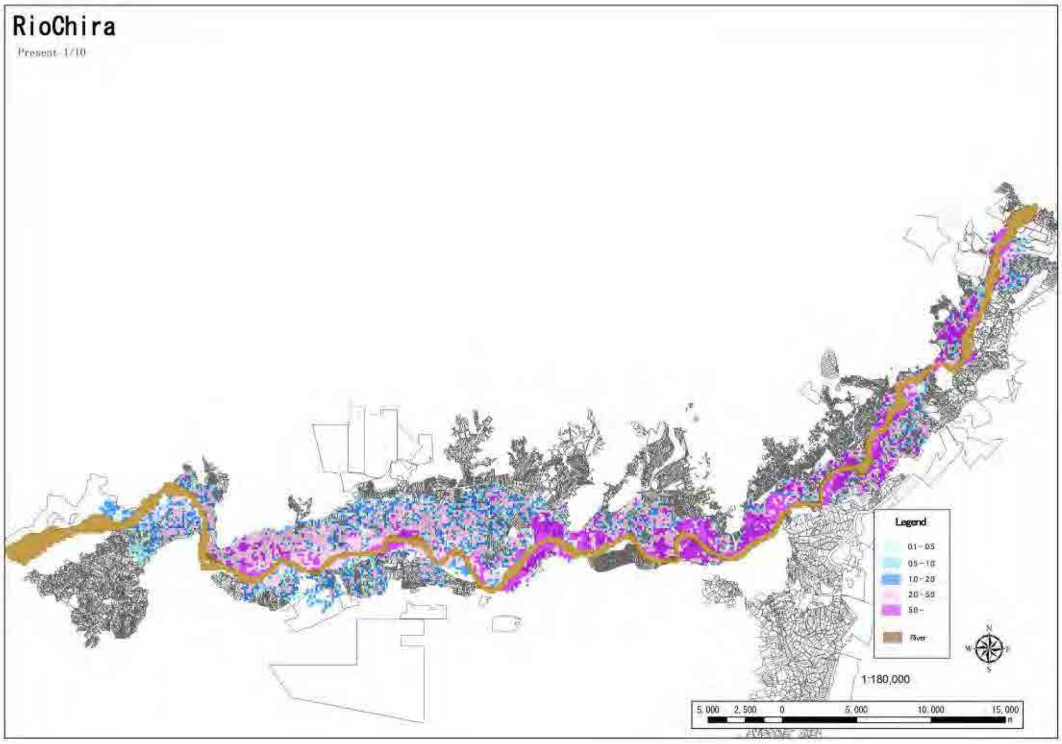
(3) Chira River (1/25 Year Probable Flood) Without Case



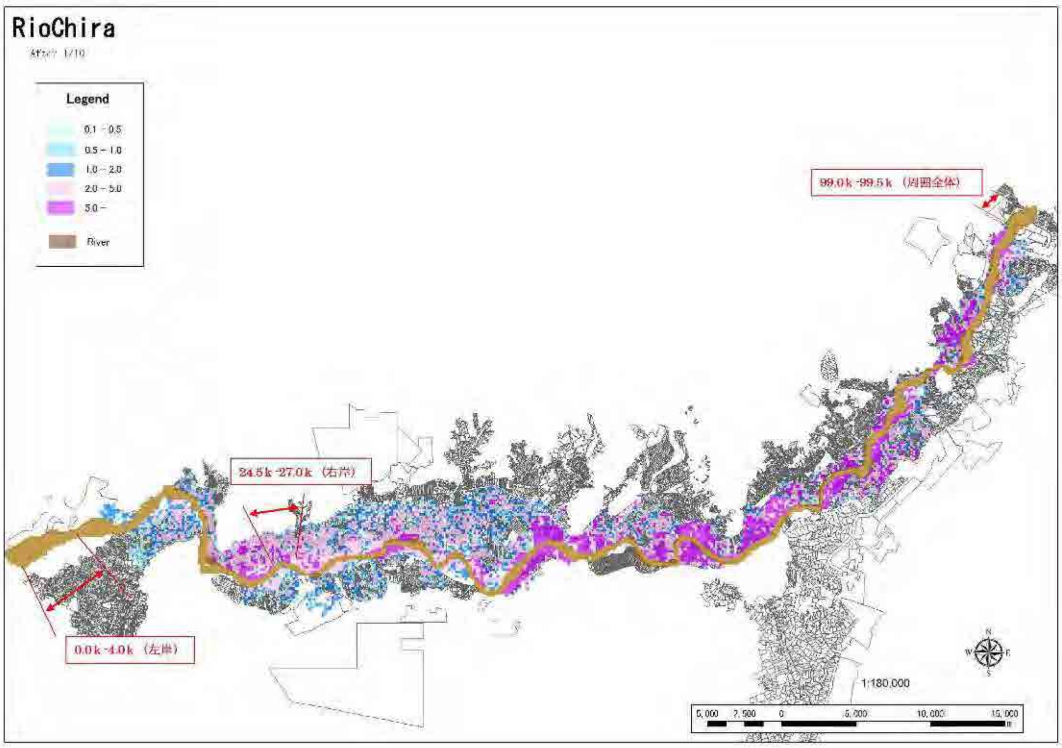
(4) Chira River (1/25 Year Probable Flood) With Case



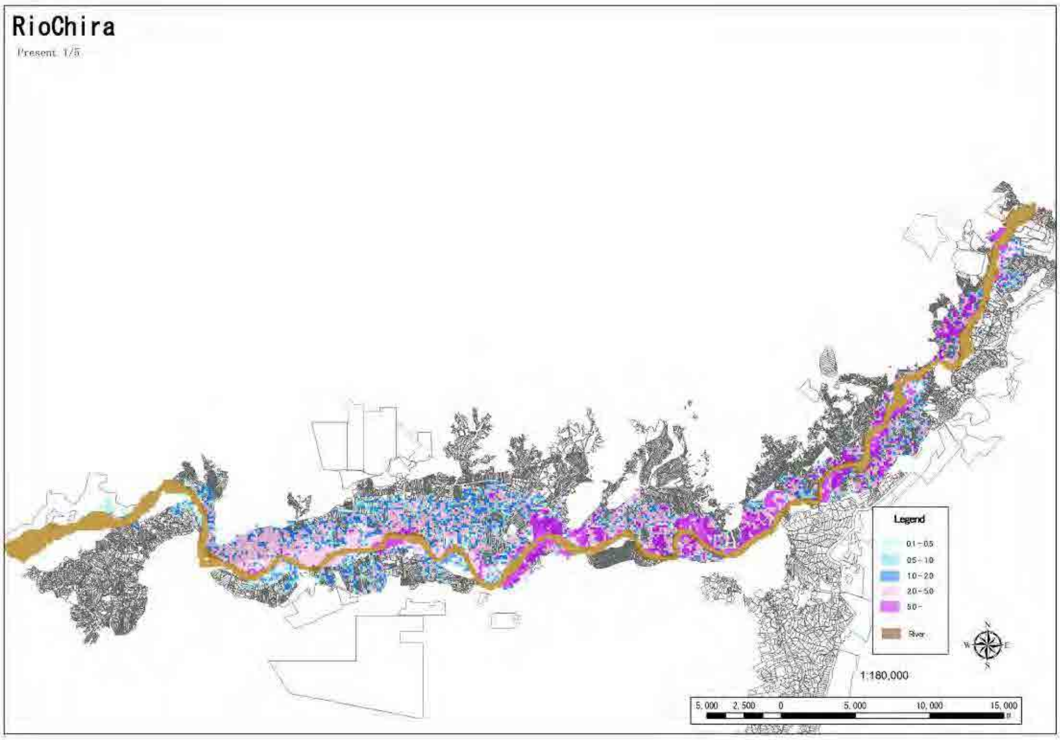
(5) Chira River (1/10 Year Probable Flood) Without Case



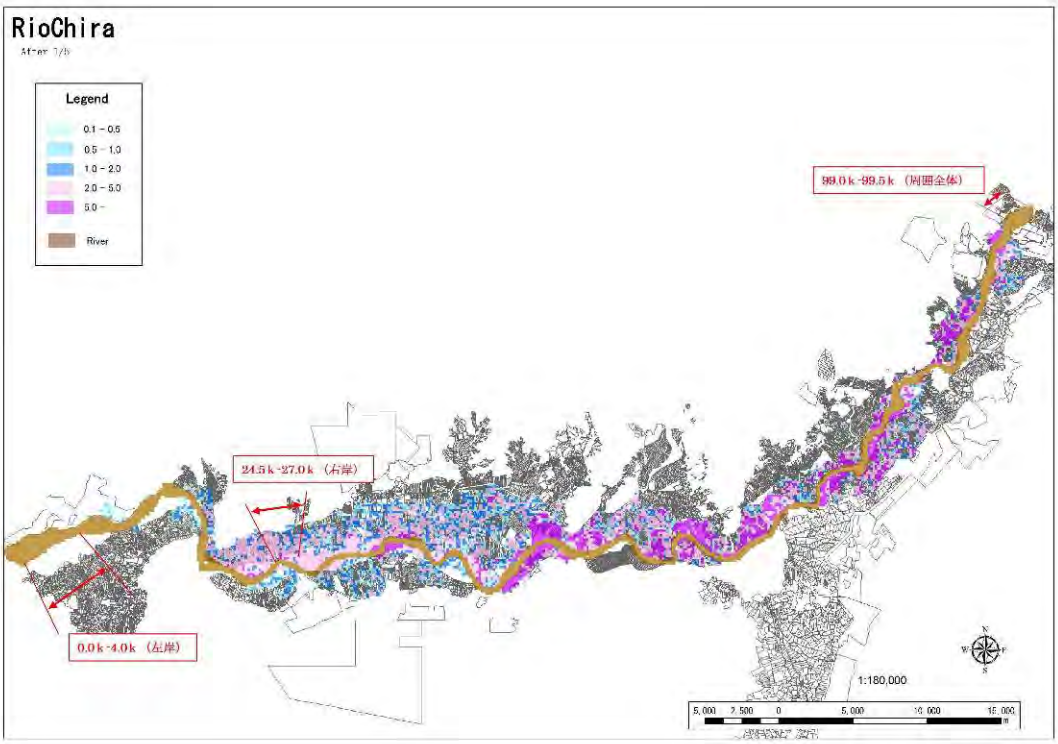
(6) Chira River (1/10 Year Probable Flood) With Case



(7) Chira River (1/5 Year Probable Flood) Without Case

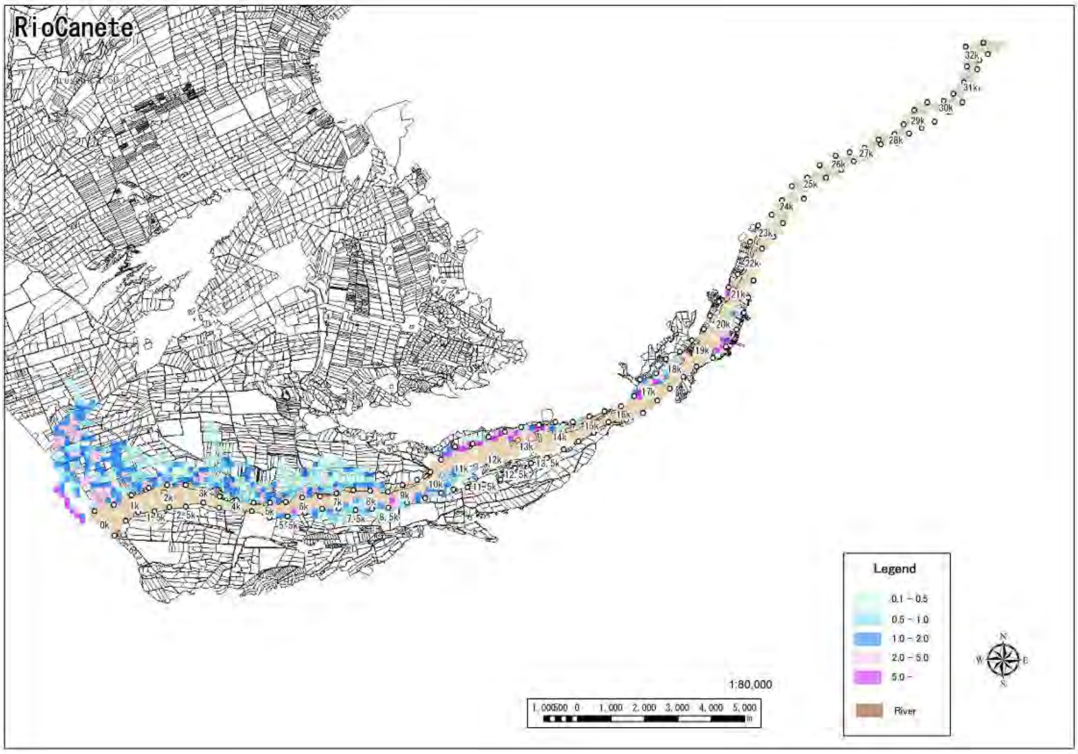


(8) Chira River (1/5 Year Probable Flood) With Case

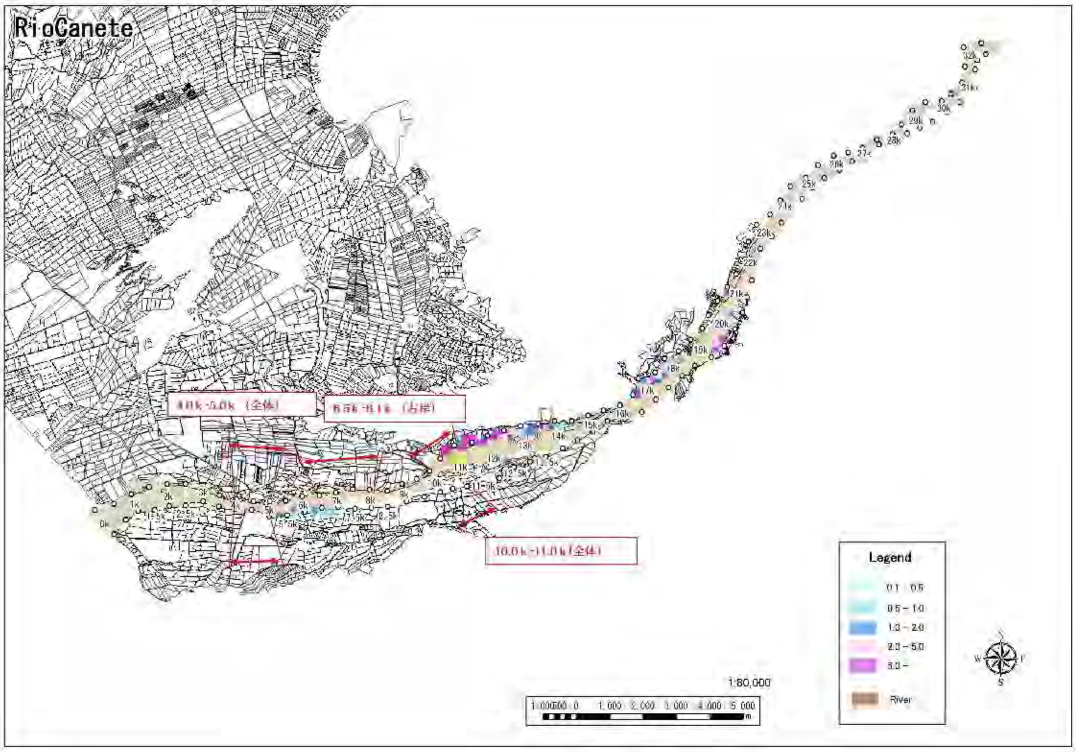


3.2 Canete River

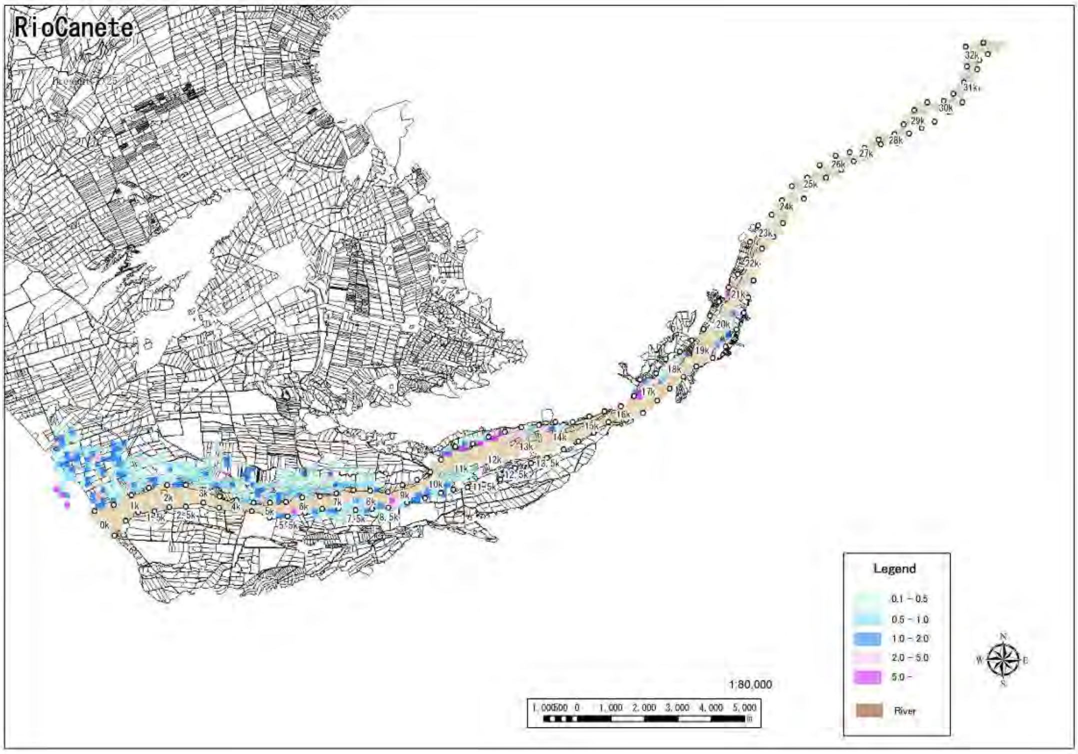
(1) Canete River (1/50 Year Probable Flood) Without Case



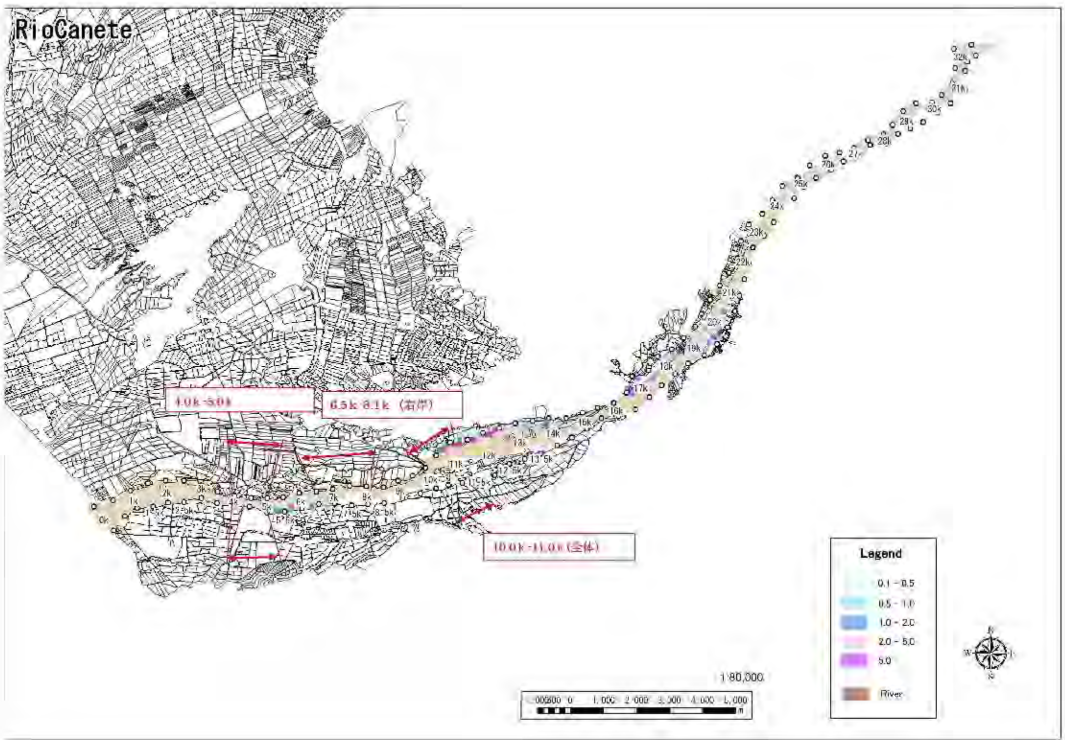
(2) Canete River (1/50 Year Probable Flood) With Case



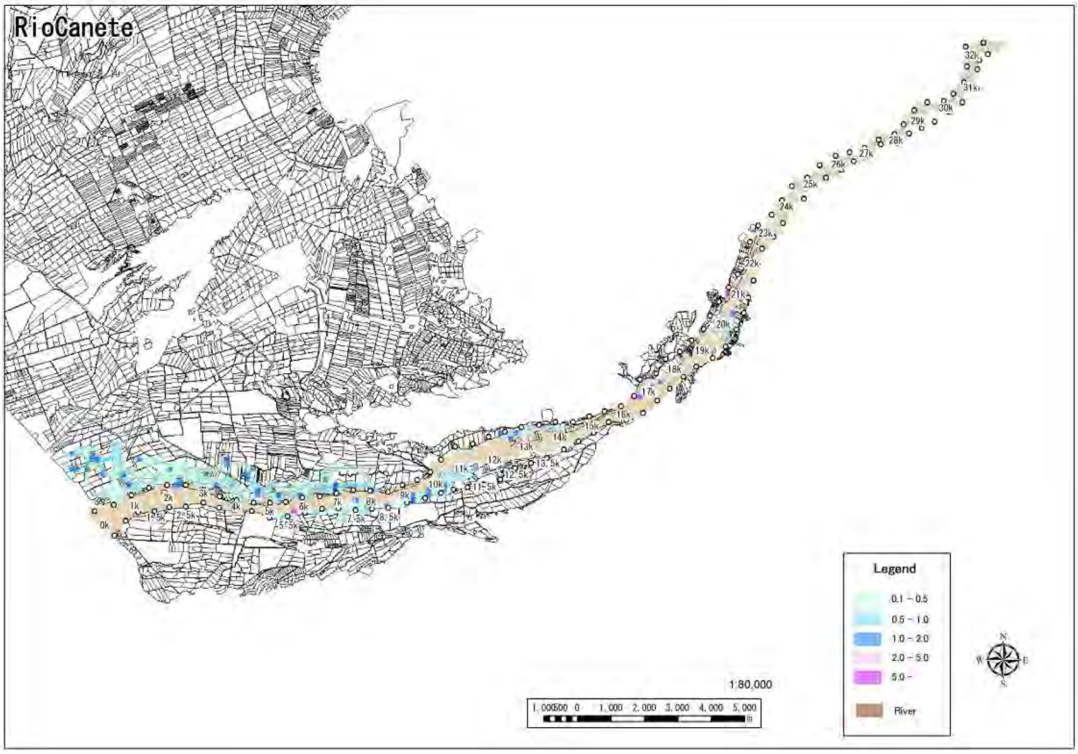
(3) Canete River (1/25 Year Probable Flood) Without Case



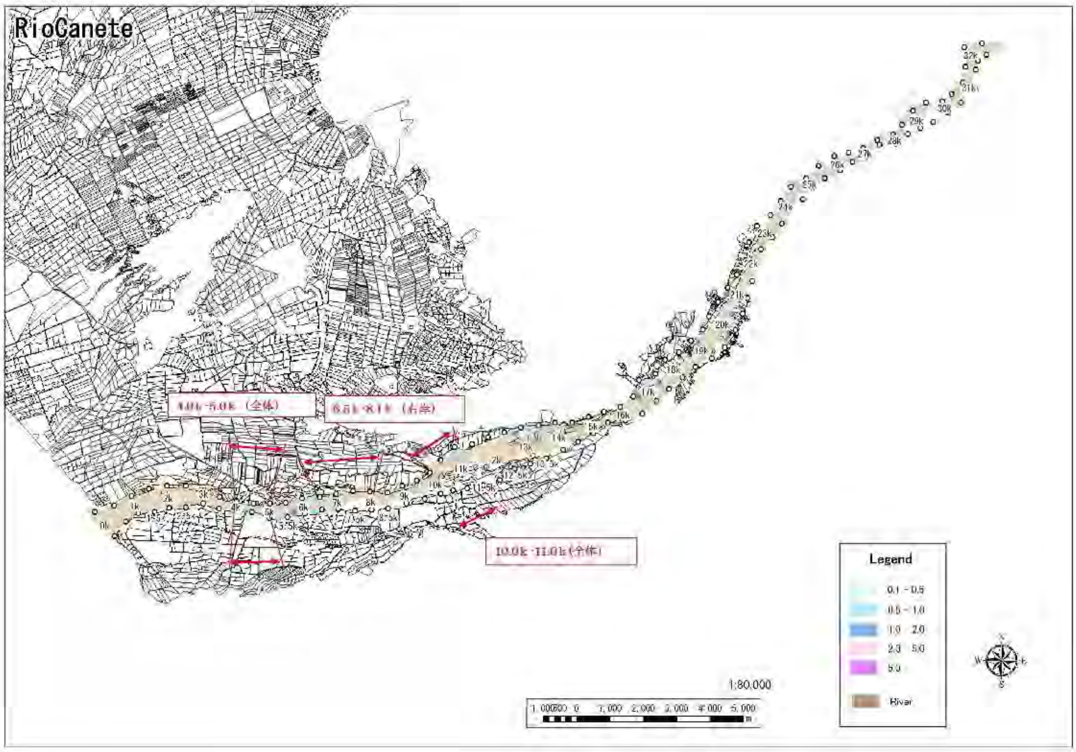
(4) Canete River (1/25 Year Probable Flood) With Case



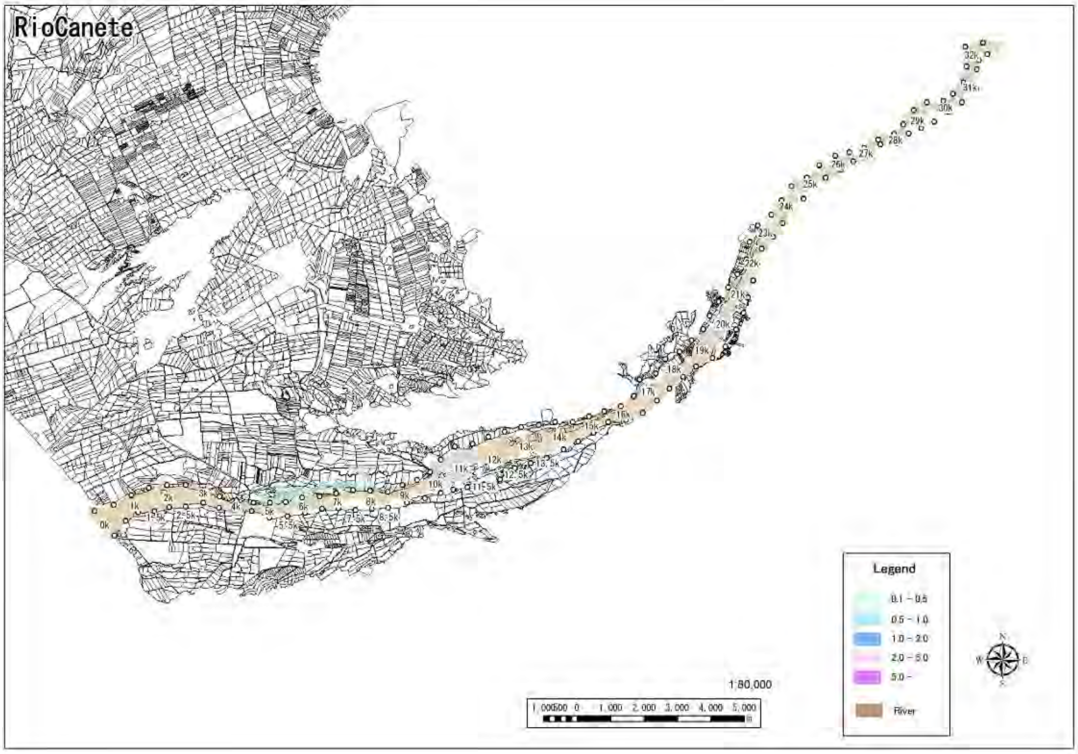
(5) Canete River (1/10 Year Probable Flood) Without Case



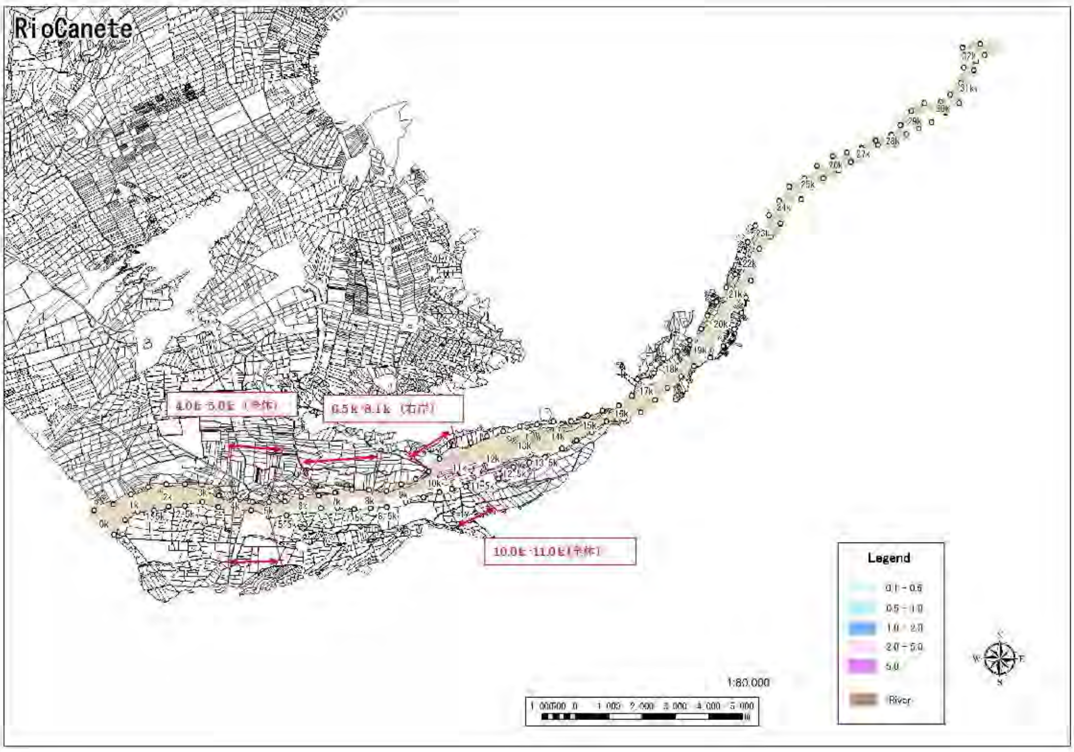
(6) Canete River (1/10 Year Probable Flood) With Case



(7) Canete River (1/5 Year Probable Flood) Without Case

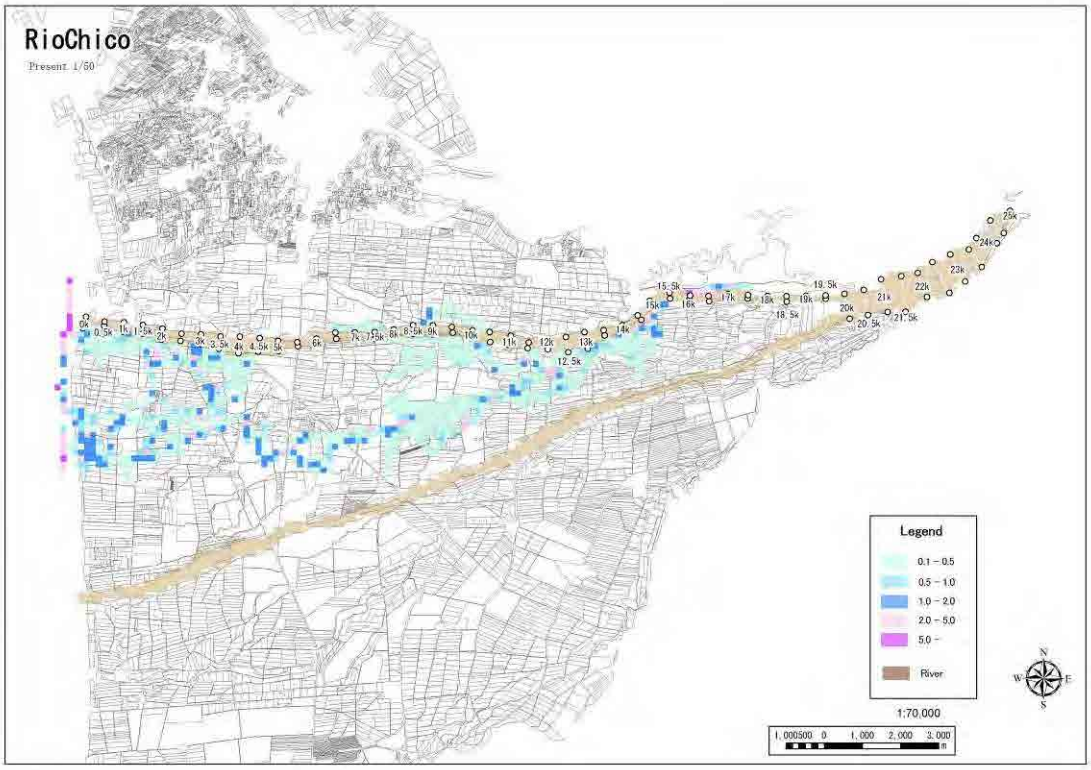


(8) Canete River (1/5 Year Probable Flood) With Case

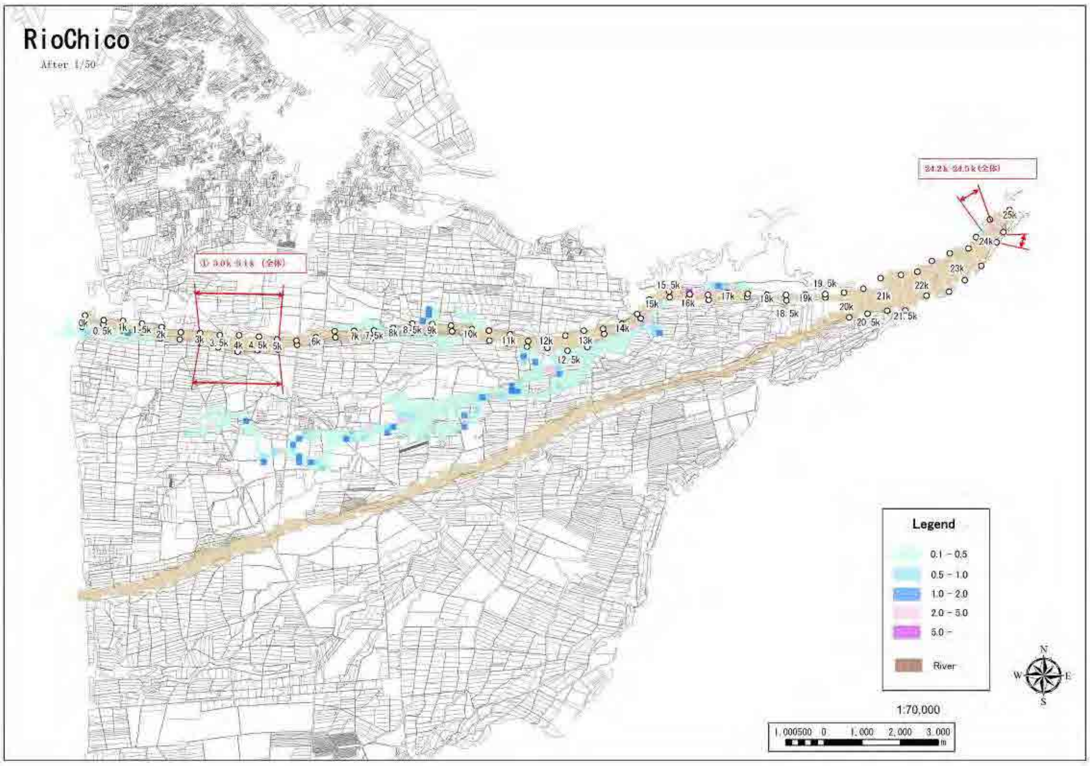


3.3 Chincha (Chico) River

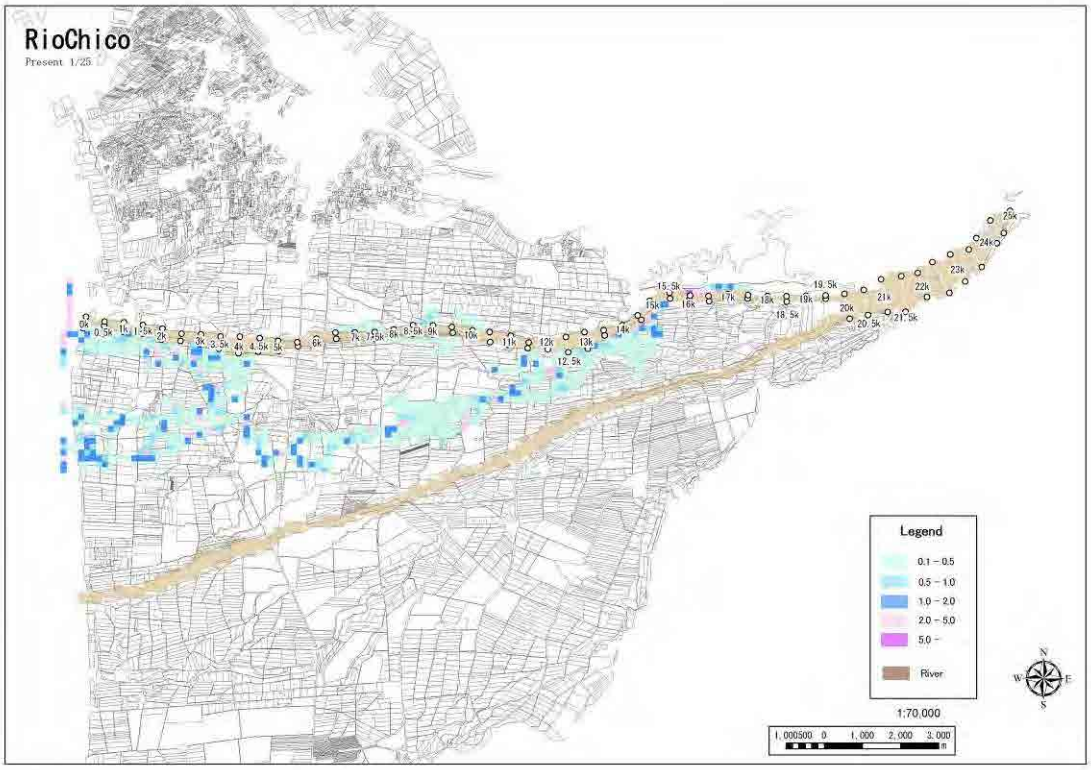
(1) Chincha (Chico) River (1/50 Year Probable Flood) Without Case



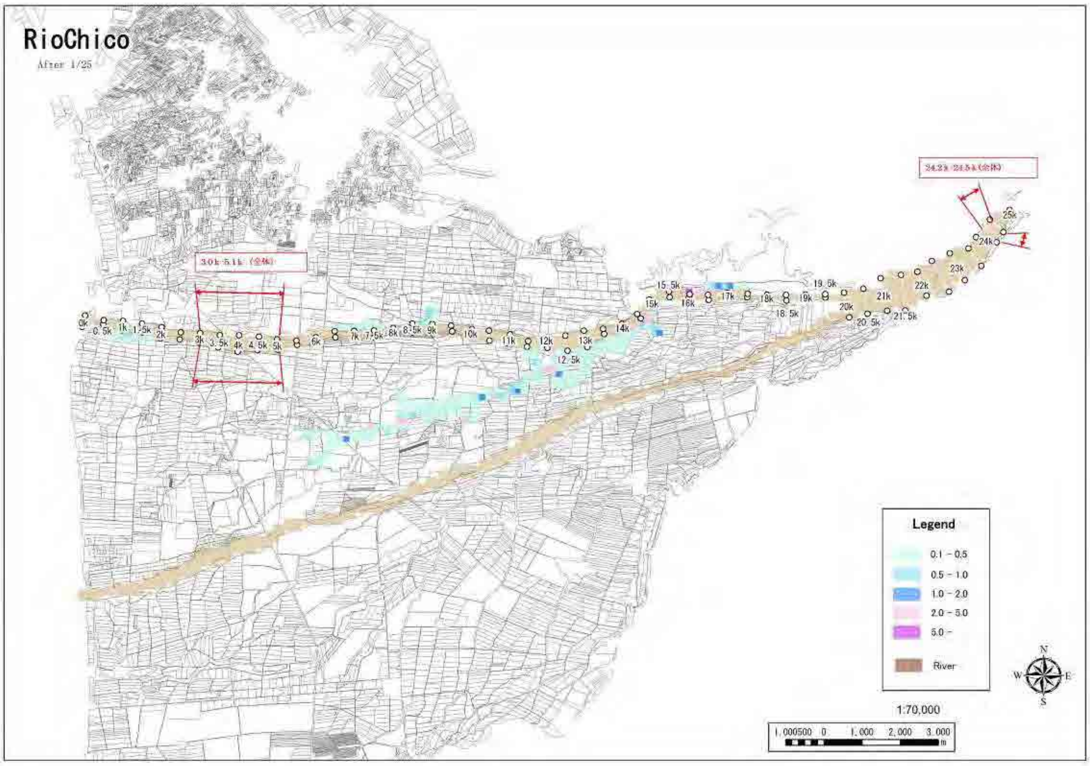
(2) Chincha (Chico) River (1/50 Year Probable Flood) With Case



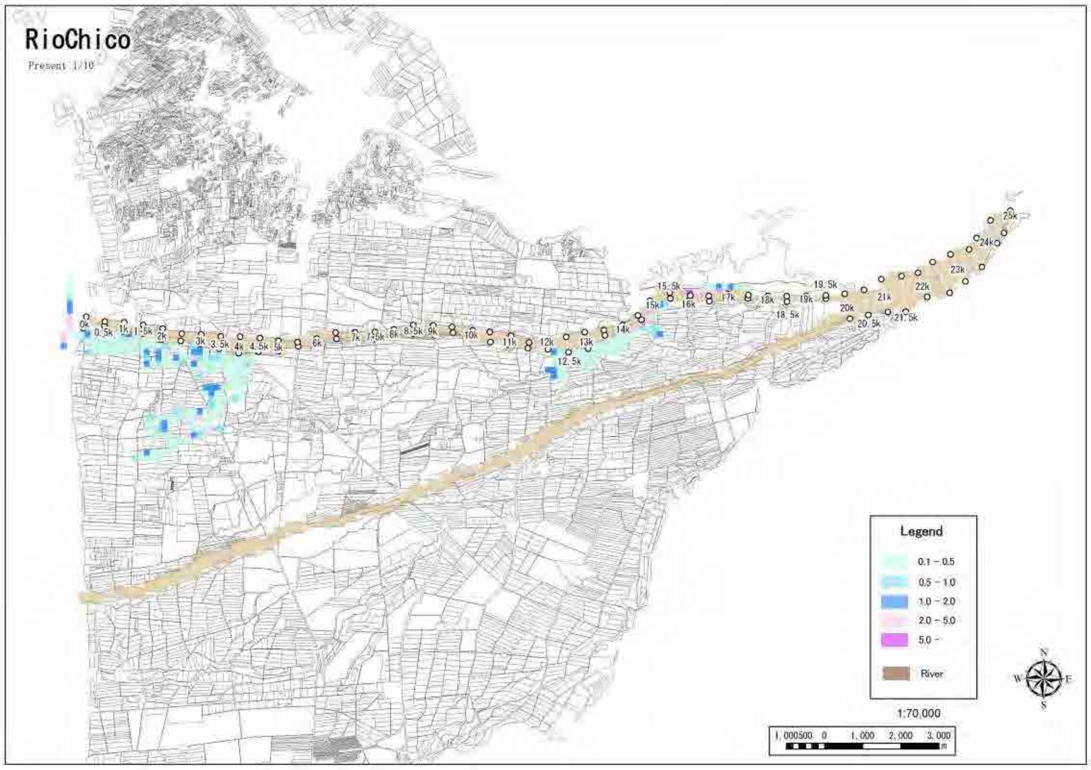
(3) Chincha (Chico) River (1/25 Year Probable Flood) Without Case



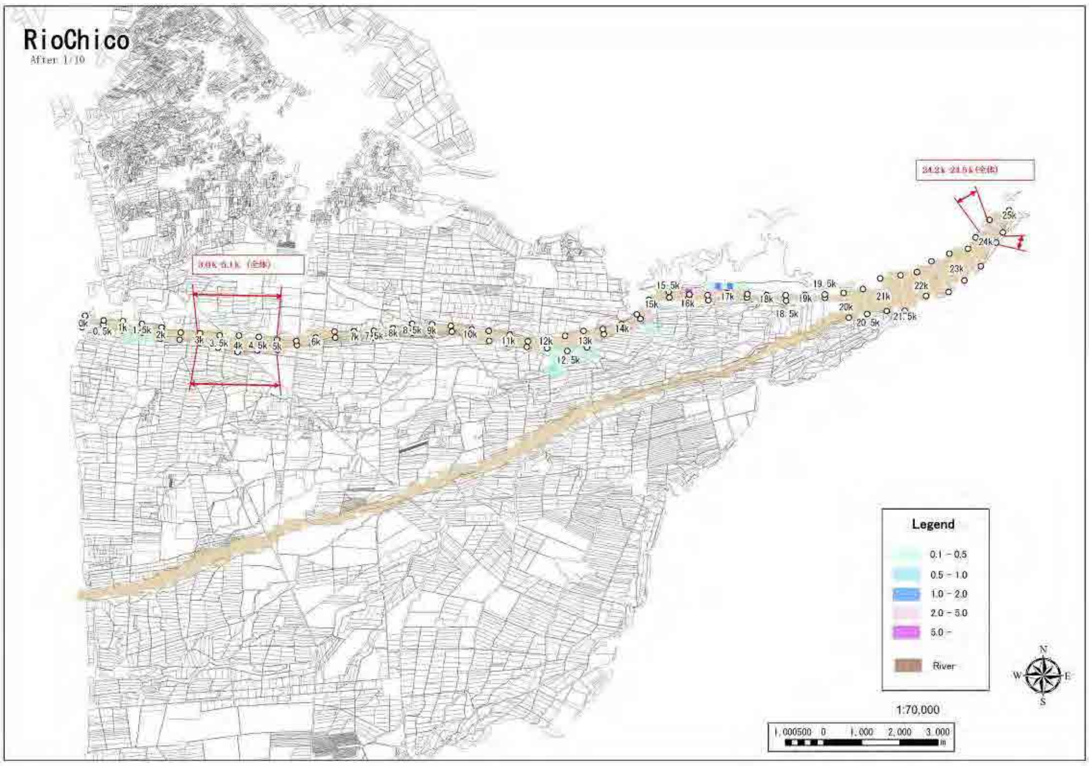
(4) Chincha (Chico) River (1/25 Year Probable Flood) With Case



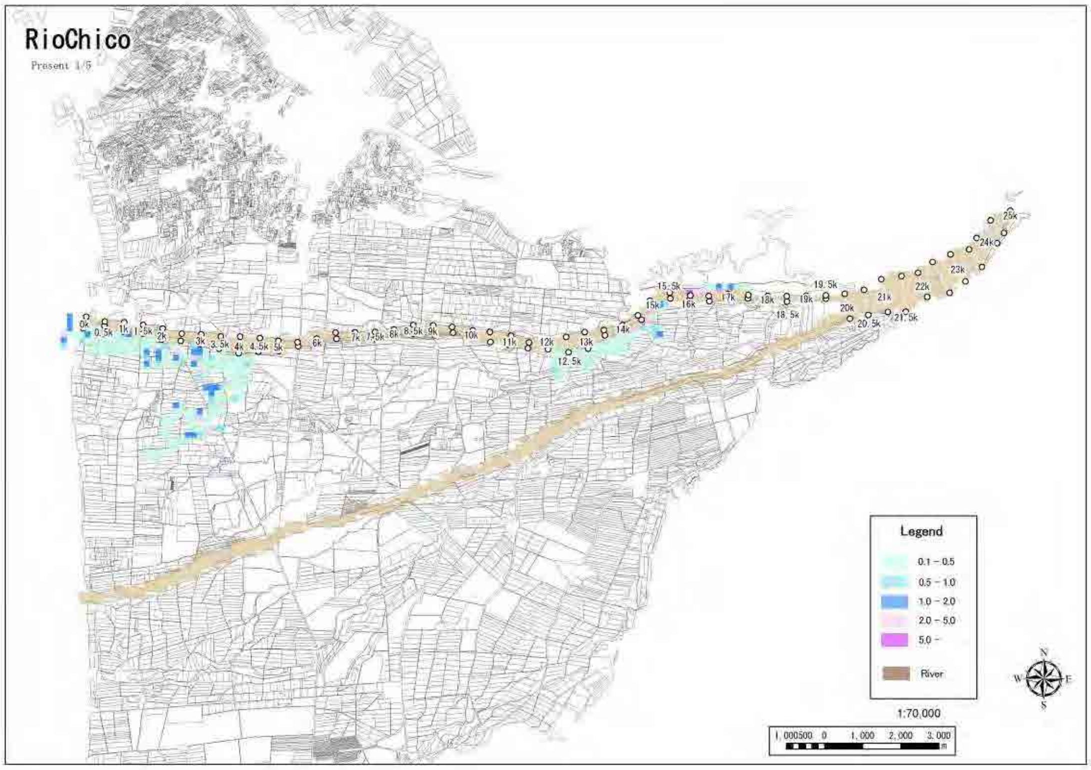
(5) Chincha (Chico) River (1/10 Year Probable Flood) Without Case



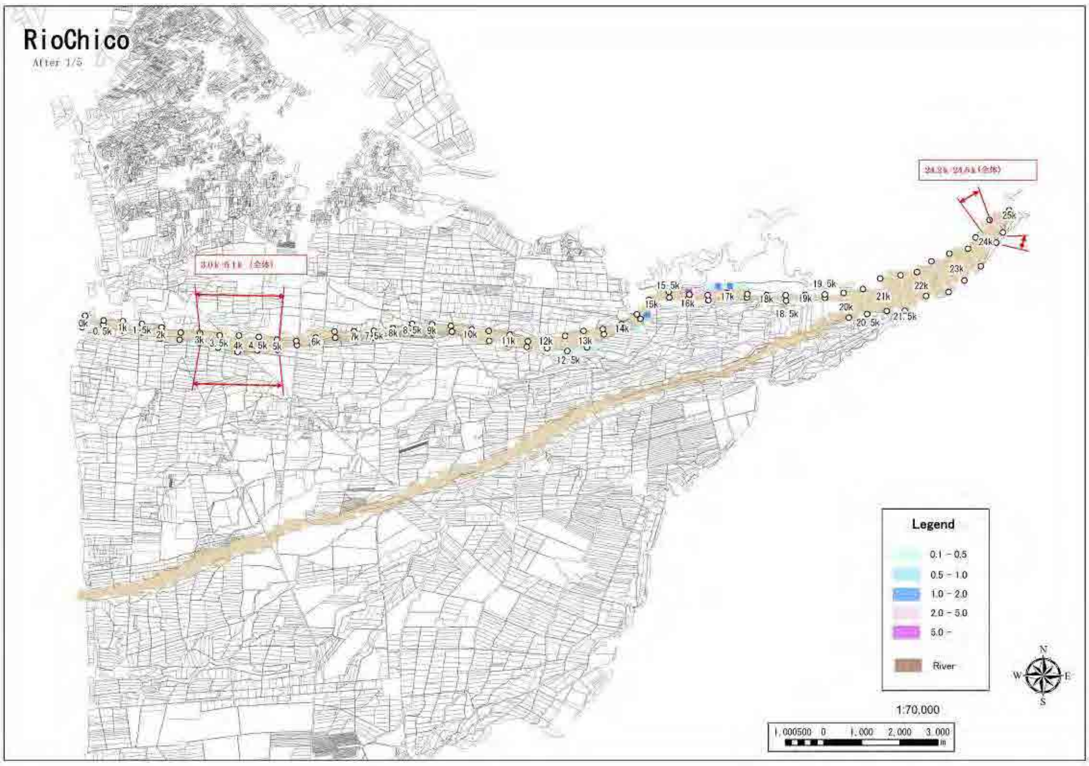
(6) Chincha (Chico) River (1/10 Year Probable Flood) With Case



(7) Chincha (Chico) River (1/5 Year Probable Flood) Without Case

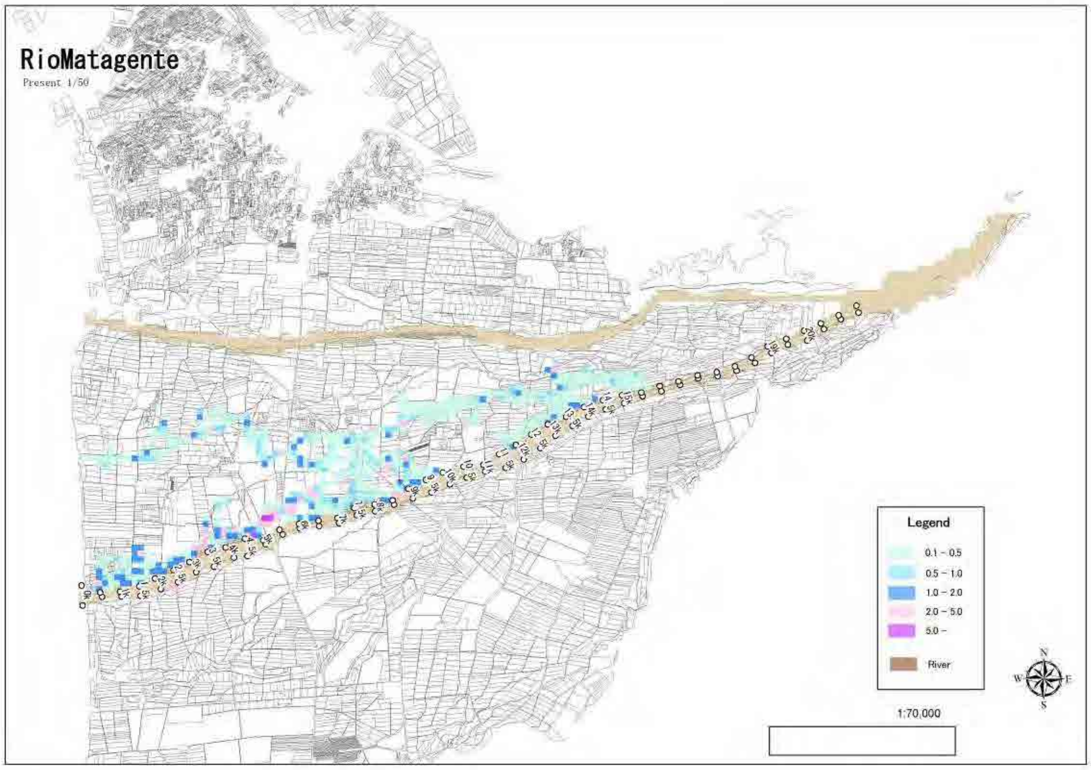


(8) Chincha (Chico) River (1/5 Year Probable Flood) With Case

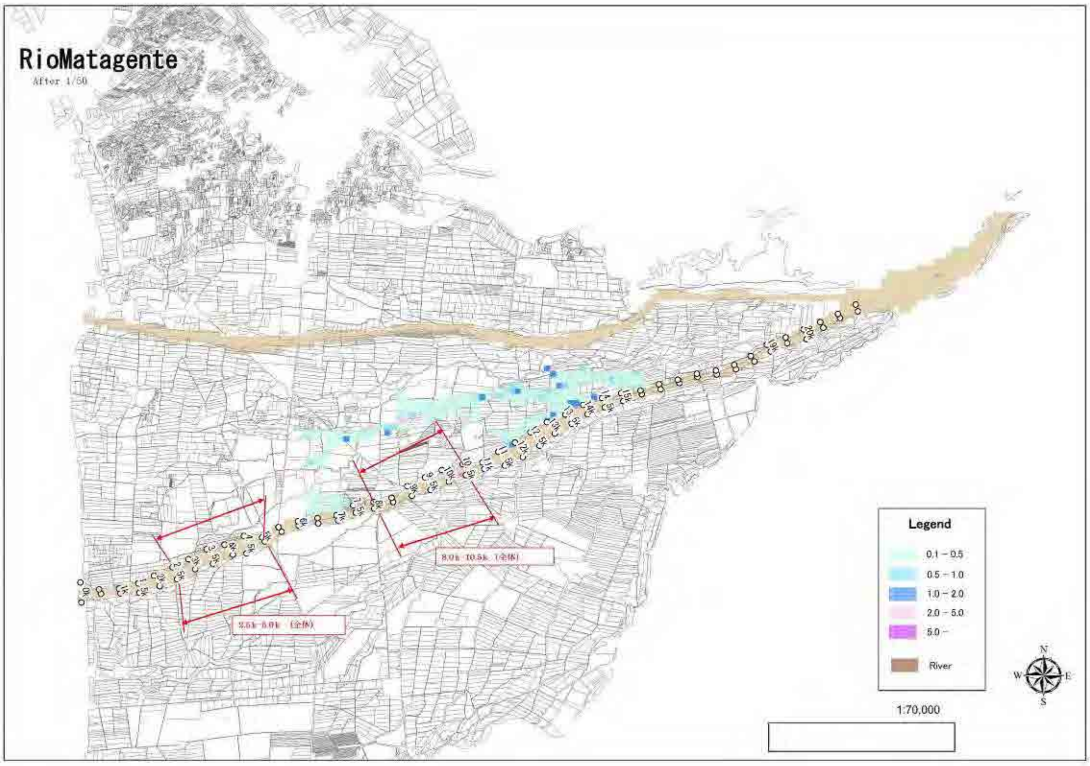


3.4 Chincha (Matagente) River

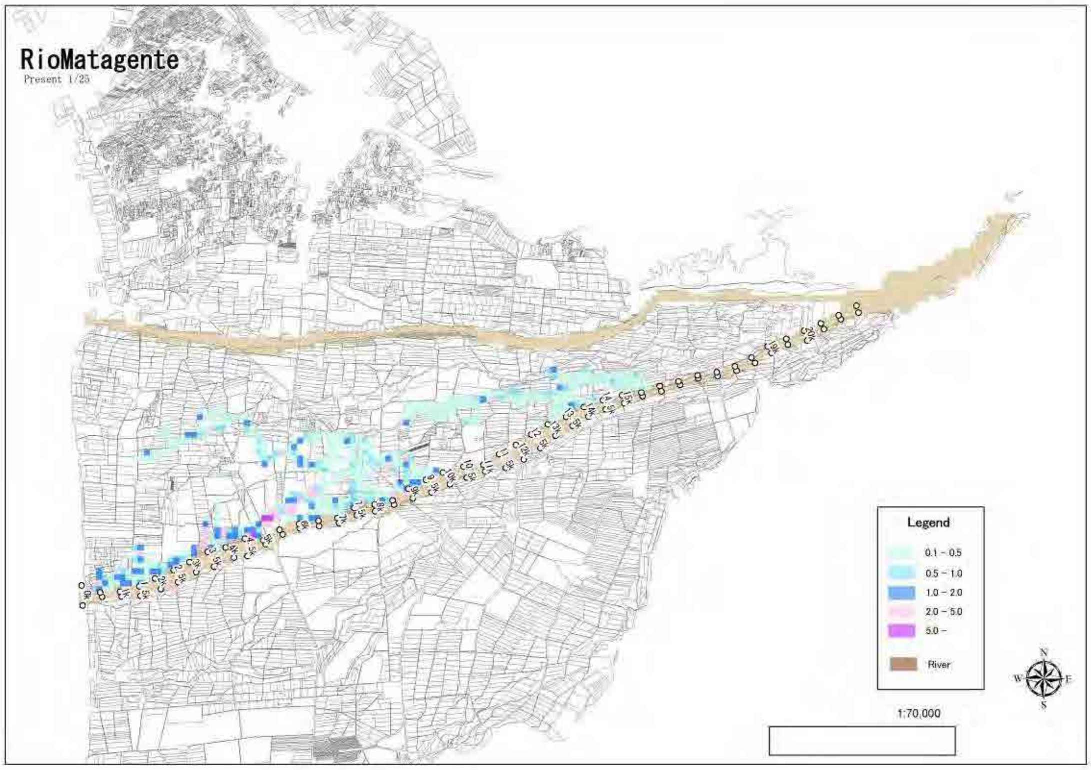
(1) Chincha (Matagente) River (1/50 Year Probable Flood) Without Case



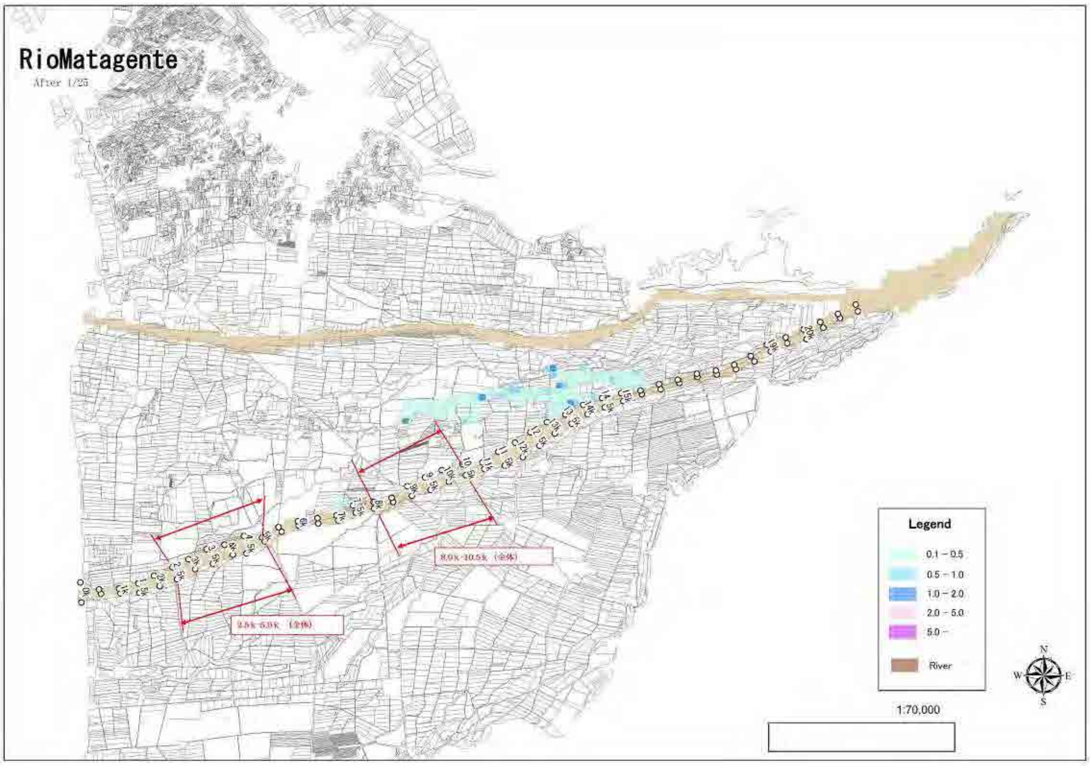
(2) Chincha (Matagente) River (1/50 Year Probable Flood) With Case



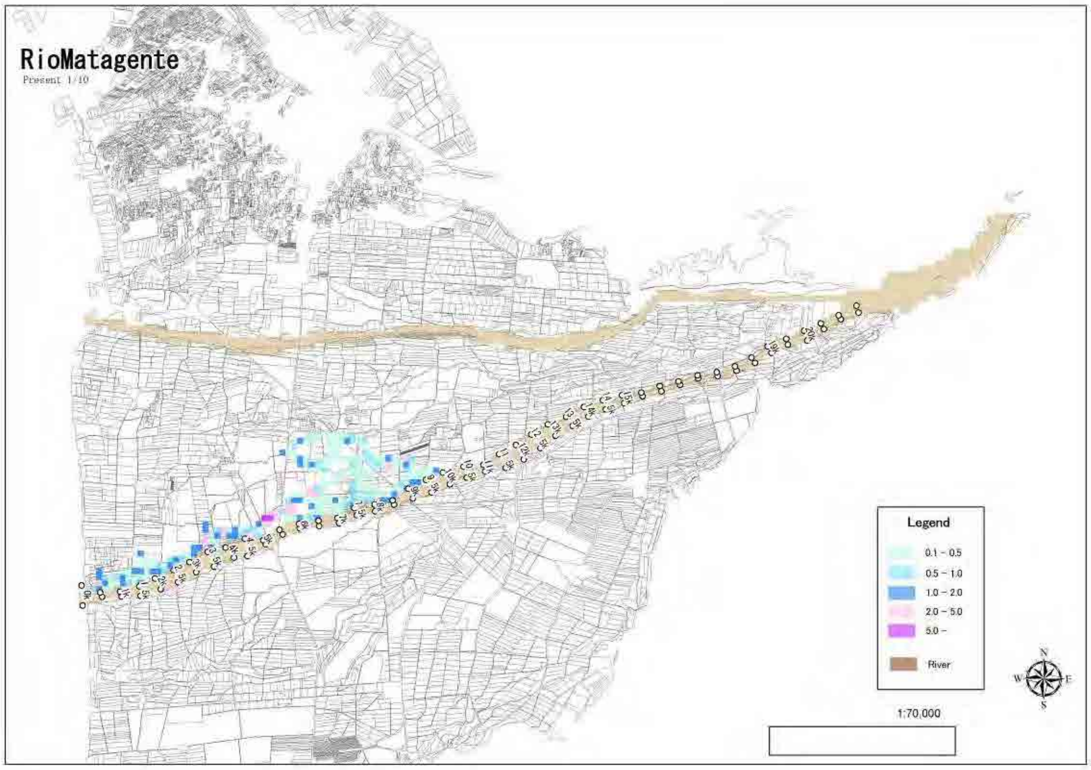
(3) Chincha (Matagente) River (1/25 Year Probable Flood) Without Case



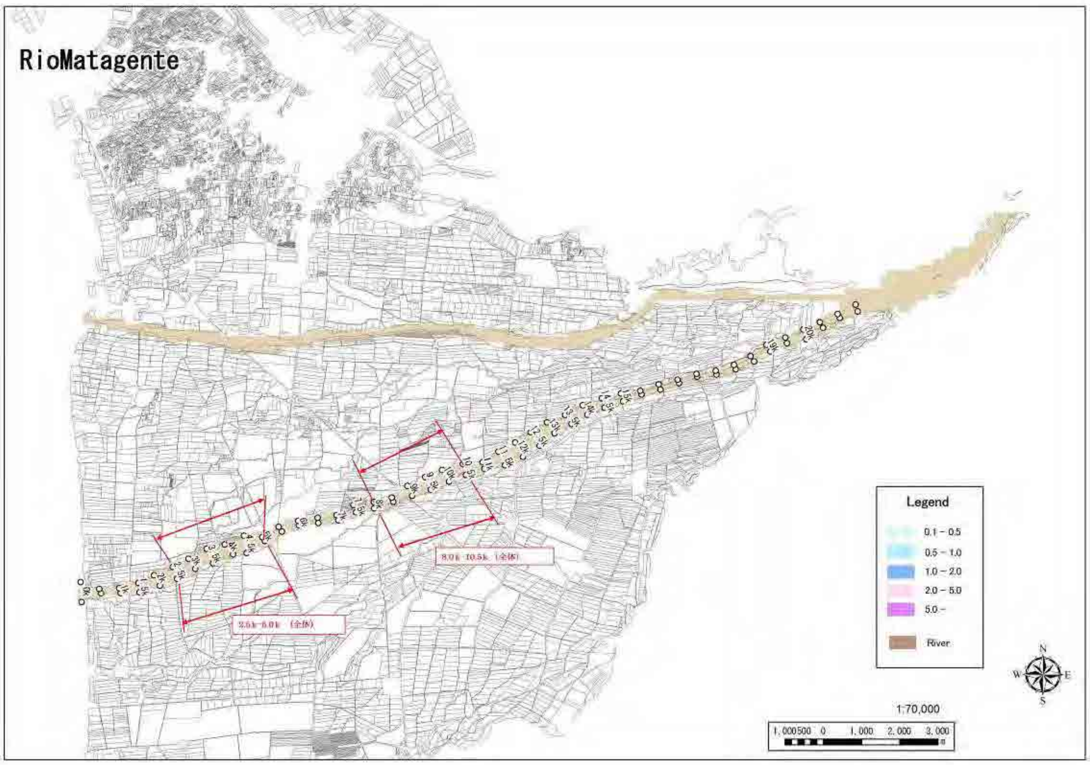
(4) Chincha (Matagente) River (1/25 Year Probable Flood) With Case



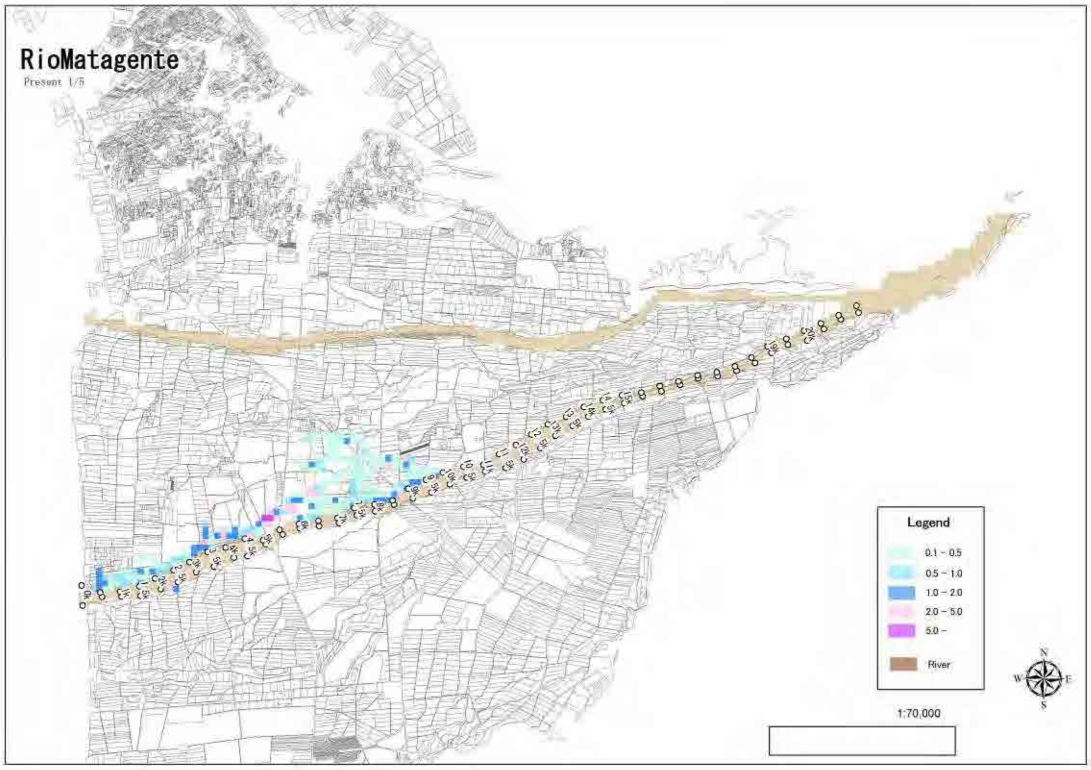
(5) Chincha (Matagente) River (1/10 Year Probable Flood) Without Case



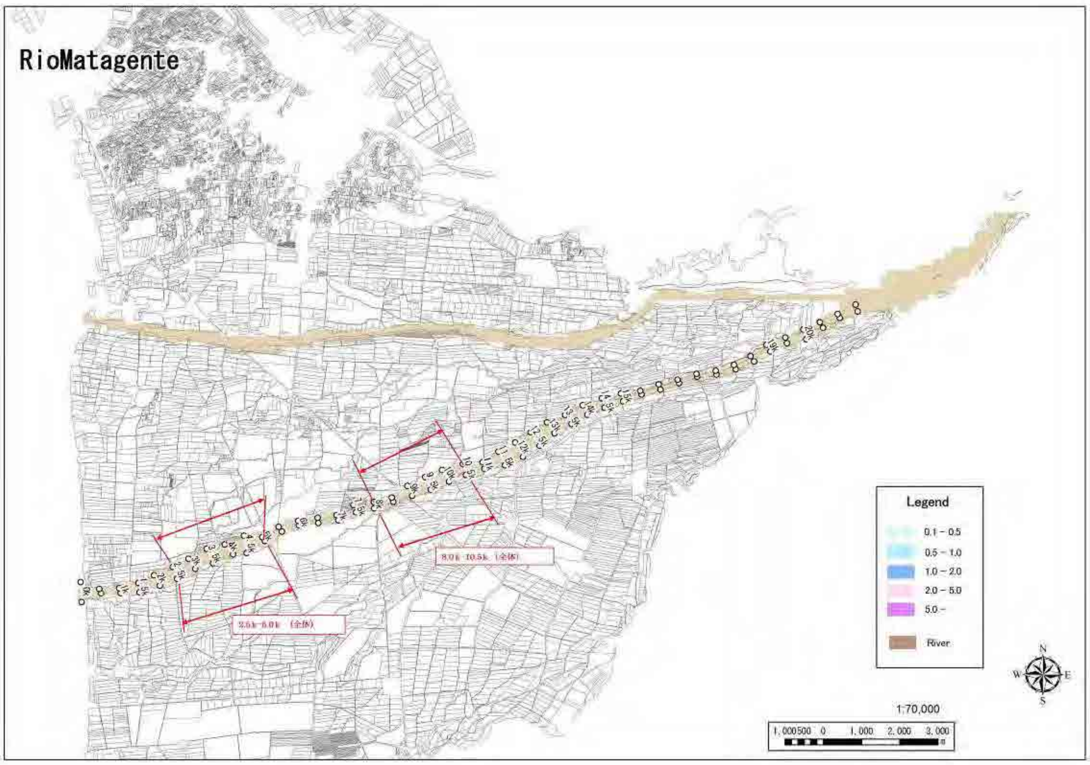
(6) Chincha (Matagente) River (1/10 Year Probable Flood) With Case



(7) Chincha (Matagente) River (1/5 Year Probable Flood) Without Case

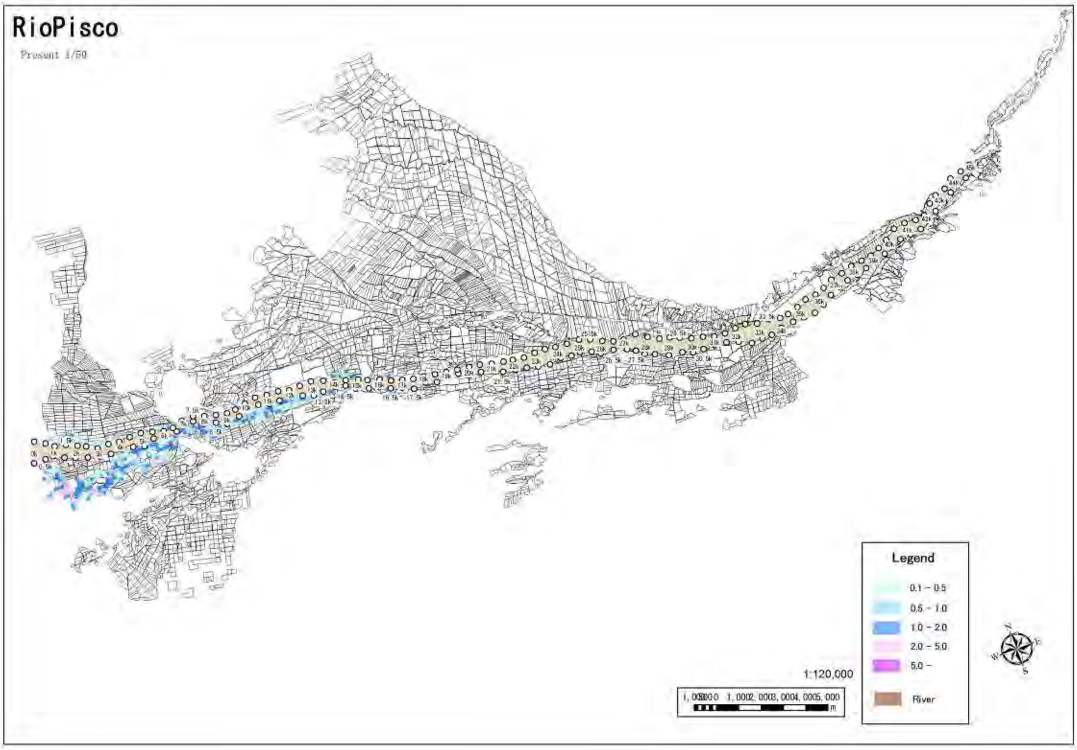


(8) Chincha (Matagente) River (1/5 Year Probable Flood) With Case

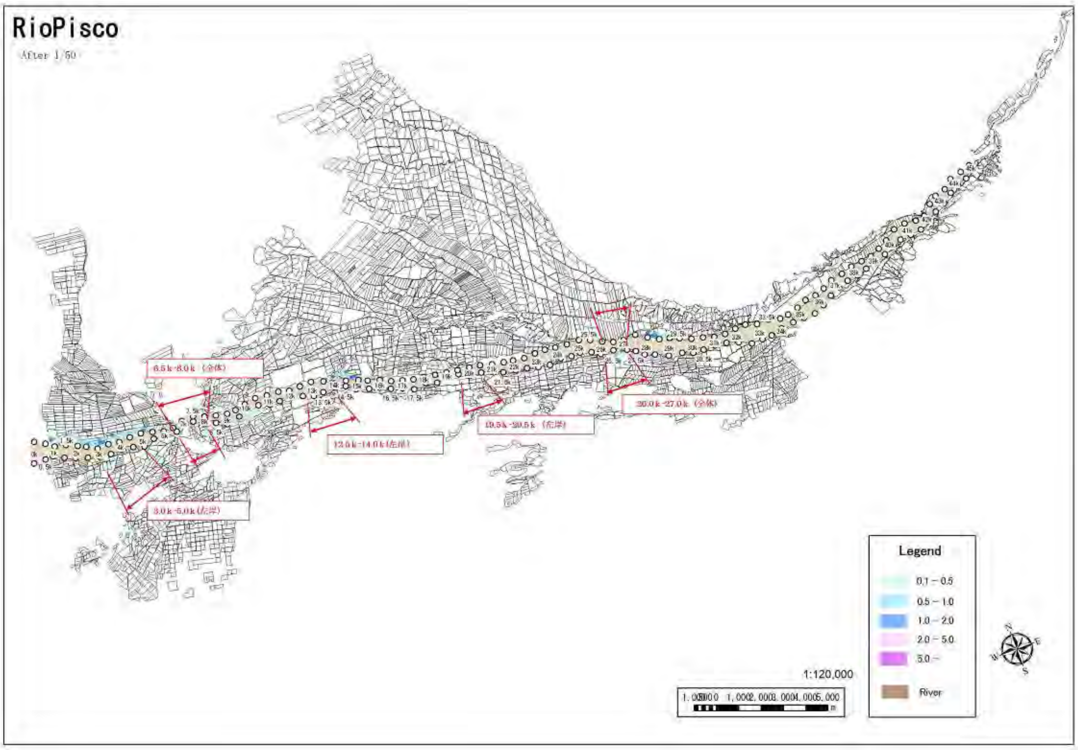


3.5 Pisco River

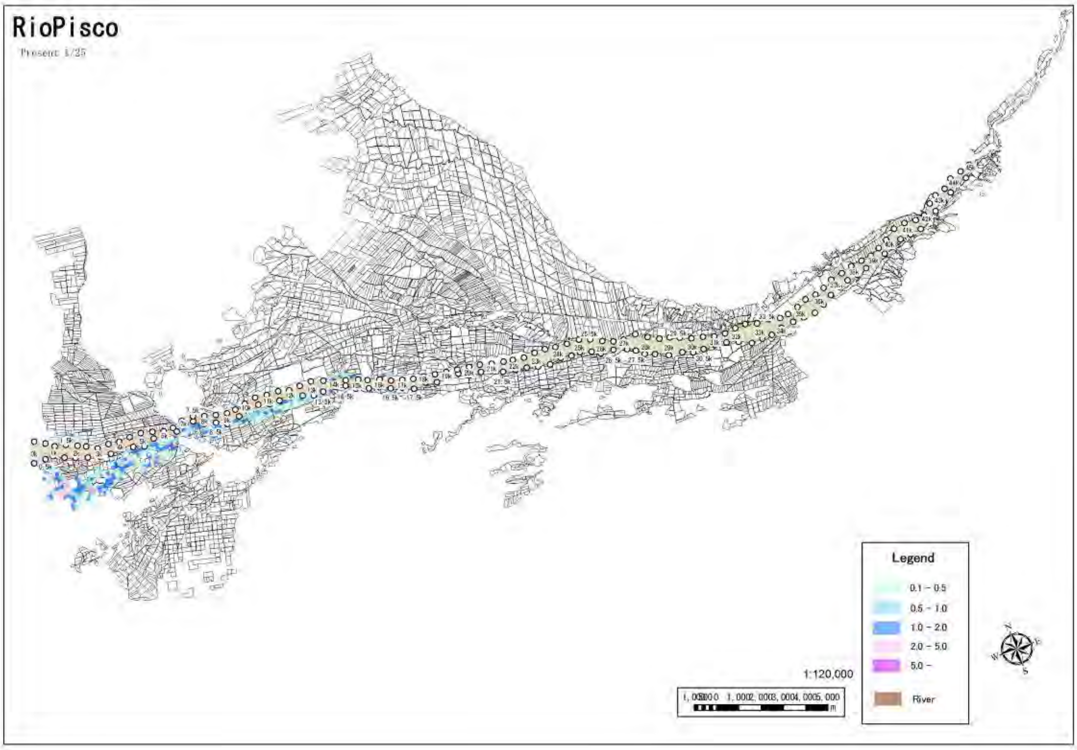
(1) Pisco River (1/50 Year Probable Flood) Without Case



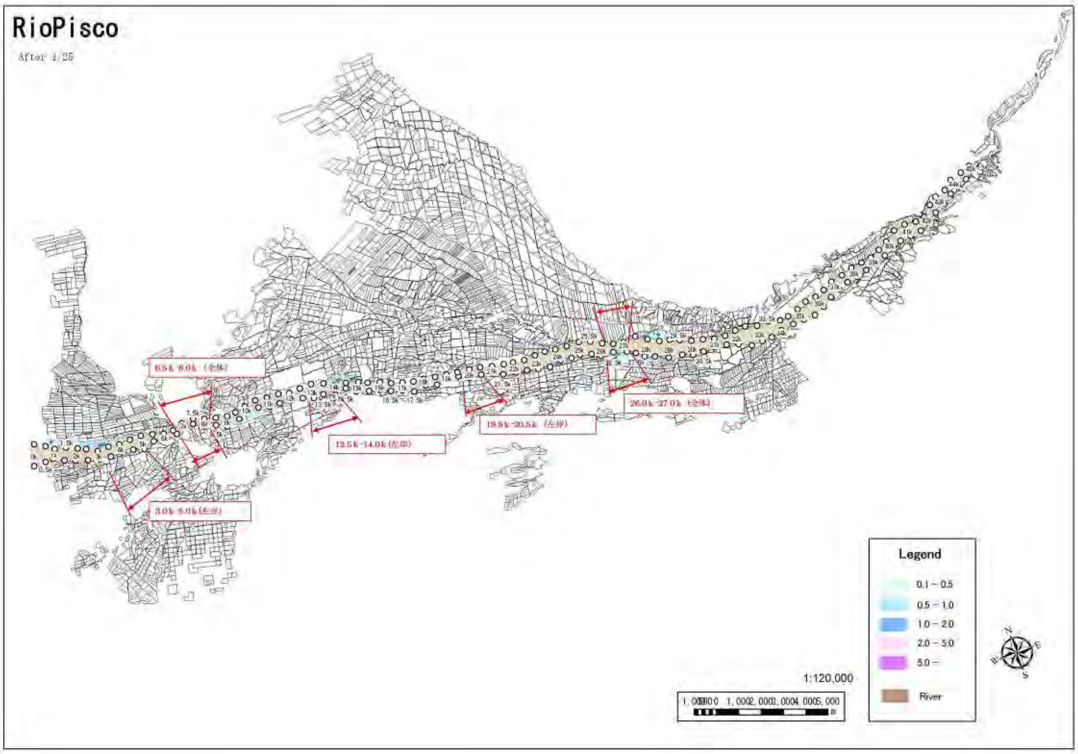
(2) Pisco River (1/50 Year Probable Flood) With Case



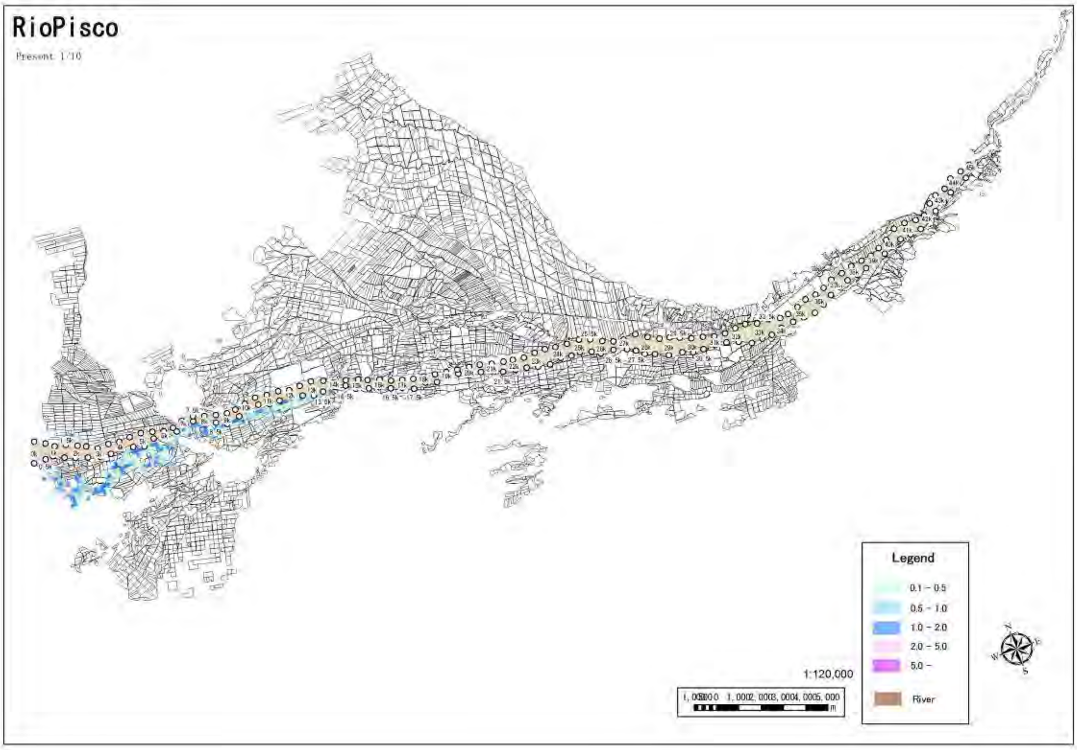
(3) Pisco River (1/25 Year Probable Flood) Without Case



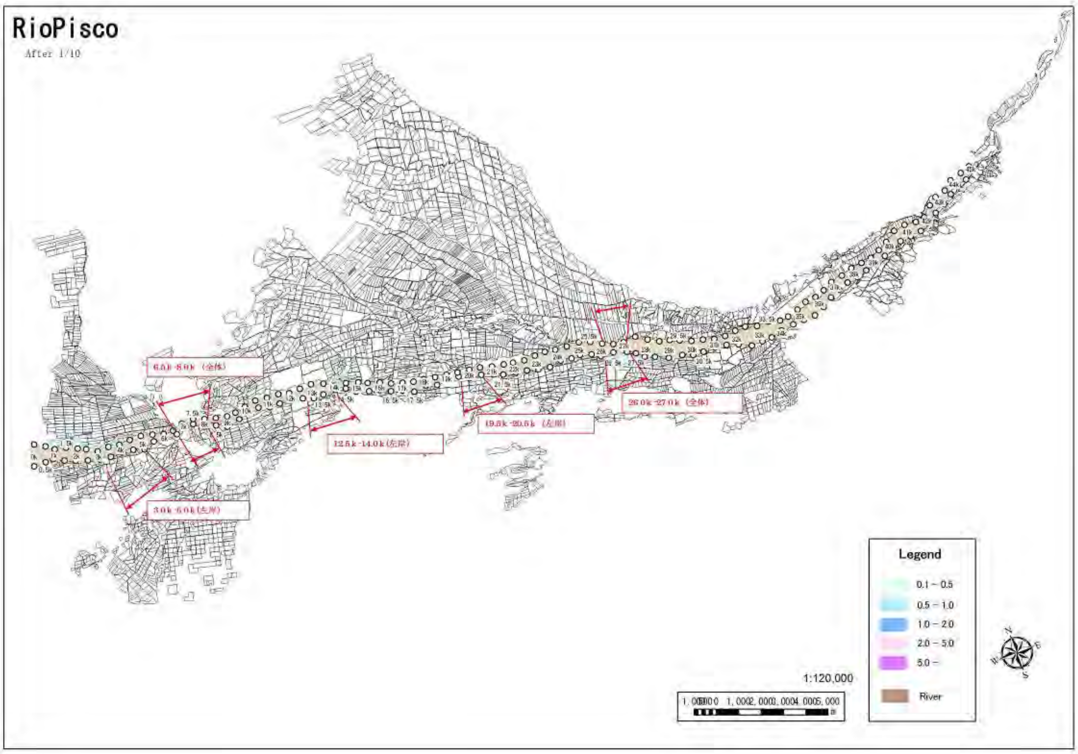
(4) Pisco River (1/25 Year Probable Flood) With Case



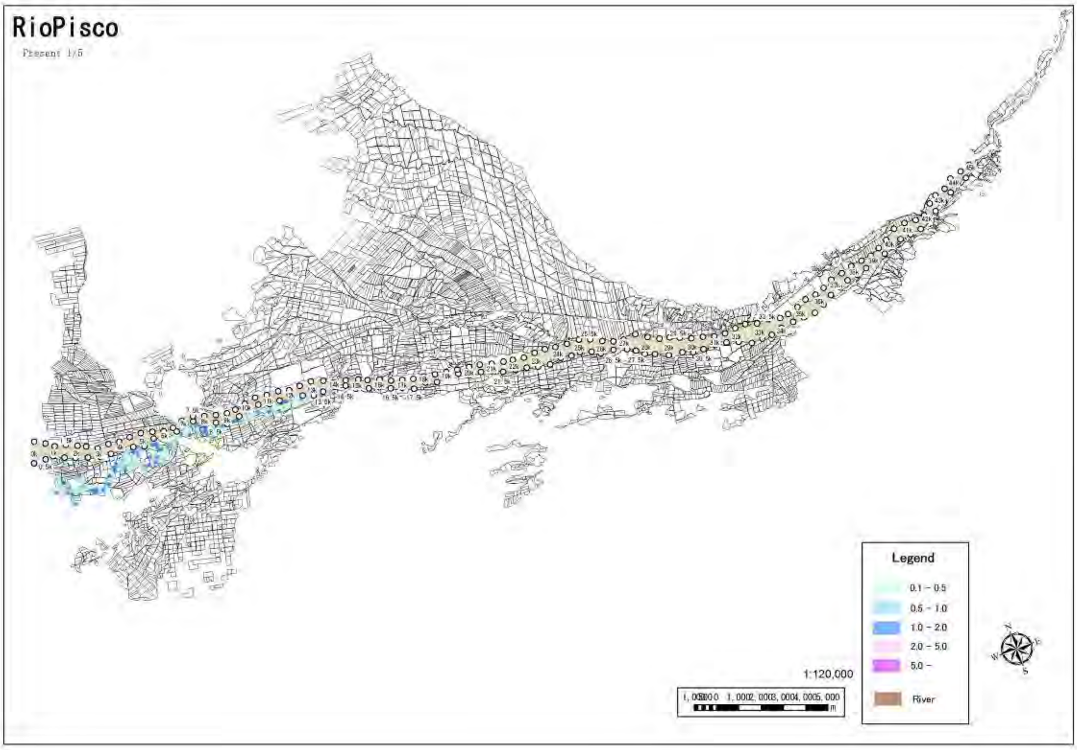
(5) Pisco River (1/10 Year Probable Flood) Without Case



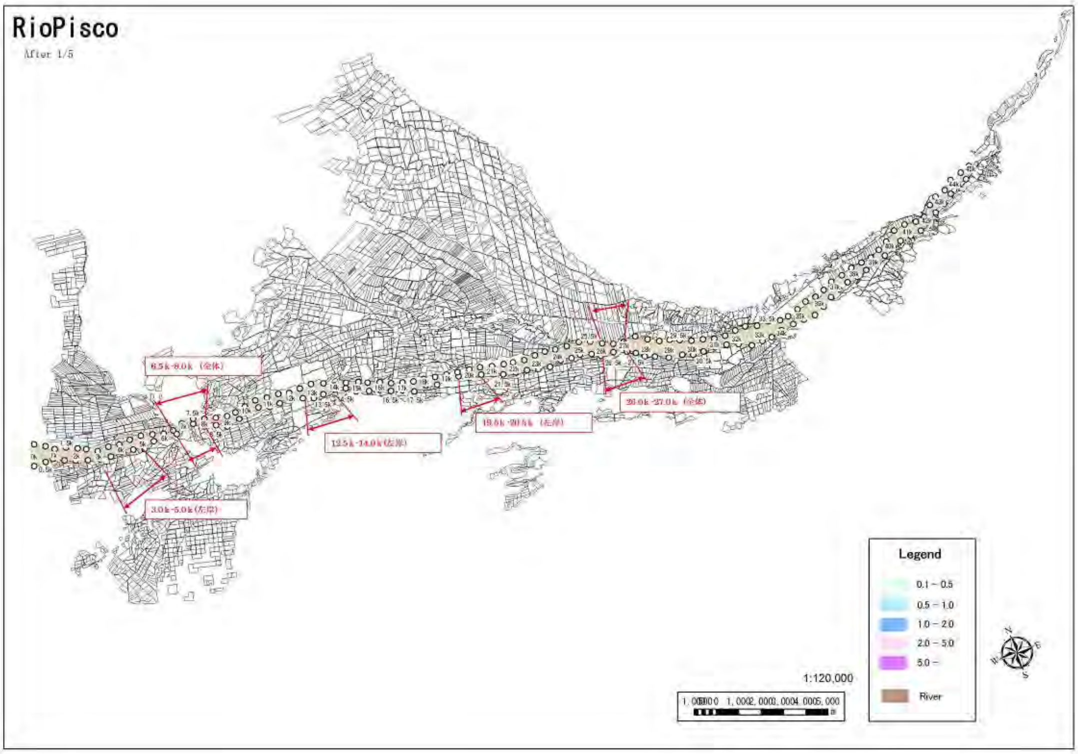
(6) Pisco River (1/10 Year Probable Flood) With Case



(7) Pisco River (1/5 Year Probable Flood) Without Case

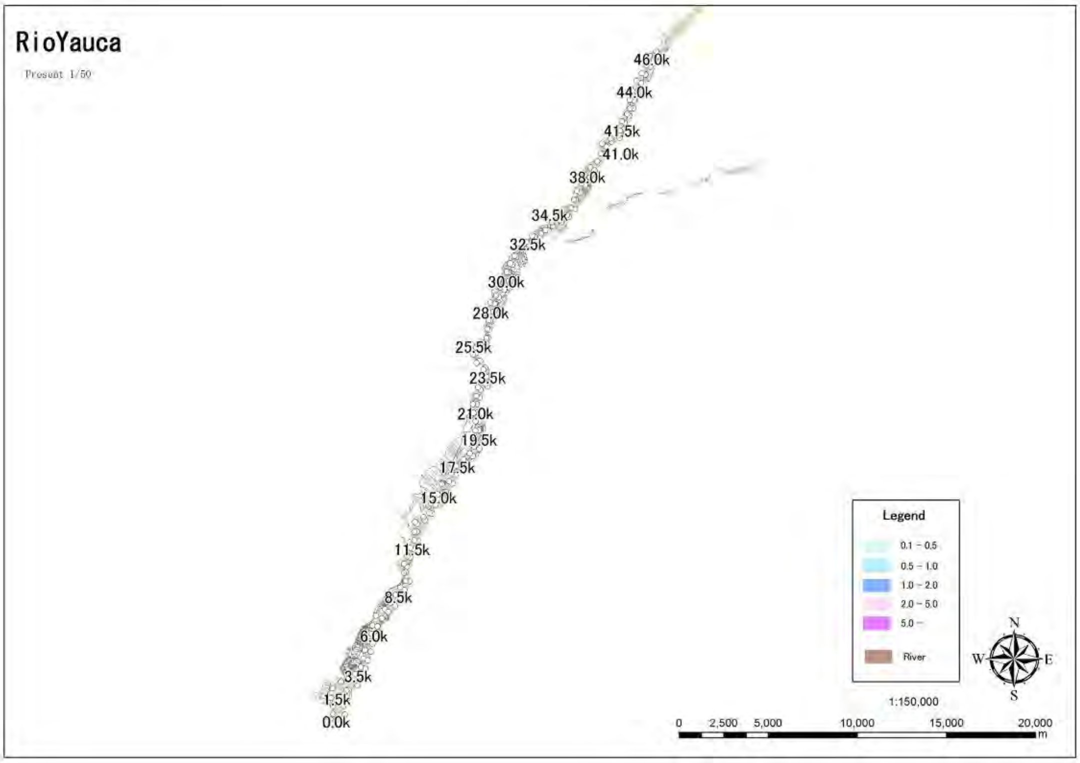


(8) Pisco River (1/5 Year Probable Flood) With Case

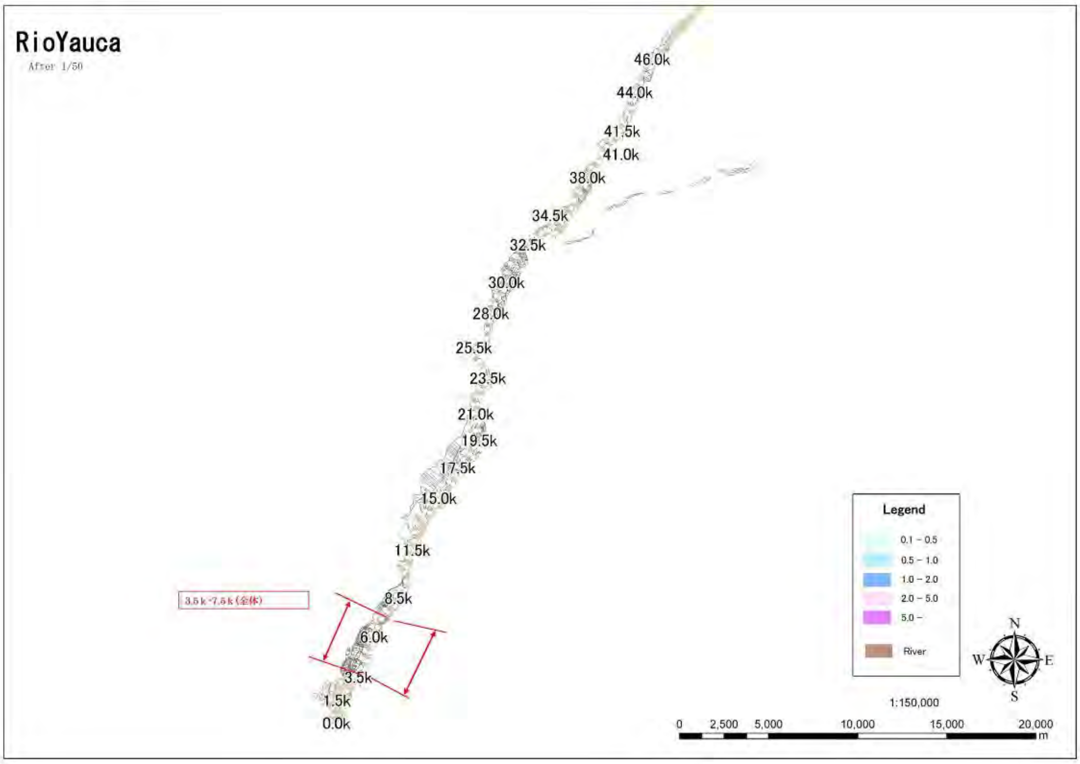


3.6 Yauca River

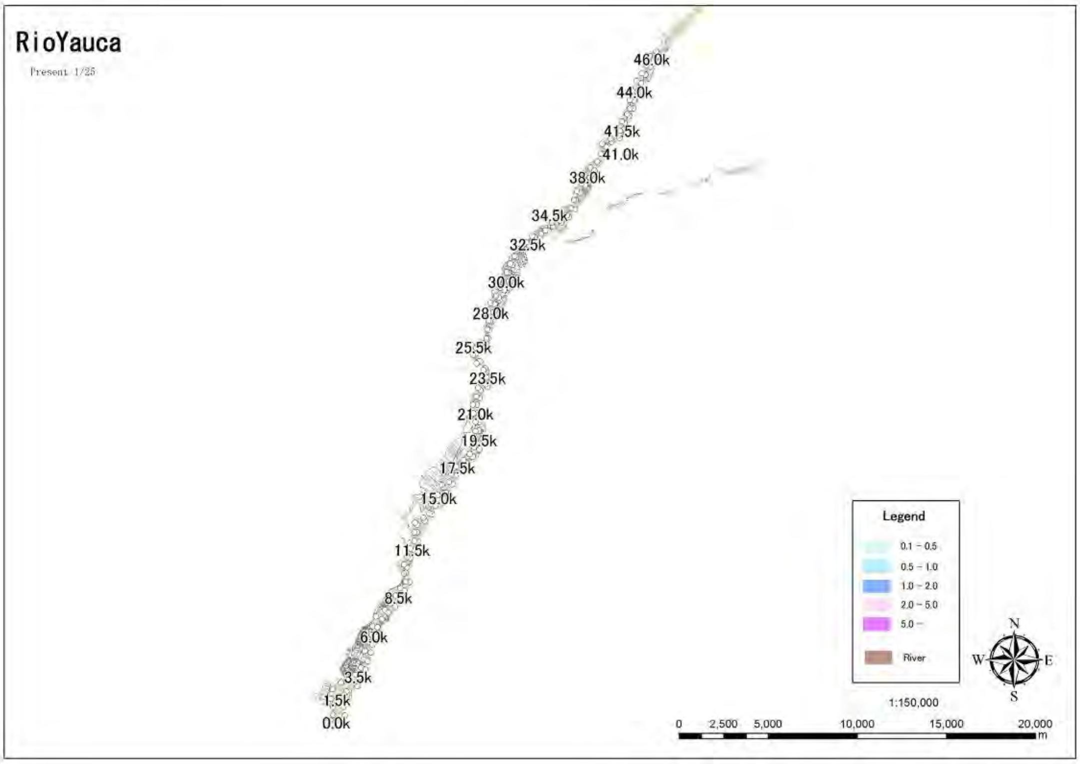
(1) Yauca River (1/50 Year Probable Flood) Without Case



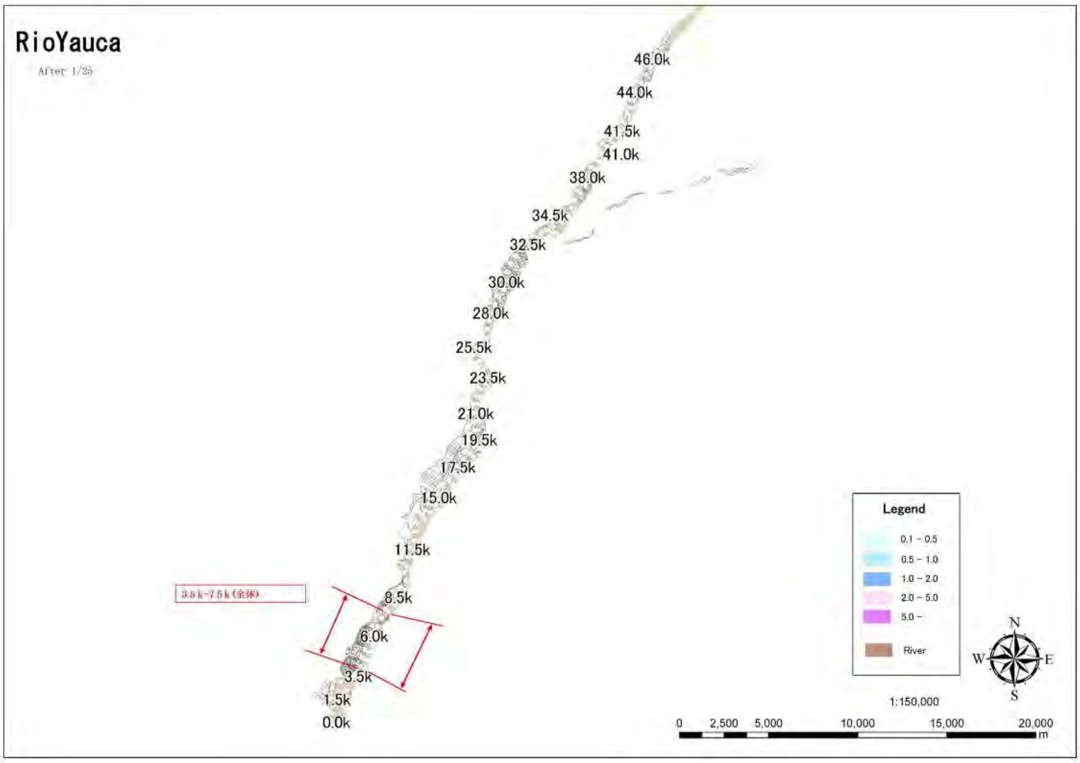
(2) Yauca River (1/50 Year Probable Flood) With Case



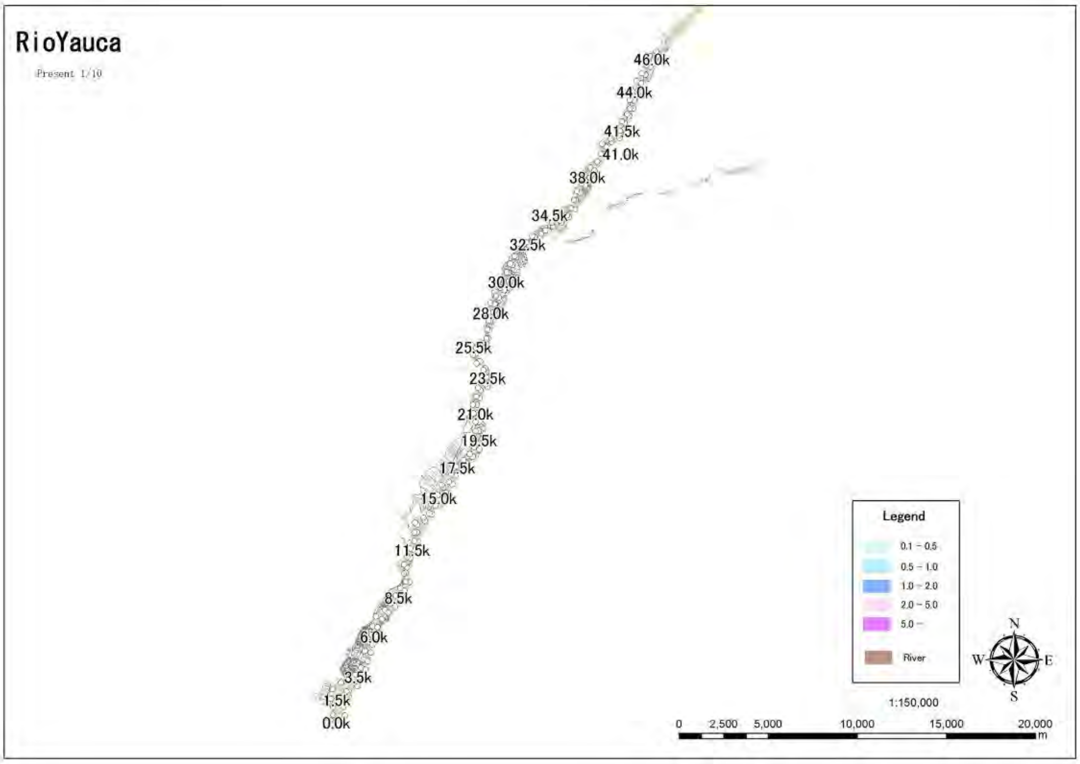
(3) Yauca River (1/25 Year Probable Flood) Without Case



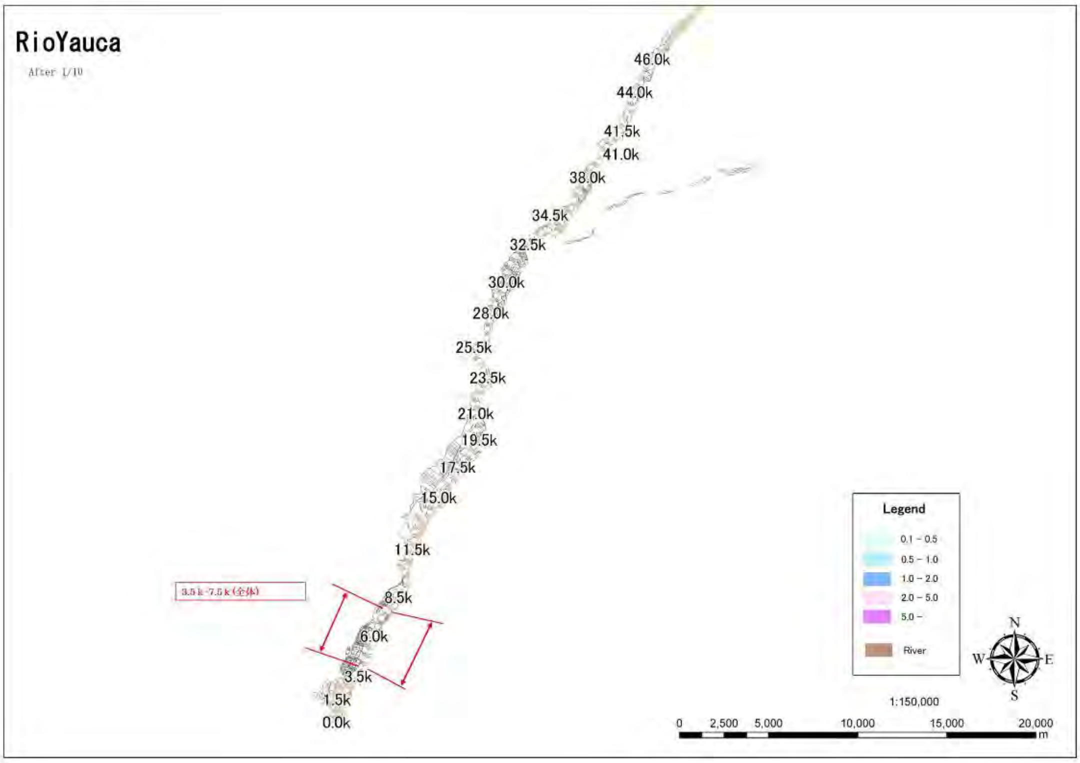
(4) Yauca River (1/25 Year Probable Flood) With Case



(5) Yauca River (1/10 Year Probable Flood) Without Case

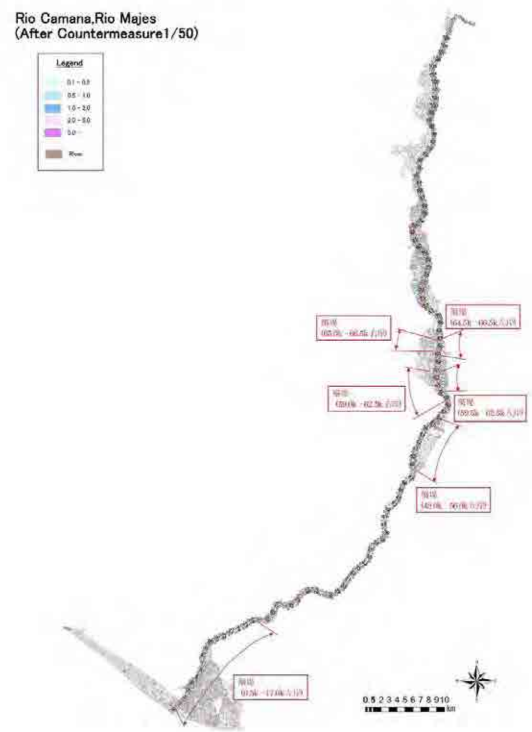


(6) Yauca River (1/10 Year Probable Flood) With Case

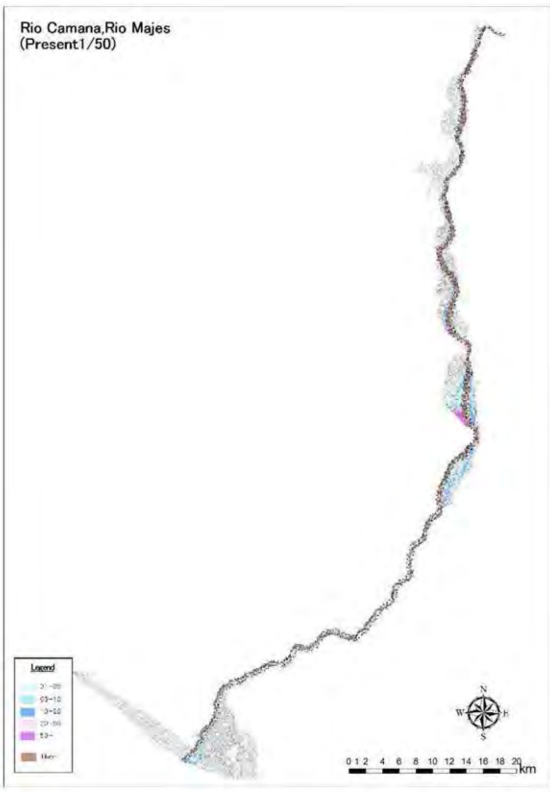


3.7 Majes-Camana River

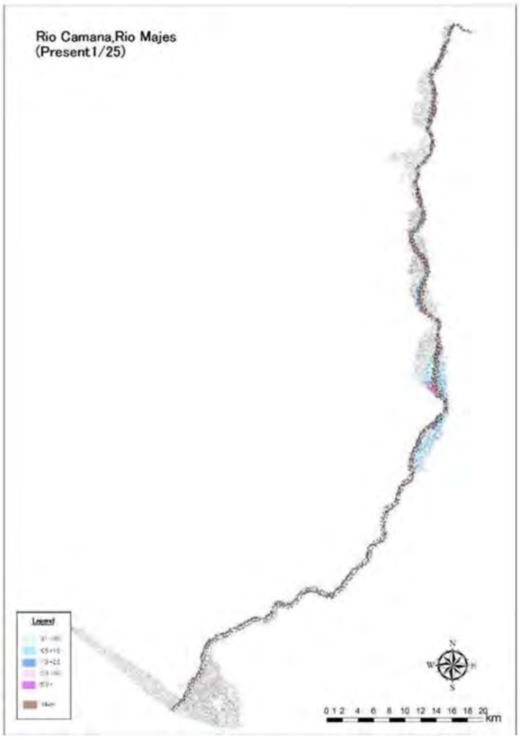
(1) Majes-Camana River (1/50 Year Probable Flood) With Case



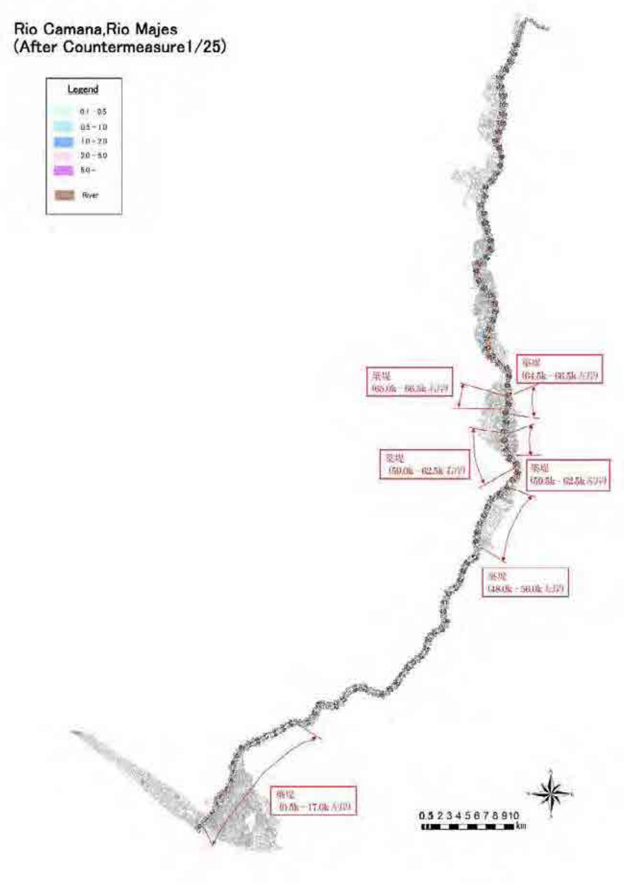
(2) Majes-Camana River（1/50 Year Probable Flood）Without Case



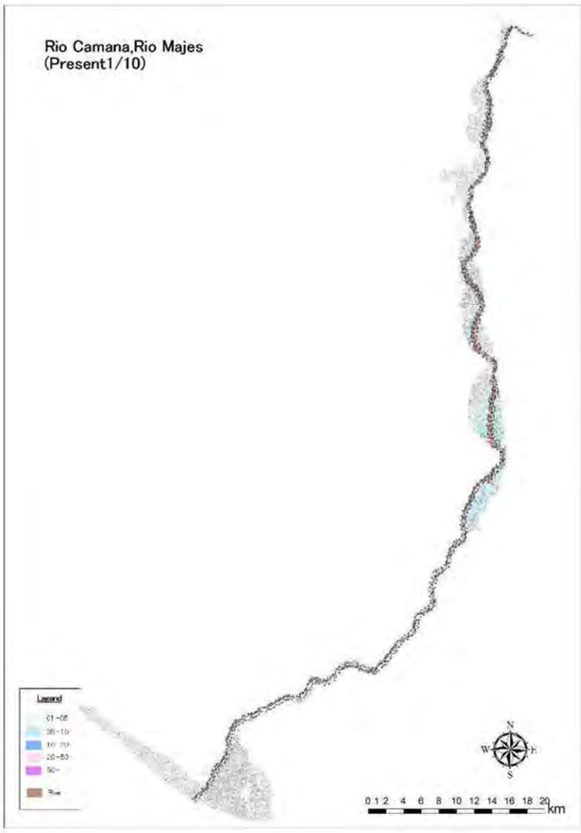
(3) Majes-Camana River（1/25 Year Probable Flood）Without Case



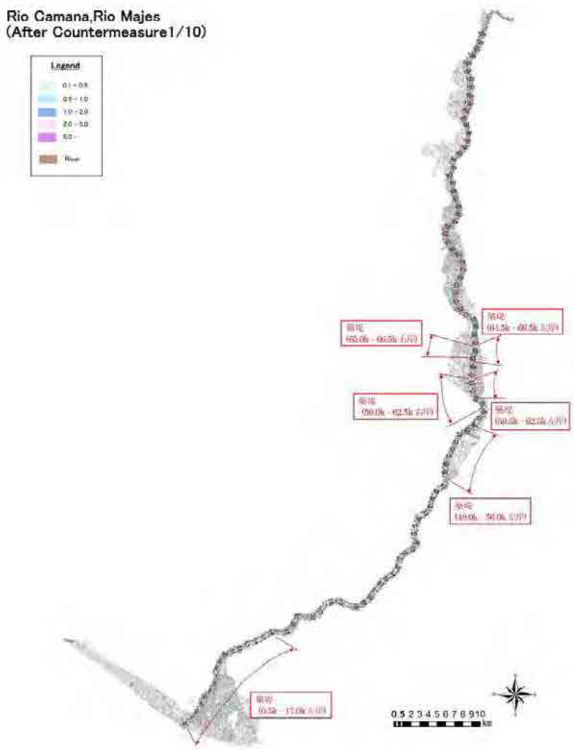
(4) Majes-Camana River（1/25 Year Probable Flood）With Case



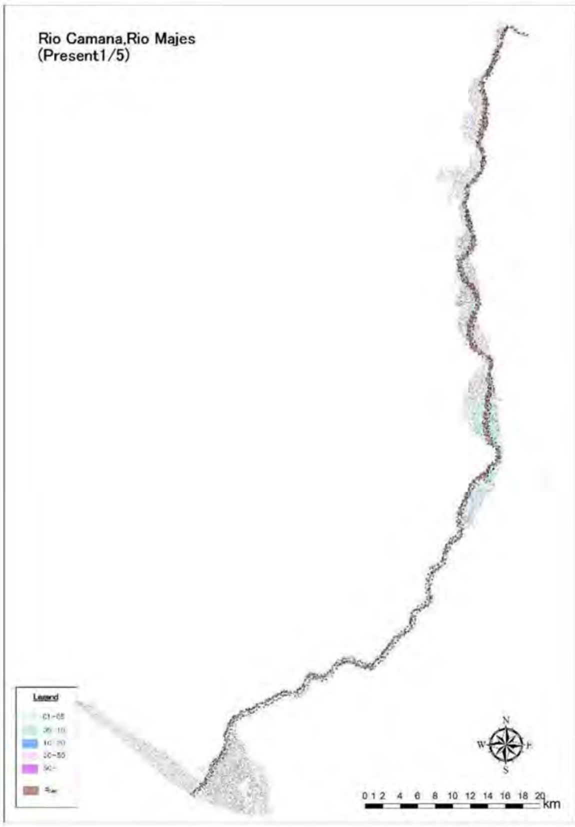
(5) Majes-Camana River（1/10 Year Probable Flood）Without Case



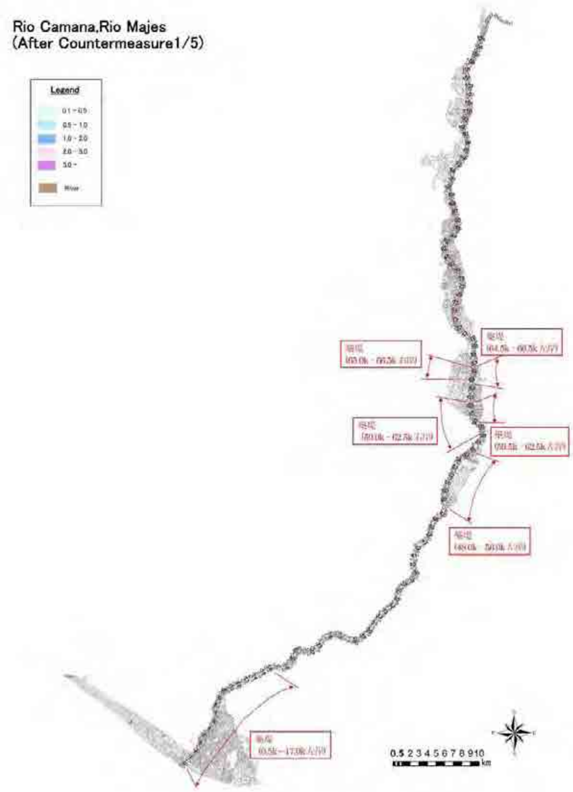
(6) Majes-Camana River（1/10 Year Probable Flood）With Case



(7) Majes-Camana River（1/5 Year Probable Flood）Without Case



(8) Majes-Camana River（1/5 Year Probable Flood）With Case



Ministry of Agriculture
Republic of Peru

THE PREPARATORY STUDY
ON
PROJECT OF THE PROTECTION OF FLOOD PLAIN AND VULNERABLE RURAL POPULATION AGAINST FLOOD IN THE REPUBLIC OF PERU

FINAL REPORT
I-6 SUPPORTING REPORT
ANNEX-3 RIVERBED FLUCTUATION
ANALYSIS

March 2013

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

YACHIYO ENGINEERING CO., LTD.
NIPPON KOEI CO., LTD.
NIPPON KOEI LATIN AMERICA –
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COLOMBIA
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PERU
BRAZIL
BOLIVIA
CHILE
SOUTH PASIFIC OCEAN
PIURA
Chira
LIMA
Canete
Chincha
Pisco
ICA
Yauca
AREQUIPA
Camana/Majes
LORETO
AMAZONAS
LAMBAYEQUE
CAJAMARCA
SAN MARTIN
LA LIBERTAD
ANCASH
HUANUCO
PASCO
UCAYALI
JUNIN
MADRE DE DIOS
CUSCO
HUANCAVELICA
AYACUCHO
APURIMAC
PUNO
MOQUEGUA
TACNA
Legend
International boundary
Province boundary
Project Area
Taget Rivers
National capital
Department capital
Railroad
Road
0 100 200 Km
0 100 200 Miles

Study Area

THE PREPARATORY STUDY ON PROJECT OF THE PROTECTION OF FLOOD PLAIN AND VULNERABLE RURAL POPULATION AGAINST FLOOD IN THE REPUBLIC OF PERU
FEASIBILITY STUDY REPORT
SUPPORTING REPORT

Annex-3
Riverbed Fluctuation Analysis

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CHAPTER 1 OUTLINE OF ANALYSIS

The flood management plan shall be formulated to secure the long-term flood safety with the examination of future riverbed fluctuation.

In order to clarify the aggradation and degradation of riverbed and to identify the issues for the formulation of flood management plan, the numerical simulation was conducted for the future 50-year riverbed fluctuation regarding the targeted five (5) rivers (valley).

1.1 Analysis Flow

The work flow for analysis is shown in ***Figure 1.1***.

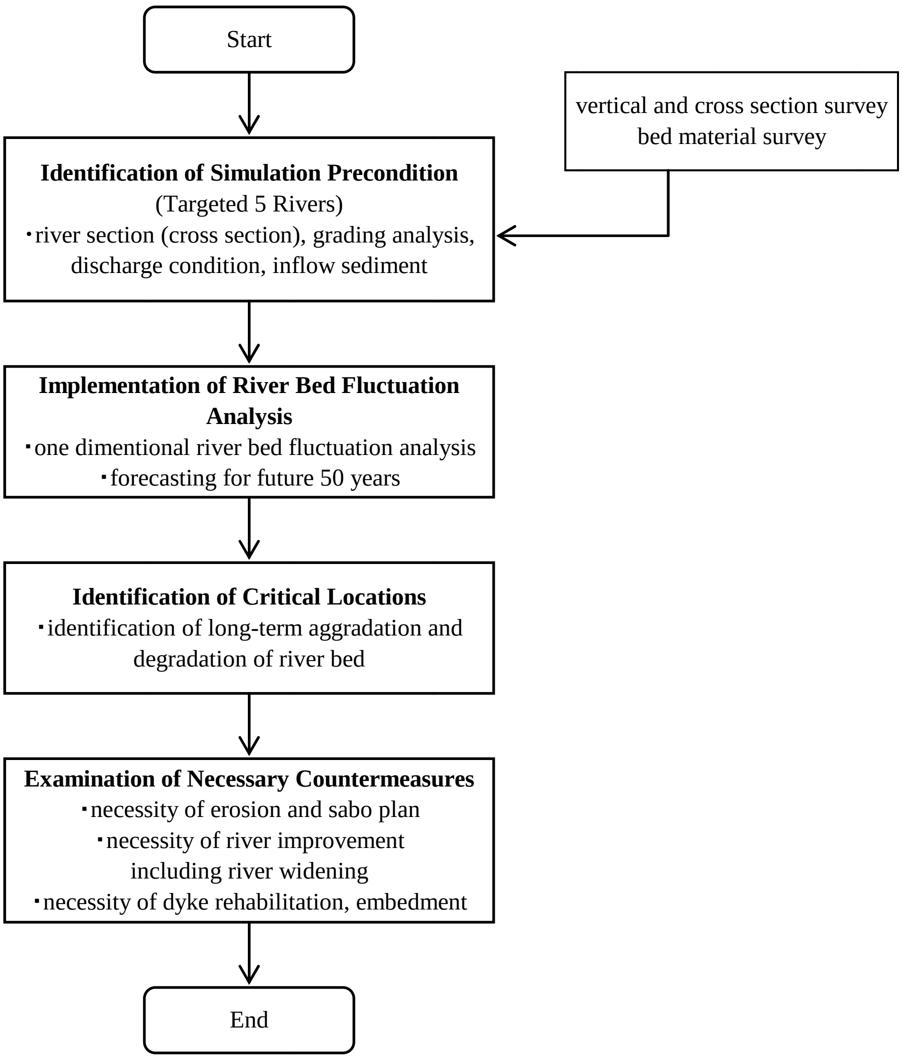


Figure 1.1 **Work Flow for Analysis**

1.2 Outline of Riverbed Fluctuation Analysis

For the implementation of riverbed fluctuation analysis, one-dimensional (1D) model was utilized. The Study aims at the long-term estimation and at grasping the aggradation and degradation of riverbed at narrowed and wide areas and the change of average bed height along with the sediment transport from the upstream. Therefore, for the practical implementation and evaluation of these parameters, the 1D analysis method is the most suitable. ***Table 1.1*** shows the outline of riverbed fluctuation analysis used in the Study.

Table 1.1 **Outline of Riverbed Fluctuation Analysis**

Items	Content
Water Flow	One-dimensional Non-uniform Flow Model
Sediment Transportation	One-dimensional Mixed Grain Size Riverbed Fluctuation Model
Bed Load	Ashida & Michiue's Bed load formula
Suspended Load	Ashida & Michiue's Suspended Load formula considering non-equilibrium of suspended sediment
Calculation Method	MacCormack Method

1.2.1 Basic Equation

Basic equation consists of equation of flowing water and sediment transportation. Regarding the flowing water, a continuous equation of water and dynamic equation are adopted, and for the sediment transport, continuous equation of moving sediment, transport equation for suspended sediment and sediment continuous equation on exchange layer. As shown in ***Figure 1.2***, The basic equation is shown as follows. The analysis area consists of three parts, which are flowing water, movable bed and fixed bed. X-axis means longitudinal direction. Z-axis means vertical direction.

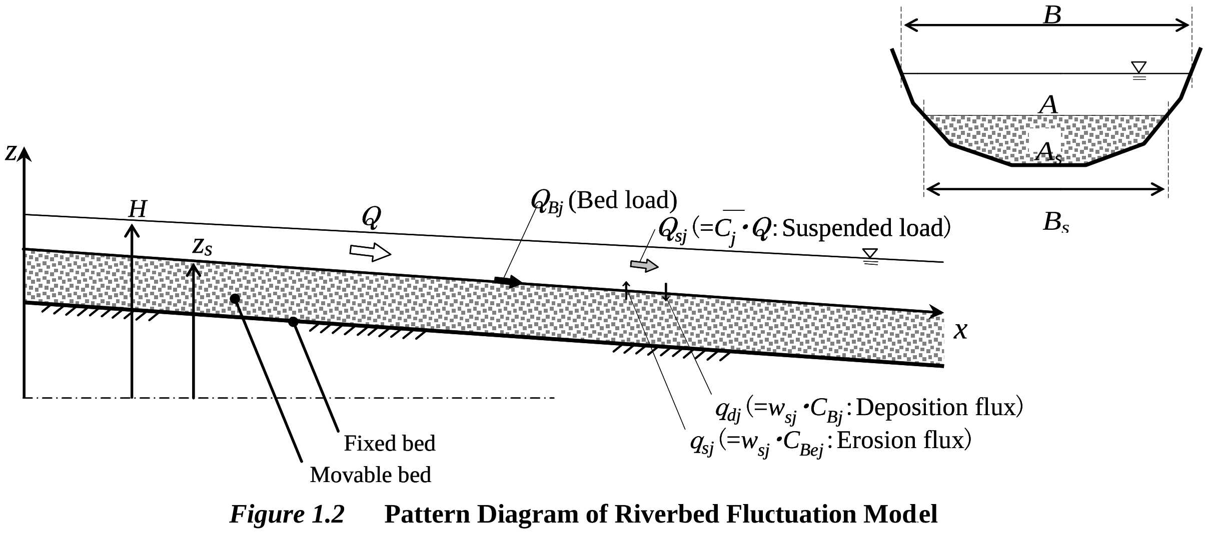


Figure 1.2 **Pattern Diagram of Riverbed Fluctuation Model**

Equation of continuity for water flow

Eq.(1)

Equation of motion for water flow

Eq.(2)

Equation of continuity for sediment flow

Eq.(3)

Equation of transportation for suspended sediment load

Eq.(4)

Equation of continuity for exchange layer

in the case of aggradation

Eq.(5)

in the case of degradation

Eq.(6)

: erosion flux Eq.(7)

Where, A=cross-sectional area of water flow (m2), Q=flow rate (m3/s), t=time (s), x=longitudinal distance (m), z=vertical height from reference level (m), g=gravitational acceleration (m/s2), H=water surface height from reference level (m), As=cross-sectional area of riverbed (m2), λ=porosity of riverbed, Qbj=bed load (m3/s), qsj=erosion flux of suspended load (m/s), qdi=deposition flux of suspended load (m/s), wsj=particle settling velocity (m/s), CBj=concentration of bottom layer (m3/m3), C=cross-sectional average concentration of suspended sediment, R=hydraulic radius (m), CBej=sediment concentration at reference level (m3/m3), Psj=grain size distribution of exchange layer, Asa=cross-sectional area of exchange layer (m2), Asb= cross-sectional area of riverbed except for exchange layer (m2), Ps1j=Psj at previous time (t0) (t0=t-dt), P0j= grain size distribution of sub layer under exchange layer, a= thickness of exchange layer (m), Bsu=cross-sectional width which erosion and deposition can occur (m), n=Manning's roughness coefficient.

1.2.2 Calculation Procedure

The general procedure of riverbed fluctuation calculation is shown in ***Figure 1.3***. At first, resulting in the calculation of flow fields, the water surface profile and longitudinal distribution of flow rate are identified, and the amount of sediment transport (bed load and suspended load) is estimated based on these hydraulic quantity and theoretical formula (ex. Ashida & Michiue's formula). Then, by the riverbed fluctuation calculation with the amount of sediment transport, the riverbed form is realized. Finally, by using the calculated riverbed form and the amount of sediment transport, the particle size distribution of exchange layer is estimated.

In the actual calculation of flow field and the amount of sediment transport, several disparities will be identified, but in principle, the riverbed fluctuation calculation is conducted with the above procedure.

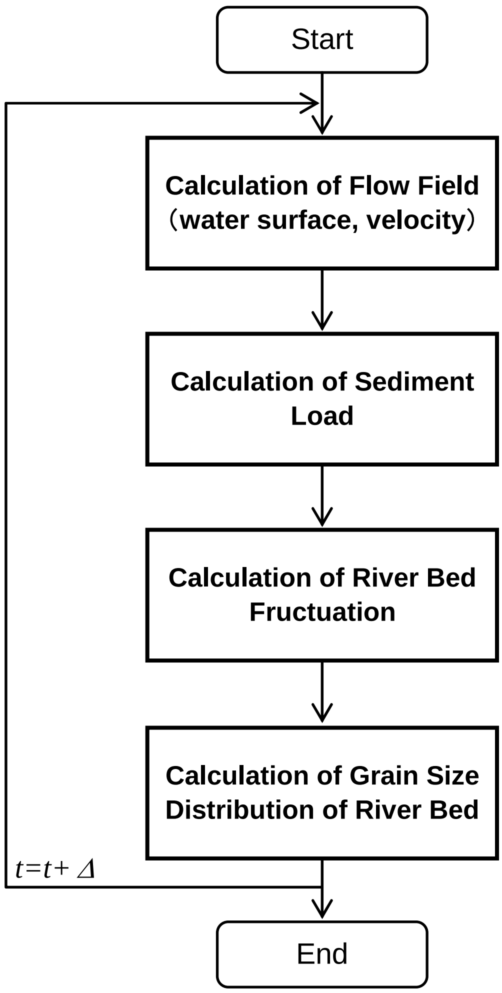


Figure 1.3 **Main Procedure of Riverbed Fluctuation Calculation**

1.3 Main Assumption for Calculation

1.3.1 Topographic Condition

(1) Specification of Topographic Data

As a result of field survey, it was identified that the topographic data in targeted five (5) rivers to be used for the analysis is the only date obtained from the river survey conducted by JICA. Therefore, for the riverbed fluctuation analysis, these survey results were used in principle. The specifications of survey data for each river are shown in ***Table 1.2***.

Table 1.2 **Specifications of Longitudinal and Cross Section Survey**

River	Length of Section	Interval	Implementation Date
Chira	99.5km	500m	December, 2010
Canete	32.5km	500m	November, 2010
Chincha	46.0km	500m	November, 2010
Pisco	45.0km	500m	November, 2010
Yauca	46.0km	500m	November, 2010
Majes-Camana	115.0km	500m	September, 2010

(2) Average Height of Riverbed

Since the average riverbed height is estimated with one-dimensional riverbed fluctuation analysis, as an initial condition of calculation, the average height of current river channel shall be identified. The average height of each targeted river was clarified based on the topographic survey results.

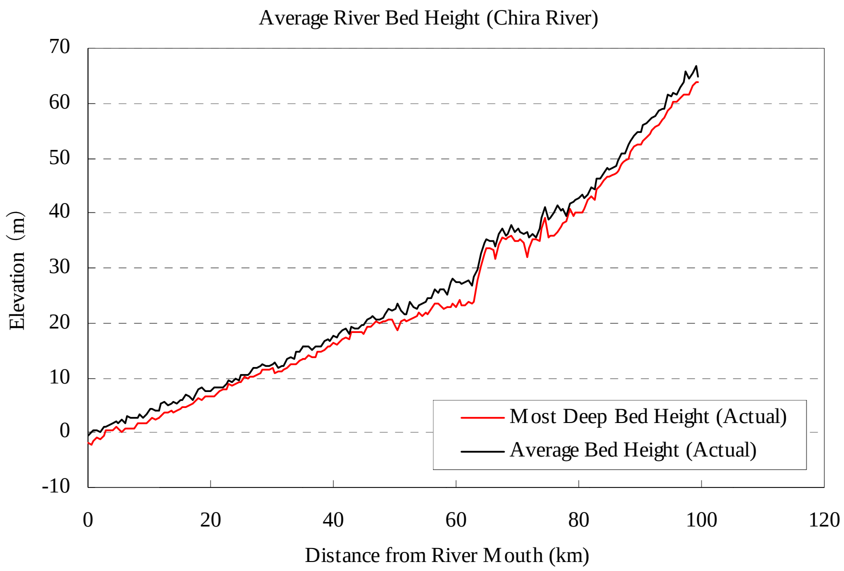


Figure 1.4 **Average Height of Riverbed (Chira River)**

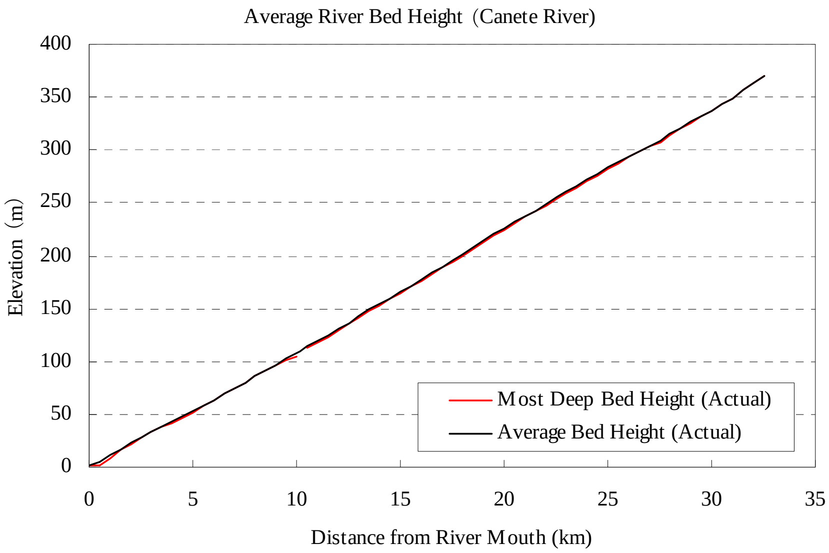


Figure 1.5 **Average Height of Riverbed (Canete River)**

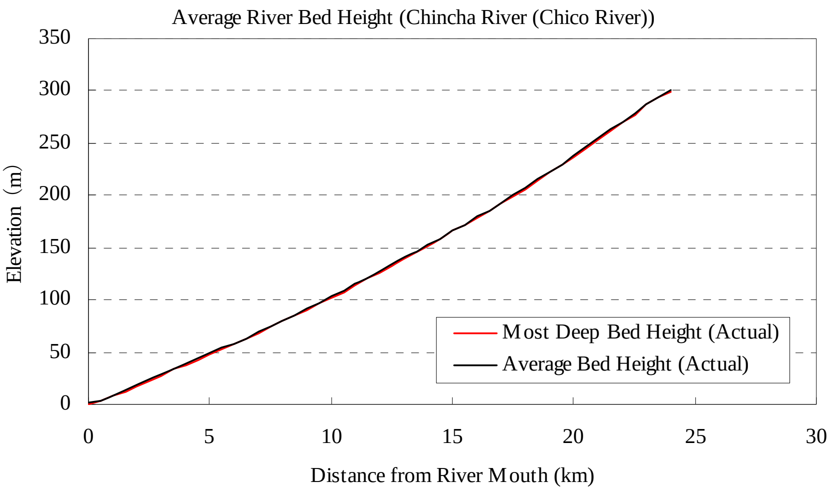


Figure 1.6 **Average Height of Riverbed (Chincha River (Chico River))**

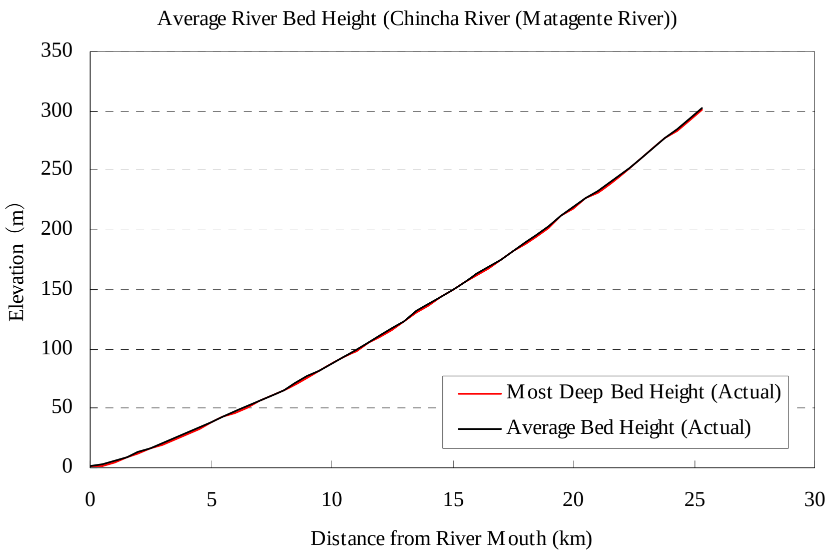


Figure 1.7 **Average Height of Riverbed (Chincha River (Matagente River))**

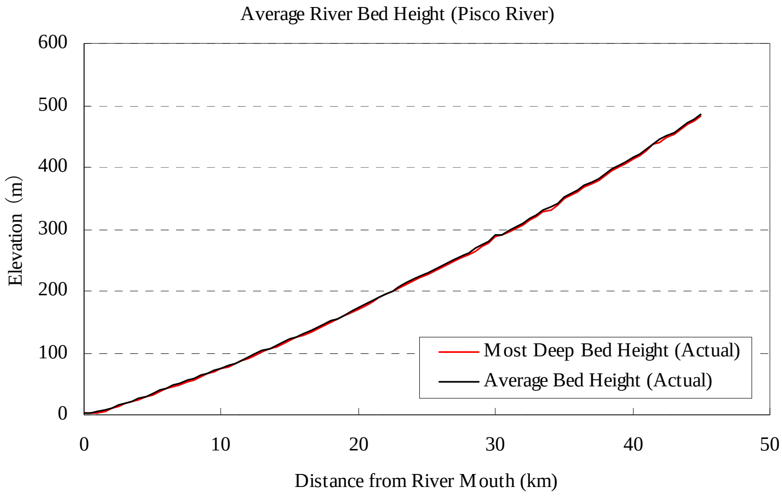


Figure 1.8 **Average Height of Riverbed (Pisco River)**

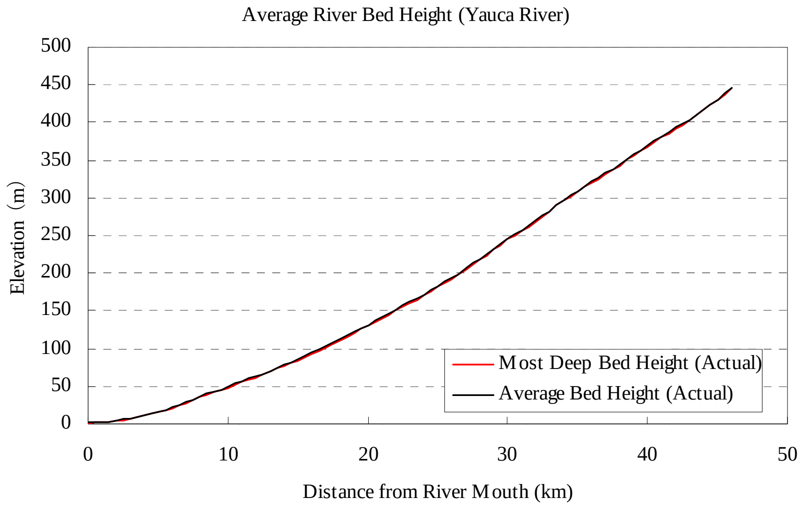


Figure 1.9 **Average Height of Riverbed (Yauca River)**

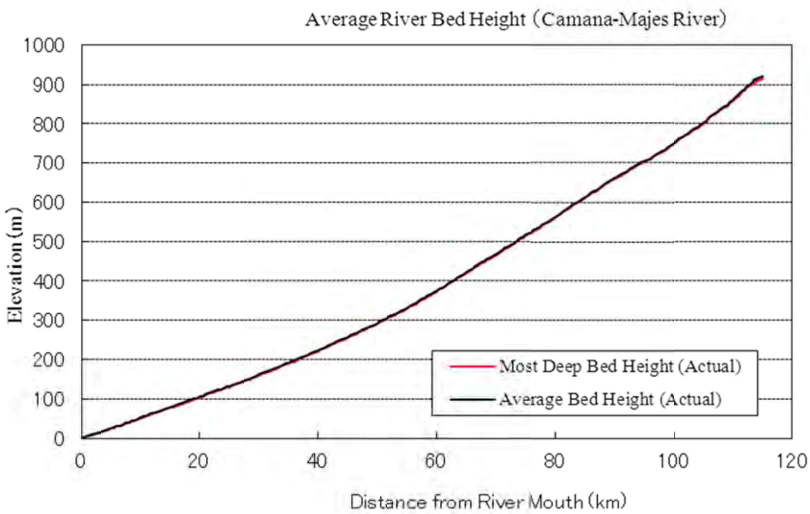


Figure 1.10 **Average Height of Riverbed (Majes-Camana River)**

1.3.2 Grain Size Distribution

Regarding the grain size distribution for bed materials, the condition of grain size distribution was determined by the results of survey in each river. The survey overview and results are shown as follows.

(1) Survey Overview

The overview of bed material survey is shown in ***Table 1.3***. Chincha River is divided into two (2) rivers, the site survey was conducted in both rivers as well.

Table 1.3 **Overview of bed material survey**

River	Number of Survey Location	Survey Location	Implementation Date
Chira	4 locations	4k,42k,60k,93.5k	December, 2010
Canete	4 locations	3k,12.5k,18k,25.5k	November, 2010
Chincha	8 locations (Chico: 5 locations) (Matagente: 3 locations)	Chico: 4k,11k,18k,21.5k,24.5k Matagente: 4k,12k,18k	November, 2010
Pisco	4 locations	5.5k,20k,35k,43k	November, 2010
Yauca	4 locations	5.5k,19k,29k,42k	November, 2010
Majes-Camana	4 locations	7k,30k,55k,80k,100k	September, 2010

(2) Survey Method

The sampling areas with 1m × 1m are set at each site, the riverbed materials were gathered from the 1m depth from the surface. The size and weight of materials with grain size of more than 76.2mm were measured at site, and the grain size distribution of materials with more than 76.2mm was measured by screening test at laboratory. The grain size distribution was completely identified with combination of these results. The site survey is shown in ***Figure 1.11*** to ***Figure 1.16*** and follows.

Figure 1.11 **Riverbed Material Sampling Survey (Chira River No. 3)**

Figure 1.12 **Riverbed Material Sampling Survey (Canete River No. 4)**

Vista panorámica del sector explorado

Llenado de agua a la calicata para determinar el volúmen excavado

Materiales extraidos de la excavación de la calicata

Figure 1.13 **Riverbed Material Sampling Survey (Chincha River No. 4)**

Vista panorámica del sector explorado

Materiales extraidos de la excavación de calicata

Determinación del peso por tamaños de los materiales extraidos de la calicata

Llenado de agua a la calicata para determinar el volúmen excavado

Figure 1.14 **Riverbed Material Sampling Survey (Pisco River No. 1)**

Vista panorámica del sector explorado

Llenado de agua a la calicata para determinar el volúmen excavado

Materiales extraidos de la excavación de la calicata

Figure 1.15 **Riverbed Material Sampling Survey (Yauca River No. 1)**

Vista panorámica del sector explorado

Llenado de agua a la calicata para determinar el volúmen excavado

Materiales extraidos de la excavación de la calicata

Figure 1.16 **Riverbed Material Sampling Survey (Majes-Camana River No. 2)**

(3) Survey Result

The survey results are shown from ***Figure 1.17*** to ***Figure 1.23*** below.

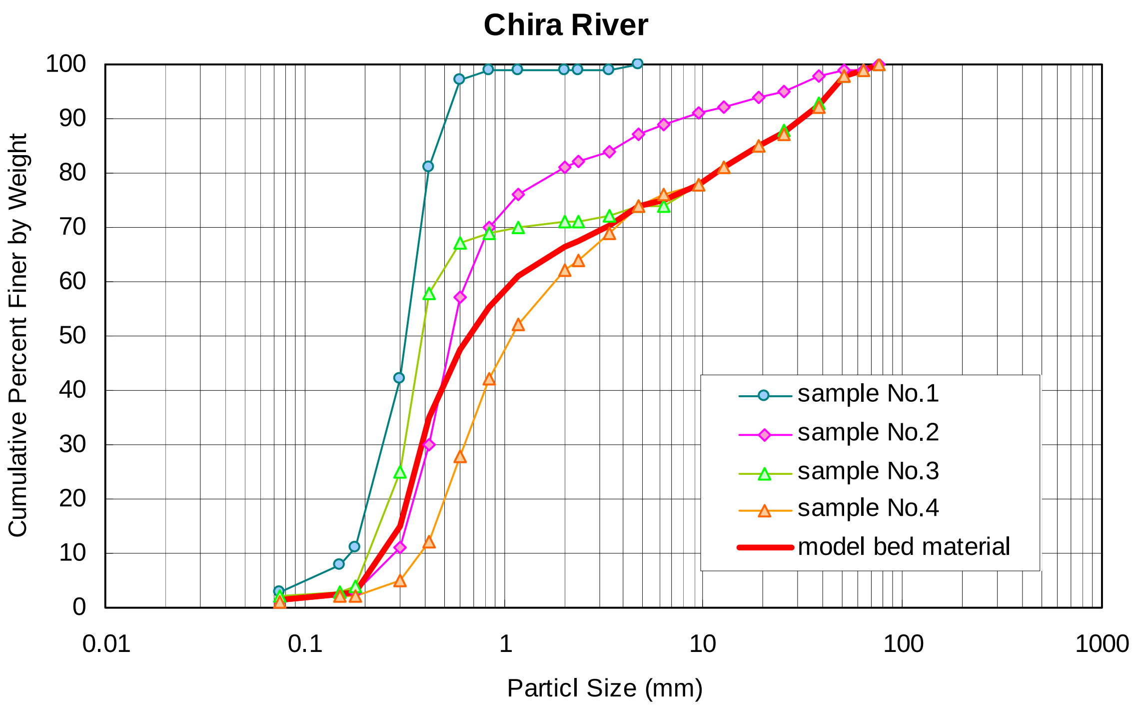


Figure 1.17 **Survey Result of Grain Size Distribution (Chira River)**

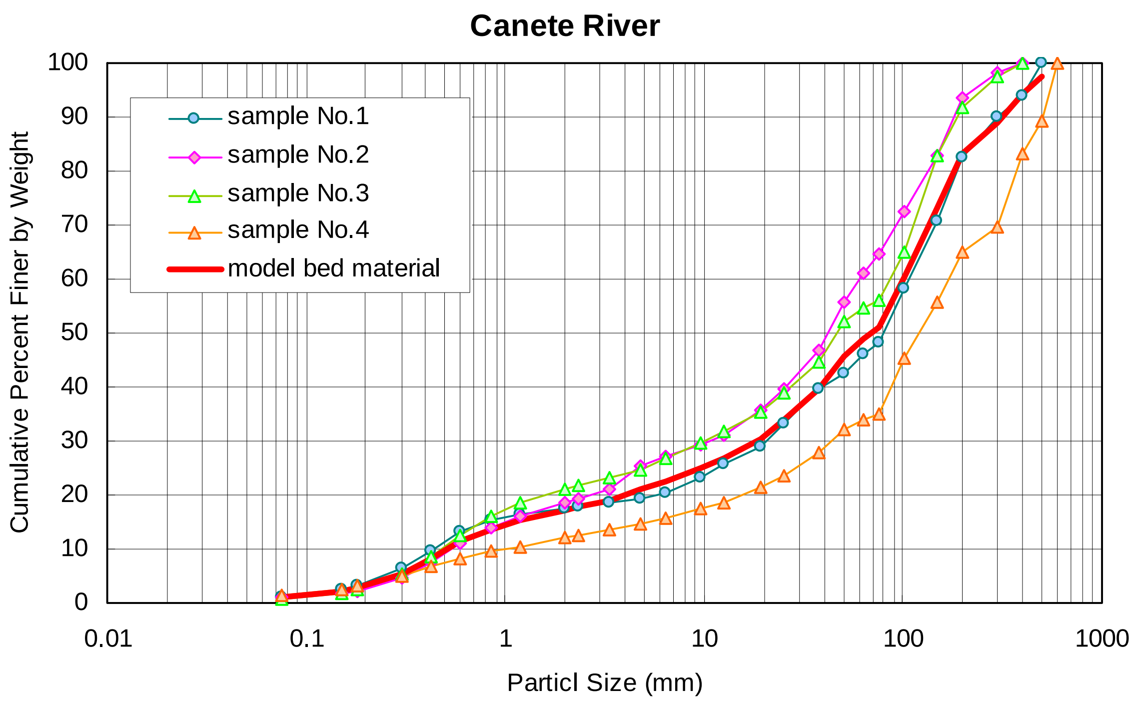


Figure 1.18 **Survey Result of Grain Size Distribution (Canete River)**

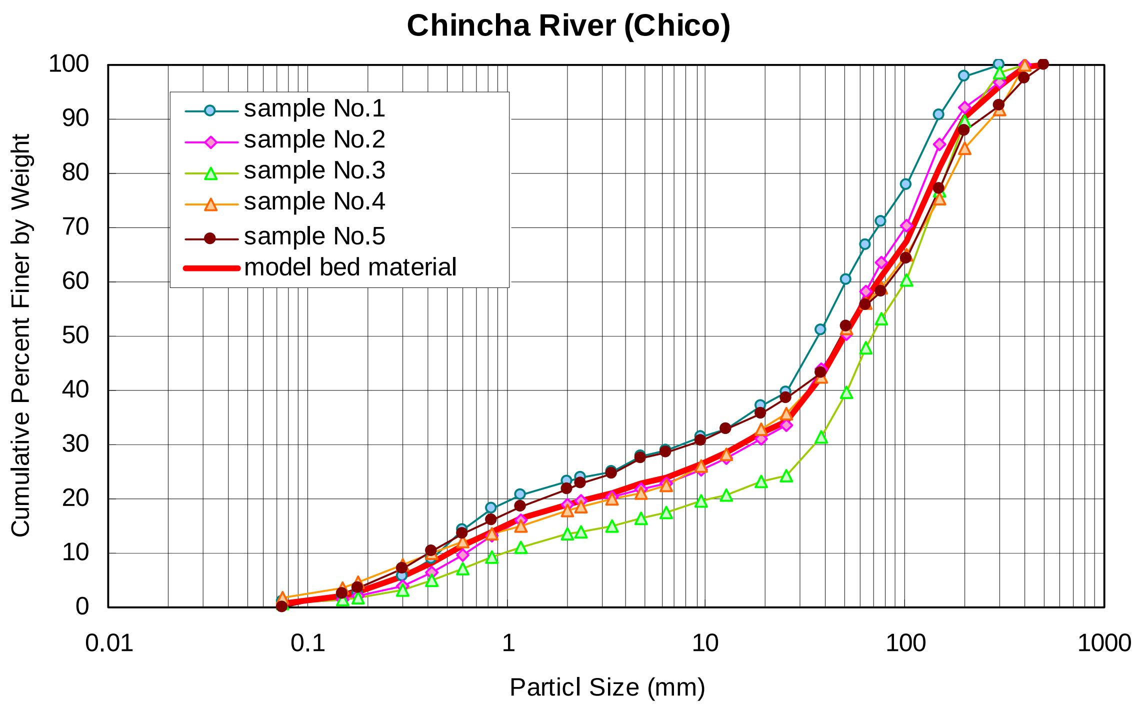


Figure 1.19 Survey Result of Grain Size Distribution (Chincha River (Chico River))

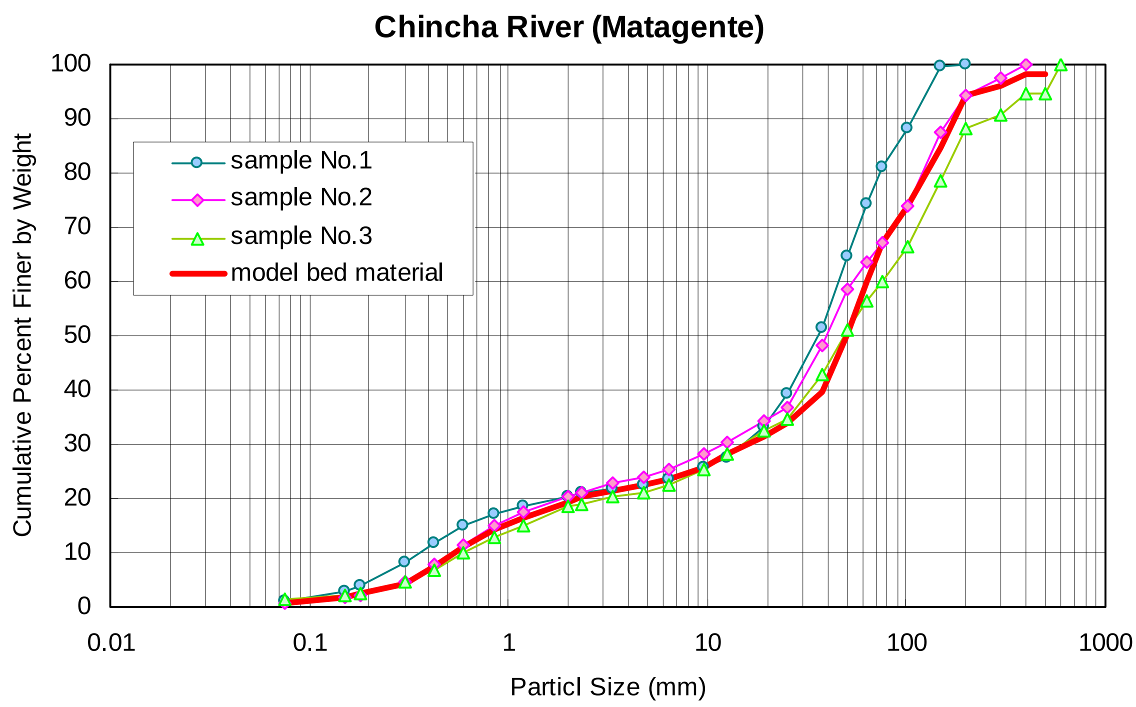


Figure 1.20 **Survey Result of Grain Size Distribution (Chincha River (Matagente River))**

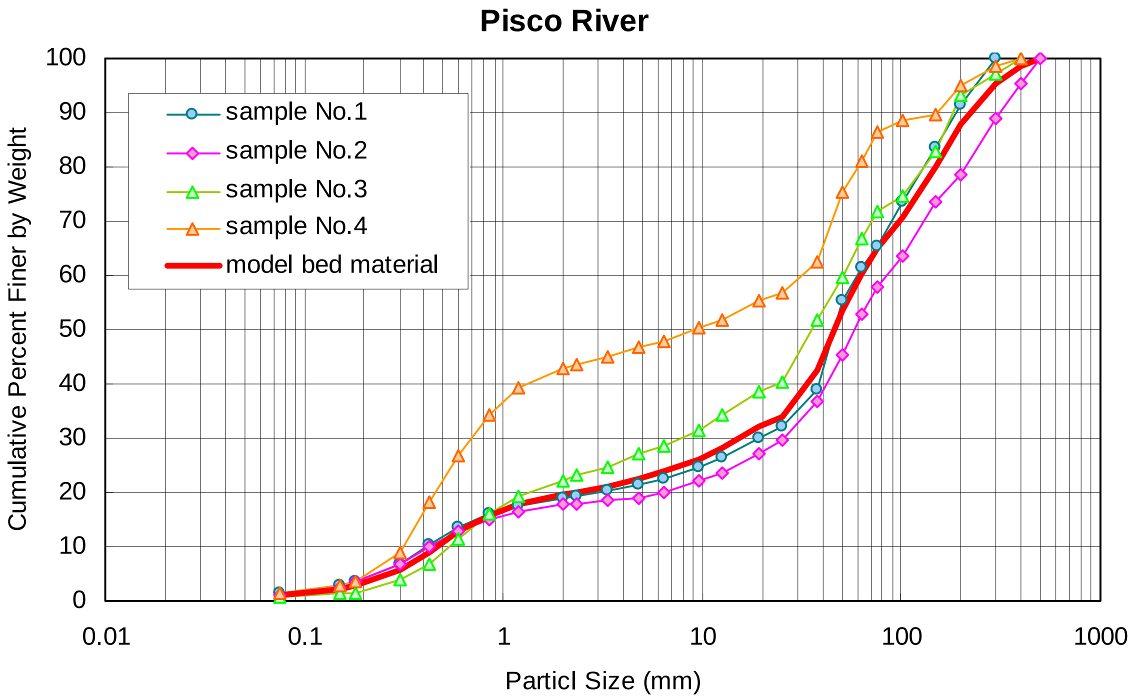


Figure 1.21 **Survey Result of Grain Size Distribution (Pisco River)**

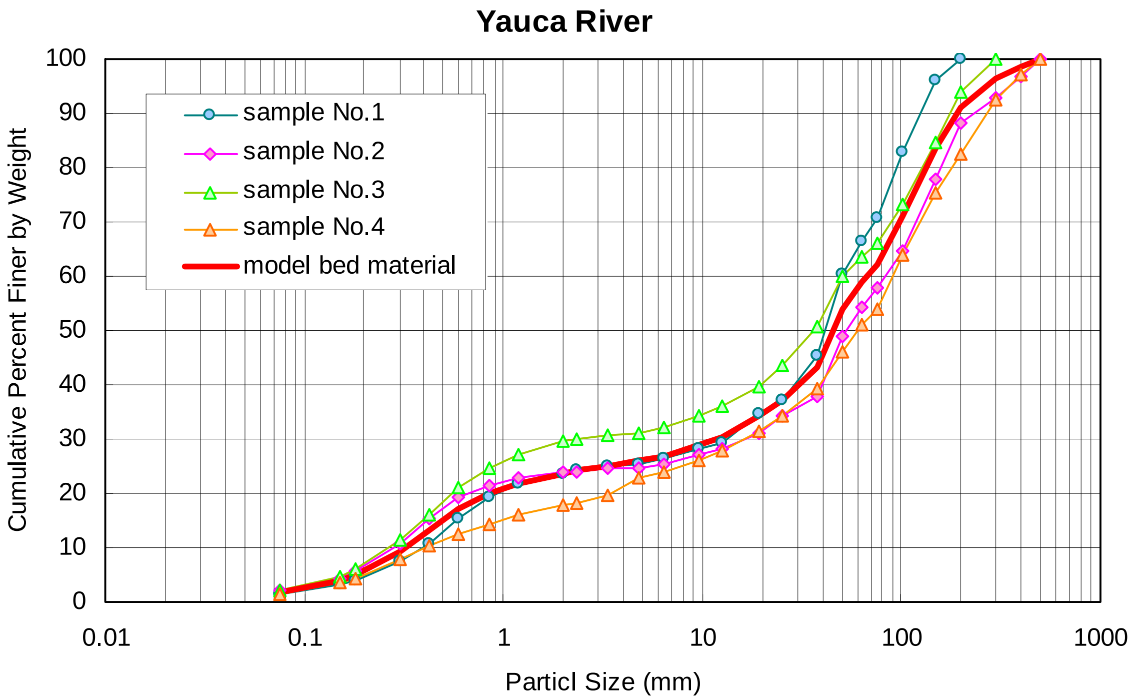


Figure 1.22 **Survey Result of Grain Size Distribution (Yauca River)**

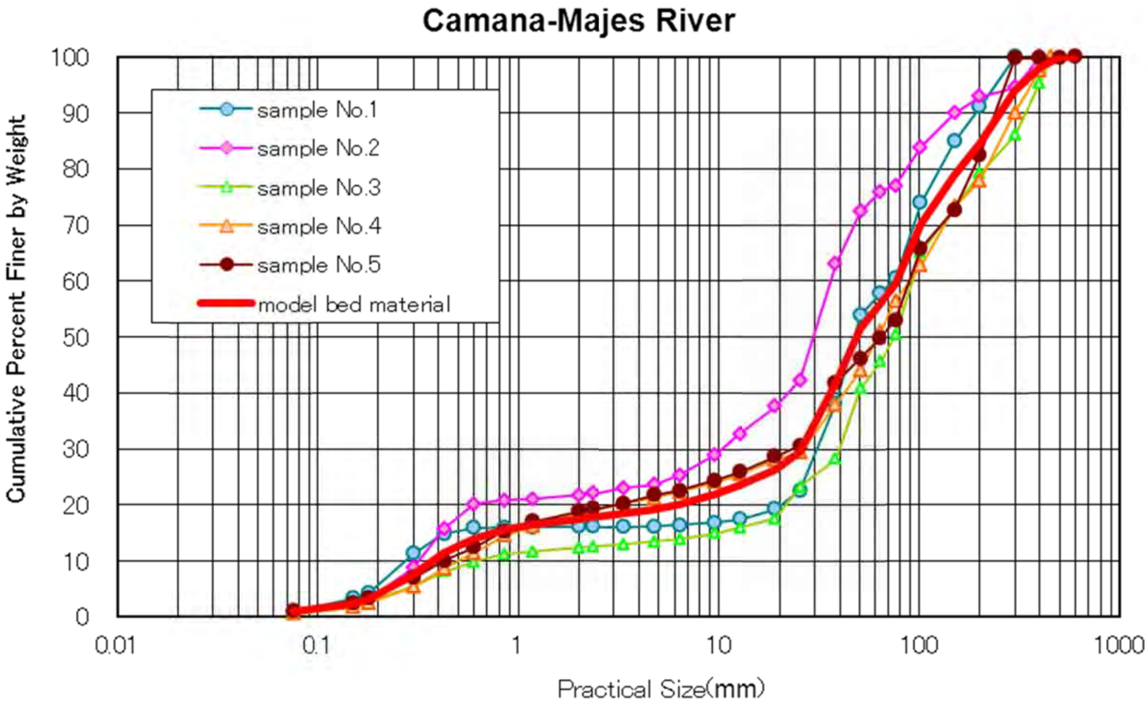


Figure 1.23 **Survey Result of Grain Size Distribution (Majes-Camana River)**

(4) Grain Size Segment used for Calculation

By using the riverbed fluctuation analysis, the movement and deposit of various sizes of grains on actual riverbed will be analyzed. However, for the implementation of analysis, the grain size is categorized into ten (10) classes, and the representative size of each class is determined. In the analysis, based on the results of river bed material sampling survey in targeted five (5) rivers, the size classification was determined as follows. In addition, since the percentage of grain with more than 500mm is high in Canete River, the classification with more than 500mm was additionally set.

Table 1.4 **Size Classification of Grain Size Distribution used for Analysis**

Classification		Size Classification (mm)			Representative Grain Diameter (mm)
Grain Size 1	Boulders	500.0	～	75.0	193.6
Grain Size 2	Cobbles	75.0	～	22.4	41.0
Grain Size 3	Coarse Gravel	22.4	～	6.69	12.2
Grain Size 4	Fine Gravel	6.69	～	2.00	3.66
Grain Size 5	Coarse Sand	2.000	～	0.669	1.16
Grain Size 6	Medium Sand	0.669	～	0.224	0.39
Grain Size 7	Fine Sand	0.224	～	0.075	0.13
Grain Size 8	Silt/Clay	0.075	～		0.075

1.3.3 Assumption on River Flow Volume

In each river, the river flow volume has been periodically observed; especially annual peak flow is recorded for the long term (see in ***Table 1.5***). However, the detailed chronological data is not well organized. Therefore, the results of runoff analysis with probable rainfall in the Study (see in **Annex-1** report) are identified as a representative time-series flood hydrograph. Moreover, the supplementary the hydrograph is used as an assumed river flow volume to match the peak flow of representative hydrograph with annual peak flow. The observed data of annual peak flow used for the analysis is shown from ***Figure 1.24*** to ***Figure 1.30***.

Table 1.5 **Condition of River Flow Observation and Adoption to Analysis**

River	Period of Data Availability	Adoption Period for Analysis	Remarks
Chira	Inflow Volume into Poechos Dam (23 years)	1975-1997 (23 years)×2 times + 1975-1978 (4 years)	Since Poechos dam exists in 99.5km, the outflow discharge of the dam will be used for analysis. In addition, inflow volume of the dam will be used for setting the flow volume of tributaries.
	Outflow Discharge from Poechos Dam (23 years)	Ditto	
Canete	1926-2006 (74 years)	1957-2006 (50 years)	Using latest 50 years
Chincha	1950-2006 (57 years)	1957-2006 (50 years)	
Pisco	1933-2008 (76 years)	1959-2008 (50 years)	
Yauca	1961-2008 (48 years)	1961-2008 (48 years) + 1961-1962 (2 years)	
Majes-Camana	1971-2002 (32 years)	1971-2002 (32 years) + 1971-1988 (18 years)	

* Used data is annual peak flow

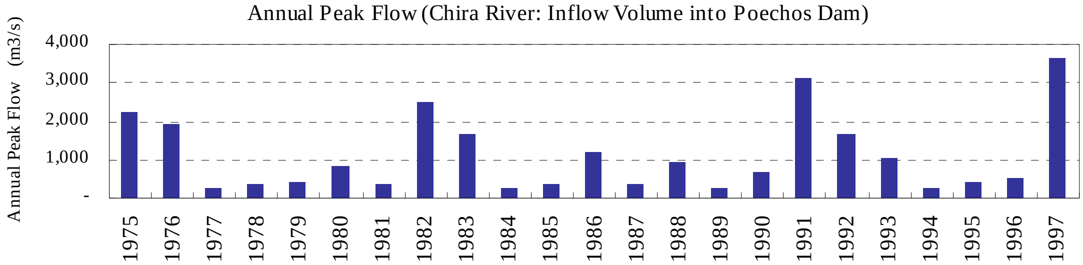


Figure 1.24 **Annual Peak Flow (Observed Data: Chira River: Inflow Volume into Poechos Dam)**

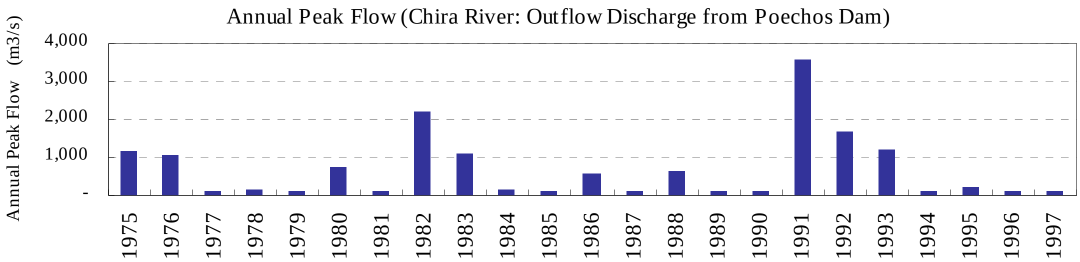


Figure 1.25 **Annual Peak Flow (Observed Data: Chira River: Outflow Discharge from Poechos Dam**

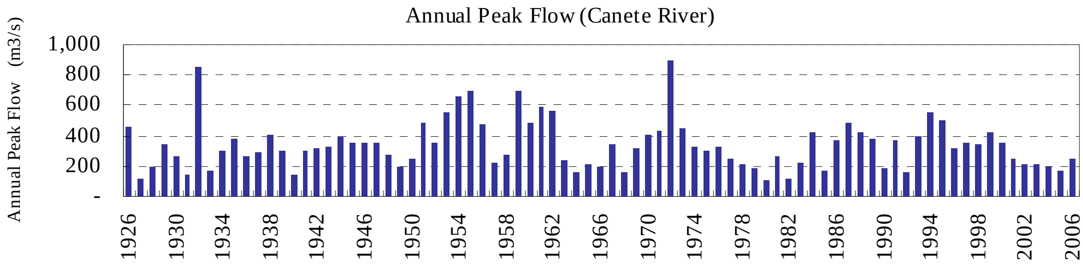


Figure 1.26 **Annual Peak Flow (Observed Data: Canete River)**

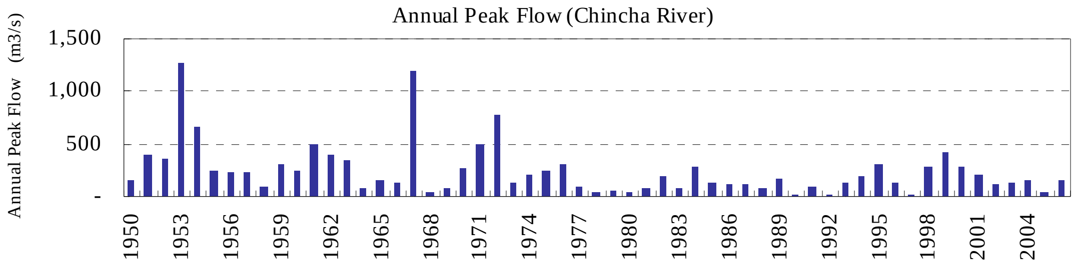


Figure 1.27 **Annual Peak Flow (Observed Data: Chincha River)**

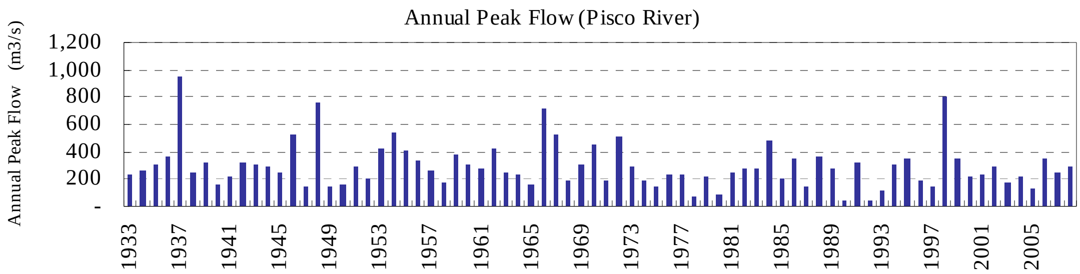


Figure 1.28 **Annual Peak Flow (Observed Data: Pisco River)**

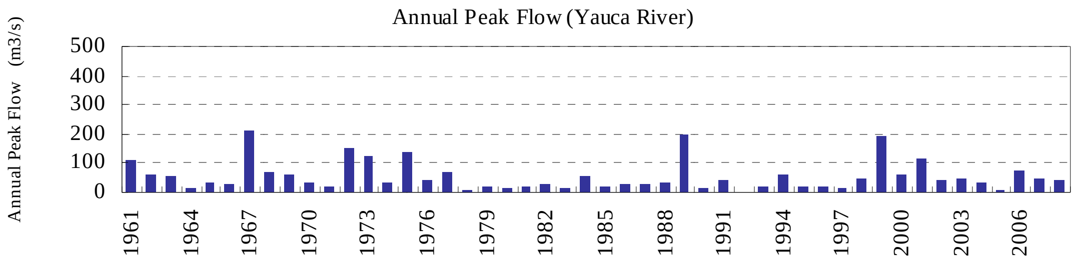


Figure 1.29 **Annual Peak Flow (Observed Data: Yauca River)**

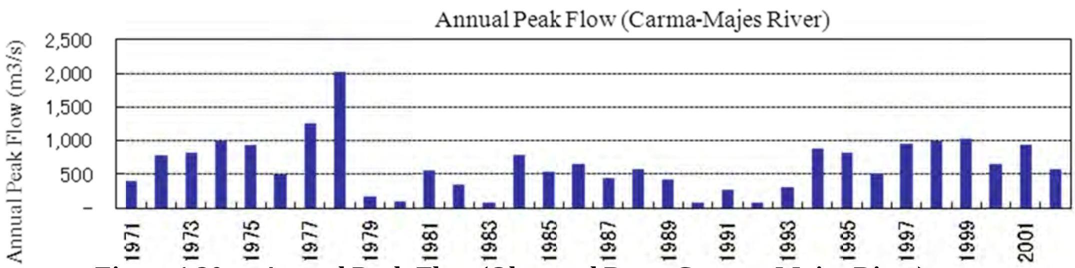


Figure 1.30 **Annual Peak Flow (Observed Data: Camara-Majes River)**

1.3.4 Assumption of Inflow Sediment

(1) Estimation Method

The following describes the set of inflow sediment volume from the upstream, which is important factor for analysis. The method for setup of inflow sediment volume is considered as two (2) alternatives: 1) estimation by existing sediment discharge equation and 2) estimation based on actual sedimentation data in the dam. As for the first method, by substituting the obtained parameters on river course features (shape, bed slope, bed material) into the equation, the inflow sediment volume of each targeted flow will be estimated. On the other hand, the second method using the actual sedimentation data is an analysis method to estimate sedimentation volume inflowing from the upstream based on the annual observed data at Poechos dam which is constructed in Chira River.

In this Study, the riverbed fluctuation analysis was conducted by using both methods, and assumption of inflow sediment was defined with these methods. As a result of analysis, it was realized that the actual river bed condition was reproduced by using the first method. Therefore, the assumption of inflow sediment defined by the first method was adopted for the five (5) targeted rivers.

In addition, since Poechos dam exists at the upstream of Chira River, it was assumed there was no sediment flowing into the river. However, relatively big tributary named Chipillico river flows into the river just downstream of the dam, the sediment inflow volume from the tributary was considered in analysis.

Table 1.6 **Assumption of Sediment Discharge at Upstream**

River	Estimation Method of Sediment Discharge	Remarks
Chira	zero (due to dam existence)	Estimated by equilibrium condition for tributary
Canete	Theoretical formula	Estimated by sensitivity analysis
Chincha	same as above	Equilibrium condition *
Pisco	same as above	same as above
Yauca	same as above	same as above
Majes-Camana	same as above	same as above

* Equilibrium condition: moving maximum sediment volume based on river course feature and flow condition at targeted locations

(2) Set of Inflow Sediment Volume in Canete River

Regarding the Canete River, since the remarkable riverbed fluctuation at upstream was estimated by setting the inflow sediment volume from the upstream as equilibrium sediment volume, the riverbed fluctuation analysis was conducted on the following three (3) cases. The results of the analysis will be described later.

Case	Inflow Sediment Volume	Remarks
Case 1	116,000 m^3/year	equilibrium sediment volume
Case 2	60,000 m^3/year	Half of equilibrium sediment volume
Case 3	30,000 m^3/year	Quarter of equilibrium sediment volume

1.3.5 Other Assumptions

The other assumptions for analysis are summarized in ***Table 1.7***.

Table 1.7 **Other Assumptions for Analysis (Targeted Six Rivers)**

Item	Assumption	Remarks
Time Unit	Δt=2sec	
Spatial Unit	Δx=500m (Chira), 100m (other than Chira)	
Number of Representative Grain Diameter	9 grain diameter (Canete) 8 grain diameter (other than Canete)	
Upstream End Flow	50-year data based on observed discharge volume (annual peak flow) of each river	
Downstream End Water Level	Normal depth	
Tributary Inflow	Chira river: considering the relatively huge tributary (Chipillico river) flowing into the river just downstream of Poechos dam Other than Chira river: without considering any tributaries since there is no big tributary in the targeted area.	
Free Volume	0.4 (constant)	Average size of sand and gravel
Roughness Coefficient	n=0.03 (Chira) n=0.05 (other than Chira river)	Riverbed materials are fine compared with others

CHAPTER 2 RESULTS OF ANALYSIS

The results of riverbed fluctuation analysis on six (6) targeted rivers are described below.

2.1 Results of Analysis (Comparison of Six (6) Rivers)

At first, regarding the analytic results of targeted six (6) rivers for future 50 years, the preliminary comparative study was conducted as shown in ***Table 2.1, Table 2.2, Figure 2.1*** and ***Figure 2.2***. Based on the results, the following characteristics are identified.

- In the five (5) rivers excluding Chira River, the average riverbed height aggrades, indicating these rivers tend to deposit the sediment. The total inflow sediment volume and total riverbed fluctuation level are higher in Majes-Camana, Chincha and Pisco Rivers than those in Canete and Yauca Rivers. In addition, since the dam (Poechos dam) exists upstream of targeted river section and the sedimentation condition has not reached to the design maximum level, almost all the sediment produced at the upstream is caught by the dam. Therefore, the riverbed just downstream of the dam tends to decrease.
- Among six (6) rivers, Majes-Camana, Chincha and Pisco Rivers have a strong trend to accelerate the deposition of sediments flowed in from upstream. This trend can be viscerally understood through the interviews in the survey areas and comparison of riverbed conditions (See in Photo 2.1-1). Inflow sedimentation of Yauca River is smaller than that of others. Because flow volume of the river, which is external force to make the sediment move, is comparatively smaller than others.
- It was realized that the inflow sediment volume in Canete River was small even though the catchment area of the river was large. This is the comprehensive evaluation based on the site survey and riverbed fluctuation analysis. The details are described later.
- The scale of inflow sedimentation of Majes-Camana River is bigger than that of others, because the river basin area is larger and scale of flood is rather bigger than other rivers, and the large amount of sediments can be flowed to downstream. In addition, although the amount of riverbed fluctuation (sediment volume) is large, the average riverbed fluctuation height (range) is about 0.2m for 50 years. The fluctuation height (range) is smaller than Chincha River.

Table 2.1 **Result of Riverbed Fluctuation Analysis**

River	Total Inflow Sediment Volume (10^3m^3)	Annual Inflow Sediment Volume (10^3m^3)	Total Bed Fluctuation (10^3m^3)	Average Bed Fluctuation (m)	Remarks
Carete	3,000	60	673	0.2	
Chincha	5,759	115	2610	0.5	Total inflow to Chico and Matagente Rivers
Pisco	8,658	173	2571	0.2	
Yauca	1,192	23.84	685	0.2	
Chira	5,000	100	- 1,648	- 0.01	Inflow sediment to main river was assumed to be zero due to dam existence.
Majes-Camana	20,956	419	5,316	0.2	

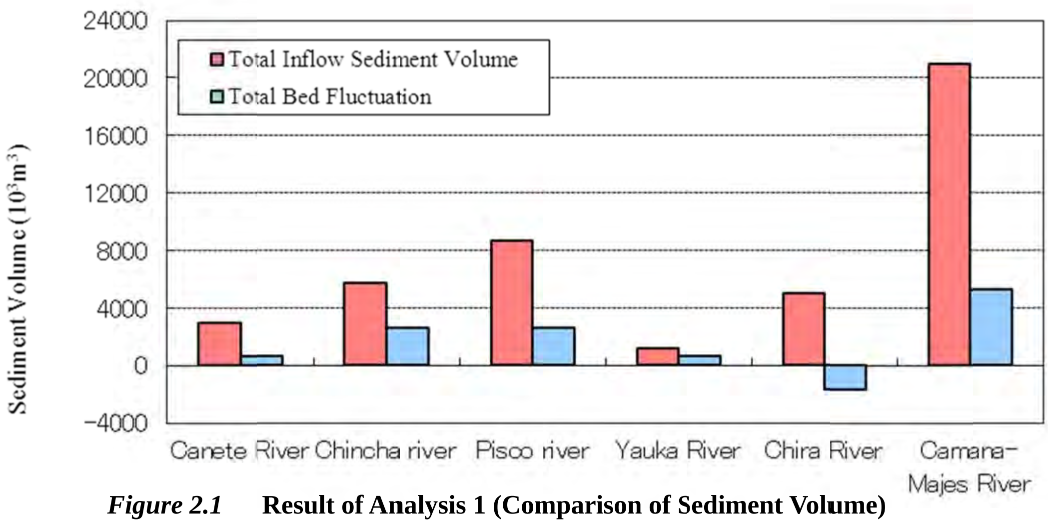


Figure 2.1 **Result of Analysis 1 (Comparison of Sediment Volume)**

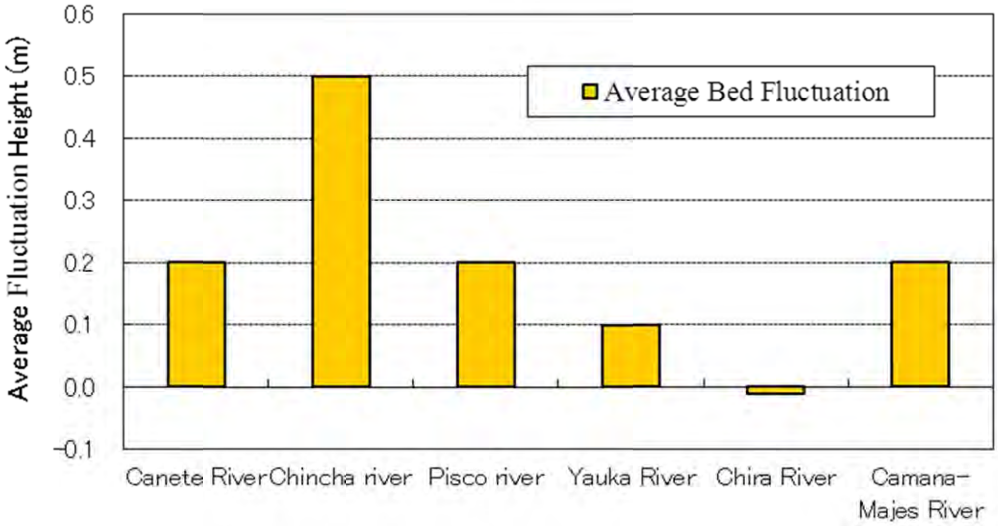


Figure 2.2 **Result of Analysis 2 (Comparison of Riverbed Fluctuation Height)**

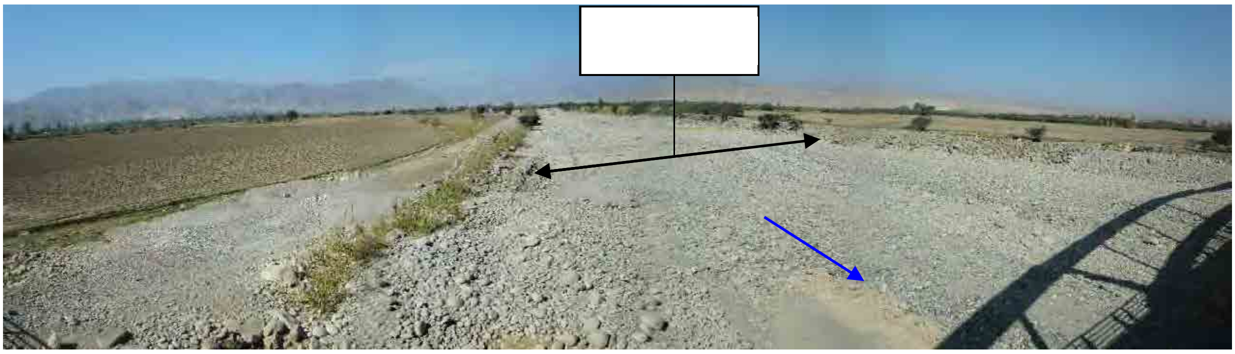
<table>
<tr><td colspan="2">Chancha River（Matagente 16km）River channel buried by Sediment</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Pisco River (14.5km) Sedimentation of upstream of narrow channel</td><td>Majes-Camana River (60km）Sedimentation in wide channel</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure 2.3 **Situation of Remarkable Riverbed Aggradation**

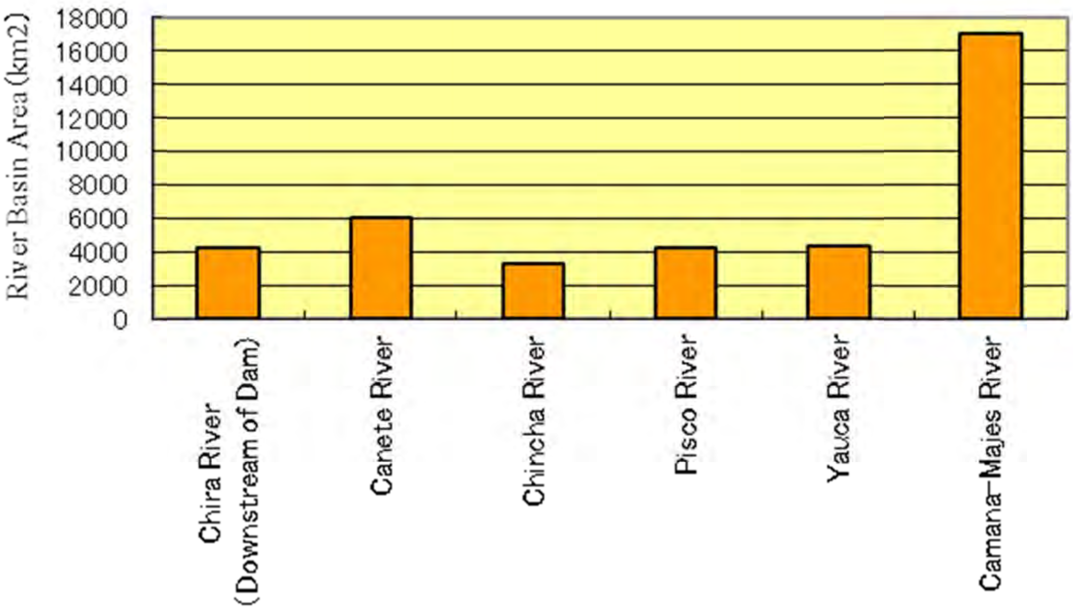


Figure 2.4 **Comparison of River Basin Area**

2.2 Future Trend of Riverbed Fluctuation in Each River

The results of riverbed fluctuation analysis in each river are shown from ***Figure 2.6*** to ***Figure 2.16***.

2.2.1 Chira River

Based on the results of analysis in Chira River, the followings are indicated.

- Since the sediment inflow is blocked by the Poechos Dam, the remarkable riverbed degradation can be identified just downstream of the dam.
- On the other hand, the sediment transport from the upstream and tributaries is deposited at the Sullana Weir located at the middle stream, the riverbed aggradation can be identified. From the short-term point of view, problems led by the sedimentation is not serious, however, there is possibility that the flow capacity will be insufficient in the future without the riverbed excavation.
- In the downstream river section, the extraordinary riverbed fluctuation will be not occurred. However, in case of big flood occurrence, the riverbed degradation will be happened at the several sections. These results correspond with the information obtained from the interview in the survey, and effectiveness of the riverbed fluctuation model was verified.

2.2.2 Canete River

By comparing to the results of analysis, it was identified that riverbed aggradation with maximum in 3.5m was estimated at the location of 27km to 31km in case 1. This results from that the river width at the location is remarkably narrow and inflow sediment from the upstream is not transported well. However, based on the local hearing and site survey results, it is said that the probability of riverbed aggradation is low due to the sediment inflow at the upstream section of Canete River. Moreover, the dam is constructed at the upstream. Therefore, as a result of two cases for analysis with decrease of inflow sediment volume, the case 2 analysis relatively represents the actual situation. In addition, the Plantanal Dam for hydro-power was constructed in upstream of the Canete River in recent years. Influence for future riverbed fluctuation affected by dam is described as follows.

Table 2.2 **Result of Riverbed Fluctuation Simulation in Canete River**

Case	Total Inflow Sediment Volume	Maximum Riverbed Fluctuation Height at Upstream	Evaluation	
Case 1	5,820,000 m3 116,000m3/yr	3.5m (50 yrs later) 1.7m (10 yrs later)	Riverbed aggradation with 0.6m can be observed at overall river channel	×
Case 2	3,000,000 m3 60,000m3/yr	2.1m (50 yrs later) 1.2m (10 yrs later)	Riverbed aggradation is smaller than that of case 1. 0.2m of riverbed rises in overall river section.	○
Case 3	1,500,000 m3 30,000 m3/yr	1.5m (50 yrs later) 0.9m (10 yrs later)	Riverbed aggradation at upstream is mitigated compared with case 1 and 2. On the other hand, riverbed degradation can be identified at 19km to 25km section.	△

(3) Influence on the downstream riverbed fluctuation by the Plantanal Dam

The Plantanal Dam is constructed for hydro-power generation. It has been operated since September, 2009. It is a small scale dam with dam height of 35.7m, storage capacity of 0.8-0.9 million m3 (See in ***Figure 2.5***).

The dam is located in the upper stream about 60km from the mouth of the river. It is in slightly upper stream out of the target study area. The sediment runoff is predicted to be almost same as the examined volume in the study area. Since the annual sediment discharge of Canete River is estimated about 60,000m3, there is high possibility that the dam will be filled up by sediment for about ten years from now on, and then sediment will be discharged again to downstream. Therefore, sediment supply will be intercepted for about ten years, and riverbed will degrade temporarily. However, it seems that the influence of sediment due to the dam to the downstream section is temporary.

In addition, after full sedimentation, dam will have a regulating function for sediment yield as a sediment-control dam. When large-scale sediment discharge occurs in upper stream in the future, the sediment yield is controlled by the dam. For this reason, although the riverbed aggrade at a rate of simulation results in the long perspectives, rapid riverbed aggradation is not predicted within the short period.

Table 2.3 **Dimension of Plantanal Dam**

Purpose	Power Generation
Dam height	35.7m
Storage Capacity	0.8～0.9×10^6m^3
Operation Start	September, 2009
Catchment Area	3,280km^2

Dam Facility	Reservoir (Upstream side)

Figure 2.5 **Overview of Plantanal Dam**

2.2.3 Chincha River

In Chincha River, caused by no operation of the diversion weir damaged by floods, the diversion rate for sediment inflow in Chico River and Matagente River is not identified. Therefore, for the future prediction, two (2) cases were analyzed: 1) case that all volumes of the inflow sediment flow into the rivers, and 2) case that half volumes of the inflow sediment flow into each river (with 1:1 ratio) (case 1) means the diversion facility does not function, and case 2) means the diversion facility functions).

The results of analysis indicate the following findings.

- In case that sediment and river flow can be divided with 1:1 ratio by rehabilitating the existing diversion weir in the future, it is estimated that the riverbed aggradation with 20cm to 30cm will be occurred fifty (50) years later. On the other hand, without rehabilitation of the existing diversion weir, if the sediment and river flow intensively flow into either river, the riverbed aggradation will be reached to 40cm to 60cm, which means the double of the above case. Therefore, the preventive function of the diversion weir for the riverbed aggradation can be identified.
- Regarding the relations between the hydraulic critical points and riverbed fluctuation, the sediment is deposited at C-1 and C-2 points in Chico River, leading the high risk of inundation at upstream of these critical points . On the other hand, deposit can be found at the M-3 and M-4 in Matagente River, also leading the possibility of the inundation. As for the countermeasure against the sedimentation, the periodical maintenance works in the river shall be required.

2.2.4 Pisco River

The analysis in Pisco River leads the following results.

- For the future fifty (50) years, the riverbed aggradation with 20cm in average was estimated. In terms of the average rate, it is not serious volume of sedimentation. However, the maximum 1m of riverbed aggradation is found in narrowed areas, so the inundation risk is high. Therefore, the periodical maintenance works such as riverbed excavation shall be required in these narrowed areas.
- The riverbed degradation can be found around the 30km distance mark, but it is in the small. Moreover, in consideration with the predictive accuracy by one-dimensional riverbed fluctuation calculation, it cannot be defined as a trouble spot without the verifiable observed data.

2.2.5 Yauca River

According to the analysis results on Yauca River, the following findings were identified.

- It was estimated that the average 10cm of riverbed aggradation will be occurred for the next fifty (50) years. Even though the partial riverbed fluctuation is identified at river mouth and upstream, the riverbed tends to be stable. The main reason for the stability of riverbed is caused by the small volume of river flow for transporting the sediment.

- In the most downstream section, the sediment deposit can be identified. However, since there is no trouble spot in the downstream, the serious problems will not be happened even though the sedimentation will be accelerated.

2.2.6 Majes-Camana River

From the output of analysis of the Majes-Camana River, the followings are identified.

- It is predicted that the riverbed in the Majes-Camana River will aggrades by an average of about 20cm in 50 years in the future. There is low possibility that a big problem will arise from the view point of flood protection. However, in the vicinities of 13km distance mark and 101km distance mark, the riverbed aggradation with about 0.8m and 1m is predicted respectively.
- The riverbed aggradation in the narrow section near 13km distance mark is caused by extension of sediment accumulation in the wide section just downstream section of narrow section. Since water intake located in 12.8km distance mark, and trouble may arise in the intake due to aggradation, maintenance works such as excavation shall be required. Moreover, the vicinity of 101km distance mark is also wide channel section just downstream of narrow section. Since this section also overflowed in the past, it will be needed for maintenance.
- In the other sections without the above-mentioned, the riverbed aggradation seems to be small in general, it is thought that the necessity for maintenance by excavation is low.
- As mentioned above, in the Majes-Camana River, the part of 13km distance mark and 101km distance mark are the sections which need maintenance from the viewpoint of flood protection and water use.

Calculated River Bed Variations

Total amount inflow volume=	5,100,000	(m3)
Annual average inflow volume=	102,000	(m3)
Total amount of bed volume variation=	-1,648,000	(m3)
Average bed height variation=	-0.0	(m)
Maximum bed height variation (aggradation)=	1.6	(m)
Maximum bed height variation (degradation)=	-1.3	(m)

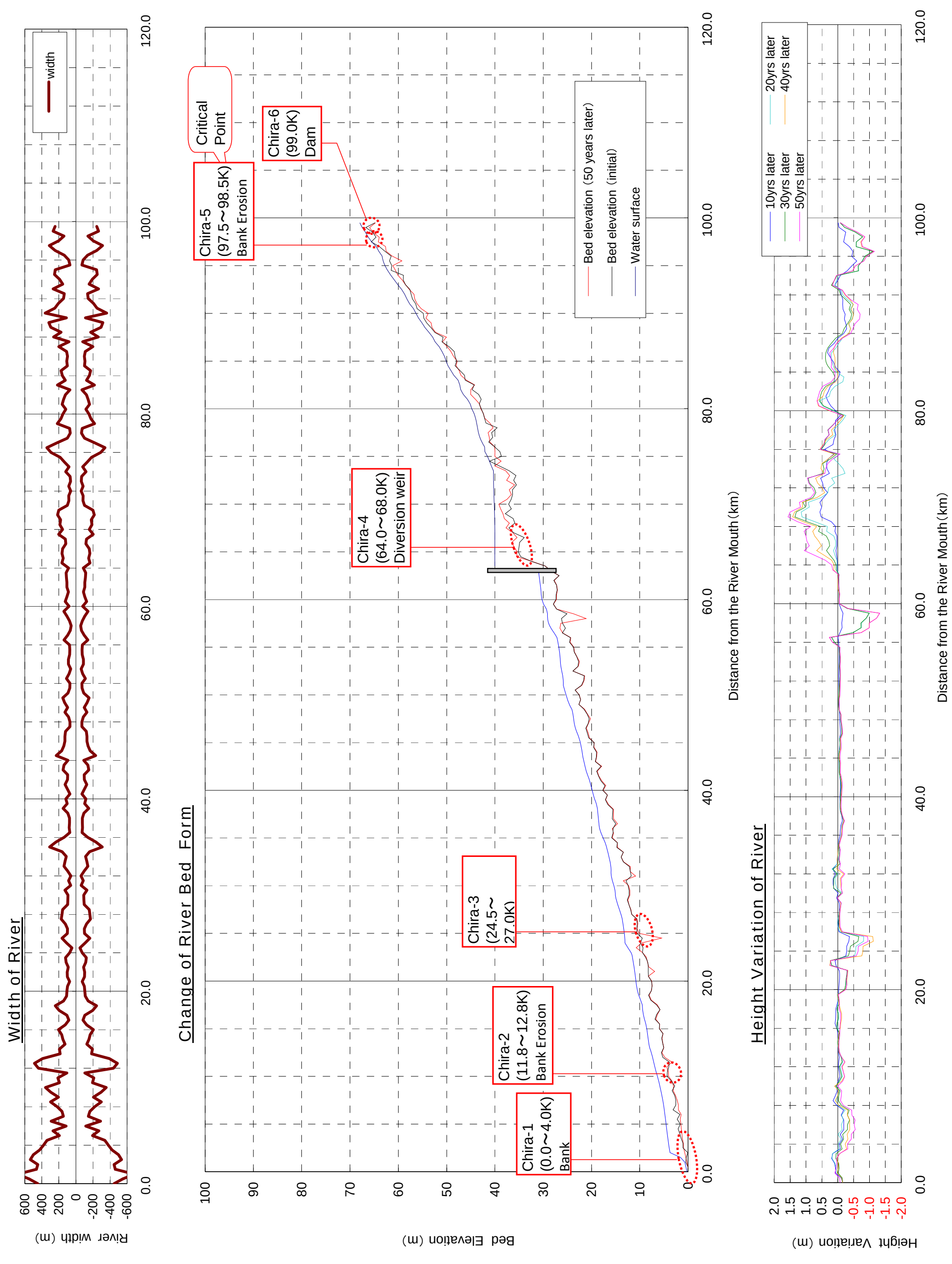
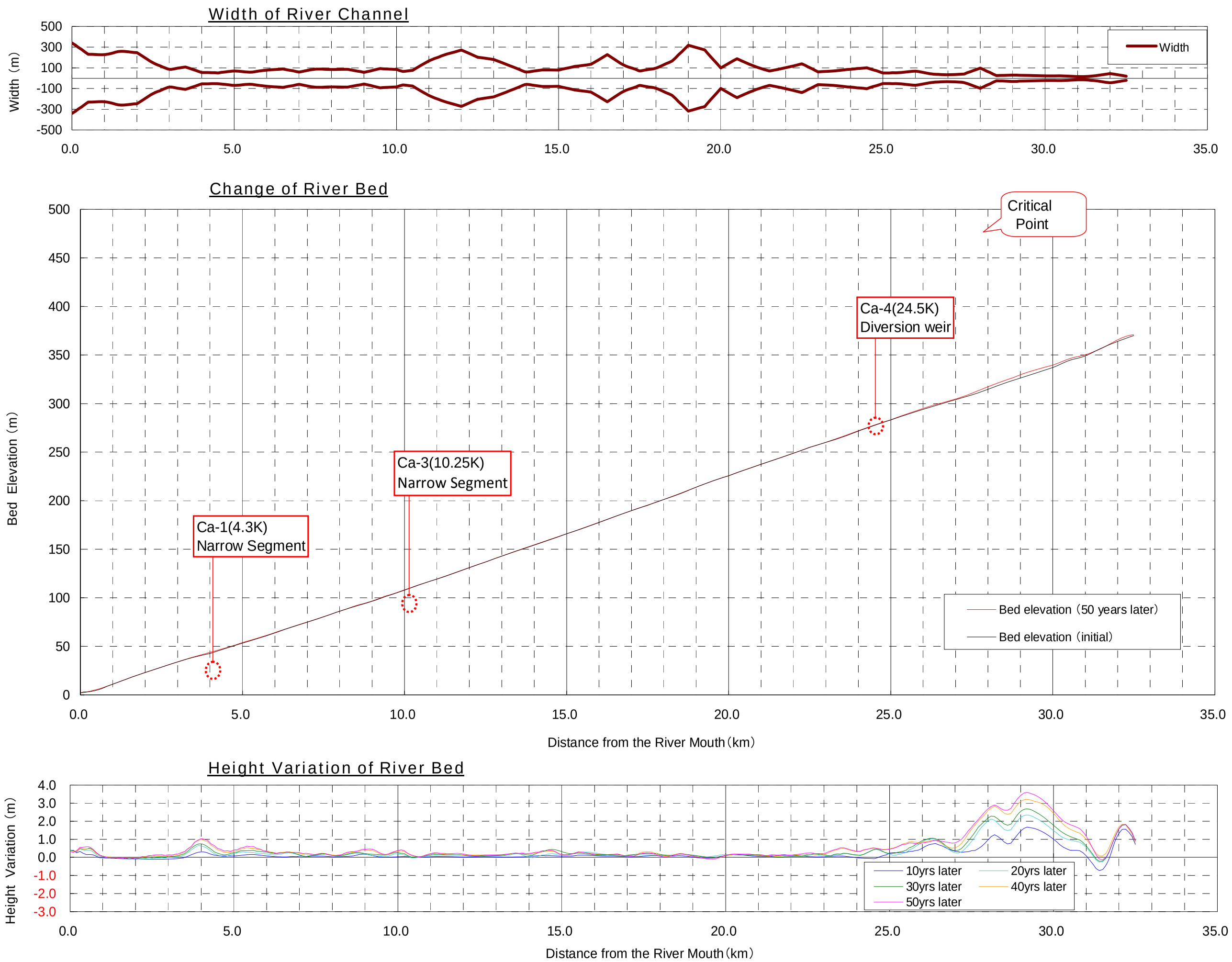


Figure 2.6 **Result of Analysis (Chira River)**



Calculated River Bed Variations

Total amount inflow volume=	5,820,000	(m3)
Annual average inflow volume=	116,000	(m3)
Total amount of bed volume variation=	2,166,000	(m3)
Average bed height variation=	0.6	(m)
Maximum bed height variation (aggradation)=	3.7	(m)
Maximum bed height variation (degradation)=	-0.5	(m)

Figure 2.7 **Result of Analysis (Canete River in Case of All Volumes of Sediment Inflow)**

Calculated River Bed Variations

Total amount inflow volume=	2,968,000	(m3)
Annual average inflow volume=	59,000	(m3)
Total amount of bed volume variation=	673,000	(m3)
Average bed height variation=	0.2	(m)
Maximum bed height variation (aggradation)=	2.4	(m)
Maximum bed height variation (degradation)=	-1.7	(m)

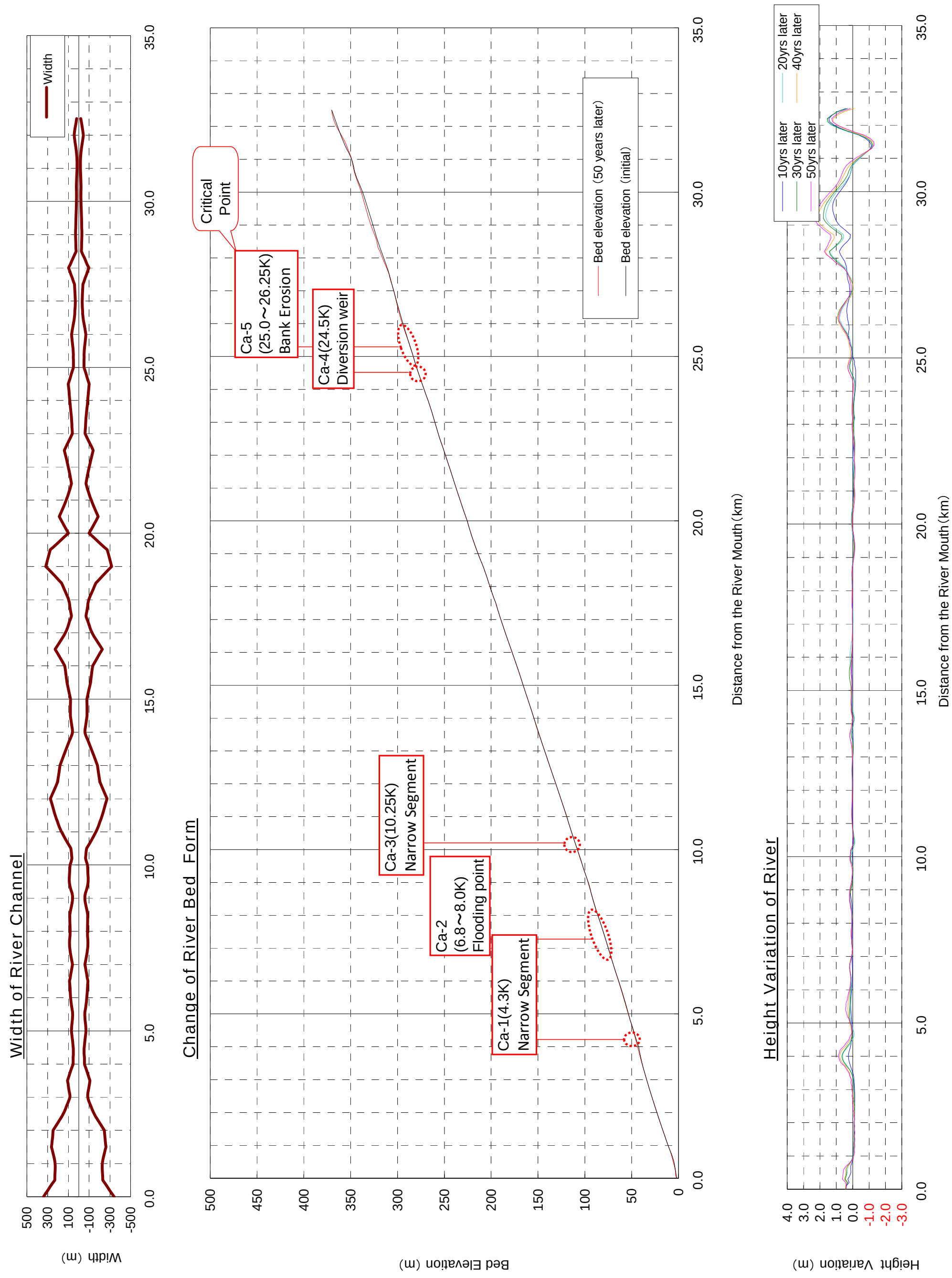
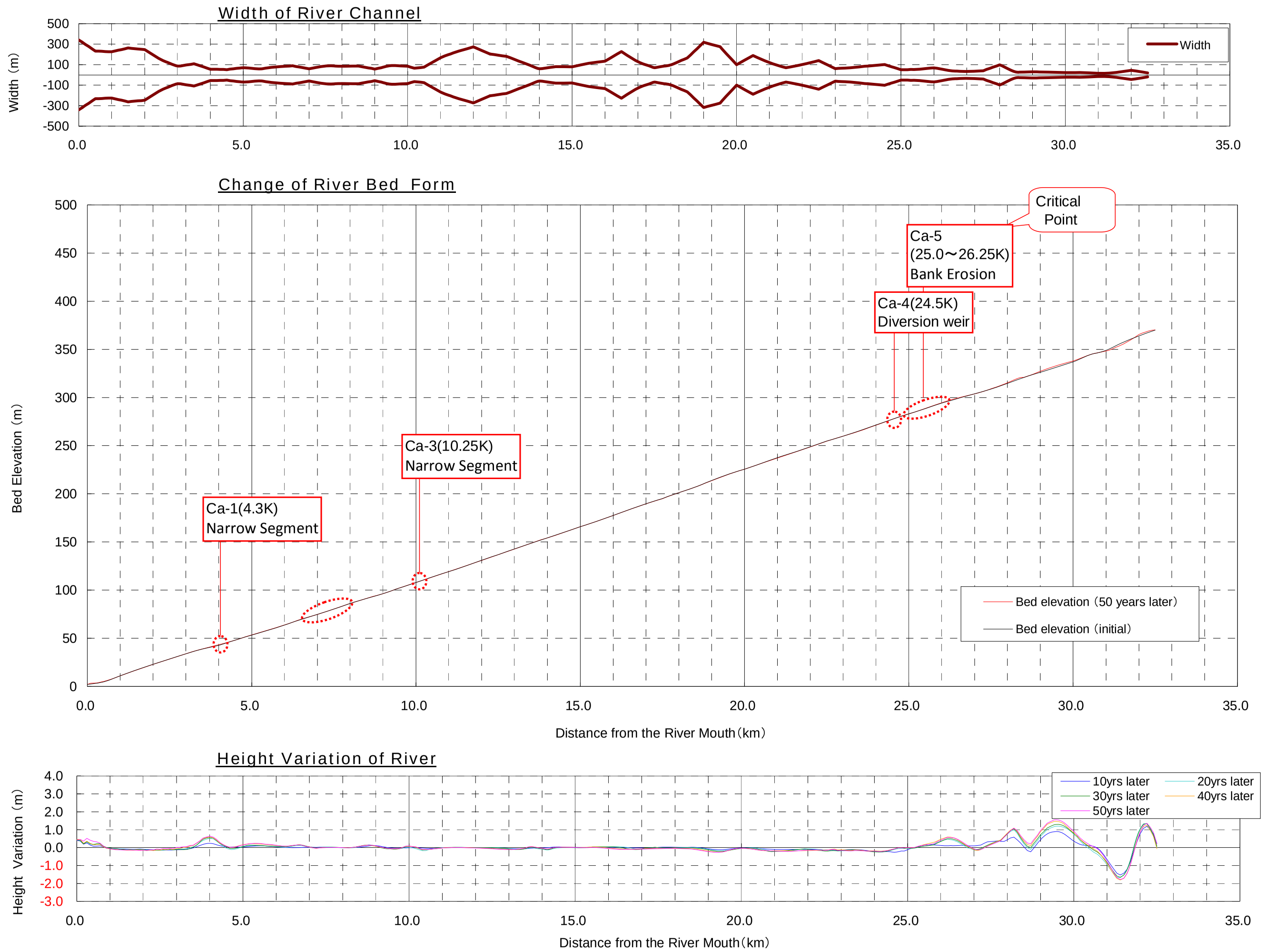


Figure 2.8 **Result of Analysis (Canete River in Case of Half Volumes of Sediment Inflow)**



Calculated River Bed Variations

Total amount inflow volume=	1,513,000	(m3)
Annual average inflow volume=	30,000	(m3)
Total amount of bed volume variation=	-79,000	(m3)
Average bed height variation=	0.1	(m)
Maximum bed height variation (aggradation)=	1.7	(m)
Maximum bed height variation (degradation)=	-2.1	(m)

Figure 2.9 **Result of Analysis (Canete River in Case of Quarter Volumes of Sediment Inflow)**

Assuming the condition existing diversion weir

Calculated River Bed Variations

Total amount inflow volume=	5,759,000	(m3)
Annual average inflow volume=	115,000	(m3)
Total amount of bed volume variation=	1,131,000	(m3)
Average bed height variation=	0.4	(m)
Maximum bed height variation (aggradation)=	1.4	(m)
Maximum bed height variation (degradation)=	-1.8	(m)

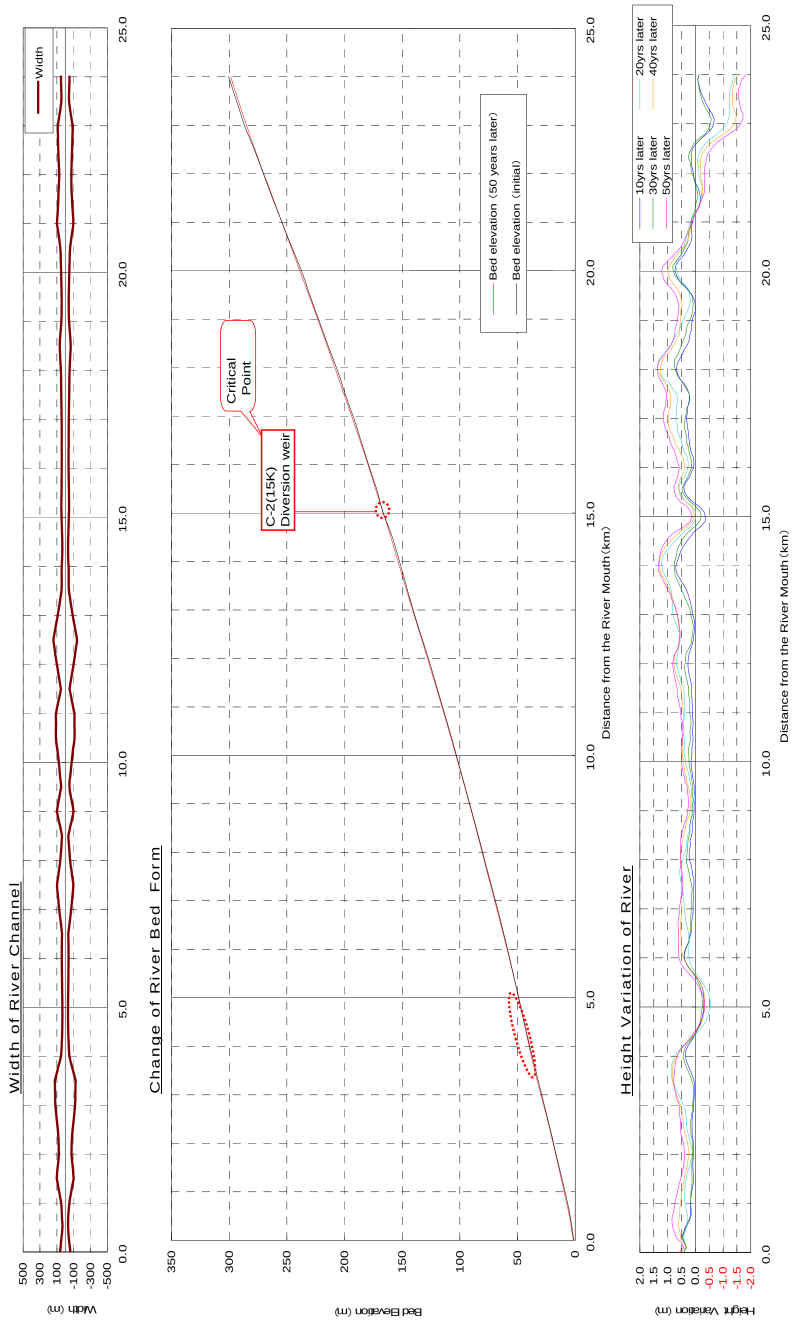


Figure 2.10 **Result of Analysis (Chincha River (Chico River) in Case of All Volumes of Sediment Inflow)**

Assuming the condition existing diversion weir

Calculated River Bed Variations

Total amount inflow volume=	2,879,000	(m3)
Annual average inflow volume=	58,000	(m3)
Total amount of bed volume variation=	822,000	(m3)
Average bed height variation=	0.2	(m)
Maximum bed height variation (aggradati	1.1	(m)
Maximum bed height variation (degradati	-0.8	(m)

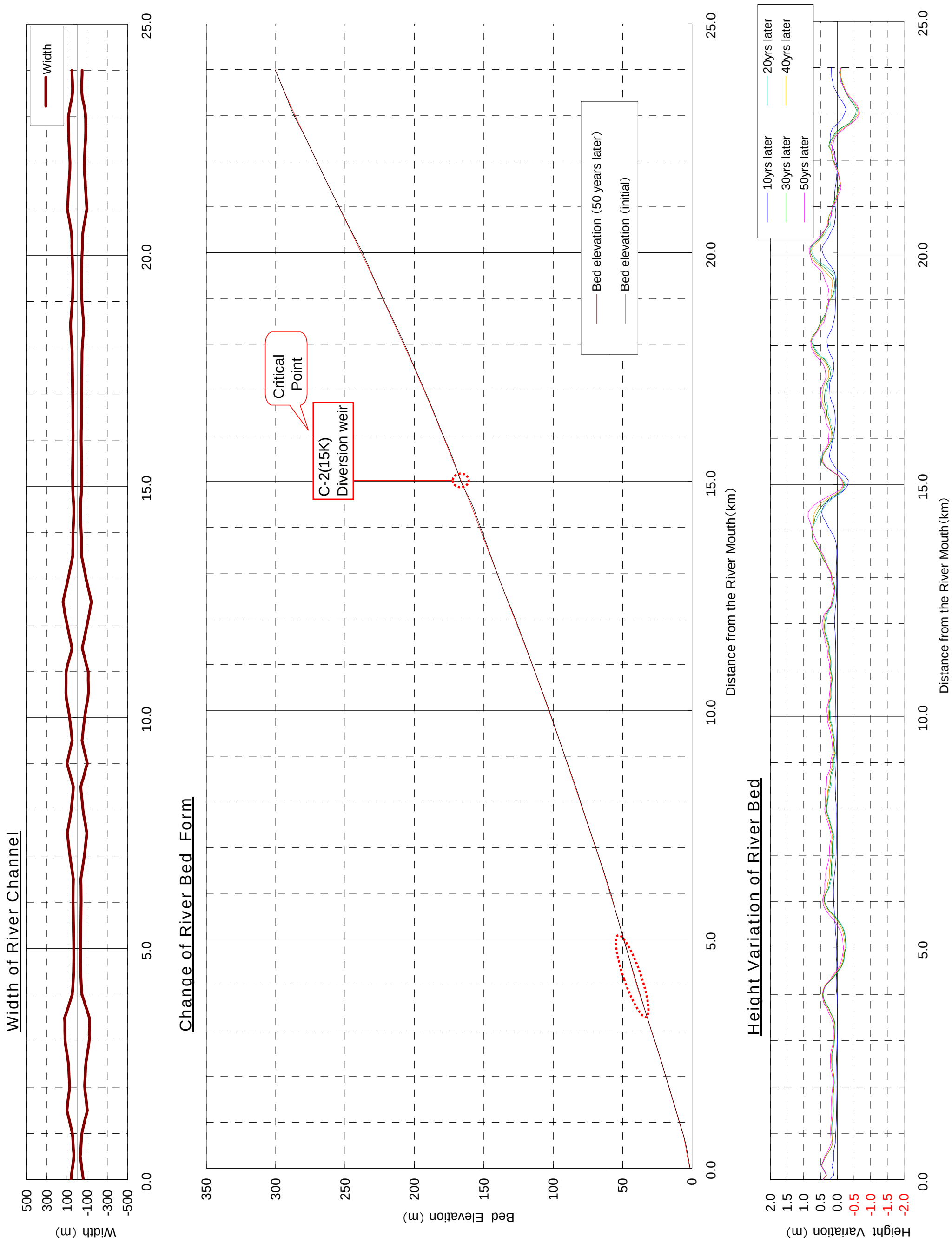
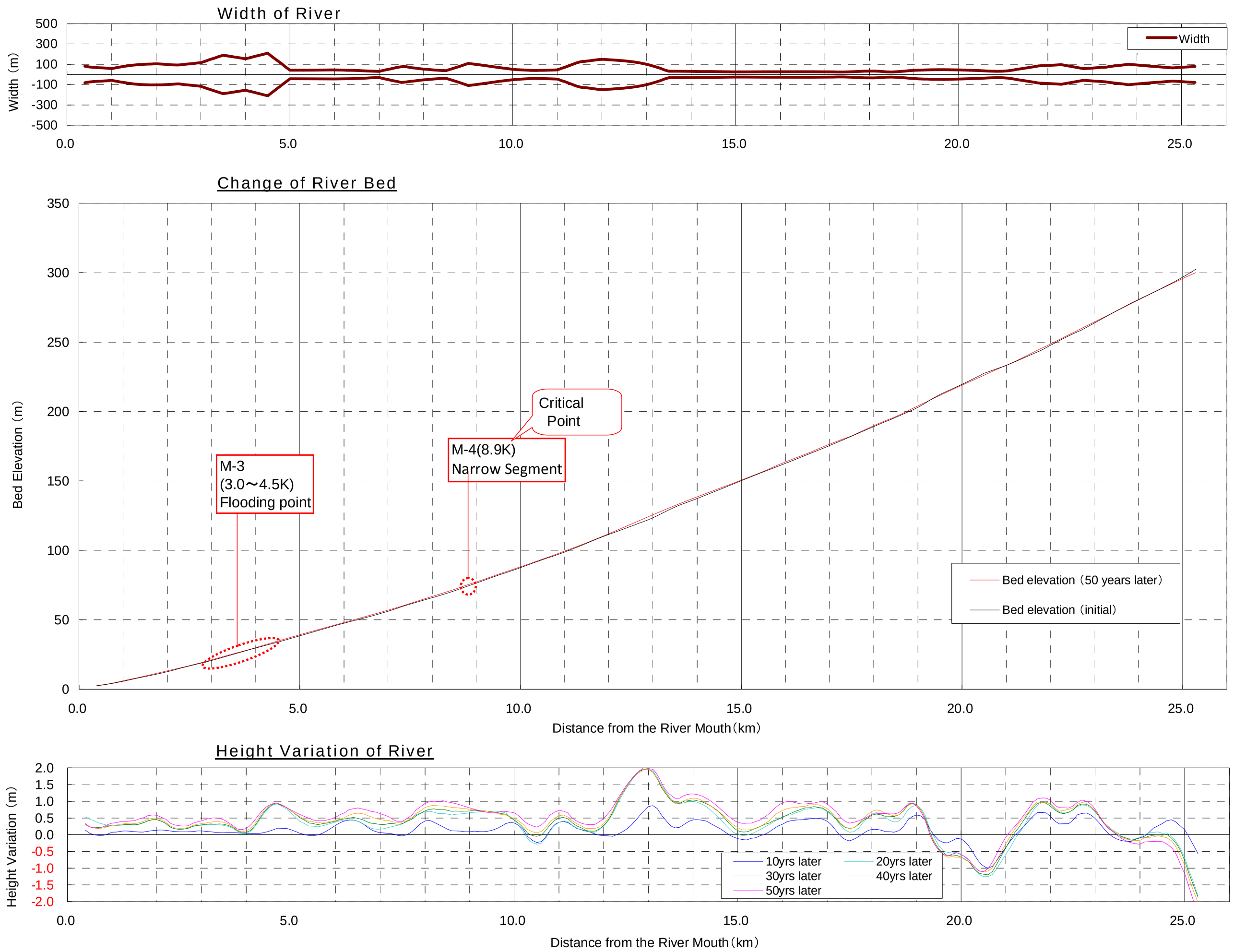


Figure 2.11 **Result of Analysis (Chincha River (Chico River) in Case of Half Volumes of Sediment Inflow)**

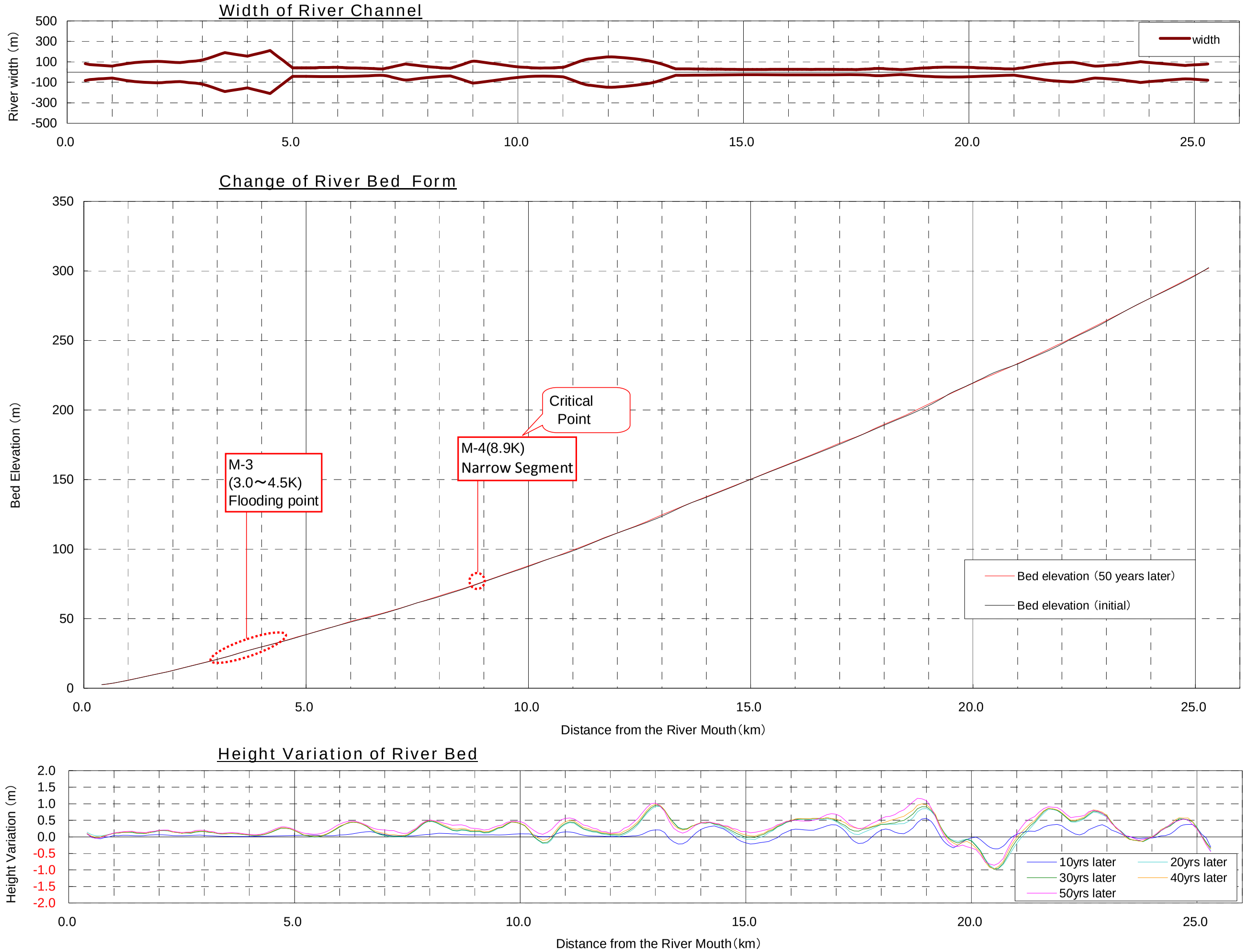


Assuming the condition existing diversion weir

Calculated River Bed Variations

Total amount inflow volume=	5,759,000	(m3)
Annual average inflow volume=	115,000	(m3)
Total amount of bed volume variation=	1,479,000	(m3)
Average bed height variation=	0.5	(m)
Maximum bed height variation (aggradation)=	2.0	(m)
Maximum bed height variation (degradation)=	-1.1	(m)

Figure 2.12 **Result of Analysis (Chincha River (Matagente River) in Case of All Volumes of Sediment Inflow)**

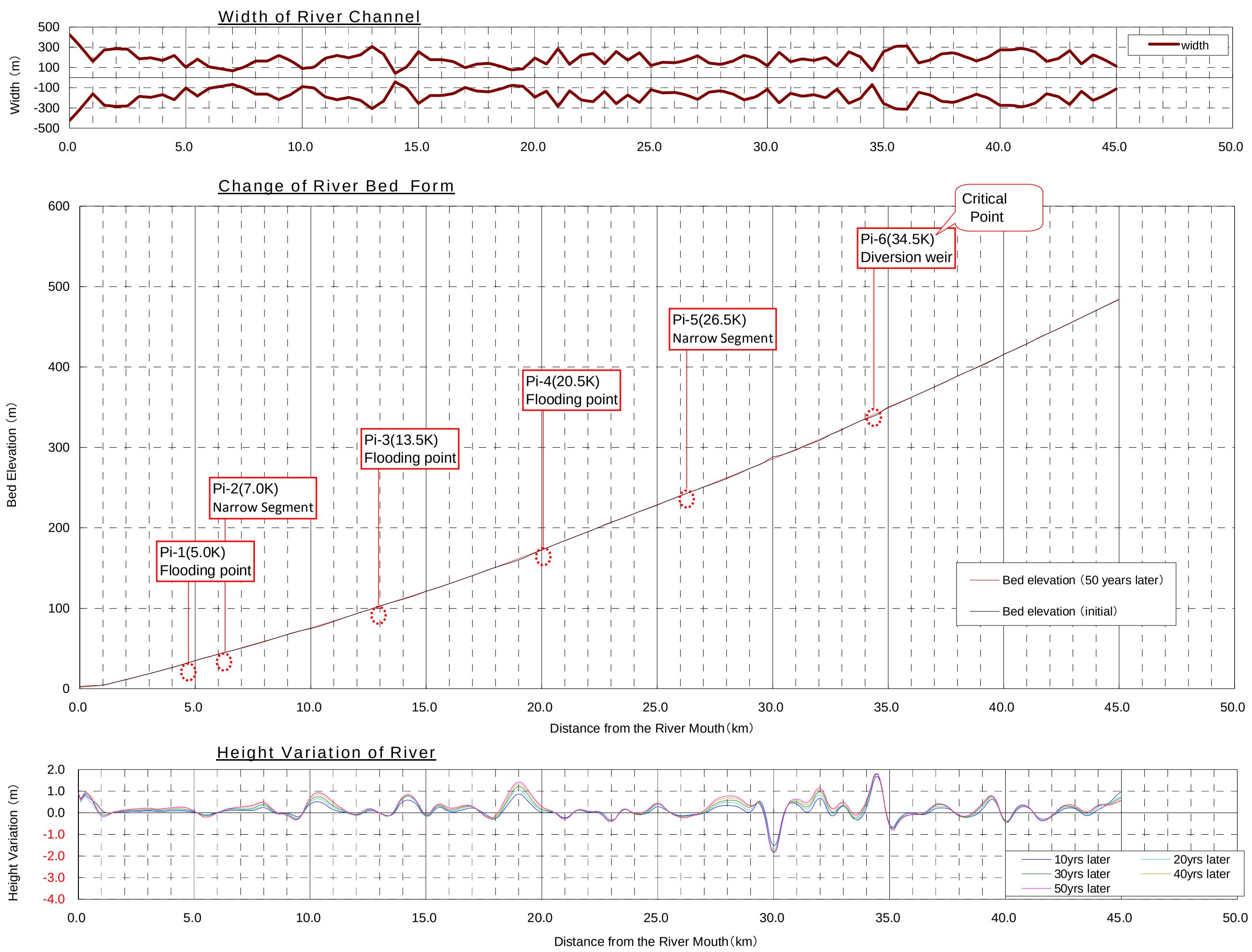


Assuming the existing condition diversion weir

Calculated River Bed Variations

Total amount inflow volume=	2,879,000	(m3)
Annual average inflow volume=	58,000	(m3)
Total amount of bed volume variation=	892,000	(m3)
Average bed height variation=	0.3	(m)
Maximum bed height variation (aggradation)=	1.4	(m)
Maximum bed height variation (degradation)=	-1.2	(m)

Figure 2.13 **Result of Analysis (Chincha River (Matagente River) in Case of Half Volumes of Sediment Inflow)**



Calculated River Bed Variations

Total amount inflow volume=	8,658,000	(m3)
Annual average inflow volume=	173,000	(m3)
Total amount of bed volume variation=	2,571,000	(m3)
Average bed height variation=	0.2	(m)
Maximum bed height variation (aggradation)=	1.8	(m)
Maximum bed height variation (degradation)=	-1.9	(m)

Figure 2.14 **Result of Analysis (Pisco River)**

Calculated River Bed Variations

Total amount inflow volume=	1,192,000	(m3)
Annual average inflow volume=	23,840	(m3)
Total amount of bed volume variation=	685,000	(m3)
Average bed height variation=	0.1	(m)
Maximum bed height variation (aggradation)=	1.7	(m)
Maximum bed height variation (degradation)=	-1.0	(m)

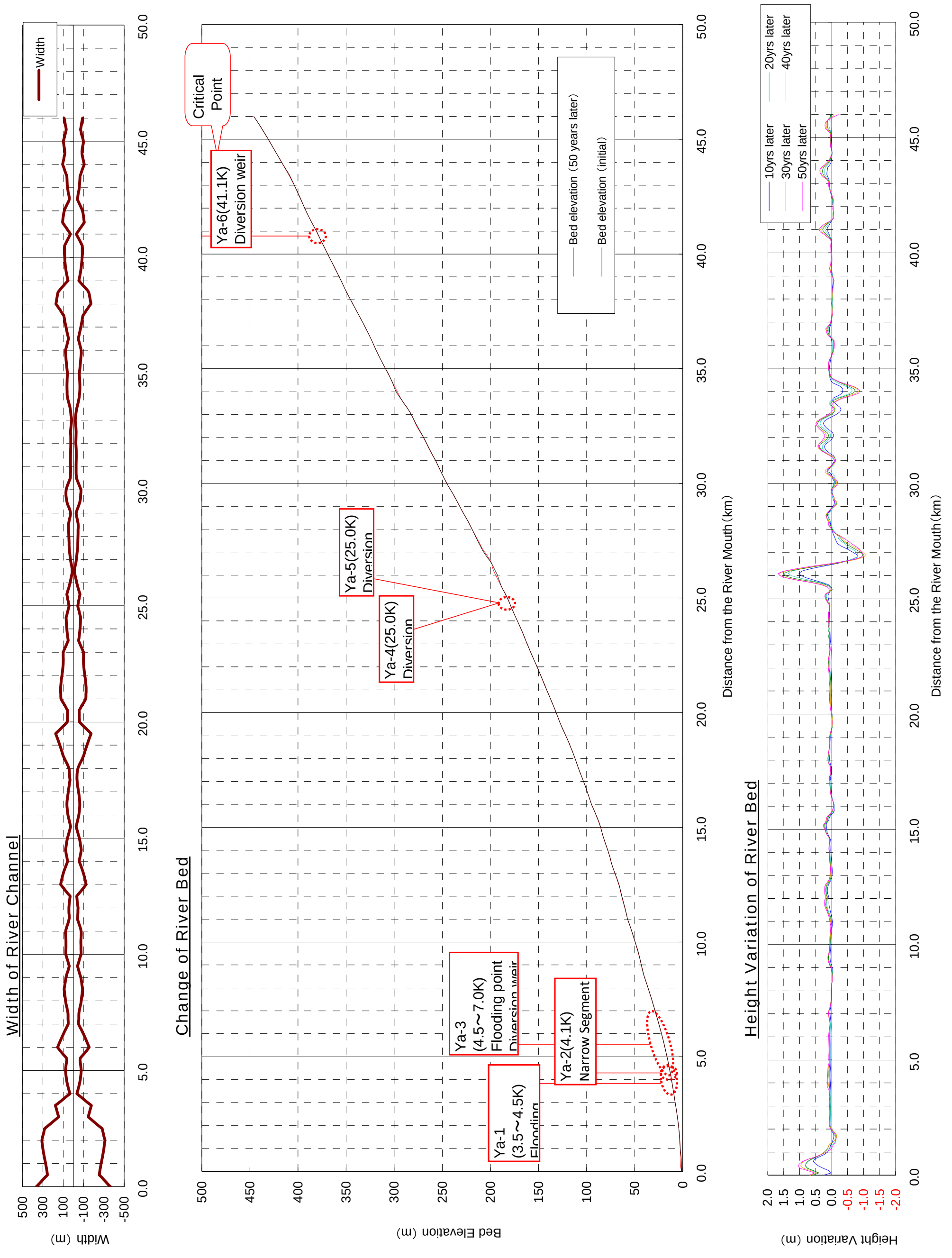


Figure 2.15 **Result of Analysis (Yauca River)**

Calculated River Bed Valiations

Total amount inflow volume=	20,956,000	(m3)
Annual average inflow volume=	419,000	(m3)
Total amount of bed volume=	5,316,000	(m3)
Average bed height variation=	0.2	(m)
Maximum bed height variation (aggradation)=	1.0	(m)
Maximum bed height variation (degradation)=	-0.4	(m)

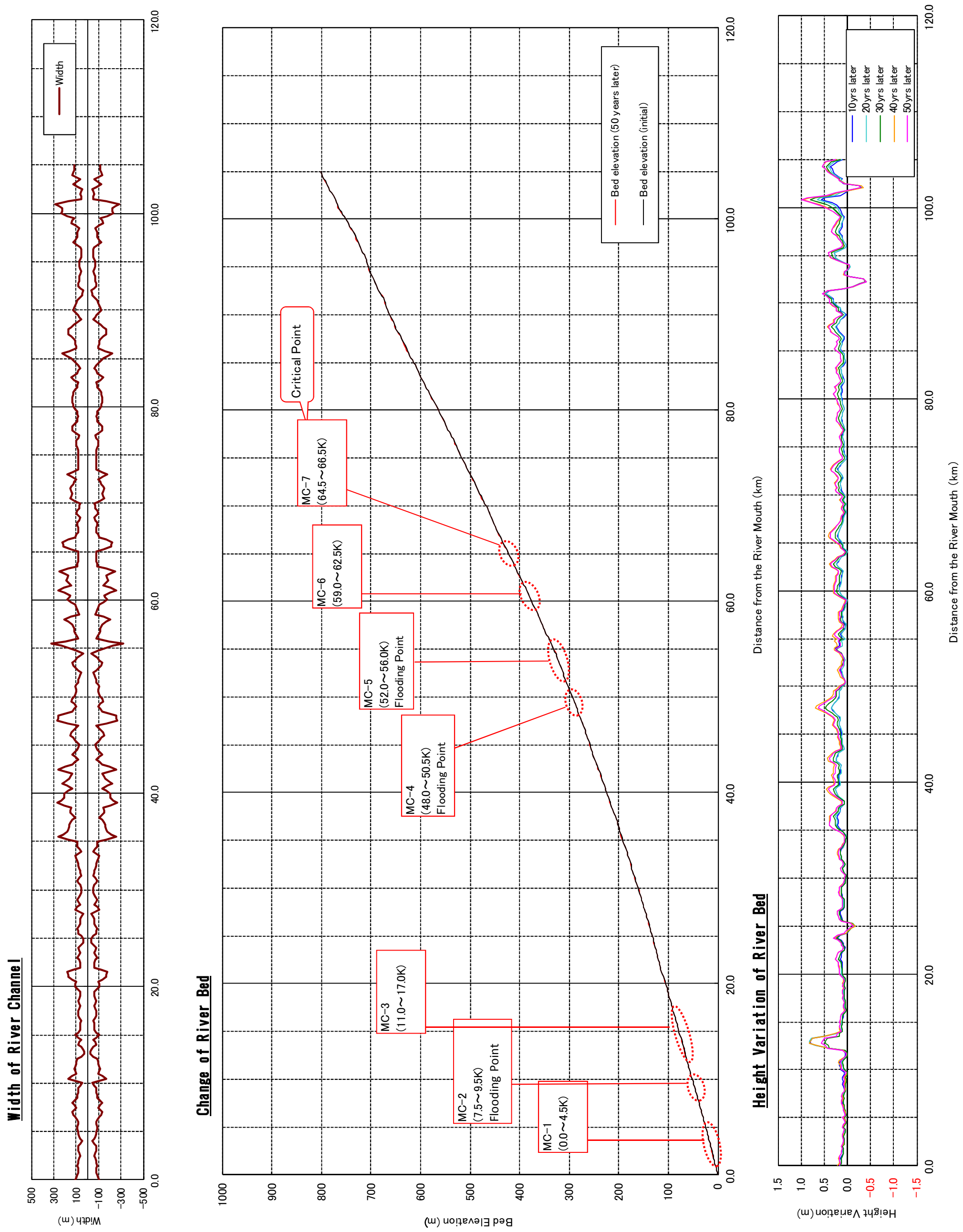


Figure 2.16 **Result of Analysis (Majes-Camana River)**

2.3 Examination on Necessity of Riverbed Maintenance

Based on the results of riverbed fluctuation analysis for the next fifty (50) years for targeted six (6) rivers, the locations requiring for the maintenance are identified.

Table 2.4 **Locations Requiring for the Maintenance (1)**

River		Excavation Section		Maintenance Method
Chira River		Location 1	Object Section: 64.0km-68.0km Object Soil Volume: 2,500,000m^3	Since it is predicted that the sediment will be deposited at the upstream of Sullana Weir, it is concerned the periodical excavation is needed. In case that sediment volume is huge and it is difficult to remove all the sediment, the excavation just upstream of fixed weir shall be focused on.
Canete River		Location 1	Object Section: 3.0km-7.0km Object Soil Volume: 135,000m^3	The periodical excavation shall be conducted since it is the existing inundation area and riverbed will gradually rise.
		Location 2	Object Section: 27.0km-31.0km Object Soil Volume: 287,000m^3	Since the object section is a narrow channel and the sediment cannot sufficiently flow, the risk on riverbed aggradation is high. Therefore, the planned excavation is considered to be required because riverbed will gradually rise and inundation will occur.
Chincha River	(Chico River)	Location 1	Object Section: 3.5km-4.5km Object Soil Volume: 53,000m^3	The periodical excavation shall be conducted since it is the existing inundation area and riverbed will gradually rise.
	(Matagente River)	Location 1	Object Section: 10.5km-13.5km Object Soil Volume: 229,000m^3	At the section, river channel is wide and sediment is deposited easily. Therefore, the planned excavation is considered to be required because riverbed will gradually rise and inundation will occur.
		Location 2	Object Section: 21.0km-23.5km Object Soil Volume: 197,000m^3	
Pisco River		Location 1	Object Section: 18.0km-20.5km Object Soil Volume: 314,000m^3	The periodical excavation shall be conducted since it is the existing inundation area and riverbed will gradually rise.
		Location 2	Object Section: 34.0km-35.0km Object Soil Volume: 255,000m^3	At the section where is just upstream of existing irrigation weir, the sediment is easily deposited due to the unconstrained location. The implementation of periodical excavation at the section will reduce the risk on the riverbed aggradation all the river course.
Yauca River		Location 1	Object Section: 25.5km-26.5km Object Soil Volume: 60,000m^3	The periodical excavation is needed to maintain the function of existing irrigation weir since the object section is just upstream of existing irrigation weir.

* object soil volume means a total sand deposit for fifty (50) years

Table 2.5 **Locations Requiring for the Maintenance (2)**

River	Excavation Section		Maintenance Method
Majes-Camana River	Location 1	Object Section: 12.0km-13.0km Object Soil Volume: 70,000m^3	Since the river channel is comparatively narrow, it is predicted to be possible that remarkable riverbed aggradation will occur even in the small amount of sediment. In consideration of the influence on intake facilities, periodical maintenance excavation every year is desirable.
	Location 2	Object Section: 100.0km-101.0km Object Soil Volume: 460,000m^3	By carrying out maintenance such as excavation in the section, effective control of riverbed aggradation in middle stream is also expectable. It is considered the place where scheduled maintenance shall be carried out from a viewpoint on river improvement.

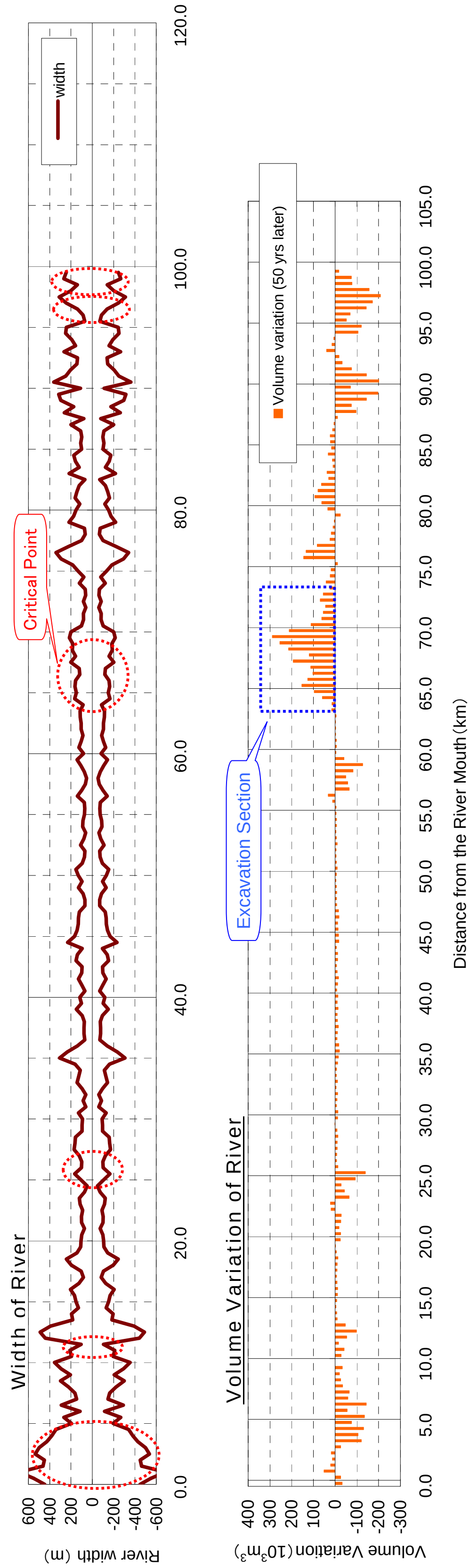


Figure 2.3-1 **Section for Requiring Maintenance (Chira River)**

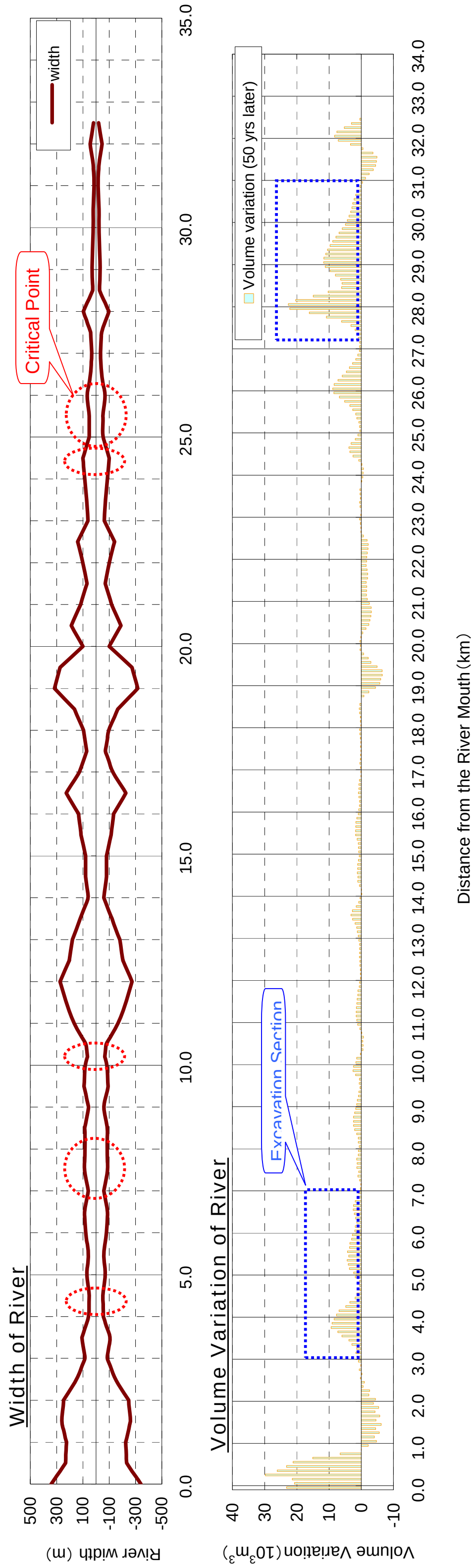


Figure 2.17 **Section for Requiring Maintenance (Canete River)**

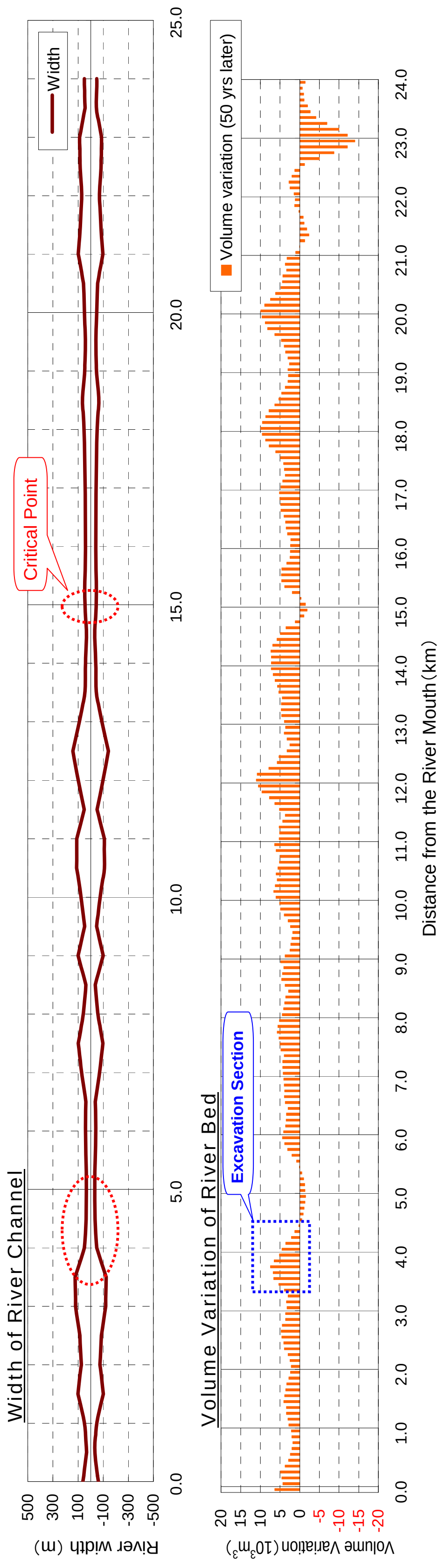


Figure 2.3-3 **Section for Requiring Maintenance (Chincha River (Chico River))**

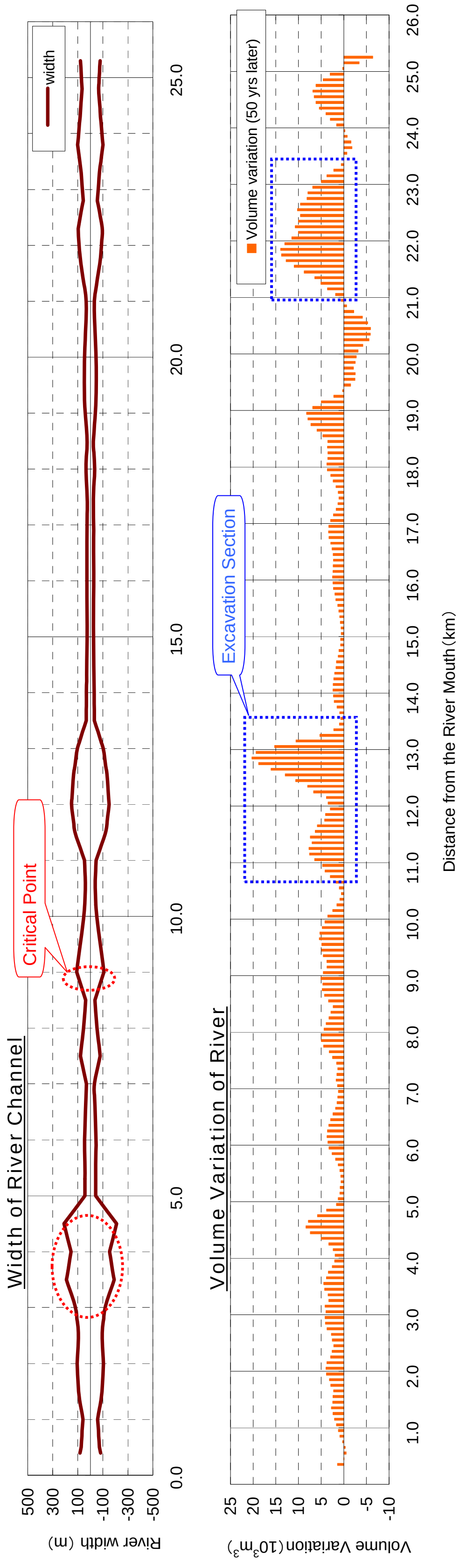


Figure 2.18 **Section for Requiring Maintenance (Chincha River (Matagente River))**

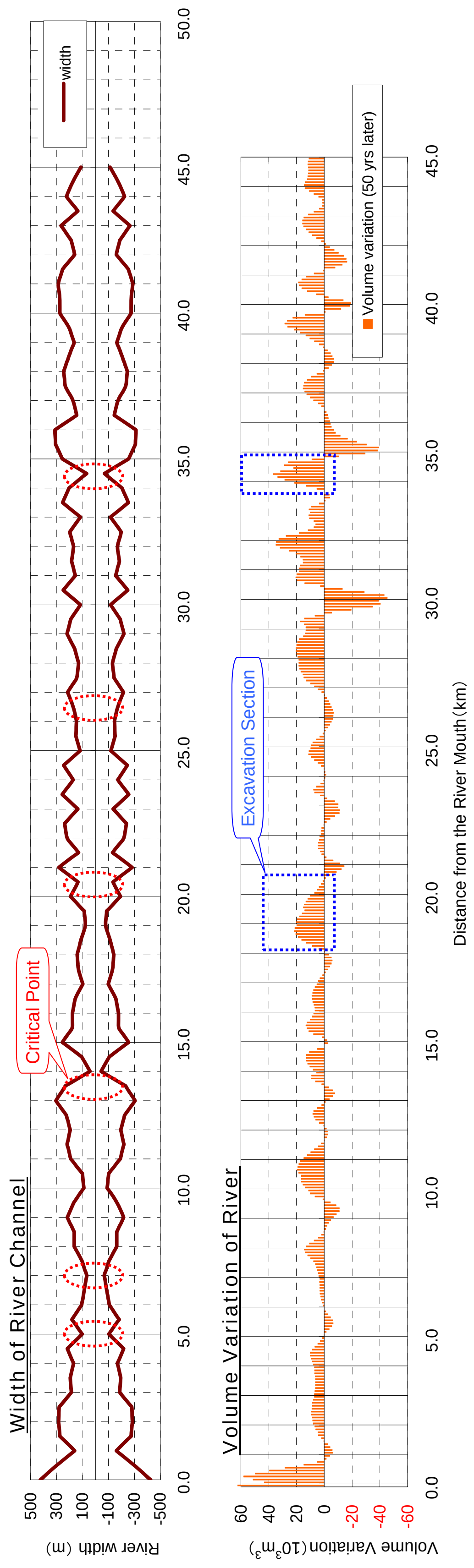


Figure 3.3-5 **Section for Requiring Maintenance (Pisco River)**

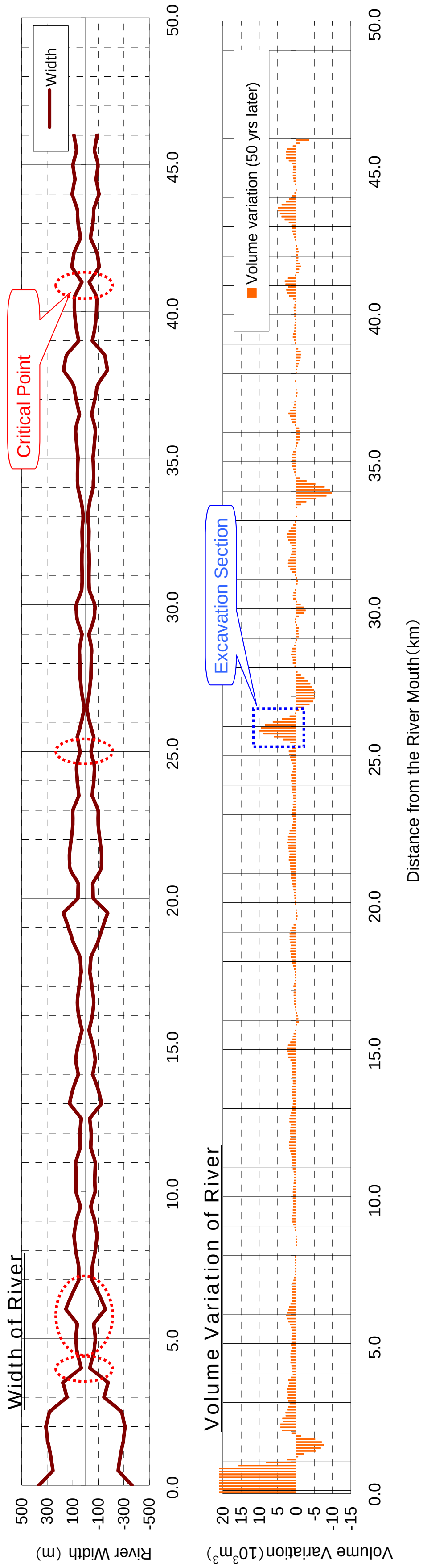


Figure 2.19 **Section for Requiring Maintenance (Yauca River)**

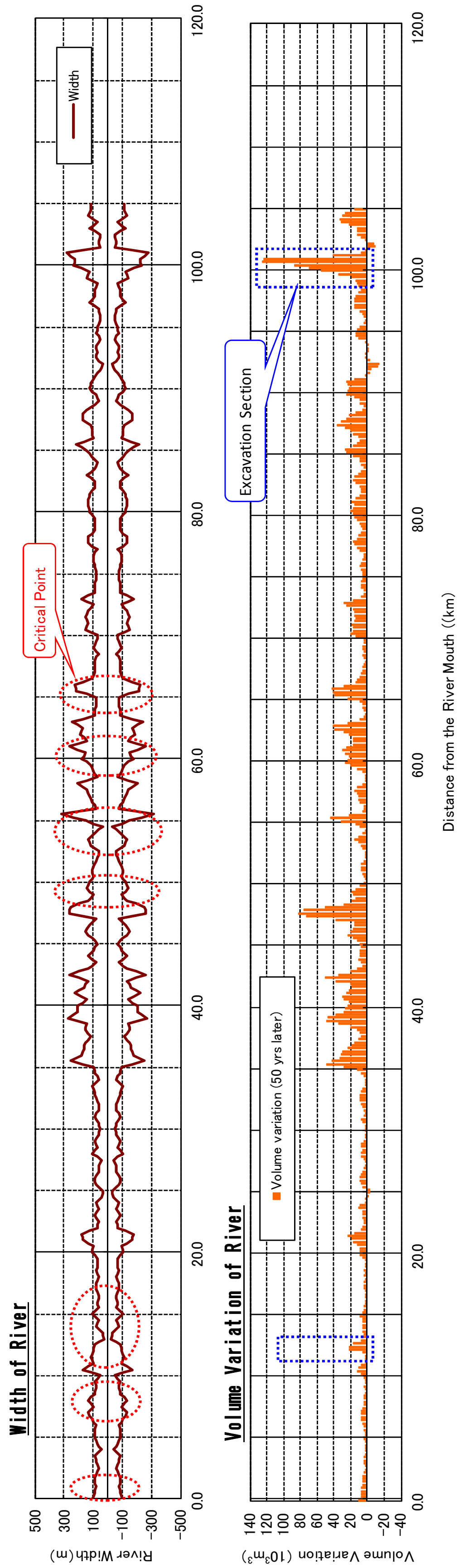


Figure 2.20 **Section for Requiring Maintenance (Majes-Camana River)**

2.4 Examination of Necessity for Countermeasures

Based on the result of analysis on the targeted five (5) rivers, the locations requiring for the countermeasures are identified in accordance with the current sediment deposit conditions as shown in ***Table 2.6***. The current sediment deposit conditions were determined by the average riverbed longitudinal profiles and vertical gradients.

Table 2.6 **Location of Sediment Deposits**

No.	River	Location	Condition	Remarks
1	Chira River	64.0km upstream (upstream of Sullana Weir)	Since the average bed slope at the upstream of Sullana Weir is very gentle, sediment deposit condition is easily identified.	Refer to ***Figure 2.4-1***
2	Canete River	4.0km	Since the average bed slope is gentle compared to that of upstream and downstream, it is assumed that the sediment is deposited.	Refer to ***Figure 2.4-2***
3	Canete River	10.0km	Ditto	Refer to ***Figure 2.4-2***
4	Chincha River (Matagente River)	9.0km	Ditto	Refer to ***Figure 2.4-3***
5	Pisco River	7.5km	Ditto	Refer to ***Figure 2.4-4***
6	Yauca River	4.5km	The average bed slope becomes gentle from the downstream of 5km point. Therefore, it is assumed that the sediment is deposited at the just downstream of 5km point.	Refer to ***Figure 2.4-5***
7	Majes-Camana River	96.0km	Since the average riverbed gradient is gentle as compared with the upstream and the downstream, it is assumed that the sediment is deposited.	Refer to ***Figure 2.4-6***

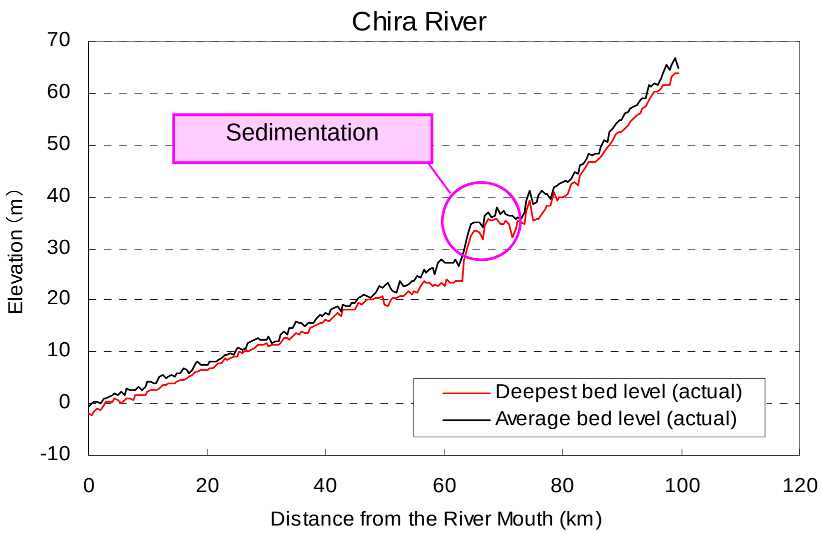


Figure 2.21 **Longitudinal Profile for Average Bed Slope in Chira River**

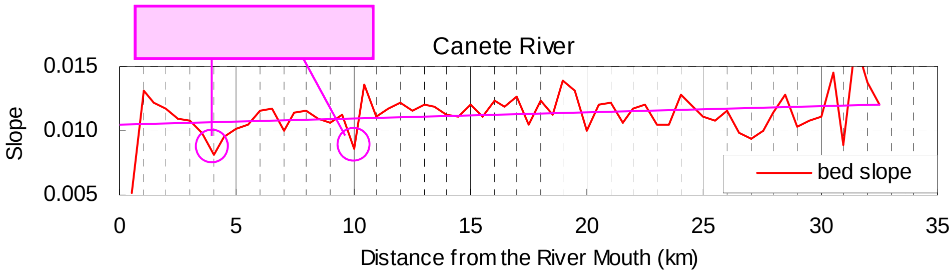


Figure 2.22 **Longitudinal Profile for Average Bed Slope in Canete River**

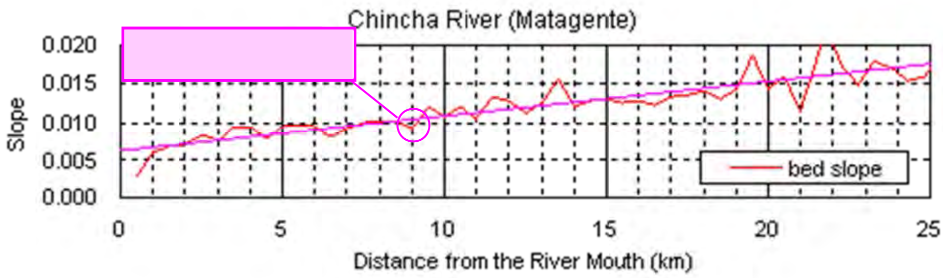


Figure 2.23 **Longitudinal profile for Average Bed Slope in Matagente River**

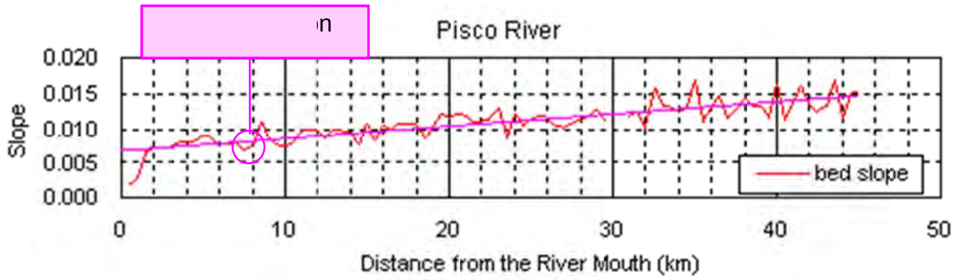


Figure 2.24 **Longitudinal Profile for Average Bed Slope in Pisco River**

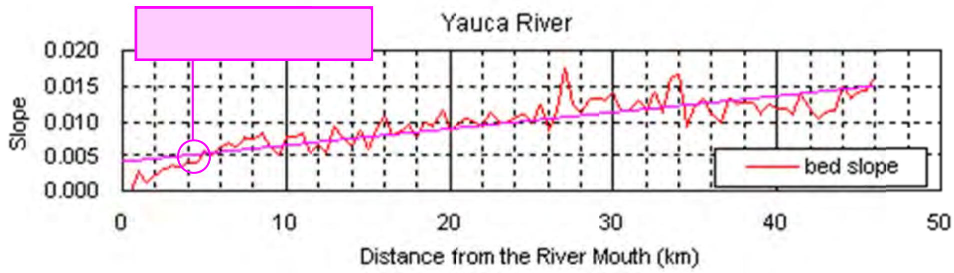


Figure 2.25 **Longitudinal profile for Average Bed Slope in Yauca River**

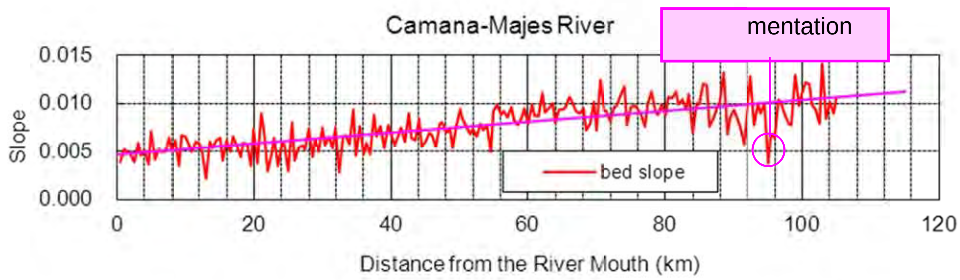


Figure 2.26 **Longitudinal Profile for Average Bed Slope in Majes-Camana River**