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-6 SEDIMENT CONTROL
(TEMPORARY VERSION)

March 2013

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

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COLOMBIA
ECUADOR
BRAZIL
BOLIVIA
CHILE
PERU
SOUTH PASIFIC OCEAN
PIURA
ピウラ州
Chira River
LORETO
Amazon
AMAZONAS
LAMBAYEQUE
CAJAMARCA
SAN MARTIN
LA LIBERTAD
ANCASH
HUANUCO
PASCO
UCAYALI
LIMA
リマ州
JUNIN
MADRE DE DIOS
Canete River
Chincha River
Pisco River
HUANCAVELICA
CUSCO
AYACUCHO
APURIMAC
PUNO
ICA
イカ州
Yauca River
AREQUIPA
アレキパ州
Majes-Camana River
MOQUEGUA
TACNA
Legend

Study Area

ABBREVIATION

Abbreviation	Official Form or Meaning
ANA	Autoridad Nacional del Agua/National Water Authority
ALA	Autoridad Local del Agua/Local Water Authority
B/C	Costo Benefit Ratio/Benefit Cost Ratio
GDP	Gross Domestic Product/Gross Domestic Product
GIS	Geographic Information System/ Geographic Information System
DGAA	Dirección General de Asuntos Ambientales/General Directorate of Environmental Affairs
DGFFS	Dirección General de Forestal y de Fauna Silvestre/Directorate General of Forest and Wildlife
DGIH	Dirección General de Infraestructura Hidráulica/Directorate General for Water Infrastructure
DGPI (Paleo-DGPM)	Dirección General de Política de Inversiones/Directorate General of Investment Policy
DNEP	Dirección Nacional de Endeudamiento Público/National Directorate of Public Debt
DRA	Dirección Regional de Aguricultura/Regional Directorate Aguriculture
EIA	Evaluación de Impacto Ambiental/Environmental Impact Assessment
FAO	Agricultura y la Alimentación Organización de las Naciones Unidas/Food and Agriculture Organization of the United Nations
F/S	Estudio de factibilidad/Feasibility Study
GORE	Gobierno Regional/Regional Government
HEC-HMS	Centros de Ingeniería Hidrológica Sistema de Modelación Hidrológica Método / Hydrologic Engineering Centers Hydrologic Modeling System Method
HEC-RAS	Centros de Ingeniería Hidrológica del Río de Análisis del Sistema Método / Hydrologic Engineering Centers River Analysis System Method
IGN	Instituto Geográfico Nacional/National Geographic Institute
IGV	Impuesto General a Ventas/General Sales Tax
INDECI	Instituto Nacional de Defensa Civil/National Institute of Civil Defense
INEI	Instituto Nacional de Estadística/National Institute of Statistics
INGEMMET	Instituto Nacional Geológico Minero Metalúrgico/National Geological and Mining Metallurgical Institute
INRENA	Instituto Nacional de Recursos Naturales/Natural Resources Institute
IRR	Tasa Interna de Retorno (TIR)/Internal Rate of Return
JICA	Japonés de Cooperación Internacional /Japan International Cooperation Agency
JNUDRP	Junta Nacional de Usuarios de Distritos del Perú/National Board of Peru Districts Users
L/A	Convenio de Préstamo/Loan Agreement
MEF	Ministerio de Economía y Finanzas/Ministry of Economy and Finance
MINAG	Ministerio de Agricultura/Ministry of Agriculture

M/M	Acta de la reunion/Minutes of Meeting
NPV	Valor Actual Neto (VAN)/NET PRESENT VALUE
O&M	Operación y mantenimiento /Operation and maintenance
OGA	Oficina General de Administración/General Office of Administration
ONERRN	Oficina Nacional de Evaluación de Recursos Naturales/National Bureau of Natural Resource Evaluation
OPI (OPP)	Oficina de Programación e Inversiones/Programming and Investment Office (Oficina de Planificación e Prespuesto/Office of Planning and Budget)
PBI	Producto Bruto Interno/Gross Domestic Product
PE	Exp. Proyecto Especial (PE) Chira-Piura/Exp. Special Project Chira-Piura
PES	Pago por Servicos Ambientales (PSA)/Payment for Environmental Services
PERFIL	PERFIL/ PROFILE (Preparatory survey of project before investment)
Pre F/S	Estudio de Prefactibilidad /Pre-Feasibility Study
PERPEC	Programa de Encauzamiento de Ríos y protección de Estructura de Captación
PRONAMACHIS	Programa Nacional de Manejo de Cuencas Hidrográficas y Conservación de Suelos/ National Program of River Basin and Soil Conservation Management
PSI	Programa de Sub Sectorial de Irrigaciones/Program of Sub Irrigation Sector
SCF	Factor de conversión estándar/Standard conversion factor
SENAMHI	Servicio Nacional de Meteorología y Hidrología/National Service of Meteorology and Hydrology
SNIP	Sistema Nacional de Inversión Pública/National Public Investment System
UF	Unidad formuladora/Formulator unit
VALLE	Valle/Valley
VAT	Impuesto al valor agregado/Value-added tax

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-6

Sediment Control
(Temporary Version)

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CHAPTER 1 SEDIMENT PRODUCTION IN THE BASINS OF THE STUDY AREA

1.1 Data Collection and Processing

(1) Organization of Collection Material

In order to evaluate the production of sediments in the basins of the project area were collected the materials as below.

Table 1.1 **List of Collected Data**

Collected information	Year	Format	Copyright organization
Topography（S=1/50,000）	2003	Shp	INSTITUTO GEOGRAFICO NACIONAL（IGN）
Geological map（S=1/10,0000）	2007	Shock Wave	Instituto Geológico Minero y Metalúrgico (INGEMMET)
Universal Traverse Mercator grid	2008	GEO TIFF	Nacional eronautics and Space Administration (NASA)
River data	2008	SHP	IGN
Basin data	2010	SHP	Autoridad Nacional del Agua (ANA)
Isohyetal line map	1965-74	PDF	ANA
Erosion map	1996	SHP	Instituto Nacional de Recursos Naturales (INRENA)
Soil map	1996	SHP	INRENA
Vegetation map	2,000 1995	SHP: Year 2000 PDF: Year 1995	Dirección General de Flora y Fauna Silvestre (DGFFS)
Rainfall data		Text	Servicio Nacional de Metereología e Hidrología del Perú (SENAMHI)
Population distribution map	2007	SHP	Instituto Nacional de Estadística e Informática (INEI)

Source:Jica Study Team

(2) Preparation of data for evaluation

The following data were made from the data collected. These data are included in the appendix.

- Hydrological map
- Map of watersheds (watersheds zoning by third-order)
- Geological and hydrographic map
- Map of erosion and hydrographic map
- Zoning map of vegetation – year 2,000
- Zoning map of vegetation - year 1995
- Geological map and bed slope
- Hydrological zoning map and bed slope
- Zoning map of soil and hydrological map
- Precipitation curve
- Population classification map

1.2 Watershed Characteristics

Watershed characteristics of the study basins is described below. Chira basin has been classified into upstream and downstream at the basic point of the Poechos dam

(1) Altitude

The altitude distribution of each basin is as shown in ***Table 1.2*** and ***Figure 1.1***. Cañete basin has a higher percentage of altitudes above 4,000 m. The altitudes above 4,000 m have a smooth rugged topography with many Snow Mountains and lakes. Cañete basin has large areas in these conditions and has more water sources and therefore greater volume of water flow, compared to other basins. Chira basin has the highest percentage of areas between 0 to 1,000m.

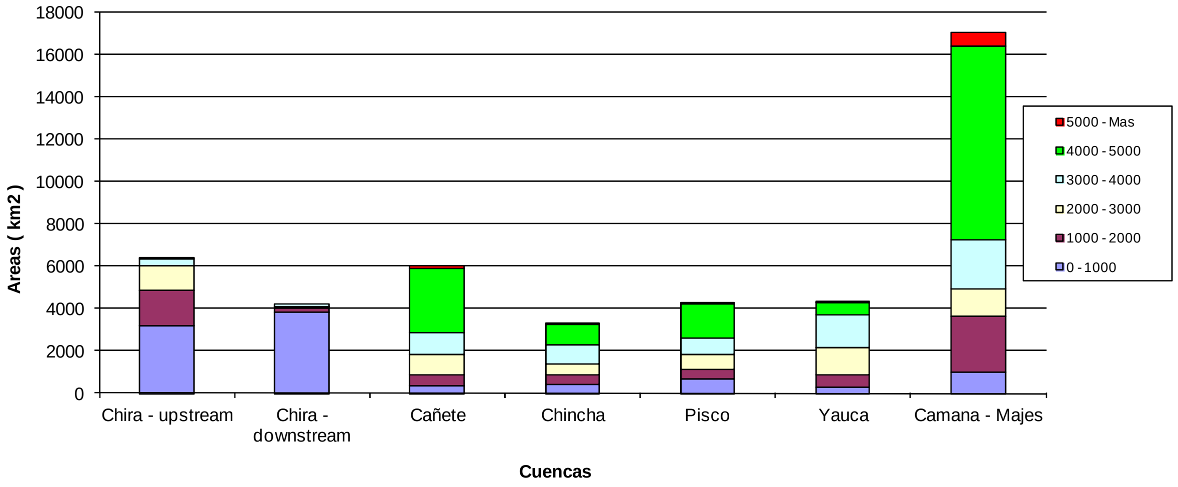


Figure 1.1 **Characteristics of each Watershed Elevation**

Source：Jica Study Team, based on NASA

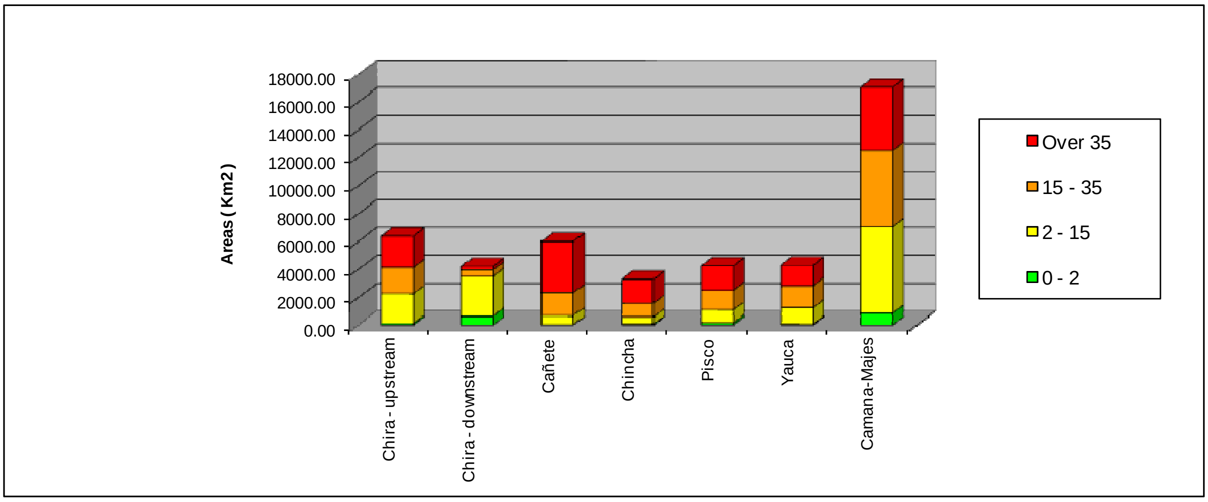
Table 1.2 **Characteristics of the Altitude of each Basin**

Altitude (m)	Area (Km^2)						
	Chira up stream	Chira downstream	Cañete	Chincha	Pisco	Yauca	Camana Majes
0 - 1,000	3262.43	3861.54	381.95	435.6	694.58	332.79	1040.56
1,000 - 2,000	1629.48	207.62	478.2	431.33	476.7	575.82	2618.77
2,000 - 3,000	1153.61	43.24	1015.44	534.28	684.78	1302.58	1277.54
3,000 - 4,000	313.74	156.11	1012.58	882.39	760.47	1504.8	2305.64
4,000 - 5,000	0.22	0.00	3026.85	1019.62	1647.8	602	9171.56
5,000 - more	0.00	0.00	108.95	0.67	6.19	0.55	635.44
TOTAL	6359.48	4268.51	6023.97	3303.89	4270.52	4318.54	17049.51
Max Altitude	4110.00		5355.00	5005.00	5110.00	5060.00	5821.00

Source：Jica Study Team, based on NASA

(2) Classification of Slope Gradient

Slope gradient map were made for each basin. ***Table 1.3*** and ***Figure 1.2*** show the percentage of slopes in each basin. This shows that the topography is more pronounced in the basins of Cañete, Chincha, Pisco, Yauca and Chira, in that order. Over 50% of total area with slopes greater than 35 ° are located in the basins of Cañete and Chincha. The stronger the mountain slopes, more is the occurrence of sediment disaster commonly, so we can estimate that the debris flow occur more often in that order mentioned above.



Source：JICA Study Team, based on NASA

Figure 1.2 **Percentage of Classification of Earrings in each Basin**

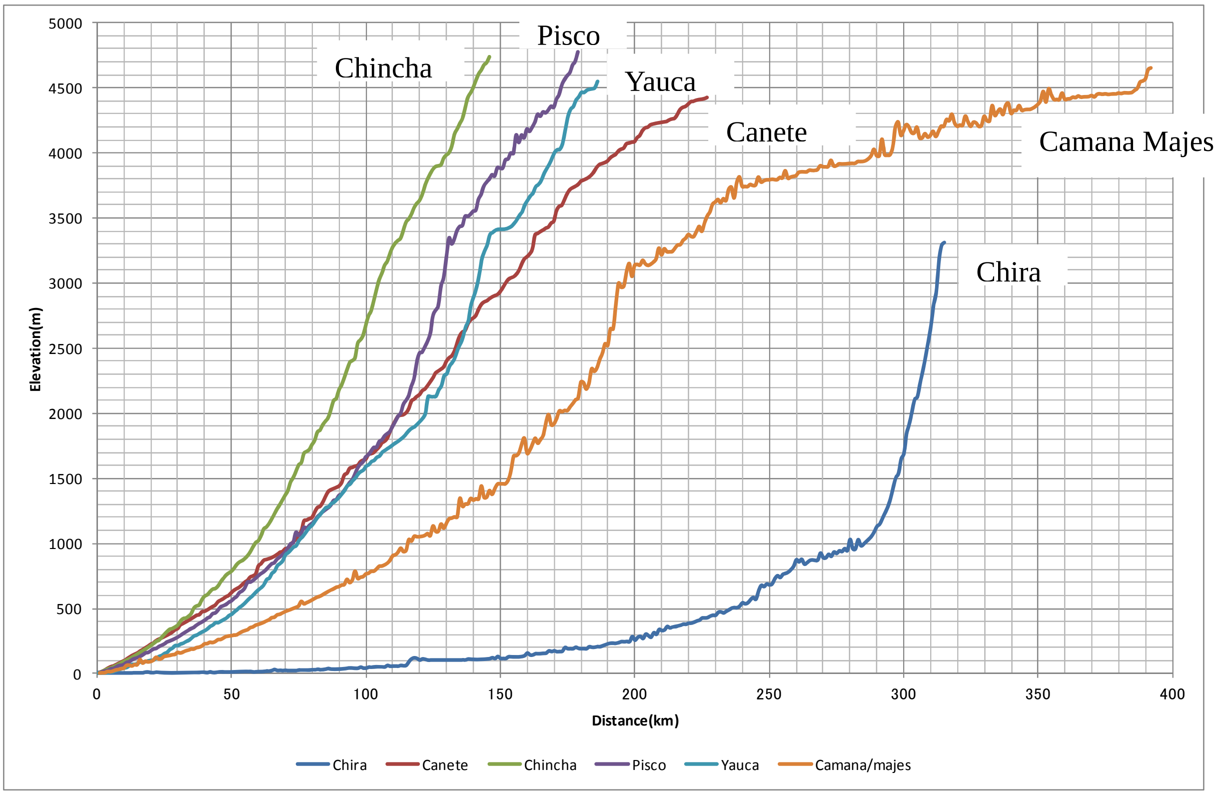
Table 1.3 **Percentage of Pending Classification Areas in each Basin**

Slope Basin	Chira upstream		Chira down stream		Cañete		Chincha	
(%)	Area(km2)	percentage	Area(km2)	Area(km2)	Area(km2)	percentage	Area(km2)	percentage
0 - 2	131.62	2%	651.28	90.62	36.37	1%	90.62	3%
2 - 15	2167.69	34%	2859.35	499.68	650.53	11%	499.68	15%
15 - 35	1852.79	29%	465.86	1019.77	1689.81	28%	1019.77	31%
Over 35	2237.64	35%	261.76	1693.82	3647.26	61%	1693.82	51%
TOTAL	6389.74	100%	4238.25	3303.89	6023.97	100%	3303.89	100%
Slope Basin	Pisco		Yauca		Camana Majes			
(%)	Area(km2)	percentage	Area(km2)	percentage	Area(km2)	percentage		
0 - 2	168.57	4%	79.01	2%	869.75	5%		
2 - 15	947.86	22%	1190.19	28%	6210.54	36%		
15 - 35	1426.18	33%	1591.21	37%	5452.97	32%		
Over 35	1727.91	40%	1458.13	34%	4516.25	26%		
TOTAL	4270.52	100%	4318.54	100%	17049.51	100%		

Source：JICA Study Team, based on NASA data

(3) River Profile

The river Profile of each river is as shown in ***Figure 1.3***. The river profiles of Canete, Chincha, Pisco and Yauca river analogize. The river profile of Camana-Majes river from the outlet to 200km is steep. And this river from 200km to 400km is gentleness. The river profile of Chira river from outlet to 300km is gentleness, The river profile of the upper stream from 300km is steep.



Source：JICA Study Team, based on NASA data

Figure 1.3 **River Profile in each River**

(4) Bed slope

As shown in ***Figure 1.5***, the streams can be classified into traction area and debris flow area, according to the slope of the bed. The distribution of the slope is shown in ***Figure 1.4*** and ***Table 1.4***. In general, debris flow area are found in streams with slopes greater than 1/3 and this is the longest in the basin of Cañete. The area corresponding to the sediment areas has higher percentages on slopes 1/30-1/ 6 in all basin. This indicates that in all basins sediment regulation of riverbeds is high.

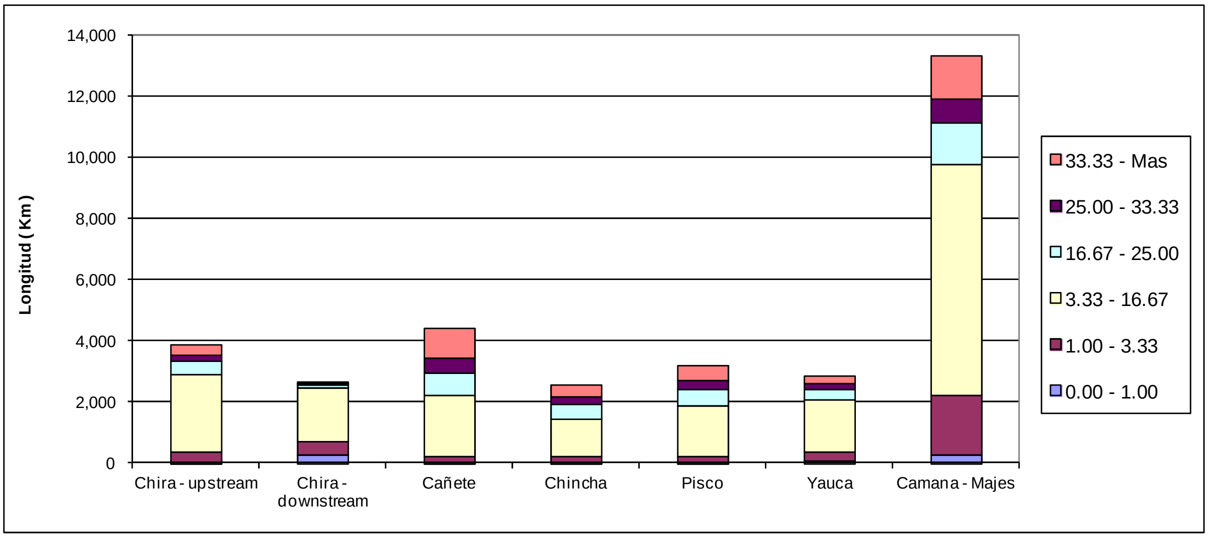


Figure 1.4 **Riverbed Slope of each Watershed**

Source：JICA Study Team, based on NASA data

Table 1.4 **River bed Slope in each Basin**

Slope River (%)	Chira upstream	Chira downstream	Cañete	Chincha	Pisco	Yauca	Camana majes
0.00 - 1.00	6.00	233.34	12.82	5.08	12.15	39.13	263.45
1.00 - 3.33	345.77	471.67	173.88	177.78	165.05	312.82	1953.19
3.33 - 16.67	2534.14	1751.16	1998.6	1250.82	1683.15	1687.19	7511.73
16.67 - 25.00	435.46	97.84	753.89	458.76	519.64	352.42	1383.17
25.00 - 33.33	201.72	37.51	467.78	255.98	291.84	185.78	761.15
33.33 - More	318.46	42.72	975.48	371.8	511.76	226.92	1425.65
TOTAL	3841.55	2634.24	4382.45	2520.22	3183.59	2804.26	13298.34

Source：JICA Study Team, based on NASA

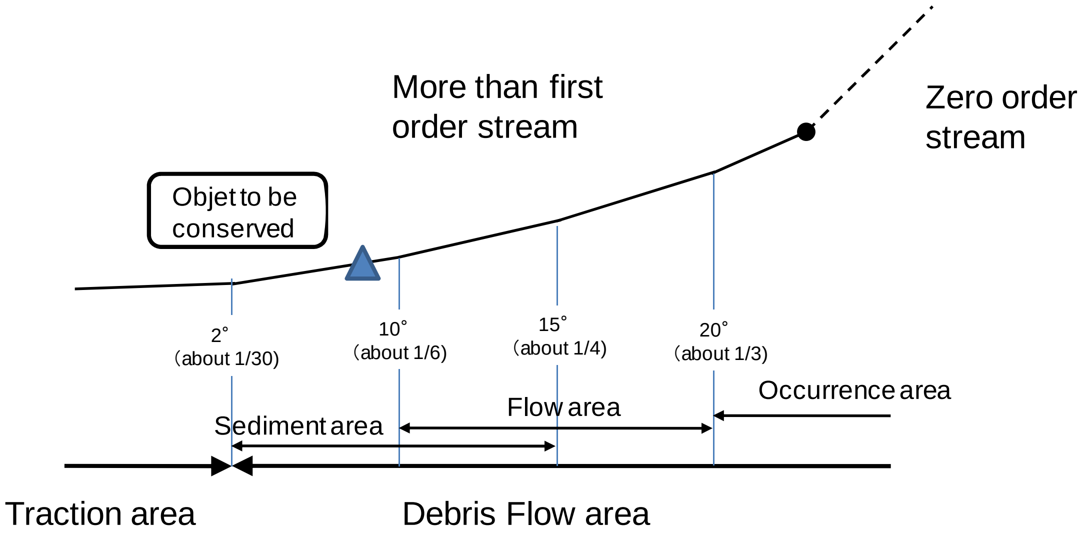


Figure 1.5 **Classification of basins according to the slope bed**

Source：JICA study team

(5) Vegetation

(a) Cuencas de Cañete, Chincha, Pisco y Yauca

The latest vegetation study in Peru was carried out by FAO mainly with cooperation of INRENA (Department of Natural Resources, Ministry of Agriculture) in 2005. This study used the data of "vegetation maps 1995" and the description of the maps, which was carried out in 1995 by INRENA and the General Department of Forest. The National Institution of Planning (Instituto Nacional de Planificacion) and the National Office of Natural Resource Evaluation (ONERN : Oficina Nacional de Evaluacion de Recursos Naturales) prepared "the list of the evaluation and rational use of the natural resources in the coastal area in Peru" which describes the characteristics of the natural condition and vegetation in the coastal area in Peru. In accordance with the vegetation maps in 1995, the river basins of Canete, Chincha, Pisco and Yauca cover whole areas from the coastal line until the Andes highland. The vegetation distribution is characterized by the elevation (please refer to T*able 1.5*). It can be said as below. i) the vegetation is very poor in the area between the coastal line to about 2,500m above sea level (Cu, Dc in the maps). There is only the cactus and grasses in this area and they are major vegetations in this area. Some scattered shrubs can be found in the high elevation area. ii) the shrub forests can be found in the area between 2,500m to 3,500m, where the rainfall is enough much for the vegetation. iii) the grasses becomes major in the area where higher than 3,500m above the sea level, because the temperature is too low for the vegetation in the area. In four (4) river basins, the size of the trees is about 4m in maximum even in the shrub forests. Exceptionally, the tree species along the rivers can grow up toll.

***Table 1.5* List of the typical vegetation in the watersheds of Cañete, Chincha,Pisco and Yauca**

Symbol	Name of Zone	Elevation	Annual Rainfall	Major Vegetation
1)Cu	Agriculture lands in the coastal area	Coastal area	Almost zero	Agricultural lands in the coastal area
2)Dc	Desarts inthe coastal area	0 - 1,500m	Almost zero. There are some places with fog.	There are almost no vegetation, juts small areas covered with grasses can be found in the fog areas.
3)Ms	Dry-grass/shrub area	1,500 - 3,900m	120 - 220m	Cactus and grasses
4)Msh	Semi-humidgrass/ shrub area	In North & central area: 2,900 - 3,500m In Andes highland: 2,000 - 3,700m	220 - 1,000m	Evergreen & Low trees which are not toller than 4m.
5)Mh	Humid grass/shrub area	Northern area: 2,500 - 3,400m Southern area: 3,000 - 3,900m	500 - 2,000m	Evergreen trees, height is lower than 4m
6)Cp	Grass lands in Andes highland	Around 3,800m	(no description)	Poaceous grasses
7)Pj	Grass land	3,200 - 3,300m Central-southern area: up to 3,800m	In Southern rainless area: lower than 125m Eastern Slopes: more than 4,000m	Poaceous grasses
8)N	Snowpacked mountain	-	-	-

Source: JICA Study Team based on the vegetation maps in 1995 (INRENA)

(b) Chira River Basin

In accordance with the vegetation maps and the description in 1995, the xerophile forest is major in this zone as different with the other four river basins. There are three types of xerophile forest as, i) savanna xerophile (Bas a), ii) terrace xerophile forest (Bs co), and iii) mountainous xerophile forest (Bs mo). These forest types have characteristics by the elevation (Refer to ***Table 1.6***). The major plant species in this zone is Algarrobo (Prospis pallida). Toll trees and shrubs are mixed in Algarrobo forest. The tree species in the terrace xerophile forest and the mountainous xerophile forest is almost same; deciduous tree species. And the height of the trees is about 12m. There are some evergreen trees with more than 10cm diameters along the rivers, because the groundwater level there is high. It is difficult to recover the vegetation naturally in the xerophile forests in case of being destroyed once. The vegetation of the mountainous humid forest type has rich in plant species and the height of the most of trees is less than 10m.

Table 1.6 **List of Major Vegetation in Chira River Basin**

Symbol	Name of Zone	Elevation	Annual Rainfall	Major Vegetation
1)Bs sa	Savanna xerophile forest	0 to 500m	160 to 240mm	Algarrobo forest (evergreen tree forest) . Deciduous trees & shrubs/grasses can be found in high elevation areas.
2)Bs co	Terrace xerophile forest	400 to 700m	230 to 1,000mm	Almost same situation as mountainous xerophile forest
3)Bs mo	Montainus xerophile forest	500 to 1,200m	230 to 1,000m	Evergreen tree is major. The average height of high layer trees in the forest is about 12m.
4)Bh mo	Mountainoushu mid forest	Up to 3,200m (in the areas of Amazon highland to the Northern areas in Peru) Up to 3,800m (in the central southern areas in Peru)	Fogs are common in this zone, there are some mist forests.	The high layer tree measure about 10m in height, palm trees measure 2 to 4m. There are grasses too, and the vegetation is rich in this type.
In addition to above, as described fore, there are the desert area (Dc and Cu), semi-humid shrub forest (Msh), and humid shrub forest (Mh) in this river basin.				

Source: JICA Study Team based on the vegetation maps in 1995 (INRENA)

(6) Geology

Table 1.7 shows geology are organized according to examples of sediment disaster that occur in Japan. This makes it clear that these are more disaster-prone in areas with volcanic rocks, andesitic and basaltic land and tertiary lulita. These geological formations are deposited in all basins object widely, it is clear that the geological conditions tend to take place sediment disaster. the characteristic of each basin are described below.

Table 1.7 **List of Geological conditions frequently suffered from debris flow**

Site of occurrence		Geology
Hokkaido	Mt Usu (Ousu river)	Hokkaido
	Nishiyama River、shousu River)	
Iwate pref	Mt.iwaki （Kuasuke River）	Iwate pref
Ibaragi pref	Mt.Akanag（Arasawa,Inari River）	Ibaragi pref
Niigata Pref	Hiramaru	Niigata Pref
	Mt. shishino	
Nagano pref	Mt. yakedake (Joujouhiri River）	Nagano pref
	(Nigori River）	
Gifu pref	Gifu pref	Gifu pref
Hyogo pref	Shodoshima	Hyogo pref
Kumamoto pref	Amakusa	Kumamoto pref
Kagoshima pref	Sakurajima（Nojiri River）	Kagoshima pref

Source: JICA Study Team

(a) Chira basin

Downstream of Poechos dam are alluvial deposits. The east upstream area of Poechos Dam are volcanic rocks and Cretaceous volcanic rocks correspond to 32% of the catchment area in Peru. In this basin are basaltic rocks and diorites, which represent 18% of the catchment area on the Peruvian side. The slopes in these areas are quite steep, above 35 degrees. In the west side are Cretaceous sedimentary rocks.

(b) Cañete Basin

Alluvial formation are deposited in the study area. At a distance from the outlet to 15-30km are granodiorites. From 1,000m to 2,000m are diorites and between 2,000 and 4,000 m are granodiorite and sedimentary rocks. The upper level from 4,000m are Mesozoic and Cenozoic sedimentary rocks. The slopes of the high are gentler , in this area there are the 447 natural lakes. Much of these lakes were formed by erosion and melting glacial sedimentation, but some of them were shaped by the landslide.

(c) Chincha Basin

Alluvial formation are deposited up to 1,000m. Between 1,000 and 3,000 m of altitude are granites and granodiorites. From 3,000m to 4,000m are granodiorites and Mesozoic sedimentary rocks. The upper level from 4,000m are Mesozoic and Cenozoic sedimentary rocks

(d) Pisco Basin

Alluvial formation are deposited up to 1,000m. Between 1,000 and 3,000m of altitude are granites and granodiorites. From 3,000 m to 4,000m are Mesozoic sedimentary rocks. The upper level from 4,000m are Cenozoic sedimentary rocks.

(e) Yauca Basin

Alluvial formation are deposited up to 1,000m. Between 1,000 and 3,000m of altitude are granites and granodiorites. From 3,000 m to 4,000m are Mesozoic sedimentary rocks. The upper level from the 4,000m are basaltic rocks.

(f) Camana-majes Basin

Alluvial formation are deposited up to 1,000m. Between 1,000 and 4,000 m of altitude are Mesozoic sediment, granites and granodiorites. The upper level from 4,000 m are Jurassic sedimentary rocks. There are The Colca Valley that is one of the deepest valley in the world Between 1,000m and 4,000m.

(7) Precipitation

Isohyetal maps were produced by rainfall data for the period from 1965 to 1974 collected by the SENAMHI produced isohyetal maps for each basin (refer to ***Figure 1.6*** to ***Figure1.11***). Below are the characteristics of rainfall in each basin.

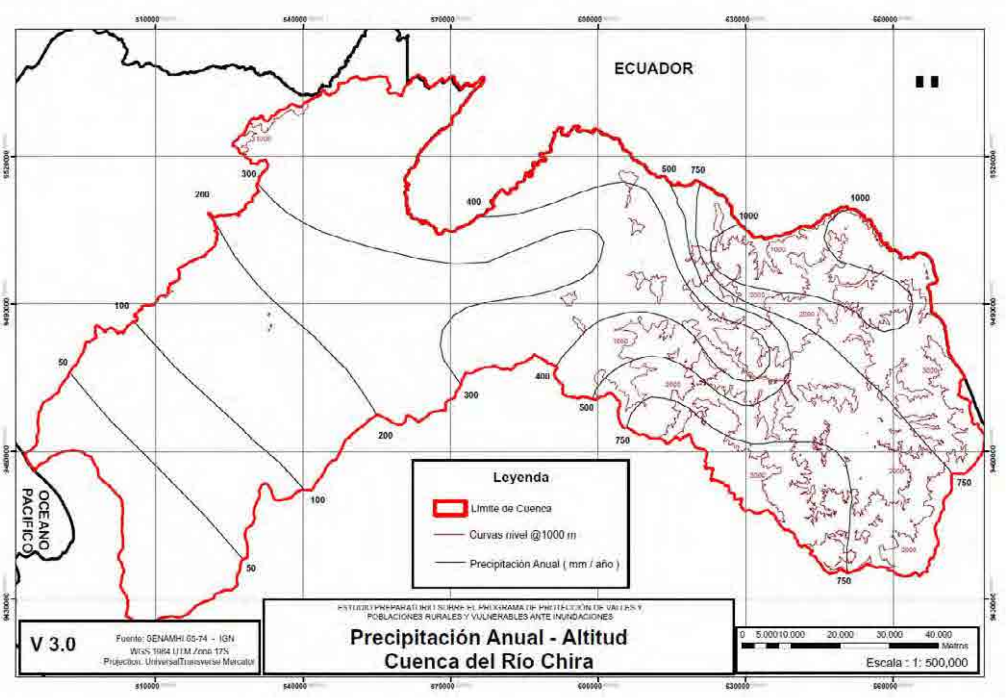


Figure 1.6 **Isohyetal Map (Chira Basin)**

Source：JICA Study Team, based on SENAMHI data

The annual rainfall in study areas is 0-200mm. The annual rainfall in the east area with above 2,000 m altitudes is 750-1,000 mm.

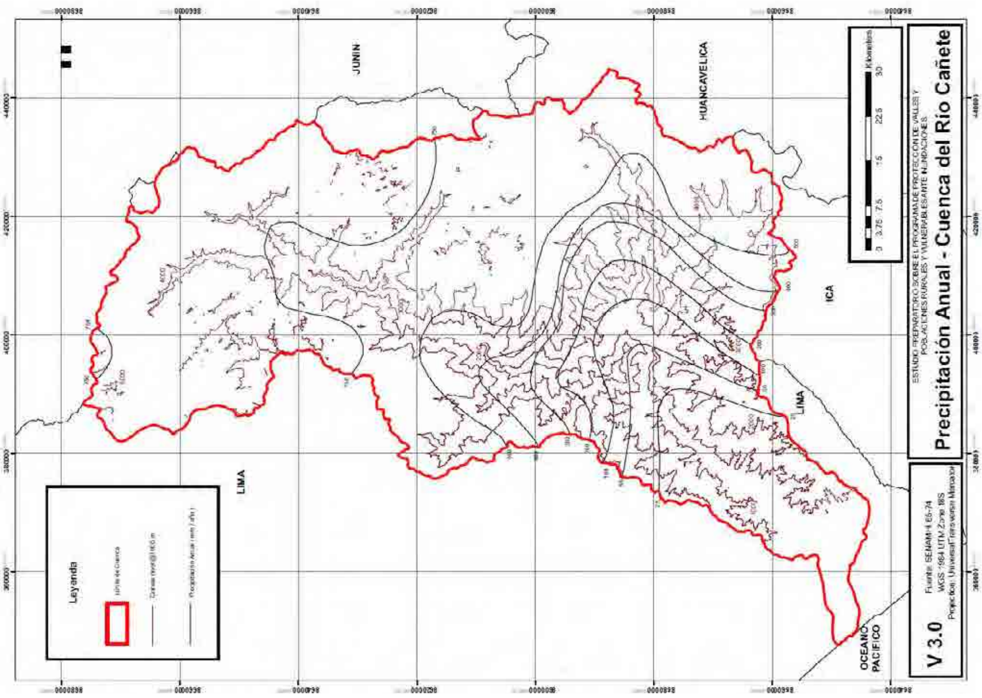


Figure 1.7 **Isohyetal Map (Cañete Basin)**

Source：JICA Study Team, based on SENAMHI data

The annual rainfall in study areas is 0-25mm. The annual rainfall in the north area with 4,000 m altitudes is 750-1,000 mm.

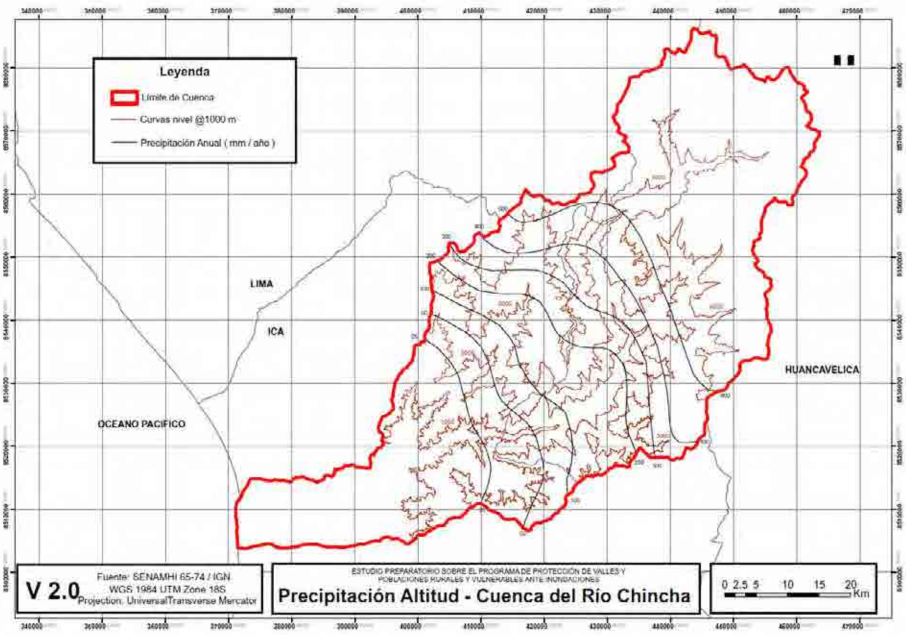


Figure 1.8 **Isohyetal Map (Chincha Basin)**

Source：JICA Study Team, based on SENAMHI data

The annual rainfall in study areas is 0-25mm. The annual rainfall in the east area with 4,000 m altitudes is 500-750mm.

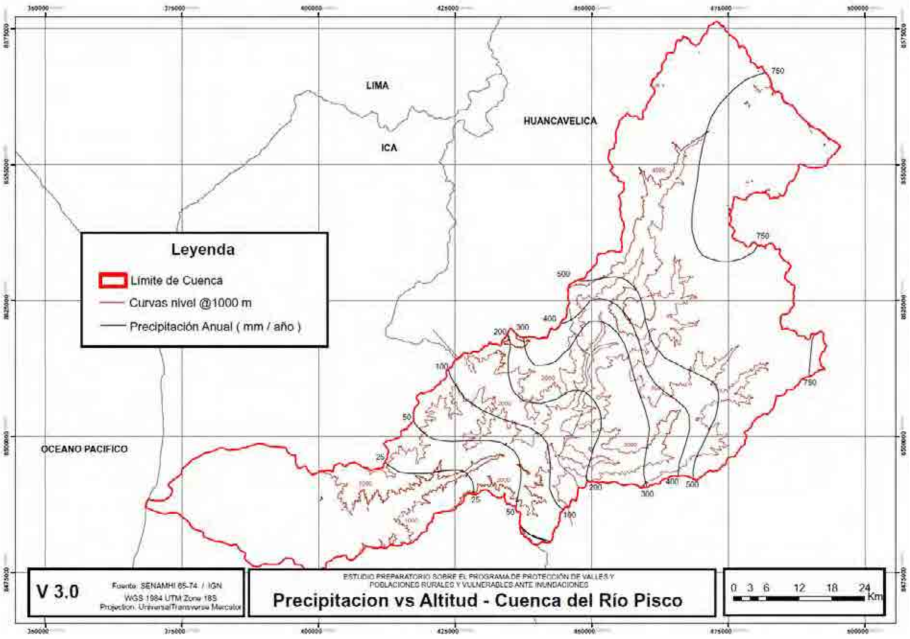
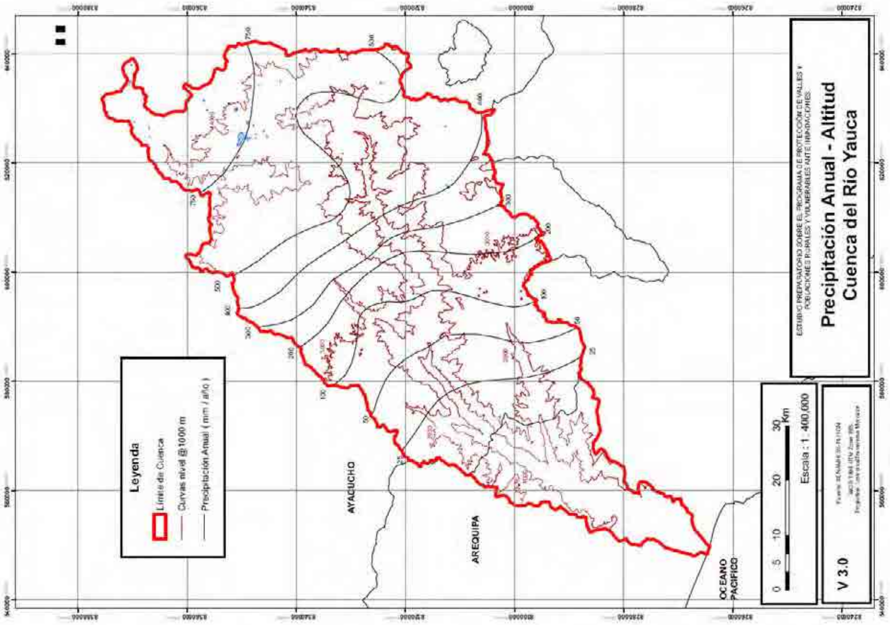


Figure 1.9 **Isohyetal Map (Pisco Basin)**

Source：JICA Study Team, based on SENAMHI data

The annual rainfall in study areas is 0-25mm. The annual rainfall in the east area with 4,000 m altitudes is 500-750mm.



Source：JICA Study Team, based on SENAMHI data

Figure 1.10 **Isohyetal Map (Yauca Basin)**

The annual rainfall in study areas is 0-25mm. The annual rainfall in the north area with altitudes between 3,000-4,000 m is 500-750mm.

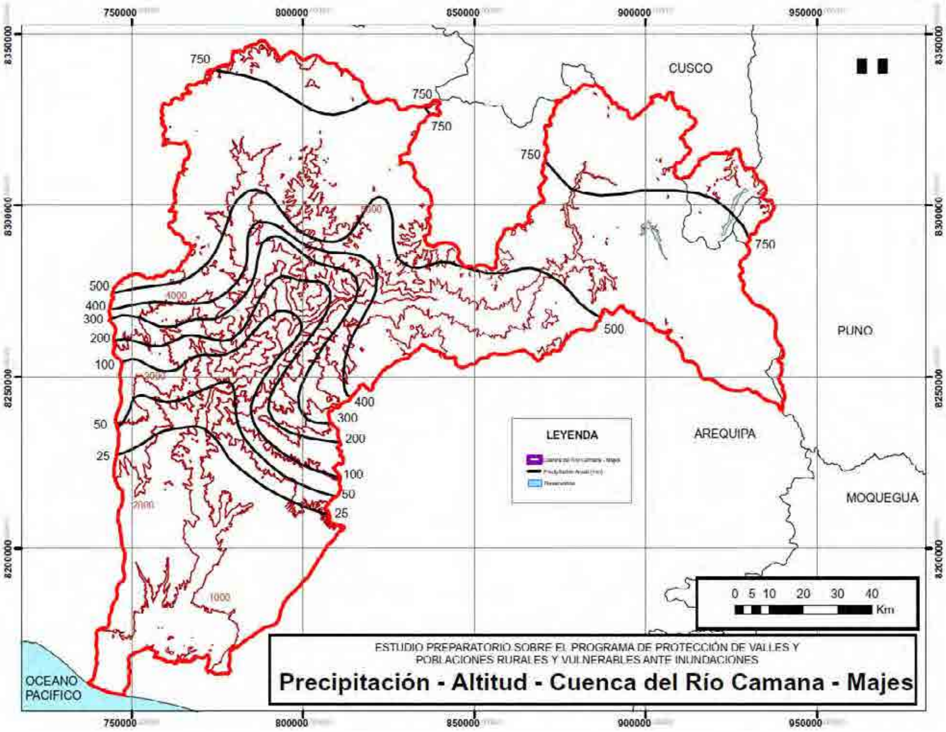


Figure 1.11 **Isohyetal Map (Camana-majes Basin)**

The annual rainfall in study areas is 0-50 mm. The annual rainfall in the southeast area with 3,000-4,000 m altitudes is 500-750mm.

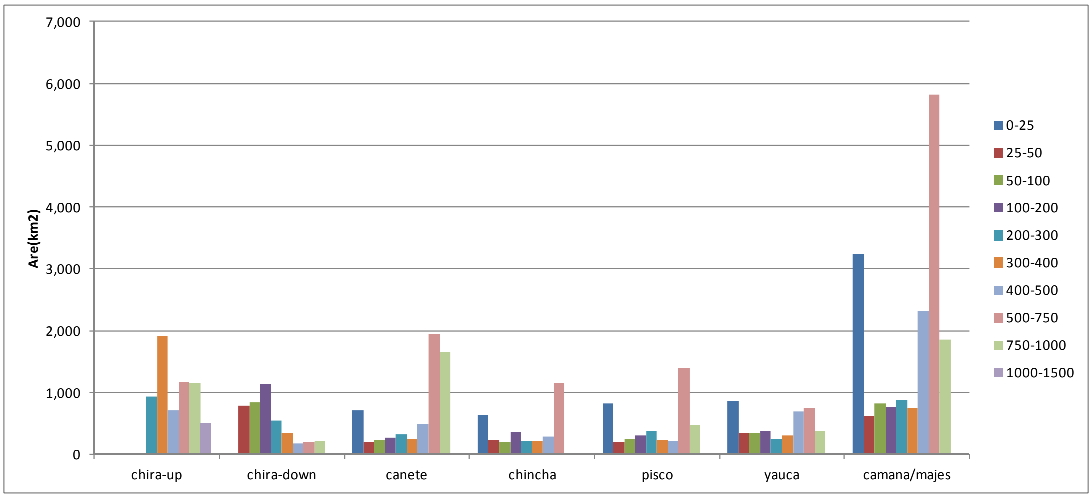
Calculated the area between the spaces of the distribution curves the distribution map of curves. (Refer to ***Table 1.8*** and ***Figure 1.12***).

- In the upper basin of Chira, there are many areas with 300-400mm, representing 30% of the total. There are some areas with rainfall ranging from 1,000 to 1.500 mm.
- In the lower basin of Chira, many of the areas have 0-200mm annual rainfall, with a comparatively low volume of rainfall.
- In Cañete there are many areas with 500 to 1,000 mm and these areas account for half of the total basin.
- In Chincha , Pisco and Camana-Majes basin, there are many areas with 500mm-750mm rainfall, these areas account for about 30% of the each total basin.
- In Yauca, compared to other basins ,a rainfall volume is very low, and 0-25mm areas account for 20% of the total basin.

Table 1.8 **Areas of Annual Rainfall Volume in each Basin**

Precipitation	Chira upper stream		Chira down stream		Cañete		Chincha		Pisco		Yauca		Camana Majes	
0-25		0%		0%	703	12%	643	19%	829	19%	865	20%	3,243	19%
25-50		0%	789	19%	198	3%	226	7%	191	4%	338	8%	624	4%
50-100		0%	847	20%	237	4%	202	6%	257	6%	349	8%	823	5%
100-200		0%	1,127	27%	263	4%	353	11%	307	7%	379	9%	762	4%
200-300	936	15%	551	13%	318	5%	211	6%	377	9%	247	6%	869	5%
300-400	1,909	30%	340	8%	252	4%	220	7%	231	5%	314	7%	746	4%
400-500	713	11%	172	4%	495	8%	296	9%	211	5%	701	16%	2,313	14%
500-750	1,167	18%	200	5%	1,955	32%	1,153	35%	1,390	33%	754	17%	5,816	34%
750-1,000	1,162	18%	213	5%	1,645	27%		0%	479	11%	375	9%	1,849	11%
1,000-1500	502	8%		0%		0%		0%		0%		0%		0%
total	6,390	100%	4,238	100%	6,066	100%	3,304	100%	4,272	19%	4,323	100%	17,049	100%

Source：Jica Study Team, based on SENAMHI data

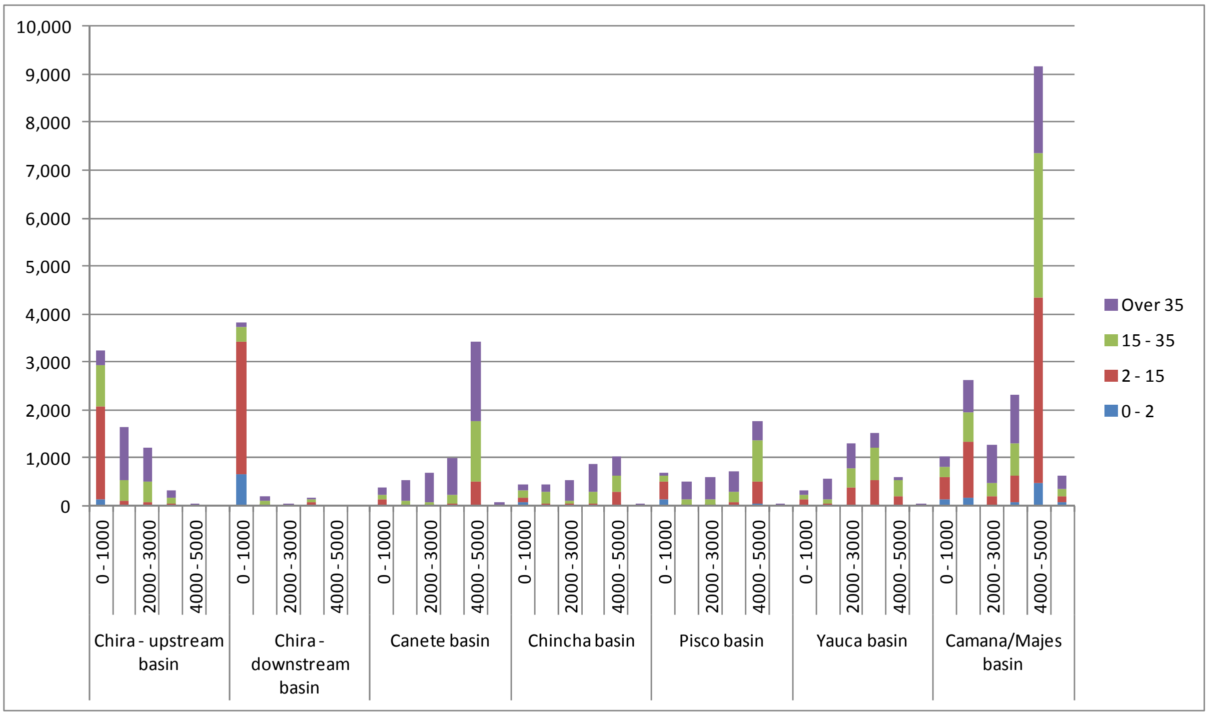


Source：JICA Study Team, based on SENAMHI data

Figure 1.12 **Surface Rainfall Volume in each Basin**

(8) Slope and Altitude

The relationship between slope and altitude in each basin was analyzed (refer to ***Figure 1.13*** and ***Table 1.9***). In the upper basin of Chira, at altitudes between 1,000 ~ 3,000 m are many slopes steeper than 35 degrees. In the lower basin slopes with 2 ~ 15° represent 67% of the total. In Cañete basin, slopes greater than 35° represent 60%, there are many areas more than 35°, mainly at altitudes between 4,000 ~ 5,000 m. In Chincha Basin at altitudes between 2,000~4,000 m, slopes over 35° are predominant. In Pisco Basin, slopes over 35° are numerous at altitudes between 1,000~4,000 m. At altitudes above 4,000 m, the slopes become more gentle, less than 35°. In Yauca basin, slopes over 35 ° are most common at altitudes between 1,000 ~ 3,000m. For altitudes above 3,000m, slopes are gentl, with the slope less than 35°. In Camana Majes basin, landform change at altitudes between 1,000 ~ 4,000m is large. There is Colca valley that is one of deepest valley in the world.



Source：JICA Study Team based on SENAMHI data

Figure 1.13 **Relationship between Slope and Altitude in each Basin**

Table 1.9 **Relationship between Slopes and Elevations in each Basin**

Basin	Slope degree	Altitude (m)												Total
		0 - 1,000		1,000 - 2,000		2,000 - 3,000		3,000 - 4,000		4,000 - 5,000		5,000 - More		
Chira upper stream	0 - 2	129.06	98%	1.34	1%	0.83	1%	0.39	0%	0.00	0%	0.00	0%	131.62
	2 - 15	1934.27	89%	99.74	5%	84.46	4%	49.22	2%	0.00	0%	0.00	0%	2167.69
	15 - 35	859.87	46%	443.18	24%	432.88	23%	116.86	6%	0.00	0%	0.00	0%	1852.79
	Over 35	319.67	14%	1084.79	48%	677.65	30%	155.31	7%	0.22	0%	0.00	0%	2237.64
Chira Down stream	0 - 2	647.61	99%	0.21	0%	0.13	0%	3.33	1%	0.00	0%	0.00	0%	651.28
	2 - 15	2777.68	97%	12.58	0%	6.70	0%	62.39	2%	0.00	0%	0.00	0%	2859.35
	15 - 35	300.77	65%	87.38	19%	10.34	2%	67.37	14%	0.00	0%	0.00	0%	465.86
	Over 35	100.13	38%	108.92	42%	31.86	12%	20.85	8%	0.00	0%	0.00	0%	261.76
Cañete	0 - 2	15.51	60%	0.56	2%	0.15	1%	0.52	2%	8.88	35%	0.05	0%	25.67
	2 - 15	111.54	17%	18.13	3%	11.10	2%	35.27	5%	490.68	73%	3.26	0%	669.98
	15 - 35	101.99	6%	75.00	4%	64.27	4%	193.48	11%	1252.70	73%	21.88	1%	1709.32
	Over 35	141.11	4%	435.02	12%	604.91	17%	751.43	21%	1668.31	46%	59.99	2%	3660.77
Chincha	0 - 2	78.15	86%	0.00	0%	0.00	0%	0.00	0%	12.47	14%	0.00	0%	90.62
	2 - 15	80.09	16%	5,000	10%	47.83	10%	32.12	6%	289.52	58%	0.12	0%	499.68
	15 - 35	148.11	15%	234.91	23%	64.87	6%	256.02	25%	315.65	31%	0.21	0%	1019.77
	Over 35	129.25	8%	146.42	9%	421.58	25%	594.25	35%	401.98	24%	0.34	0%	1693.82
Pisco	0 - 2	132.09	76%	1.79	1%	2.08	1%	3.58	2%	33.74	19%	0.02	0%	173.30
	2 - 15	371.35	39%	25.01	3%	23.33	2%	67.75	7%	459.43	48%	1.51	0%	948.38
	15 - 35	118.98	8%	107.69	8%	101.38	7%	230.25	16%	856.43	60%	4.06	0%	1418.79
	Over 35	60.92	4%	373.82	22%	479.29	28%	415.34	24%	398.45	23%	3.8	0%	1731.62
Yauca	0 - 2	21.13	27%	1.48	2%	14.72	19%	25.07	32%	16.56	21%	0.05	0%	79.01
	2 - 15	106.81	9%	40.14	3%	350.89	29%	498.75	42%	193.38	16%	0.22	0%	1190.19
	15 - 35	86.07	5%	94.66	6%	399.92	25%	685.64	43%	324.82	20%	0.10	0%	1591.21
	Over 35	118.78	8%	439.54	30%	537.05	37%	295.34	20%	67.24	5%	0.18	0%	1458.13
Camana Majes	0 - 2	140.95	15%	158.22	17%	14.72	2%	78.54	8%	480.22	51%	61.23	7%	140.95
	2 - 15	446.73	7%	1164.54	18%	350.89	5%	560.22	9%	3850.12	59%	128.91	2%	446.73
	15 - 35	222.03	4%	622.51	12%	399.92	8%	673.63	13%	3014.22	59%	154.69	3%	222.03
	Over 35	230.75	5%	677.32	15%	537.05	12%	993.25	22%	1823.81	40%	290.08	6%	230.75

Source：JICA Study Team, based on SENAMHI data

(9) Watershed characteristics

The characteristics without Chira basin are as shown ***Figure 1.14***. In altitudes below 500 m, there is no vegetation and the rainfall volume and sediment volume is very small (Area A). This area, which is called the Costa (coastal area), consist of the desert area covering N-S 2,414 km from Ecuador to Chile and E-W below 500m from the Pacific. In altitudes between 1,000 ~ 4,000 m, the vegetation is sparse with accented with infertile land topography (Area B). This area is called the Sierra region, Quechua region and Suni region. Sierra region that take over 28% of all country is area in altitudes between 500m and 1,500m. Quechua region is moderate area which altitude is between 2,300 and 3,500m. Suni region is microthermal climate area which altitude is between 3,500 and 4,000m. Above 4,000 m, the rainfall volume is intense and the temperature is low. The surface is covered by low vegetation, characteristic of low temperatures and as the topography is smooth, erosion is not significant (Area C). ***Table 1.10*** shows the relationship of each basin and altitude.

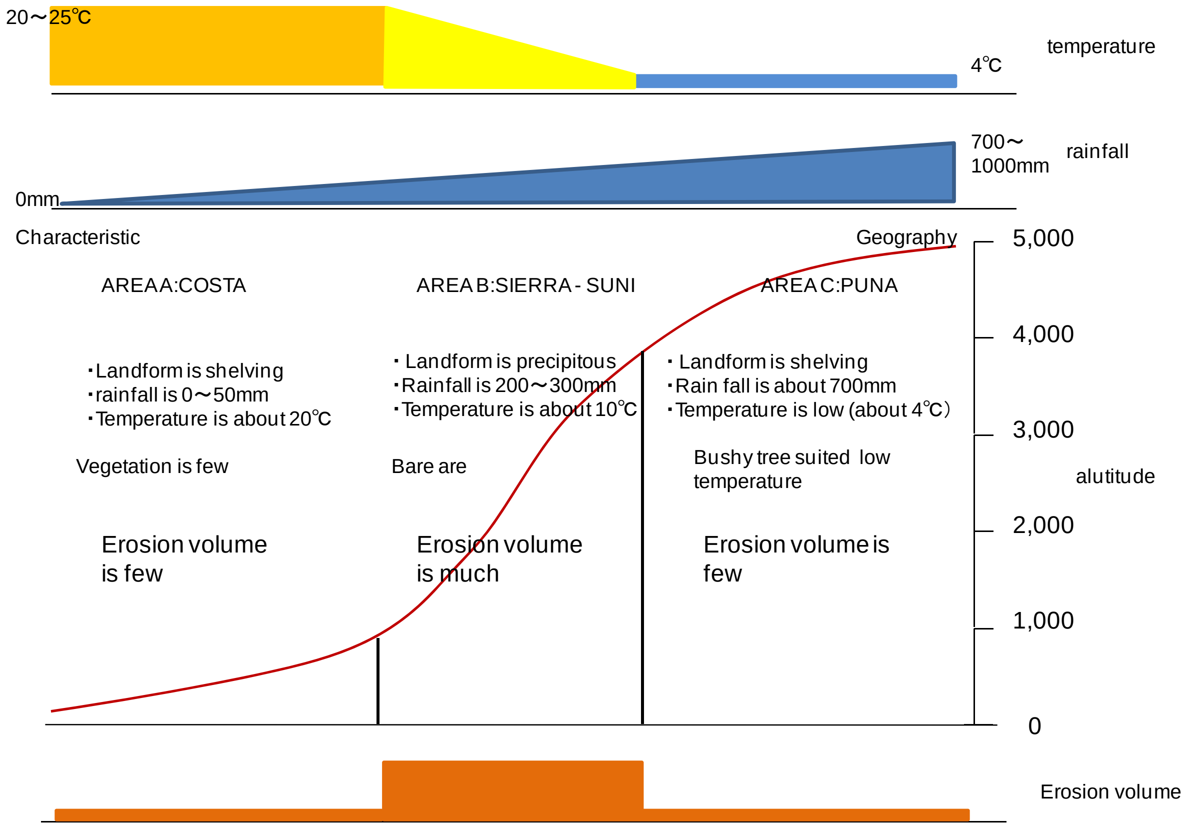


Figure 1.14 **Characteristics of Watersheds**

Source: JICA Study team

Table 1.10 **Relationship between Area and Altitude of each Basin**

Area	Cañete	Chincha	Pisco	Yauca	Camana Majes
A	0-1,000	1,000-5,000	1,000-5,000	0-1,000	0-1,000
B	1,000-5,000	1,000-4,000	1,000-4,000	1,000-3,000	1,000-3,000
C	4,500-5,000	4,000-5,000	4,000-5,000	3,000-5,000	3,000-5,000

Source:JICA Study team

1.3 Condition of sediment production

(1) Results of field survey

Field survey was conducted in the watersheds of Pisco ,Cañete and Camana-Majes.

With the exception of Chira and Camana-Majes , all the other 4 basins are close and almost similar conditions. In the upper basin of the Chira River, there is the Poechos dam and sediments become deposited down, so the sediments cannot flow to the downstream from this dam. Characteristics of the Pisco, Canete basin and Camana-majes basin are described below.

(a) Pisoco and Canate basin

- On the slopes of the mountains are observed deposit formation crushed materials released by the collapse or wind erosion.
- Production patterns differ depending on the geology of the rock base. If the rock is andesite or basalt base, the mechanism mainly consists of large gravel falling and fracturing (refer to ***Figure 1.15*** and ***Figure 1.16***)
- As shown in ***Figure 1.17***, there is no rooted vegetation probably due to the sediment transport in ordinary time in the joints of the andesitic bedrock, etc., where little sediment movement occurs has been observed algae growth and cactus.
- In almost all channels are observed the formation of the lower terraces. In these places, the sediment washed from the slopes do not enter directly into the channel, but are deposited on the terrace. For this reason, most of the sediment entering the river, probably provided by the deposits of the terrace sediments eroded or accumulated due to the alteration of the bed. (***Figure 1.18***)
- In the upper basin there was less terraces and sediment washed from the slopes fall directly into the river confirmed, although its volume is extremely low.

Figure 1.15 **Areas of detachment or Basaltic Andesite Bases**

Figure 1.16 **Location of Sediment yield of Sedimentary Rocks**

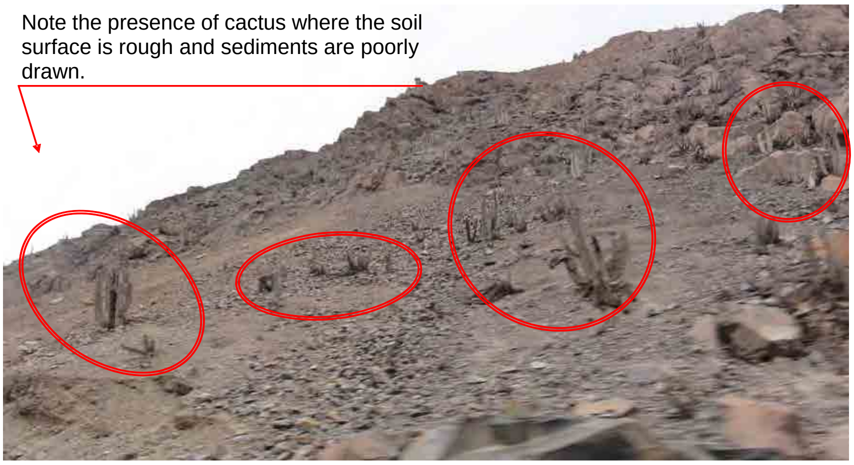


Figure 1.17 **Location of the Invasion of Cactus**

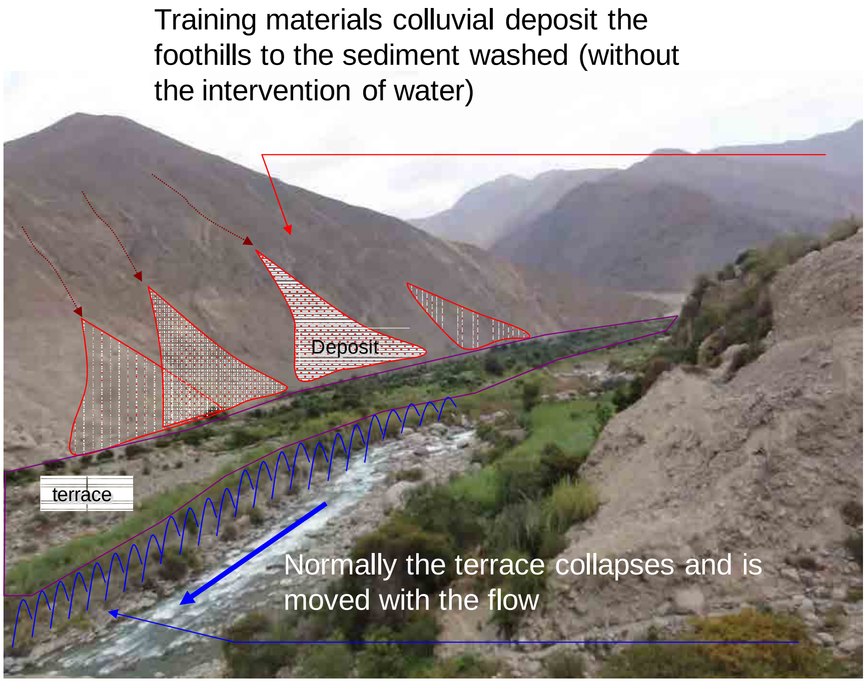


Figure 1.18 **Location of erosion of the terraces**

(b) Camana-Majes Basin

- Camana Majes river run in the valley that has been fretted about 800m depth. The Valley width is 4.2 km, the width of the river is 400m (***Figure 1.21***). It has similar landform to Yauca basin. However, the depth and width of the basin-Majes Camaná is larger than Yauca basin.
- On the mountain surface there is no vegetation, however there are deposits released by the collapse or wind erosion. (***Figure 1.27***)
- The Mesozoic sedimentary rocks are distributed in this area mainly. Almost of sediment production are made by slope failure and wind erosion. (***Figure 1.27***)
- As shown in ***Figures 1.21*** and **1.27**, there is no rooted vegetation on the slope due to moving of the deposit in ordinary time.
- In the study are, There are deposits on the terrace side the river, because there are the lower

terraces under the slope due to river width. For this reason few sediment enter the river directly. (***Figure 1.27***).

- In the upper stream, because there are few terraces, sediment enter the river in the river directly from the slope. but this volume is few. (***Figure 1.27***).
- Due to the interviews for local people, the situation of debris flow is as shown in ***Table 1.11***. And observation of sediment in the river is not conducted.
- In the valley, there are many terraces, the foot of the terraces contact with the flow channel at various points. It is supposed that the ordinary water flow brings the sediments.

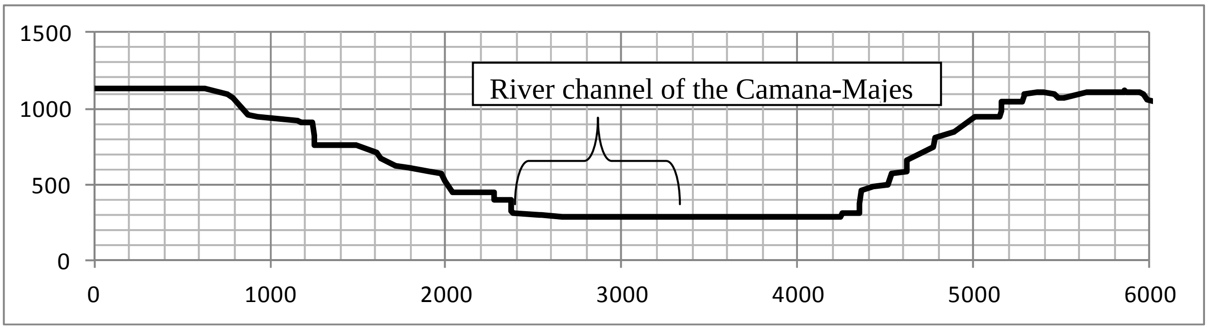


Figure 1.19 **Cross section of Majes valley（At the 50km areas From the outlet）**

Table 1.11 **The List of the Debris Flows in the Majes River**

No	River name	Distance from the outlet	Situation
1	Cosos (***Figure 1.23***)	Around 88km	In the rainy season the debris flows have occurred once a one month. And Sediments cover the city road. The recovery period is one day. Sometimes Water supplying pipe are visited by debris Flows.
2	Ongoro (***Figure 1.24***)	Around 103km	In 1998 The debris flows occurred and two people died from the debris flows. The irrigation cannels were visited and the recovery period was one month. The earth sounds occured before 30minutes, so inhabitants escaped this debris flow.
3	San Fransisco (***Figure 1.25***)	Around 106km	In 1998 the debris flows occurred and two people died from the debris flows. The irrigation cannels were visited and the complete recovery period was 4 years. The height of this debris flow is about 10 m.
4	Joron (***Figure 1.26***)	Around 106km	The flood was generated sediment and crawled up the main river. The size of the alluvial sediments of sand has been 10m. in height. It is said that has dragged 100,000 to 1,000, 000 m3 of sediment.

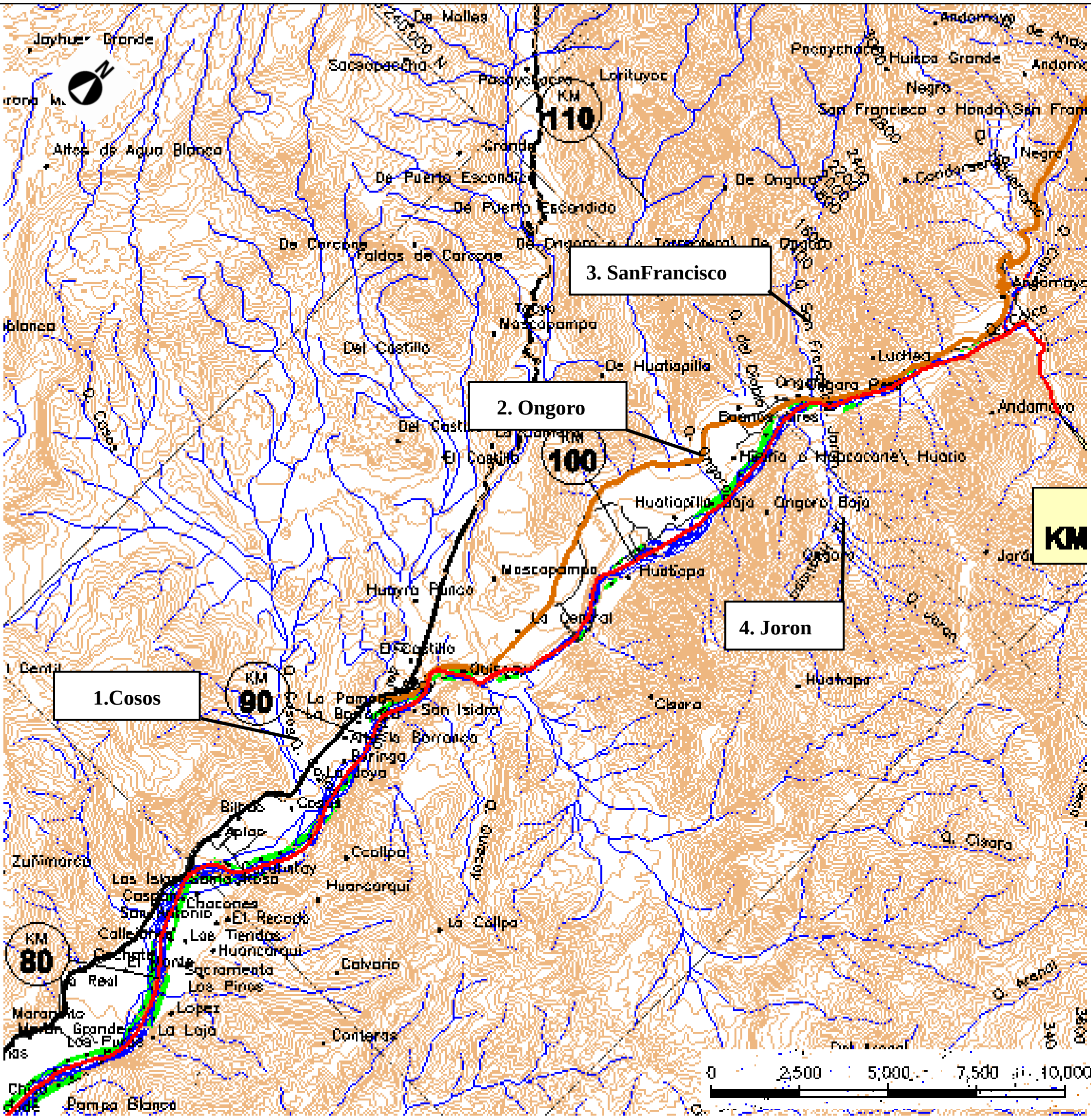


Figure 1.20 **The Location map of the Debris Flows in the Majes River**

Figure 1.21 **Situation around Km 60 (The width of the Valley is about 5km)**

Figure 1.22 **Location of Sediment Deposit in the Cosos River (width approx. 900m)**

Figure 1.23 **Rural road Pass Cosos River (In rainy season sediment covering the rural road, but it is restored in a day)**

Figure 1.24 **Situation of Ongoro River (In 1998, 2 people died because of flood)**

Figure 1.25 **Location of sediment deposit in the San Francisco River (The irrigation canals was visited by the disaster. The height of sediment was 10m)**

Figure 1.26 **Location Horon river (alluvial sediments gone into the Majes river in 1998)**

Figure 1.27 **Situation around 110 km from the outlet (Inlet Flow to the River from the Sediment of the Slopes is Small).**

Figure 1.28 **Intersection of River Andamayo Camaná and river (the Andamayo river is a Spillway)**

(2) Relationship of sediment disaster and precipitation

In 1998, it has many sediment disaster occurring in the Camaná-Majes basin. Therefore, a study for the precipitation in 1998 was conducted. The precipitation data was obtained from the hydrologic analysis supporting report Annex 1.We checked the rain gauge stations (***Table 1.13***) closest points that sediment disaster have occurred, obtained information of precipitation for-t years and the highest 24 hours rainfall in 1998, as shown in ***Table 1.12***. In Chuquibamba was observed probability of precipitation data for 150 years, in Pampacolca 25 years in Huambo and Aplao only 2 years.In general, the El Niño in 1998 is considered to have been rainfall of 50 years, and therefore it was determined that sediment disaster has been occurred by rainfall of 50 years periods.

Table 1.12 **List of Rainfall Stations Verified the Precipitation**

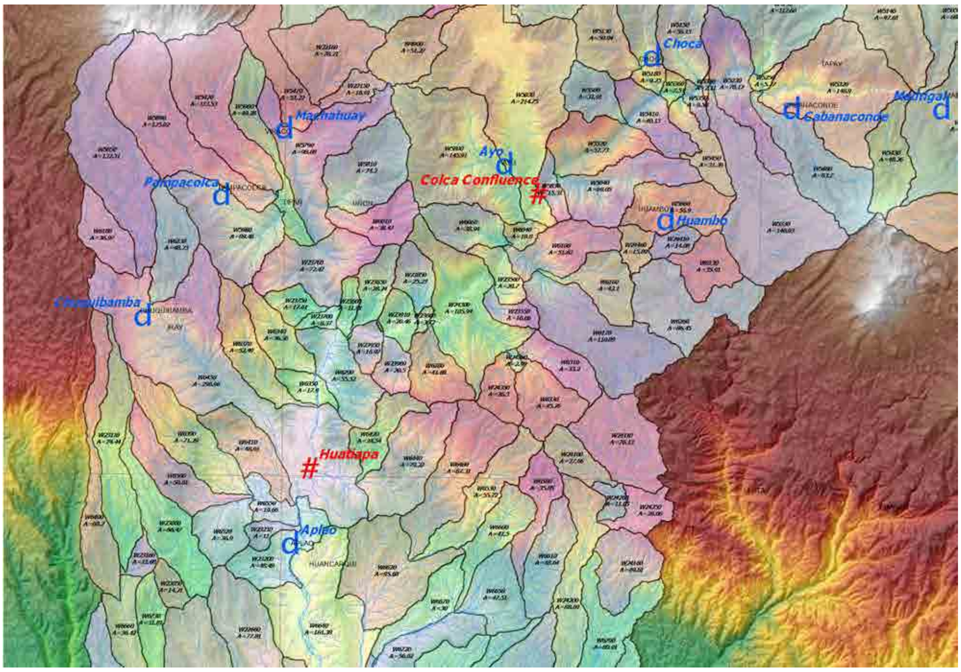
	Coordinates		
Station	**Latitude**	**Longitude**	**Altitude (m)**
Aplao	16° 04'10	72° 29'26	625
Chuquibamba	15° 50'17	72° 38'55	2839
Huambo	15° 44'1	72° 06'1	3500
Pampacolca	15° 42'51	72° 34'3	2895

Source JICA Study team

Table 1.13 **The Precipitation of 2, 5, 10, 25, 50, 100 and 200-yr return periods in each Rainfall stations and the maximum 24-hr maximum precipitation in 1998**

Station	**Precipitaiton for-t(years)**							**Precipitaiton**
	2	**5**	**10**	**25**	**50**	**100**	**200**	**in 1998**
Aplao	1.71	5.03	7.26	9.51	10.71	11.56	12.14	1.20
Chuquibamba	21.65	36.96	47.09	59.89	69.39	78.82	88.21	82.00
Huambo	22.87	30.14	34.96	41.05	45.57	50.05	54.52	25.30
Pampacolca	21.13	29.11	34.40	41.08	46.04	50.95	55.86	42.40

Source JICA Study team



Source JICA Study team

Figure 1.29 **Location Map of Rainfall Station**

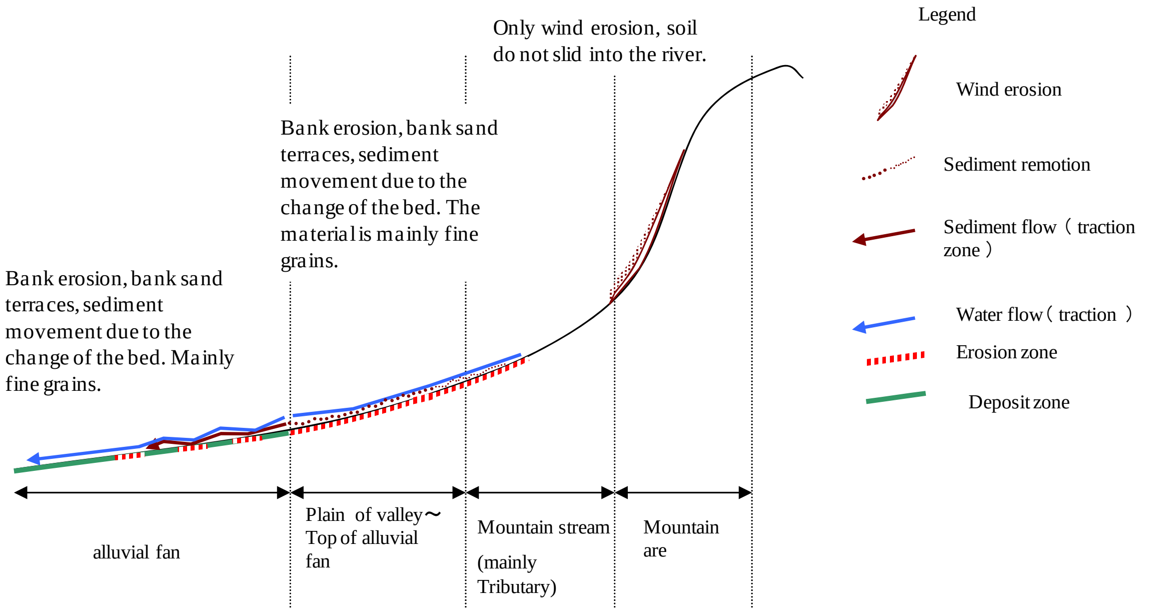
(3) Projected Production and Sediment Transport

It is considered that the condition of production and sediment transport depend on factors such as rainfall, flow, etc. Since no survey has been performed, here are some qualitative observations for a typical year, a year with rainfall of El Nino and special flood.

(a) Ordinary years

Figure 1.30 shows the sediment production during normal times.

- There is virtually no sediment production from the slopes.
- The sediments on the foot of the slope and terraces are produced by the water stream collision against the sediment deposition.
- It is considered that the sediment transport occurs by the following mechanism: the sediments accumulated in the sand banks are pushed into the river and carried downstream by changing the channel during small floods.



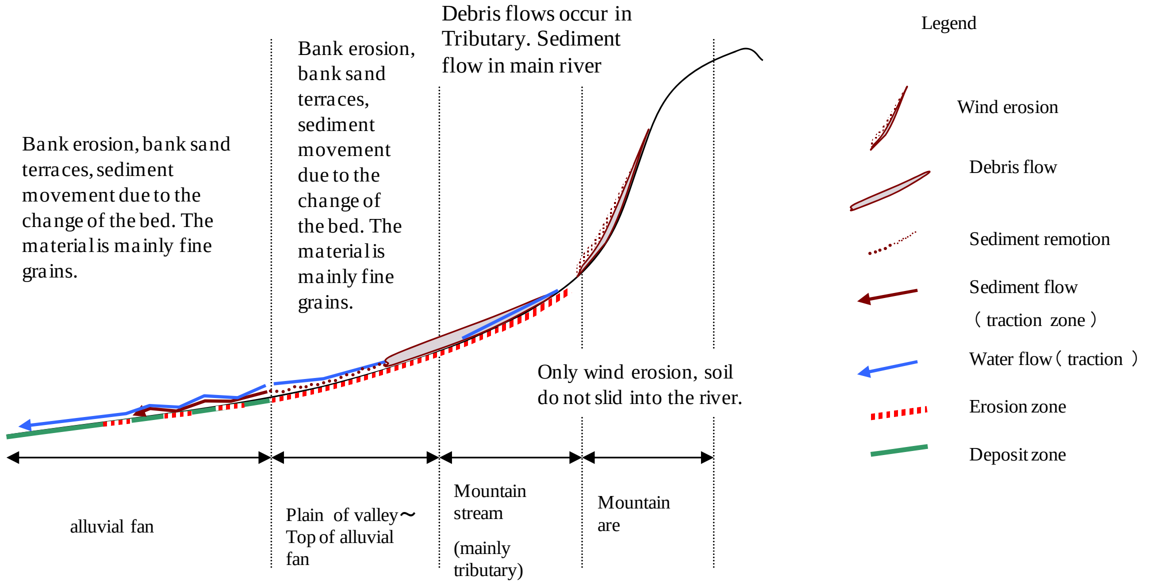
Source JICA Study team

Figure 1.30 **Location of Sediment Production in Normal Circumstances**

(b) Rains of Similar Magnitude to El Niño

According to the interviews conducted in the locality, In the phenomenon of El Niño, at all times the debris flows occur in the tributaries. However, the river has sufficient capacity to regulate sediment transport, the sediment yield deposit in the river. Hence the influence of the downstream is few. ***Figure 1.3-16*** shows the production and sediment transport during the heavy rains like El Niño that return period is 50 years.

- The debris flow from reaching tributaries enter the main river.
- Since the channel has sufficient capacity to regulate sediment transport, the sediment yield deposit in the river. Hence the influence of the downstream is few.



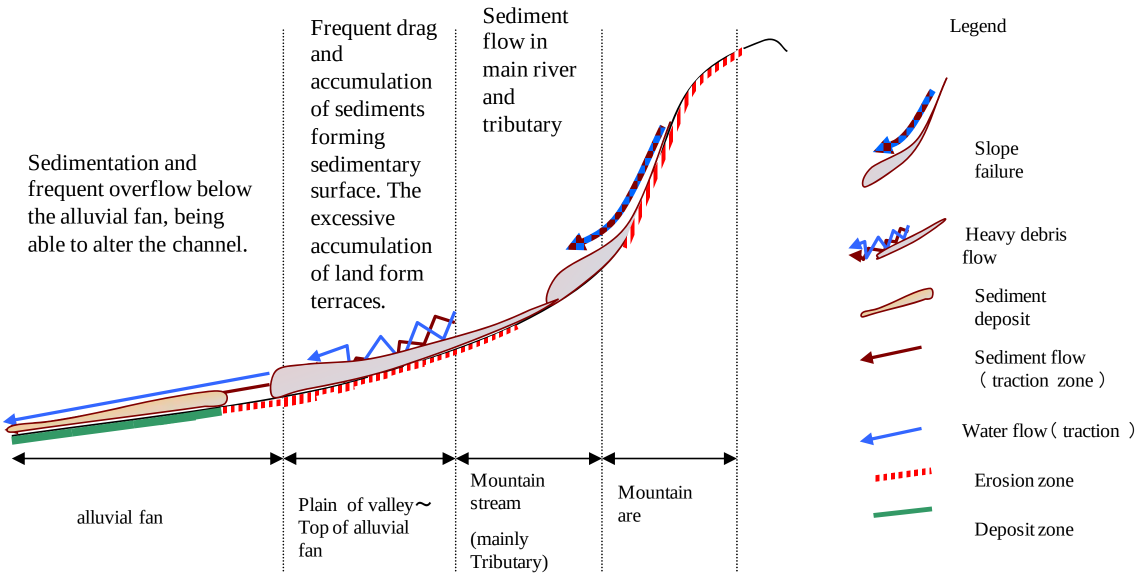
Source JICA Study team

Figure 1.31 **Location of Sediment Production in the Rainy Season with El Niño**

(c) Rains of enormous magnitude (which can lead to the formation of terraces similar to those present), with a return period of years several thousands

In the Costa area, the rainfall of 100-years return periods is approximately 50 mm. Hence sediment transport is few. However, the potential for sediment production is very high. So enormous magnitude rains cause serious sediment disaster and sediment transport described below (Refer ***to Figure 1.32***). Meanwhile, the frequency of large scale flooding has been estimated at several thousand years that match the heating cycle - global cooling.

- Sediment transport from the hillsides occur commensurate with water volume.
- Sediment transport is increase, and landslides and debris flows occur. The rivers are closed by these sediment.
- Destruction of the natural prey of closed channels by sediments, the debris flows due to destruction of towhead and sediment flow occur.
- In the lower basin amount of the sediment deposit in the river . Many terraces are formed. Cross section of the river becomes small.
- Water overflows occur in the alluvial fan.

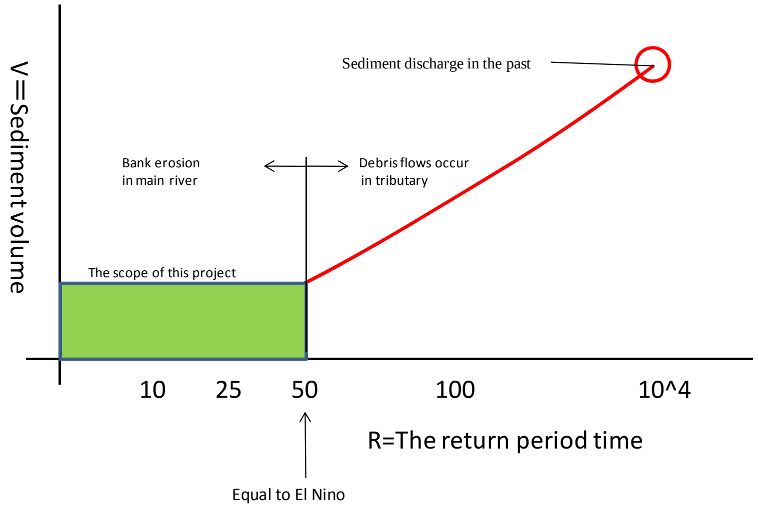


Source JICA Study team

Figure 1.32 **Production of Sediment in Large Flood (Geological Scale)**

(d) Scope of the Study

The scope of this study is focused on rainfall under return period of 50 years, equivalent to rainfall that cause the debris flows from the tributaries.



Source JICA Study team

Figure 1.33 **Relationship between the Sediment yield Volume and Rainfall Volume**

1.4 Calculation of Sediment Yield

To analyze deformation of the riverbed, it is necessary to calculate the sediment inflow volume. Hence the sediment production volume in each basin were calculated. The production sediment volume was calculated by 3 sediment volume types below.

(1) The movable sediment volume

(2) Comparative sediment volume using the sediment volume from the Poechos dam

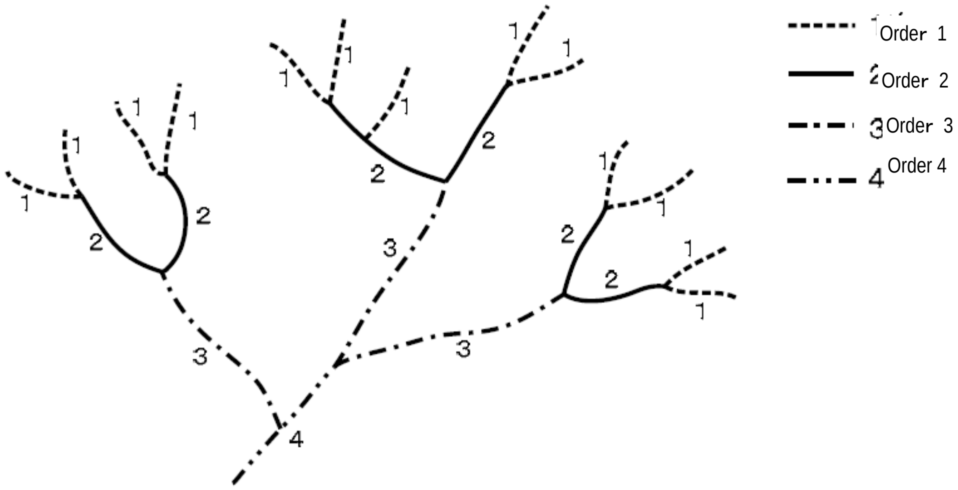
(3) Sediment volume from the flow rate

(1) Estimation of the movable sediment volume

(a) Watershed Classification

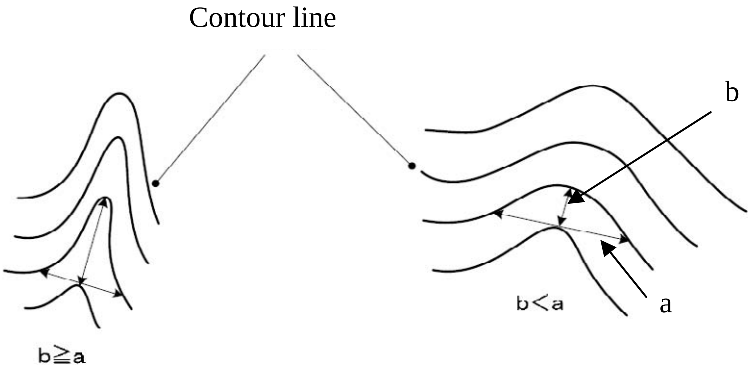
To calculate the sediment volume, hydrological maps and classification of watersheds and made. The classification of the valley by the methodology Strehler (Refer to ***Figure 1.34***) is performed. It is consider that the 0 order valley is the depression of the contour lines with depth less than the width of contour lines in the a topographic map scale S = 1/50,000.(refer to ***Figure 1.35***)

The movable sediment volume has been calculated from the sum of the movable sediment yield volume in the debris area and sediment production volume in the traction area. In Japan, the calculation of the movable sediment volume from the 0 order valley are included in the sediment transport volume. However, in this study are, once the slopes are steep and the rocks are exposed in 0 order valley and it is estimated that the sediment transport volume is small due to small rainfall, so the movable sediment volume from the 0 order valley are not include in movable sediment volume.



Source: Technical Standards River sediment Control in the Ministry of Construction in Japan.

Figure 1.34 **Classification of Basins According to Strehler**



b>=a valley
b<a not valley 0order valley

Source: Technical Standards River sediment Control in the Ministry of Construction in Japan.

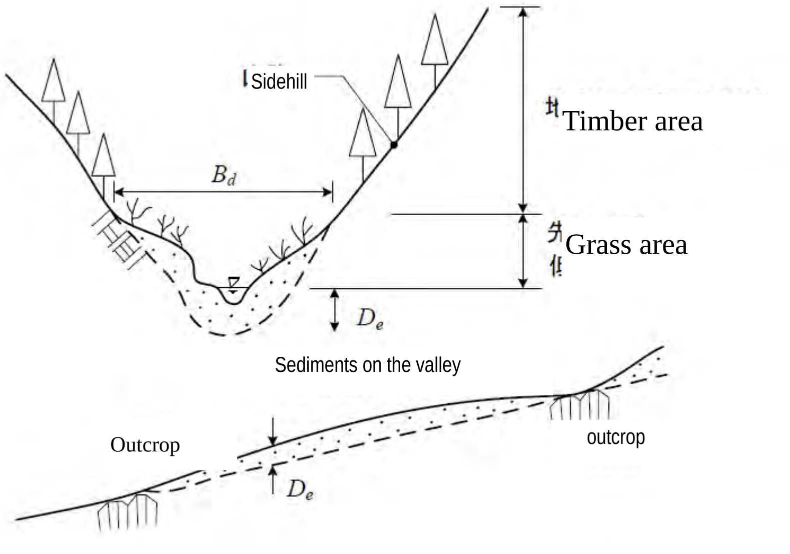
Figure 1.35 **Methodology of Primarily of Basins**

(b) Calculating the movable sediment volume in the debris flow area

The movable sediment volume in the debris flow area is calculated from the sum of movable sediment volume on the riverbed and the sediment volume due to slope failure. The movable sediment volume from the 0 order valley are not include in movable sediment volume because of thickness of weathered layer.

(c) Movable sediment volume on the riverbed

The movable sediment volume on the bed is multiplied by the average width (Bd) ,which are erodible by the debris flow, by the average depth (De) where are erodible by the debris flow.

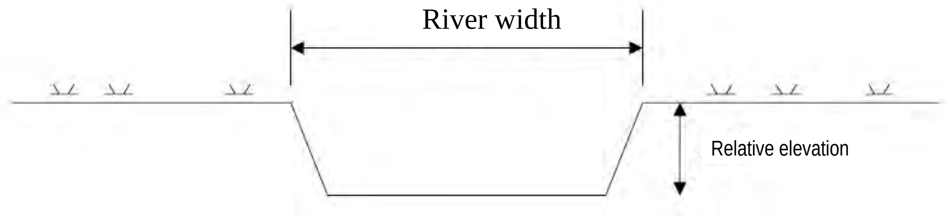


Source: Basic Methodology Guide Project Planning Sediment Control

Figure 1.36 **Methodology for Calculation of Movable Sediment Volume on the Riverbed**

(d) Calculating the sediment production volume in other areas (without debris flow area)

It is supposed that sediment yield in the traction areas are erosion of the deposit on the riverbed and bank. If it is difficult to determine the sediment yield in the channel, the method of product two to three times of the width, relative elevation and the length of design. (Refer to ***Figure 1.37***) are employed. In this study, this method is adopted. In case that the river width is large and riverbed slope is gentle and the river is not meandering two is adopted. In case that the river width is narrow and riverbed slope is steep and the river is meandering three is adopted. In this study, three is adopted due to the rivers meandering.



Source: JICA study Team

Figure 1.37 **Calculation of the Sediment Production Volume in the Traction Area**

The ***Table 1.14*** shows the width (Bd) and depth (De) used to calculate the sediment production volume in each basin. It is assumed that the 1-3 order is debris flow area and 4-7 order areas is traction area for calculation of the sediment volume.

Table 1.14 **The Widths and Depth of the Movable Sediment Volume in each Order**

Order	Classification	Widths （Bd）	Depth （De）
1	Debris	2	0.2
2	Debris	5	0.5
3	Debris	15	4
4	tranction	30	5
5	tranction	60	7
6	tranction	90	10
7	tranction	100	10

Source:JICA study Team

The movable sediment volume in each basin is shown to ***Table 1.15***. In all basins the percentage of first-order valley is 60%. There are variations between each basin, but the volume of sediment transport potential per 1 km2 is 4,000 m3 to 5,600 m3. Pisco basin has more volume per km2 compared to the others. This reason is that the 6th order river in the Pisco basin is longer than the other basins.

Table 1.15 **The Movable Sediment Volume in each Basin**

Basin			Chira basin※1			Canete basin			Chincha basin		
Area(km2)			Area(km2) 10627.99			Area(km2) 6023.97			Area(km2) 3303.89		
per 1km2			47,932		m3/km	42,122		m3/km	47,323		m3/km
order	Width (m)	depth (m)	Length (km)	Sediment volume (m3)	Ratio (%)	Length (km)	Sediment volume (m3)	Ratio (%)	Length (km)	Sediment volume (m3)	Ratio (%)
1	2	0.2	3,698	1,479,348	57%	2,500	1,000,104	57%	1,522	608,878	60%
2	5	0.5	1,210	3,025,625	19%	931	2,326,441	21%	530	1,325,893	21%
3	15	4	625	37,501,200	10%	441	26,482,162	10%	170	10,204,388	7%
4	30	5	397	59,601,000	6%	210	31,549,328	5%	132	19,728,461	5%
5	60	7	223	93,542,400	3%	162	67,845,999	4%	52	21,856,708	2%
6	90	10	81	73,269,000	1%	138	124,539,795	3%	114	102,627,283	5%
7	100	10	241	241,000,000	4%						
1-3 total			5,534	42,006,173	85%	3,872	29,808,707	1	2,223	12,139,159	88%
4-7 total			942	467,412,400	15%	510	223,935,122	0	298	144,212,452	12%
total			6,476	509,418,573	100%	4,382	253,743,830	1	2,520	156,351,611	100%
Basin			Pisco basin			Yauca basin			Camana-majes basin		
Area(km2)			Area(km2) 4270.52			Area(km2) 4318.54			Area(km2) 17049.51		
per 1km2			56,634		m3/km	39,780		m3/km	42,739		m3/km
order	Width (m)	depth (m)	Length (km)	Sediment volume (m3)	Ratio (%)	Length (km)	Sediment volume (m3)	Ratio (%)	Length (km)	Sediment volume (m3)	Ratio (%)
1	2	0.2	1,955	781,876	30%	1,681	672,547	38%	8,142	3,256,768	323%
2	5	0.5	600	1,498,775	9%	541	1,353,482	12%	2,599	6,497,925	103%
3	15	4	236	14,137,800	4%	275	16,485,824	6%	1,141	68,436,600	45%
4	30	5	102	15,259,500	2%	87	13,113,662	2%	610	91,512,000	24%
5	60	7	110	46,065,600	2%	119	50,056,950	3%	348	146,063,400	14%
6	90	10	182	164,115,000	3%	100	90,110,750	2%	459	412,911,000	18%
7	100	10									
1-3 total			2,790	16,418,451	43%	2,498	18,511,854	57%	11,882	78,191,293	471%
4-7 total			394	225,440,100	6%	307	153,281,362	7%	1,417	650,486,400	56%
total			3,184	241,858,551	49%	2,804	171,793,215	64%	13,298	728,677,693	528%

※1 Without Ecuador

Source:Jica Study Team

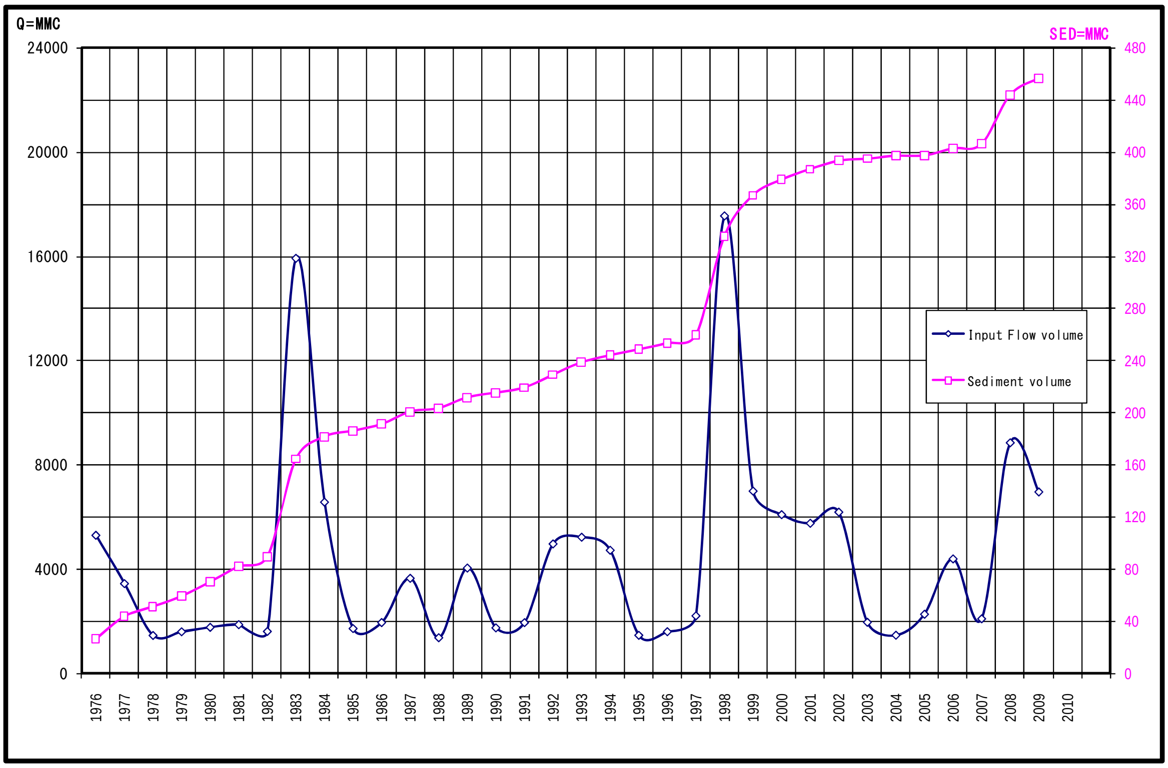
(2) Calculation of sediment volume using sediment volume in the Poechos dam

In the Poechos dam the sediment measurements have been conducted periodically. The specific discharge of sediment was calculated from this sediment volume and the sediment volume in other basin were calculated by using the specific discharge of sediment in the Poechos dam.

(a) Sediment volume in the Poechos dam

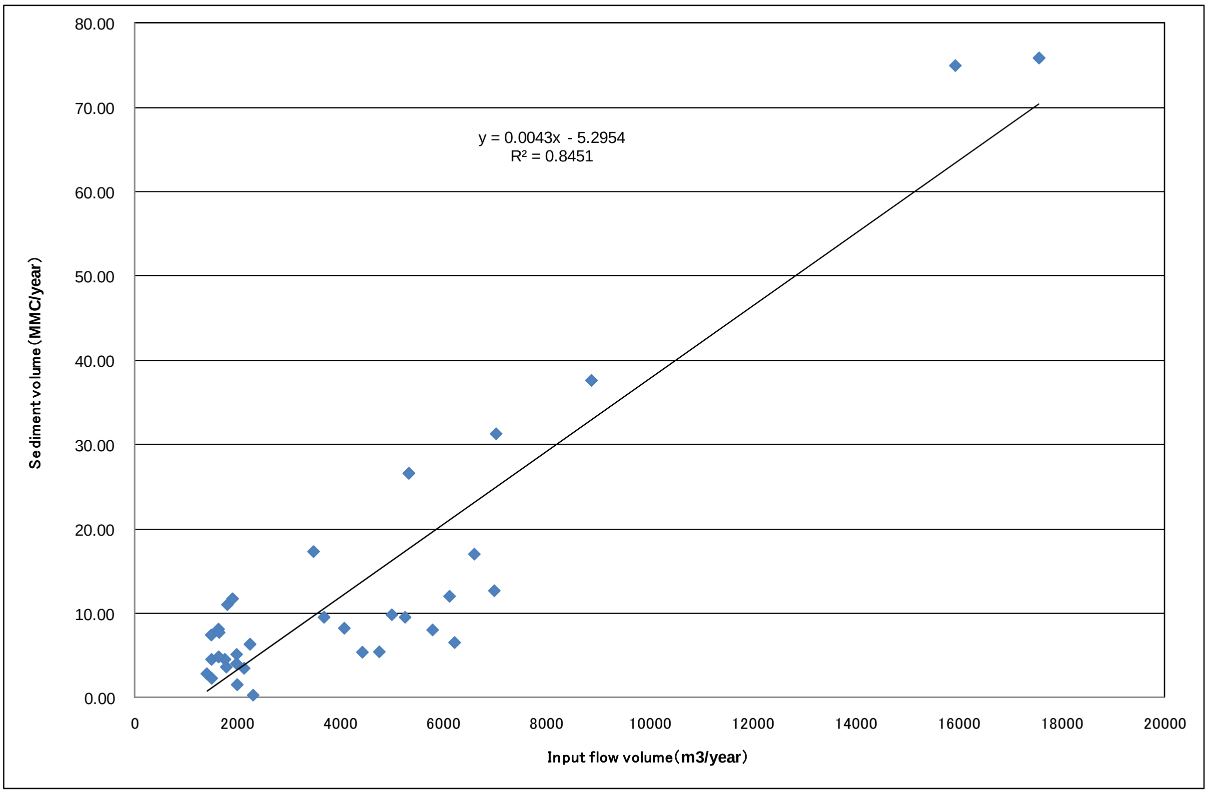
Poechos dam is located in the upper basin of the Chira River, the border with Ecuador. This dam was built during the period from 1972 to 1976 and began operations from 1976. The catchment area is approximately 13,000 km2 and half of it is located in the neighboring country of Ecuador. The storage capacity is 790 million tons, but after 34 years from the inauguration, the sediment deposited accumulated 460 million tons and storage capacity reduced to 410 million tons. Currently, problems that flood control capacity is depression. (Refer to ***Figure 1.38*** and ***Figure 1.40***). For this reason, in ordinary times the full water level has been changed 103m to 104m.

The sediment volume inflow in the years 1983 and 1998 occurred the phenomenon of El Niño were accumulated about 7,500 ton per year. The specific discharge of sediment are considered 500m3/km2/years, it reaches 6,000 m^3/km^2/year, about 10 times more than normal. In some dams in Japan too, it have been recorded that a double-digit increase in the sediment volume deposited by flood, compared to normal years. Measuring the sediment volume have been conducted by survey.



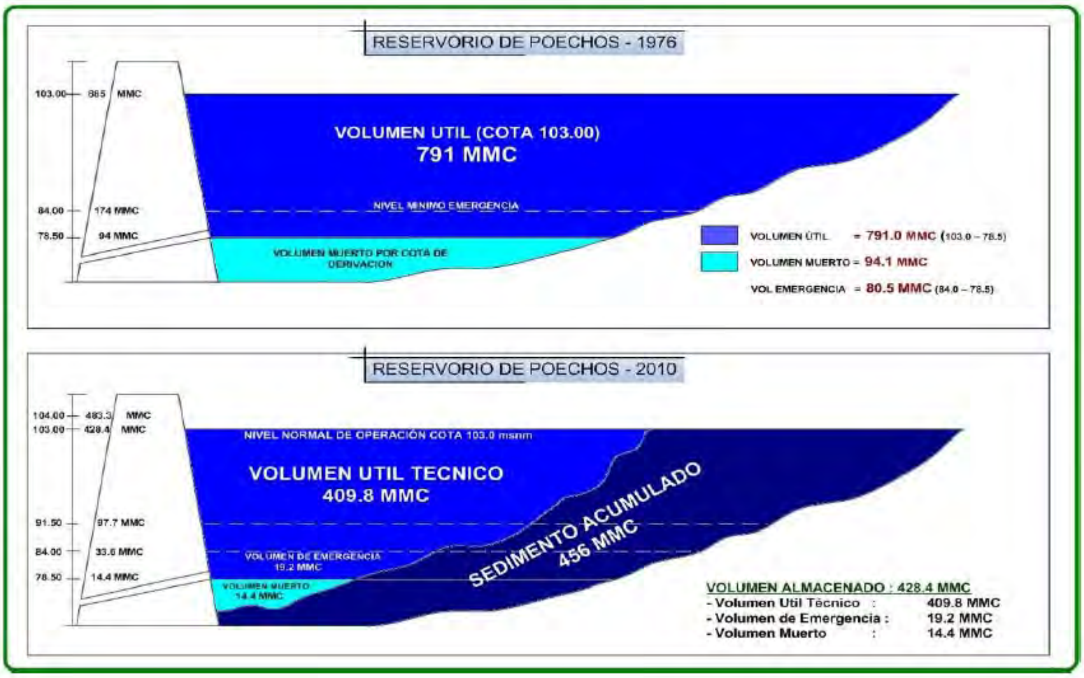
Source:PECHP

Figure 1.38 **Annual input Flow Volume and Sediment Accumulation in Poechos Dam**



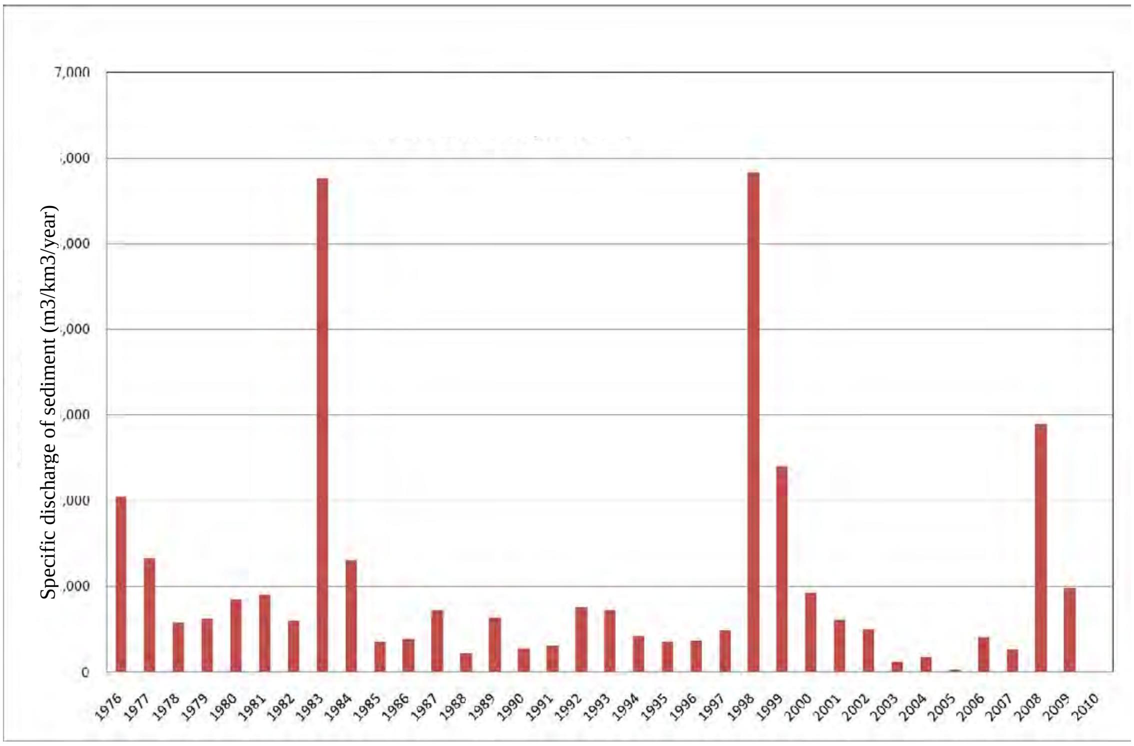
Source: JICA Study Team

Figure 1.39 **Relationship between Annual input Flow Volume and Sediment Volume**



Source: PECHP

Figure 1.40 **Diagram of sediment accumulation (from 1976 to2010)**



Source:JICA Study Team

Figure 1.41 **Annual Specific Discharge of Sediment**

(b) Calculating the comparative discharge volume

Based on data from the status of the Poechos sediment volume is calculated comparing sediment for one flood.

a) Rainfall data

Rainfall data around the Poechos were organized. ***Table 1.16*** lists rainfall station of the chira river basin. ***Figure 1.42*** shows location of rain-guage station. ***Table 1.17*** shows measurement period in each rainfall station that have long periods rainfall data. Combining rainfall data (as shown in ***Tabla1.18***) were made by these rainfall data. The catchment area covers about 6.500 km2, covering both Peru and Ecuador, as shown in ***Table 1.19***.

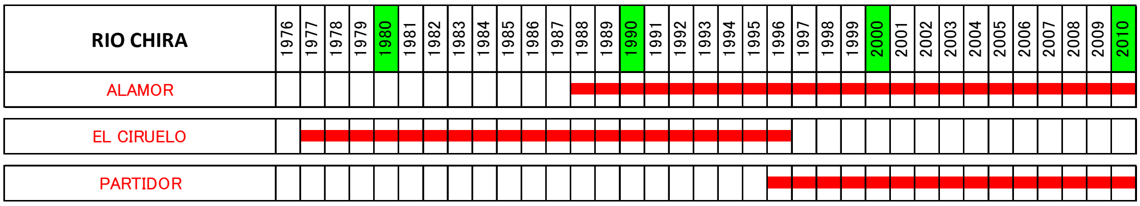
Table 1.16 **Rainfall Stations of the Chira River Basin**

Name of rainfall station	Prefecture	District	Town	Longitude	Latitude	Elevation
ALAMOR	PIURA	SULLANA	LANCONES	80░23'00.0"	04░28'00.0"	150
ALIVIADERO	PIURA	SULLANA	LANCONES	80░31'00.0"	04░43'00.0"	103
ALTAMIZA	PIURA	MORROPON	CHALACO	79░44'00.0"	05░04'00.0"	2600
ANIA CABUYAL	PIURA	AYABACA	AYABACA	79░29'00.0"	04░51'00.0"	2450
ARANZA	PIURA	AYABACA	AYABACA	79░59'00.0"	04░51'00.0"	1300
ARDILLA (SOLANA BAJA)	PIURA	SULLANA	LANCONES	80░26'00.0"	04░31'00.0"	150
ARENALES	PIURA	AYABACA	FRIAS	79░51'00.0"	04░55'00.0"	3010
ARRENDAMIENTOS	PIURA	AYABACA	LAGUNAS	79░54'00.0"	04░50'00.0"	3010
AUL (C. MEMBRILLO)	PIURA	AYABACA	AYABACA	79░42'00.0"	04░33'00.0"	640
AYABACA	PIURA	AYABACA	AYABACA	79░43'00.0"	04░38'00.0"	2700
CHALACO	PIURA	MORROPON	CHALACO	79░47'30.0"	05░02'13.0"	2276
CHILACO	PIURA	SULLANA	LANCONES	80░30'00.0"	04░42'00.0"	90
EL CIRUELO	PIURA	AYABACA	SUYO	80░09'00.0"	04░18'00.0"	202
EL TABLAZO	PIURA	PIURA	TAMBO GRANDE	80░28'00.0"	04░53'00.0"	148
ESPINDOLA	PIURA	AYABACA	AYABACA	79░30'00.0"	04░38'00.0"	2300
FRIAS	PIURA	AYABACA	FRIAS	79░51'00.0"	04░56'00.0"	1700
HACIENDA YAPATERA	PIURA	MORROPON	CHULUCANAS	80░08'00.0"	05░04'00.0"	117
HUARA DE VERAS	PIURA	AYABACA	AYABACA	79░34'00.0"	04░35'00.0"	1680
JILILI	PIURA	AYABACA	JILILI	79░48'00.0"	04░35'00.0"	1330
LA ESPERANZA	PIURA	PAITA	COLAN	81░03'38.0"	04░55'04.0"	12

LA TINA	PIURA	AYABACA	SUYO	79°57'00.0"	04°24'00.0"	427
LAGARTERA	PIURA	AYABACA	SAPILLICA	79°58'00.0"	04°44'00.0"	307
LAGUNA SECA	PIURA	AYABACA	PACAIPAMPA	79°29'00.0"	04°53'00.0"	2450
LANCONES	PIURA	SULLANA	LANCONES	80°32'50.0"	04°38'34.0"	150
LAS ARREBIATADAS	PIURA	AYABACA	AYABACA	79°28'00.0"	04°45'00.0"	3450
LAS LOMAS	PIURA	PIURA	LAS LOMAS	80°15'00.0"	04°38'00.0"	265
LAS PIRCAS	PIURA	AYABACA	FRIAS	79°48'00.0"	04°59'00.0"	3300
LOS ENCUENTROS	PIURA	SULLANA	LANCONES	80°17'00.0"	04°26'00.0"	175
MALLARES	PIURA	SULLANA	MARCAVELICA	80°42'52.9"	04°51'25.6"	47
MONTERO	PIURA	AYABACA	MONTERO	79°50'00.0"	04°38'00.0"	1070
NACIENTES DE ARANZA	PIURA	AYABACA	PACAIPAMPA	79°29'00.0"	04°53'00.0"	2450
NANGAY MATALACAS	PIURA	AYABACA	PACAIPAMPA	79°46'00.0"	04°52'00.0"	2100
OLLEROS	PIURA	AYABACA	AYABACA	79°39'00.0"	04°42'00.0"	1360
PACAYPAMPA	PIURA	AYABACA	PACAIPAMPA	79°39'46.0"	04°59'35.0"	2041
PAIMAS	PIURA	AYABACA	PAIMAS	79°57'00.0"	04°37'00.0"	545
PAITA	PIURA	PAITA	PAITA	81°08'00.0"	05°07'00.0"	3
PANANGA	PIURA	SULLANA	MARCAVELICA	80°53'00.0"	04°33'00.0"	480
PARAJE GRANDE	PIURA	AYABACA	PAIMAS	79°54'00.0"	04°37'00.0"	555
PARTIDOR	PIURA	SULLANA	LANCONES	80°15'00.0"	04°38'00.0"	265
PASAPAMPA	PIURA	HUANCABAMBA	HUANCABAMBA	79°36'00.0"	05°07'00.0"	2410
PICO DE LORO	PIURA	AYABACA	SUYO	79°52'00.0"	04°32'00.0"	1325
PUENTE INTERNACIONAL	PIURA	AYABACA	SUYO	79°57'00.0"	04°23'00.0"	408
PUENTE SULLANA	PIURA	SULLANA	SULLANA	80°41'00.0"	04°53'00.0"	32
REPRESA SAN LORENZO	PIURA	PIURA	LAS LOMAS	80°13'00.0"	04°40'00.0"	300
SAN ISIDRO	PIURA	PIURA	LAS LOMAS	80°16'00.0"	04°47'00.0"	160
SAN JACINTO	PIURA	SULLANA	IGNACIO ESCUDERO	80°52'00.0"	04°51'00.0"	103
SAN JUAN DE LOS ALISOS	PIURA	AYABACA	PACAIPAMPA	79°32'00.0"	04°58'00.0"	2150
SAPILLICA	PIURA	AYABACA	SAPILLICA	79°59'00.0"	04°47'00.0"	1456
SAUSAL DE CULUCAN	PIURA	AYABACA	AYABACA	79°45'42.0"	04°44'52.0"	980
SICCHEZ	PIURA	AYABACA	SICCHEZ	79°46'00.0"	04°34'00.0"	1435
SOMATE	PIURA	SULLANA	SULLANA	80°31'00.0"	04°45'00.0"	112
SUYO	PIURA	AYABACA	SUYO	80°00'00.0"	04°32'00.0"	250
TACALPO	PIURA	AYABACA	AYABACA	79°36'00.0"	04°39'00.0"	2012
TALANEO	PIURA	HUANCABAMBA	HUANCABAMBA	79°33'00.0"	05°03'00.0"	3430
TAPAL	PIURA	AYABACA	AYABACA	79°33'00.0"	04°46'00.0"	1890
TEJEDORES	PIURA	PIURA	LAS LOMAS	80°14'00.0"	04°45'00.0"	230
TIPULCO	PIURA	AYABACA	AYABACA	79°34'00.0"	04°42'00.0"	2600
TOMA DE ZAMBA	PIURA	AYABACA	LAGUNAS	79°54'00.0"	04°40'00.0"	585
VADO GRANDE	PIURA	AYABACA	AYABACA	79°36'00.0"	04°27'00.0"	900

Source:JICA Study Team

Table 1.17 Measurement Period of Adopted Stations



RIO CHIRA	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
ALAMOR													🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
EL CIRUELO		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥														
PARTIDOR																					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

Source: JICA Study Team

Table1.18 Details of the Combining Rainfall

Observing station	Time period adopted	Missing data period
ALAMOR	1stDec- 31thMar1996	May 1992 – June 1993 August 1995
EL CIRUELO	1st Apr1996 – 31th Dec1997	
PARTIDOR	1st Jan 1998 -25th Jun 2010	Jun1998- Dec1998 Jan 2009, May 2010

※ The years 1992 and 1993 were excluded from the analysis because no data. The months of January to May in 1998 if taken into account as it has with the respective data.

Source: JICA Study Team

Table 1.19 Catchment area of the Poechos dam

Boundary	Area (km2)
Peru side basin	6,410
Ecuator side basin	About 6,590
Total	About 13,000

Source:JICA Study Team

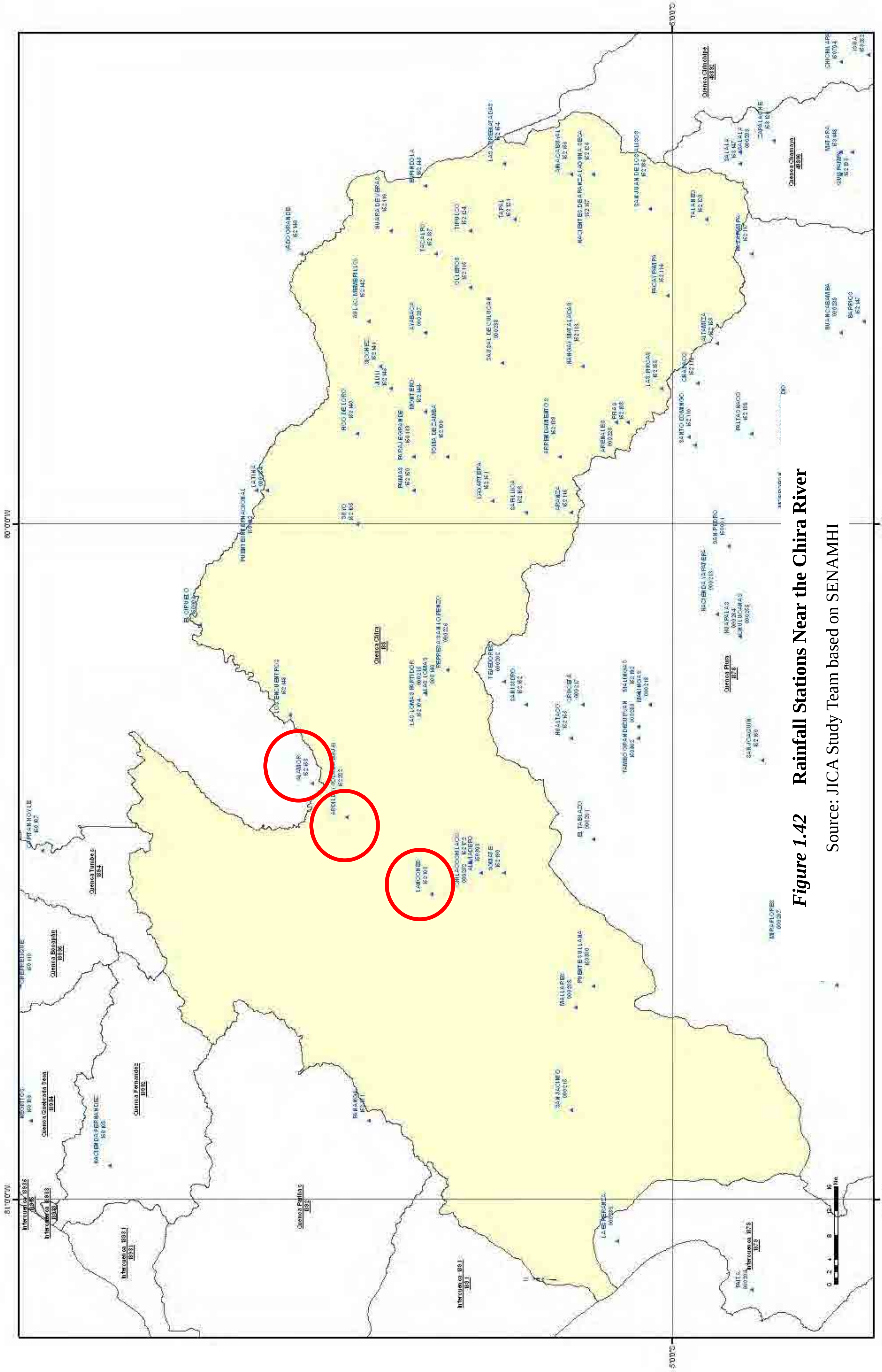


Figure 1.42 **Rainfall Stations Near the Chira River**

Source: JICA Study Team based on SENAMHI

b) Relationship between rainfall and the volume of sediment

The input flow volume, sediment volume and the rainfall are as shown in ***Table 1.20*** and ***Figure 1.43*** to ***1.49***. In the years of 1983 and 1998, occurred the phenomenon of El Niño, sediment volume was accumulated 370 million m3. The annual rainfall volume and the input flow volume are congruent, and the input flow volume and sediment volume are congruent, too. Because catchment areas of the basin is almost the same for both Peru and in Ecuador, Half of The input flow volume and the sediment volume are used for calculation of the specific discharge of sediment

Table 1.20 **Input Flow, Sediment Volume and Rainfall in the Poechos Dam**

Year	Peak rainfall per 24 hours mm	Maximum continuous rainfall mm	Annual rainfall mm	Sediment volume *1 MMC	Inflow *1 MMC	remarks
1976				13.30	2,661.5	
1977	135.9	234.1	894.2	8.65	1,736.5	
1978	28.0	38.2	149.3	3.70	744.0	
1979	30.0	70.1	181.9	4.05	814.5	
1980	72.9	187.4	360.1	5.50	900.0	
1981	93.2	450.5	555.2	5.85	951.0	
1982	100.8	199.7	488.6	3.85	821.0	
1983	209.1	942.0	3112.6	37.50	7,965.0	El Niño
1984	82.5	196.4	783.5	8.50	3,297.0	
1985	49.7	111.9	265.3	2.25	876.0	
1986	100.5	206.1	607.9	2.55	990.5	
1987	152.3	401.5	1288.8	4.75	1,838.5	
1988	16.1	25.3	120.4	1.40	701.0	
1989	91.0	185.4	973.5	4.10	2,035.0	
1990	18.3	58.3	173.9	1.80	890	
1991	105.3	163.8	416.1	2.00	989.5	
1992	186.0	411.5	1275.4	4.90	2,496.5	
1993				4.75	2,625.0	no data
1994	116.5	245.0	737.6	2.70	2,375.5	
1995	85.0	145.9	404.4	2.25	747.1	
1996	76.5	172.5	299.4	2.40	815.6	
1997	91.8	180.4	622.8	3.15	1,120.0	
1998	191.4	599.8	2816.8	37.95	8,778.0	El Niño
1999	108.6	239.5	562.9	15.65	3,508.7	
2,000	53.7	85.7	499.3	6.00	3057	
2001	99.4	495.1	983.2	4.00	2,892.5	
2002	105.6	382.6	914.1	3.25	3,105.5	
2003	55.0	58.1	149.6	0.75	996.0	
2004	35.4	36.1	140.5	1.13	747.9	
2005	48.9	128.4	238.2	0.13	1,150.5	
2006	105.6	140.3	677.1	2.68	2,210.6	
2007	48.2	78.3	202.4	1.73	1,062.9	
2008	114.3	318.6	990.7	18.82	4,433.8	
2009	51.3	87.7	377.2	6.33	3,491.4	

* 1 50% is taken as the catchment areas of Peru and Ecuador are about half the total catchment area

Source: JICA Study Team based on PECHP data.

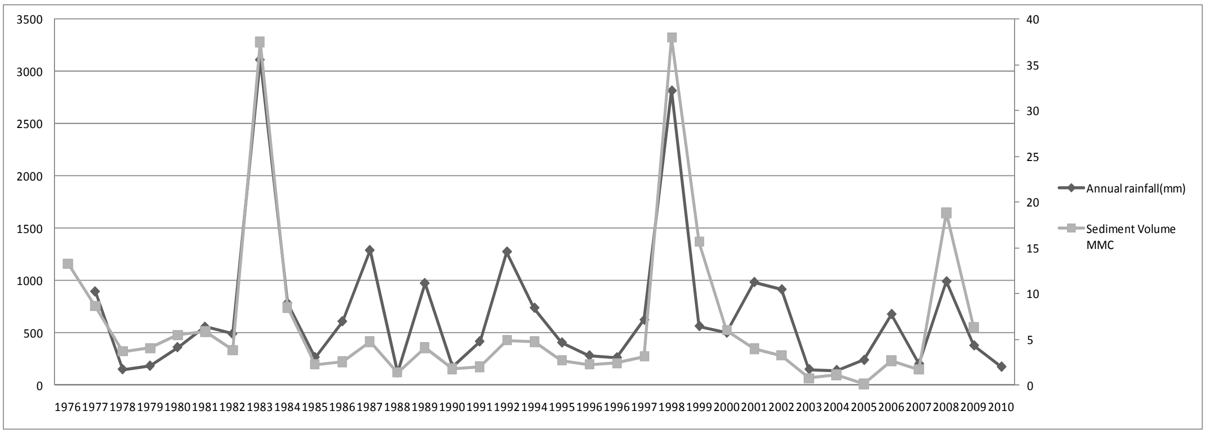


Figure 1.43 **Relationship between Annual Rainfall and Annual Sediment Volume**

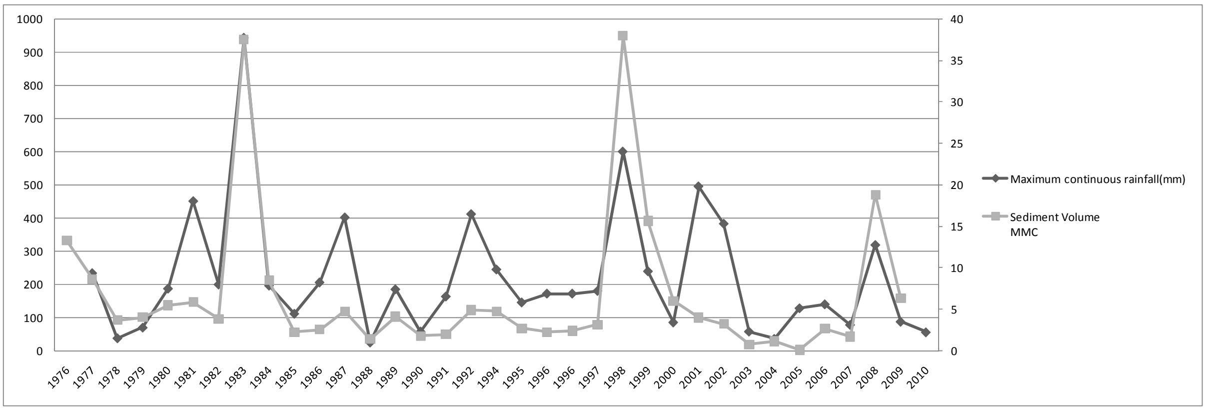


Figure 1.44 **Relationship between Maximum Continuous Rainfall and Annual Sediment Volume**

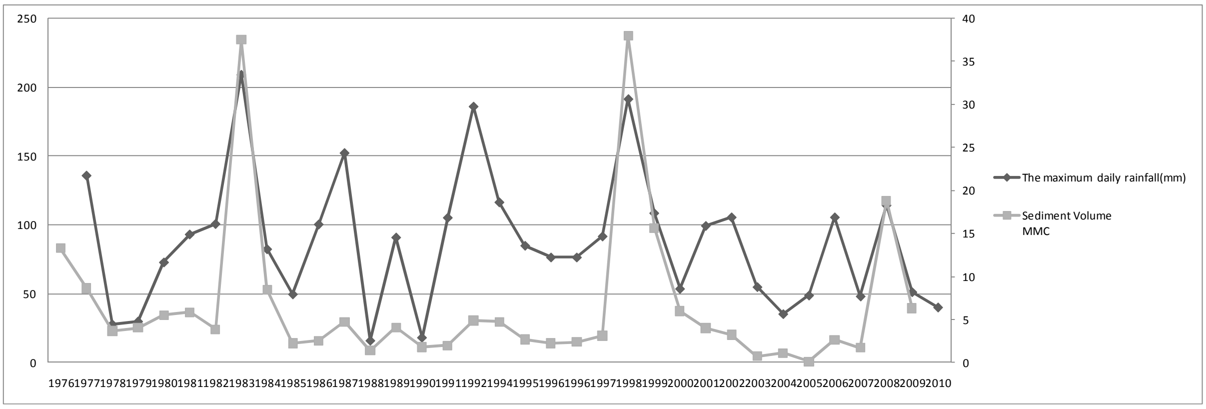


Figure 1.45 **Relationship between Maximum Daily Rainfall and annual Sediment Volume**

Source: JICA study team

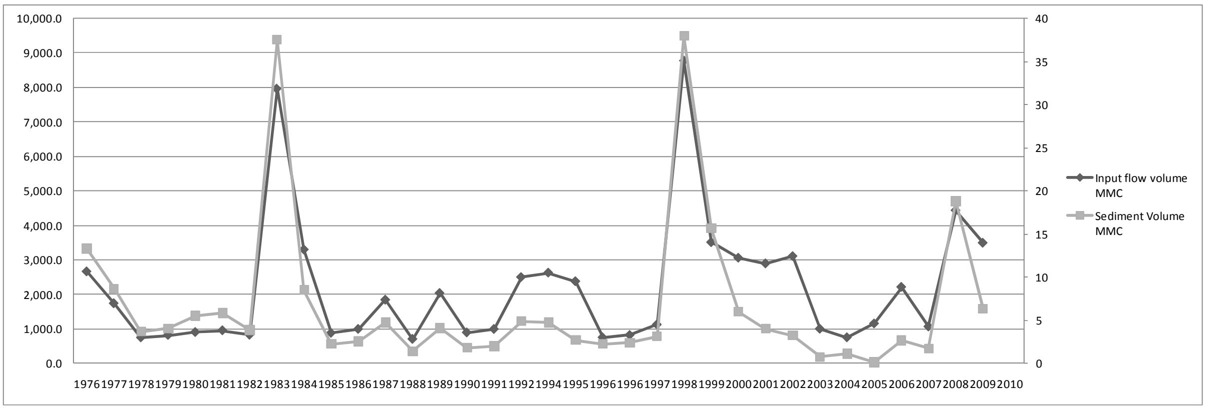


Figure 1.46 **Relationship between Annual Input Flow Volume and Annual Sediment Volume**

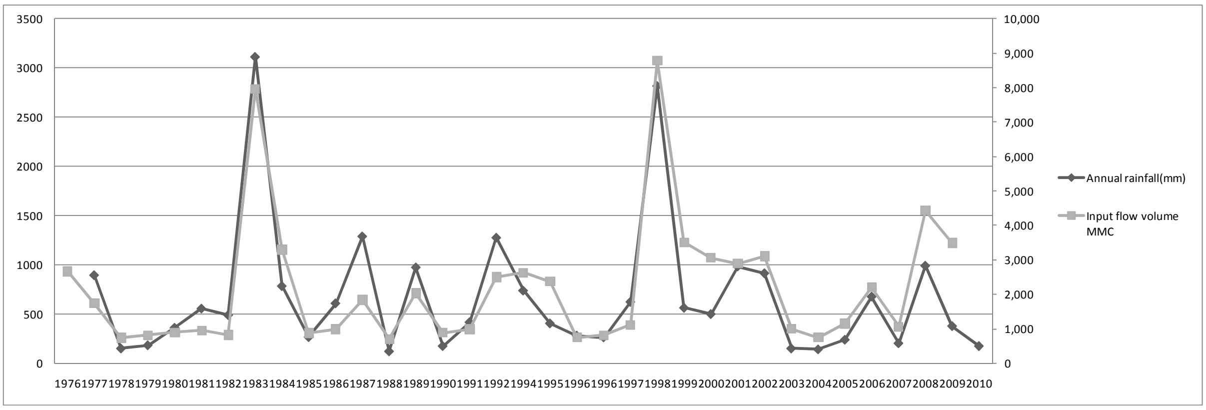
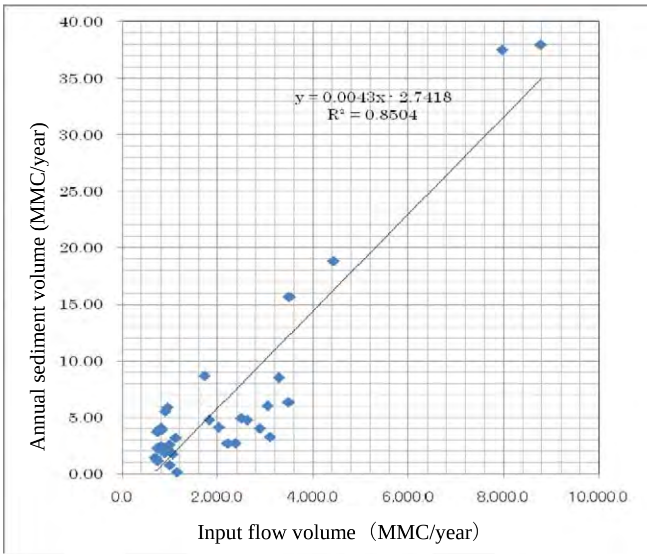


Figure 1.47 **Relationship Between Annual Rainfall and Annual Input Flow Volume**



Source: JICA study team

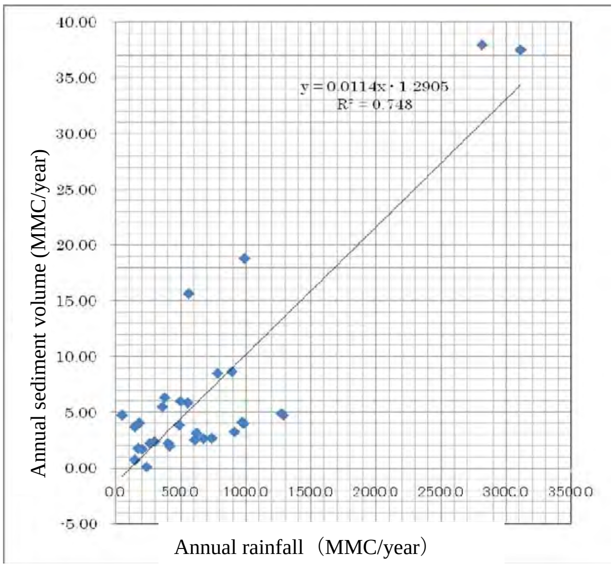


Figure 1.48 **Relationship Between Annual Input Flow volume and Annual Sediment Volume**

Figure 1.49 **Relationship Between Annual Rainfall and Annual Sediment Volume**

c) Relationship between rainfall and soil erosion

USLE (Universal Soil Loss Equation), its revised version RUSLE (Revised Universal Soil Loss

Equation) and MUSLE (Modified Universal Soil Loss Equation) are typical experimental model to estimate soil erosion volume. USLE formula shown below is consolidated by Wishmeier and others using experimental field data base on static model developed and succeeded by various researchers.

$$A = R\,K\,L\,S\,C\,P$$

Where,

A : Annual Soil loss per unit area [t ha-1 y-1]
R : Rainfall erosive factor [MJ mm ha-1 h-1 y-1]
K : Erodibility factor [t h MJ-1 mm-1]
L : Factor of slope length [a dimensional]
S : Steepness factor of the slope [a dimensional]
A(Annual soil loss) is proportional to R, K, L y S

Thus it is clear that soil loss is proportional to $R = \sum_{i=1}^{n} E_i I_{30i}$

Where,

Ei : Rainfall kinetic energy [MJ ha-1] in the random event of rain i
I30i : Maximum amount of rain for 30 minutes [mm h-1] in the random event of rain i (note units)
n : Nunber of random events of rainfall per year

Because there are only daily data, it is assumed that the volume of soil loss and rainfall volume is proportional, we have calculated the volume of soil per 1 mm rainfall and per 1 km2. There are dispersion in this result, but the results are 0.5 - 4m3/km2/mm, averaging 1.48 m3/km2/mm.

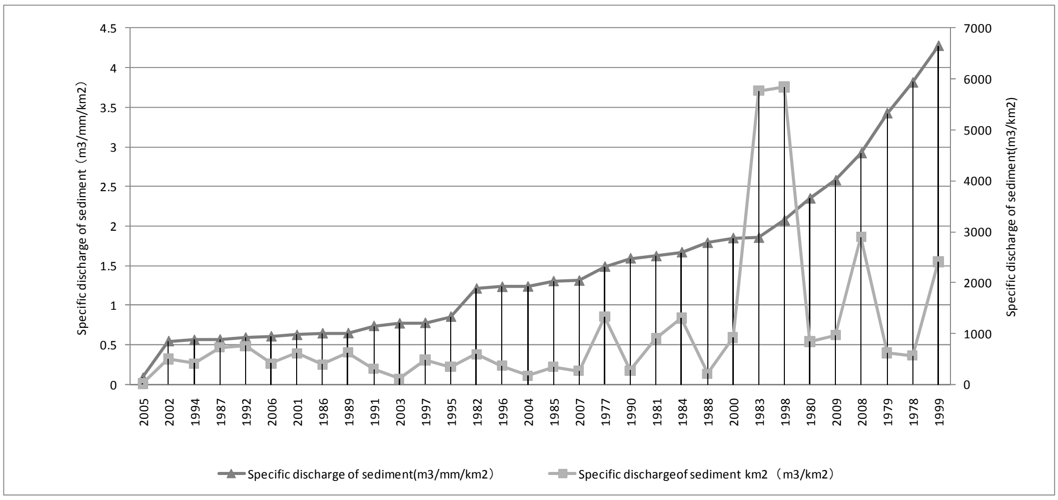
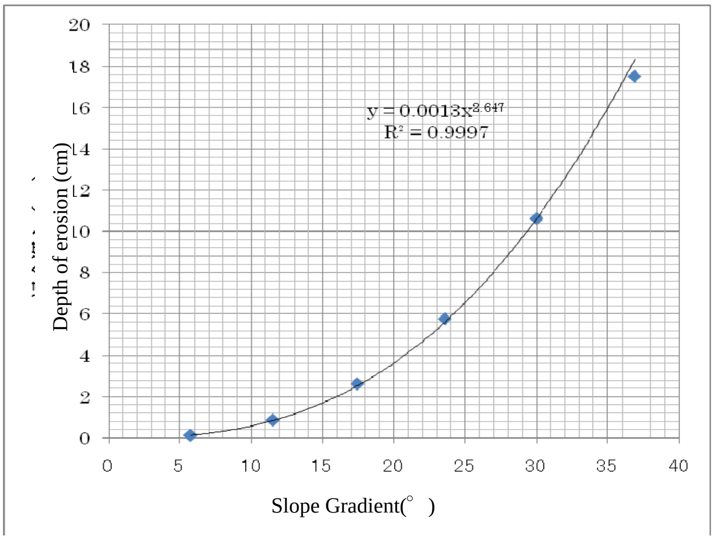


Figure 1.50 **Specific discharge of Sediment (m3/km2/1mm)&(m3/km2)**

Source: JICA study team

d) Soil erosion and slope gradient

According to Measurements in Jinzukawa River basin, it is clear that the annual erosion depth is proportionate to slope gradient mainly, so erosion depth is larger in the steeper slope. [Kazuo Ashida, Tamotsu Takahashi, Tomiaki Sawada, S60.4] The relationship between slope angle and erosion depth are as shown to below (Refer to ***Figure 1.51***) from these measured data in this study. The classification of inclination of the basin was made and using these data, weighting for slope gradient and soil erosion were conduct (Refer to ***Table 1.21***).



Source: JICA study team based on

Figure 1.51 **Relationship between slope gradient and annual erosion depth**

Table 1.21 **The weighting of erosion by the slope gradient**

Slope gradient(dgree)	Area (km2)	Percentage (%)	Weight coefficient
0-2	335.24	5%	1
2-15	2065.31	32%	1
15-35	1854.42	29%	6
35-	2155.05	34%	59
Total	6410.02	100%	

Source: JICA study team

e) Specific discharge of sediment around the Poechos dam

From this result, the sediment volume by 50 mm rainfall are as shown in ***Table 1.22***.

Table 1.22 **Sediment Volume by 50mm Rainfall due to Slope Gradient**

Slope gradient(dgree)	Sediment volume by 50mm rainfall
0-15°	3.4m3/km^2
15-35°	21.2m3/km^2
35°	199.5m3/km^2

Source: JICA study team

f) Sediment volume in other basins

Possibility of application sediment volume in the Poechos dam to other basins were considered. Ii is said that sediment volume greatly depend on the geological. Specific discharge of sediment due to the difference in geology are as shown ***Table 1.23***. Volcanic Rocks are distributed around Poechos the dam, while granitic and andesitic rocks are mainly distributed around the basins of Cañete, Chincha, Pisco, and Yauca. According to the table 1.4.10, Specific discharge of sediment in the 4 basins of Cañete, Chincha, Pisco and Yauca is between 60% and 75% compared with Chira. So it is assumed that Specific discharge of sediment in the other 4 basins without Chira is 75% of Chira, as shown in ***Table 1.24***.

Table 1.23 **Specific Discharge of Sediment due to Difference in Geology**

Basin classification	Geology	Specific discharge of sediment by 1 flood
Debris flow zone	Granic area	50,000～150,000m3/km2/1 flood
	Volcanic ejection area	80,000～200,000m3/km2/1 flood
	Tertiary area	40,000～100,000m3/km2/1 flood
	Crushed zone	100,000～200,000m3/km2/1 flood
	Otheir area	30,000～800,000m3/km2/1 flood
Traction Zone	Granic area	45,000～60,000m3/km2/1flood
	Volcanic ejection area	60,000～80,000m3/km2/1 flood
	Tertiary area	40,000～50,000m3/km2/1 flood
	Crushed zone	100,000～125,000m3/km2/1 flood
	Otheir area	20,000～30,000m3/km2/1 flood

0.5 times is used when the watershed area is 10 times the average, when 1 / 10 can use up to 3 times.
Source: JICA Study Team based on the Revised Draft Technical Standards Sediment Control of the Ministry of Construction S61

Table 1.24 **Specific Discharge of Sediment in 4 Basin without Chira Basin**

Slope Gradient	Sediment transport volume by 50mm rainfall
0-15°	$2.5\text{m}^3/\text{km}^2$
15-35°	$15.9\text{m}^3/\text{km}^2$
35°	$149.6\text{m}^3/\text{km}^2$

Source : JICA study team

g) Bedload volume calculated from the flow volume

If movable sediment is entered into the river and the possible sediment flow to the downstream by the river flow, it is possible to estimate the maximum possible sediment is discharged from the formula for sediment transport volume. The maximum movable sediment were estimated by MPM (Meyer Peter and Müller) equation that is most appropriate for mountain areas.

$$\Phi_B = 8(\tau_{*e} - 0.047)^{3/2}$$
$$\tau_{*e} = u_{*e}^{\ 2} / (sgd)$$
$$u_{*e} = (n_b / n)^{3/4} u_*$$

Where
τ*e : Critical traction force
U*c : Critical friction velocity

U* ：Friction velocity
Sg **:** Gravitational acceleration
D ：Average particle diameter

The conditions of the input data are as shown in ***Table 1.25***.

Table 1.25 **Input Data of each River**

Input condition	Cañete	Chincha	Pisco	Yauca	Camana Majes
Average grain diameter（cm）※1	1cm,10cm	3.8cm,5cm	1.2cm,3.8cm	0.9cm,6.3cm	1.3cm,6.3cm,
Density of sand gravel（σ）g/cm3	2.6	2.6	2.6	2.6	2.6
Density of water（ρ）g/cm3	1	1	1	1	1
Coeficiente de Manning (n)	0.03	0.03	0.03	0.03	0.03
Pendiente del lecho (1/I)※2	45	63	76	60	66
Ancho del rio (B)(m）※2	75	150	100	150	30

※1 The average diameter calculation was based on the results of a research laboratory (D50) made with material taken from the riverbed. The estimation was conducted with 2 results that are all sample analysis and under 150mm sample analysis.
※2 From the results of surveying activities

Source : JICA study team

Given the conditions above, the possible sediment volume was calculated from the flow volume obtained through the hydrologic analysis (Annex-1)

Table 1.26 **Sediment Volume Calculated by the Method of Flowing Soil**

Basin	Retern period	Max Discharge (m3/s)	Calculation result	
Cañete	Grain diameter		φ1cm	φ10cm
	The probability flow in 10 years	408	50,541	21,814
	The probability flow in 25 years	822	75,016	39,466
	The probability flow in 50 years	1496	111,963	67,443
	The probability flow in 100 years	2175	127,615	80,635
Chincha	Grain diameter		φ3.8cm	φ5cm
	The probability flow in 10 years	472	135,501	87,276
	The probability flow in 25 years	579.6	187,323	131,099
	The probability flow in 50 years	806.7	214,464	154,300
	The probability flow in 100 years	916.8	270,144	203,437
Pisco	Grain diameter		φ1.2cm	φ3.8cm
	The probability flow in 10 years	287	123,893	52,008
	The probability flow in 25 years	451	171,511	88,622
	The probability flow in 50 years	688	196,456	113,136
	The probability flow in 100 years	855	247,655	130,429
Yauca	Grain diameter		φ0.9cm	φ6.3cm
	The probability flow in 10 years	36.5	22,238	1

	The probability flow in 25 years	90	44,212	4,497
	The probability flow in 50 years	167	71,405	16,090
	The probability flow in 100 years	263	111,523	38,267
Camana Majes	Grain diameter		Φ1.3cm	φ6.3cm
	The probability flow in 10 years	1,166	459,173	384,896
	The probability flow in 25 years	1,921	719,715	631,326
	The probability flow in 50 years	2,658	943,849	846,222
	The probability flow in 100 years	3,562	1,192,347	1,087,202

Source : JICA study team

(1) The Sediment Volume in each Basin

Calculated for each basin, all 3 types of sediment volume was estimated for each basin. In all basins, the order of sediment volume are Case 2, Case 1, Case 3 and Case 4, in that order.

Case1: The sediment volume of sediment estimated from the flow (Grain diameter is D50 in original)

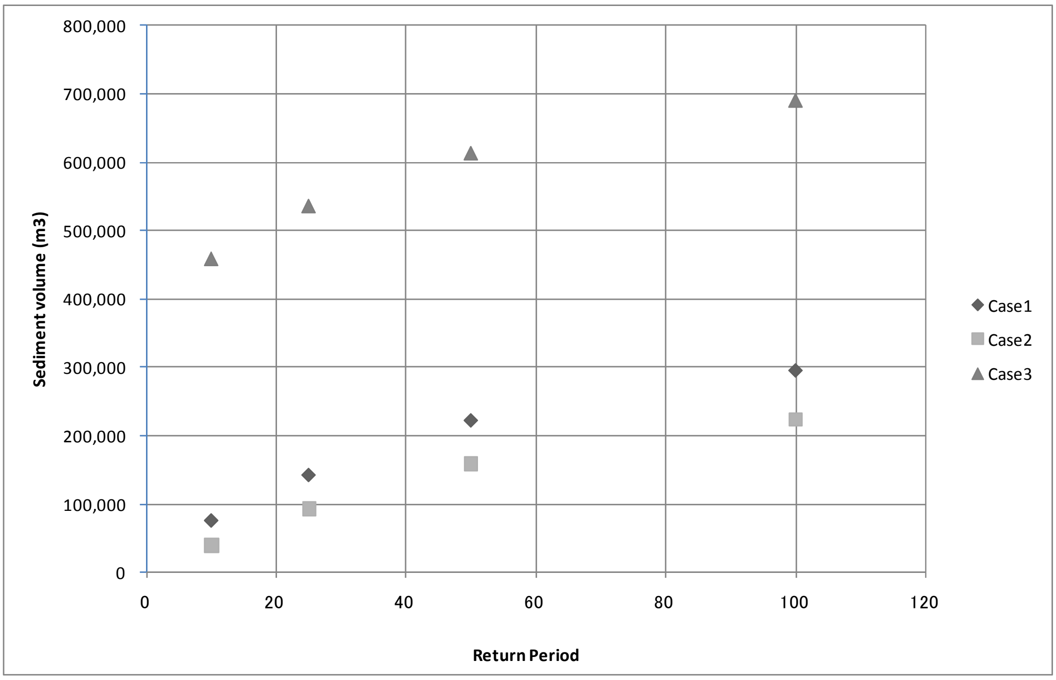
Case2: The sediment volume of sediment estimated from the flow (Grain diameter is D50 in max 150mm)

Case3: The sediment volume calculated by Poechosu dam specific discharge of sediment

Case 4: The movable sediment volume

(a) Cañete basin

The sediment yield volume in Cañete basin is as shown below. The sediment volume of Case 3 is two times of the sediment volume of Case2. In Cases 1 and 2, the diameter of the particles is different about 10 times, but it is not a significant difference in the sediment volume due to abundant.



Source : JICA study team

Figure 1.52 **Sediment Volume in Cañete Basin**

Case4 : The movable sediment volume 253,743,829m3

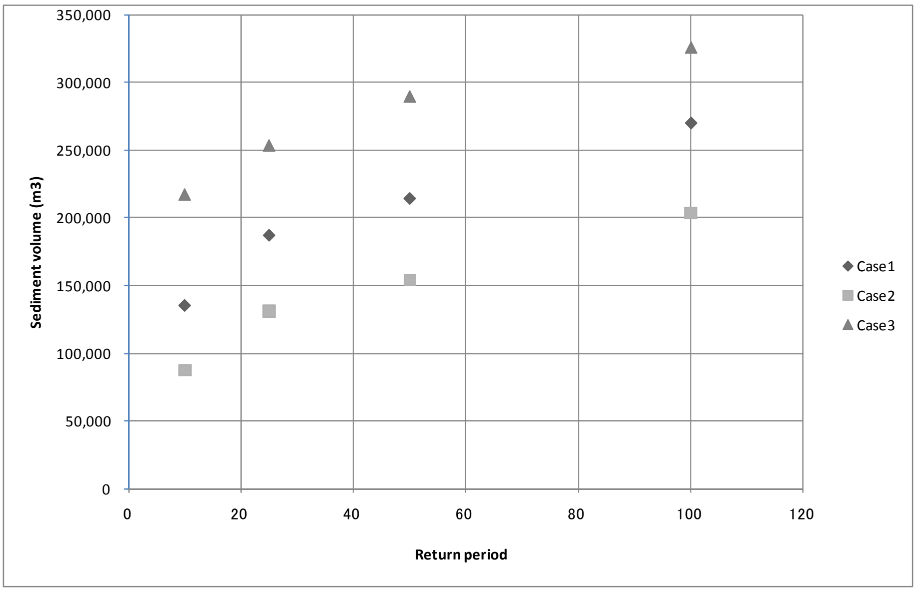
Table 1.27 **Sediment volume in Cañete basin**

Reteurn perid	Case1	Case2	Case3	Case4
	The sediment volume estimated from the flow(Grain diameter is D50 in original) φ1cm	The sediment volume estimated from the flow(Grain diameter is D50 in max 150mm) φ10cm	The sediment volume calculated by Poechosu dam specific discharge of sediment	The movable sediment volume
10	76,836	39,817	459,519	253,743,830
25	143,457	93,392	536,106	253,743,830
50	223,142	159,295	612,693	253,743,830
100	296,170	224,433	689,279	253,743,830

Source : JICA study team Unit: m3

(b) Chincha basin

The sediment volume in Chincha basin is as shown below. The sediment volume of Case 3 is 1.3 - 1.5times of one of Case1 and Case2. There is a difference of about 1.3 times in Case 1 and Case 2. This is consistent with the diameter of the particles due to the difference of diameter.



Source : JICA study team

Figure 1.53 **Sediment volume in Chincha Basin**

Case4: The movable sediment volume 156,351,611m3

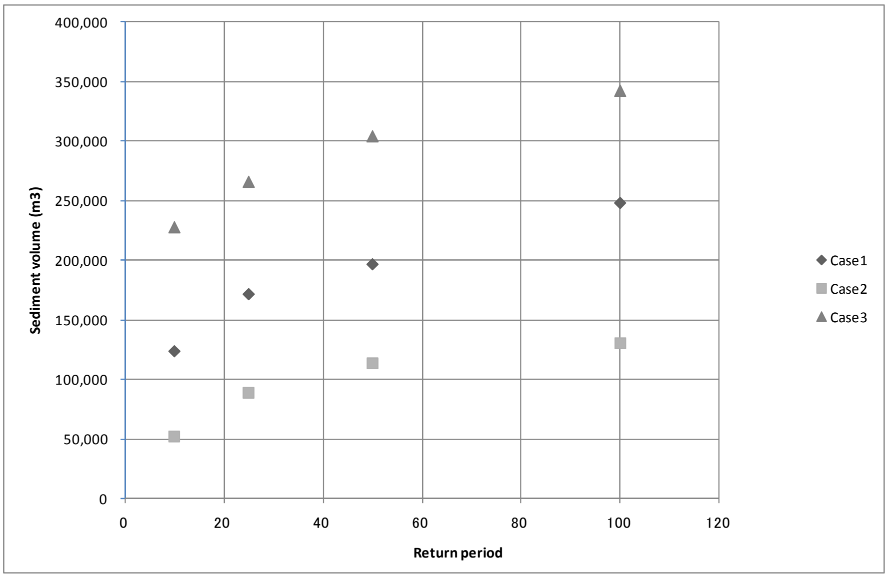
Table 1.28 **Sediment volume in Chincha basin**

Reteurn perid	Case1	Case2	Case3	Case4
	The sediment volume estimated from the flow(Grain diameter is D50 in original) φ3.8cm	The sediment volume estimated from the flow(Grain diameter is D50 in max 150mm) φ5cm	The sediment volume calculated by Poechosu dam specific discharge of sediment	The movable sediment volume
10	135,501	87,276	216,832	156,351,611
25	187,323	131,099	252,970	156,351,611
50	214,464	154,300	289,109	156,351,611
100	270,144	203,437	325,247	156,351,611

Source : JICA study team Unit: m3

(c) Pisco Basin

The production sediment volume in Pisco Basin is as shown below. The sediment volume of Case3 is about 1.5 ~ 2.0 times of case 1 and case 2. In Cases 1 and 2, the difference is about two times.



Source : JICA study team

Figure 1.54 **Sediment yield Volume in Pisco Basin**

Case 4: The movable sediment volume 241,858,551m3

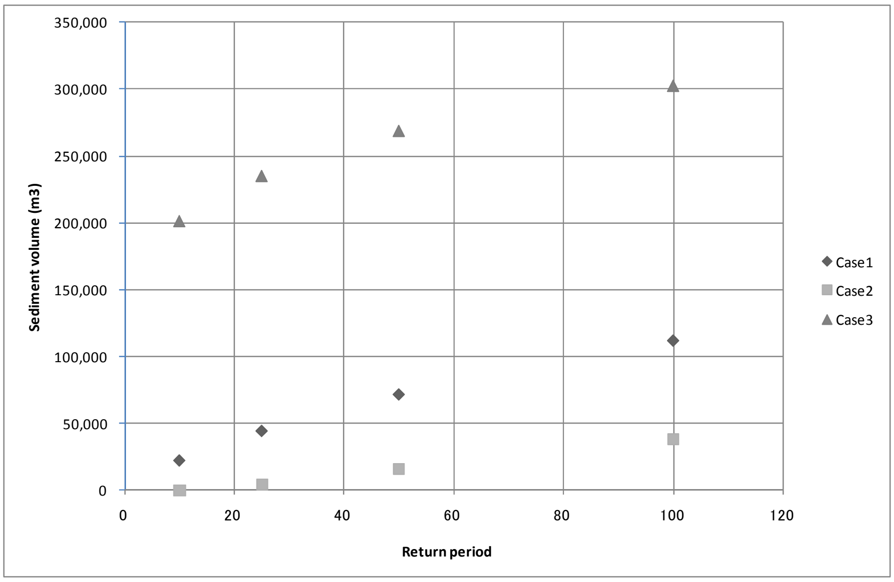
Table 1.29 **Sediment Yield in Pisco Basin**

Reteurn perid	Case1	Case2	Case3	Case4
	The sediment volume estimated from the flow(Grain diameter is D50 in original) φ1.2cm	The sediment volume estimated from the flow(Grain diameter is D50 in max 150mm) Φ3.8cm	The sediment volume calculated by Poechosu dam specific discharge of sediment	The movable sediment volume
10	123,893	52,008	227,803	241,858,551
25	171,511	88,622	265,770	241,858,551
50	196,456	113,136	303,737	241,858,551
100	247,655	130,429	341,704	241,858,551

Source : JICA study team Unit: m3

(d) Yauca Basin

The sediment volume in Yauca basin is as shown below. The sediment volume of Case 3 is about three – six times of the case 1 and case 2. In cases 1 and 2, the difference is about three times.



Source : JICA study team

Figure 1.55 **Sediment Volume in Yauca Basin**

Case 4: The movable sediment volume 171,793,215m3

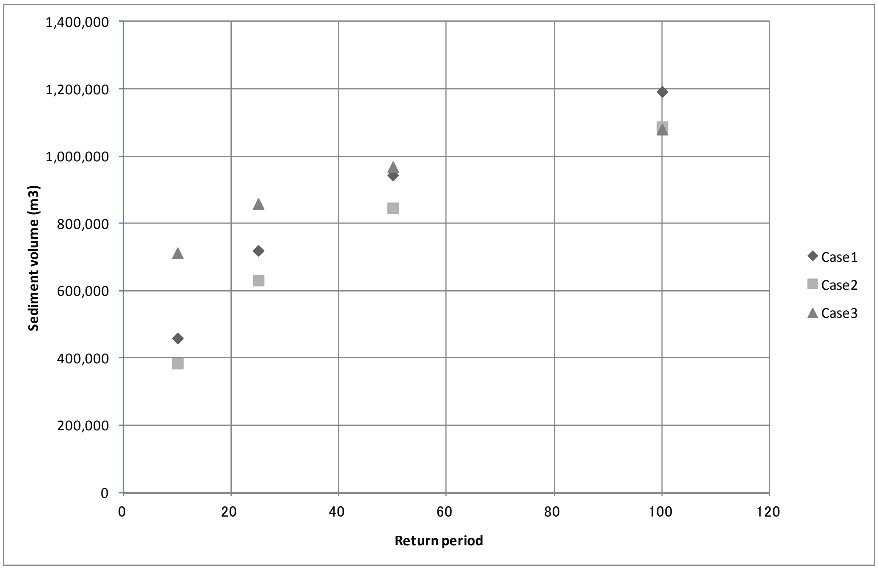
Table 1.30 **Sediment volume in Yauca Basin**

Reteurn perid	Case1	Case2	Case3	Case4
	The sediment volume estimated from the flow(Grain diameter is D50 in original) φ0.9cm	The sediment volume estimated from the flow(Grain diameter is D50 in max 150mm) Φ6.3cm	The sediment volume calculated by Poechosu dam specific discharge of sediment	The movable sediment volume
10	22,238	1	201,568	171,793,215
25	44,212	4,497	235,162	171,793,215
50	71,405	16,090	268,757	171,793,215
100	111,523	38,267	302,352	171,793,215

Source : JICA study team Unit: m3

(e) Camana-Majes basin

The sediment volume in the Camana-Majes basin is as shown below. The sediment volume of case 1, 2 and 3 is similar. This is due to large basin and much flow volume.



Source : JICA study team

Figure 1.56 **Sediment Volume in Yauca Basin**

Case 4: The movable sediment volume 728,677693 m3

Table 1.31 **Sediment Volume in Yauca Basin**

Reteurn perid	Case1	Case2	Case3	Case4
	The sediment volume estimated from the flow(Grain diameter is D50 in original) φ0.9cm	The sediment volume estimated from the flow(Grain diameter is D50 in max 150mm) Φ6.3cm	The sediment volume calculated by Ponchos dam specific discharge of sediment	The movable sediment volume
10	459,173	384,896	712,945	728,677,693
25	719,715	631,326	858,829	728,677,693
50	943,849	846,222	968,636	728,677,693
100	1,192,347	1,087,202	1,079,822	728,677,693

Source : JICA study team Unit: m3

(f) Sediment volume in each basin

Sediment volume of four basin were calculated for each basin. It is judged that Case 1 and case 2 are best suited for sediment volume in each basin by one rainfall. In relation to the diameter of the particles, it is said that a test particle size distribution for the total material is most appropriate river to express the material properties of the river. From the above, the sediment volume in each basin is as shown in ***Table 1.32***.

Table 1.32 **Sediment Volume in each Basin**

Return period	Cañete basin	Chincha basin	Pisco basin	Yauca basin	Camana Majes basin
10	39,817	87,276	52,008	1	384,896
25	93,392	131,099	88,622	4,497	631,326
50	159,295	154,300	113,136	16,090	846,222
100	224,433	203,437	130,429	38,267	1,087,202

Source : JICA study team unit: m3

1.5 Classification of Erodible Areas

The most erodible areas of each basin were determined from the slope gradient and riverbed inclination. First we analyzed the relation between the slope gradient and riverbed inclination for each basin. The both tendency is virtually similar, so The Classification of erodible areas in each basin were determined by riverbed inclination.

The debris flow areas where riverbed inclination is larger than one third. are areas where the slope of the channel is greater than 1/3. The most erodible areas have been identified according to the classification shown in ***Table 1.33***. The results are shown in ***Figure 1.57*** to ***Figure 1.62*** and ***Table 1.34***. In Cañete and Chincha basins there are large erodible areas, while in Chira and Yauca basins erodible areas are less.

Table 1.33 **Classification of Erosion**

Clasifi-cation	Degree of erosion	Conditions
A	Strong erosion	The length of the channel has slopes greater than one third is over 20%.
B	Moderate erosion	The length of the channel has slopes greater than one third is between 10% and 20%
C	Week erosion	The length of the channel has slopes greater than one third is less than 10%

Source : JICA study team

Table 1.34 **Characteristics of each River Erosion**

Basin	A		B		C		Total
	Area (km2)	Percentage	Area (km2)	Percentage	Area (km2)	Percentage	Area (km^2)
Chira	605	6%	2,115	20%	7,908	74%	10,628
Cañete	2,603	43%	1,702	28%	1,719	29%	6,024
Chincha	1,223	37%	590	18%	1,490	45%	3,304
Pisco	1,013	24%	893	21%	2,365	55%	4,271
Yauca	0	0%	1,385	32%	2,933	68%	4,319
Camana/Majes	2,273	13%	2,050	12%	12,726	75%	17,049

Source : JICA study team

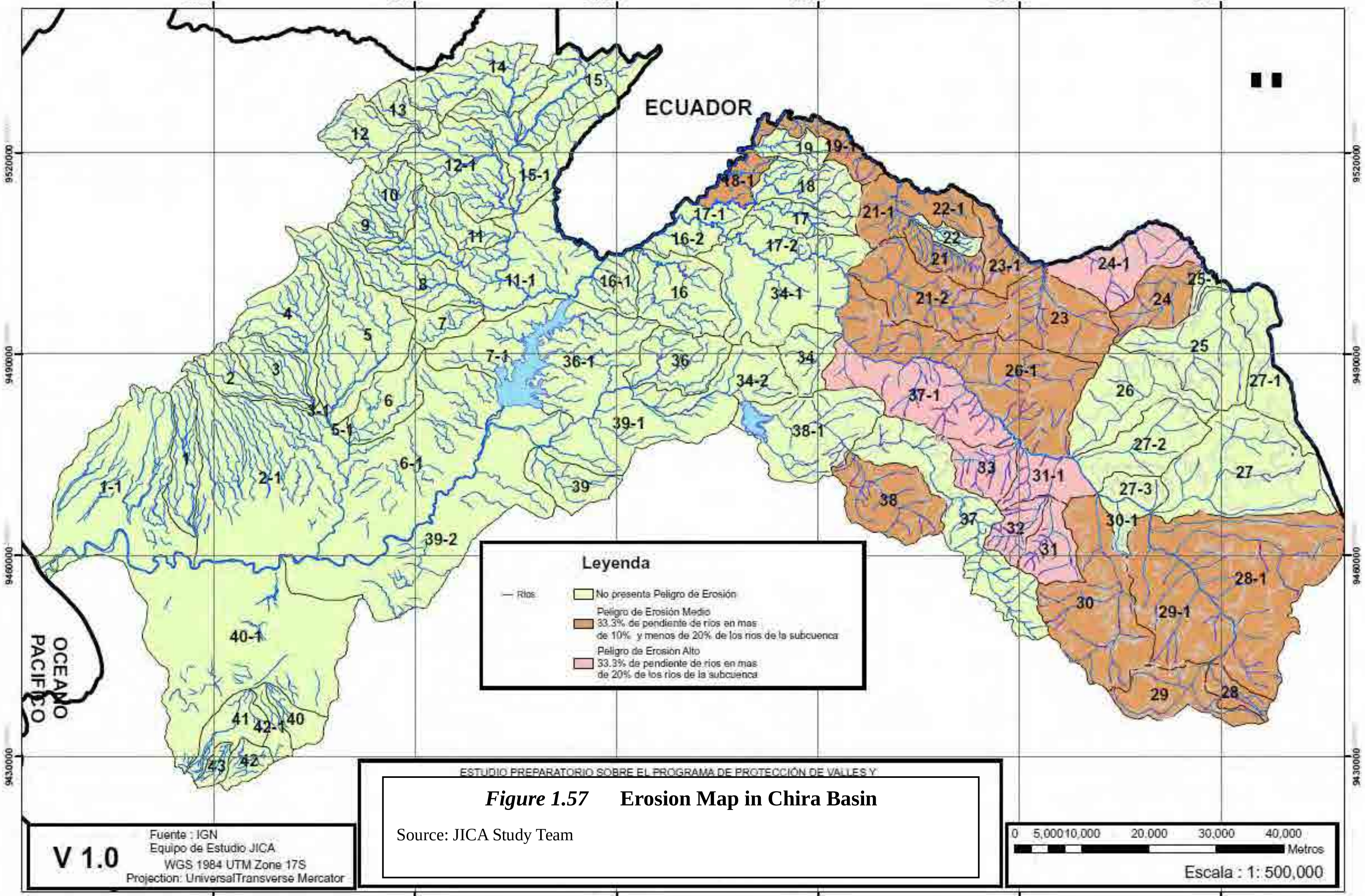
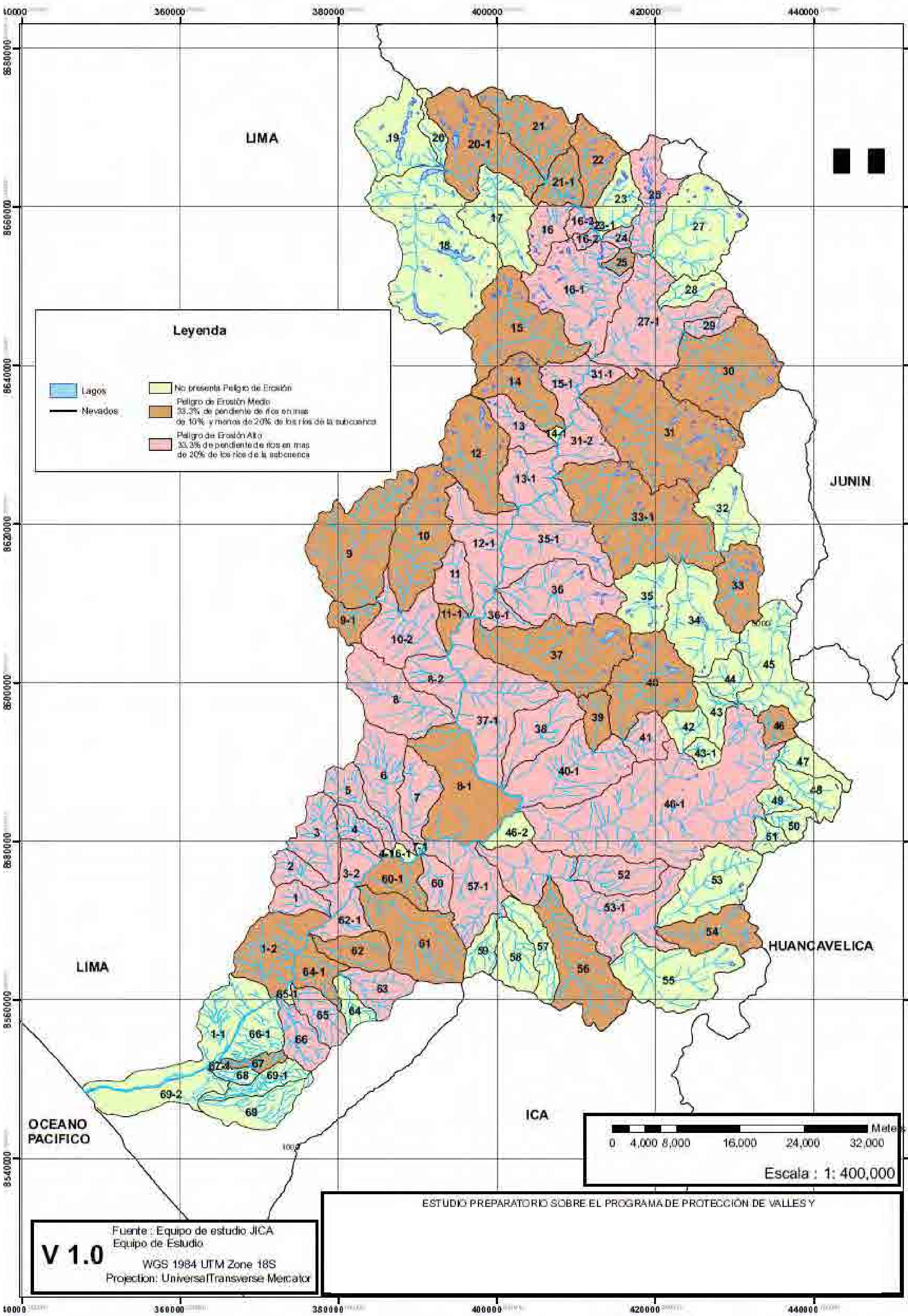


Figure 1.57 **Erosion Map in Chira Basin**

Source: JICA Study Team



Source: JICA Study Team

Figure 1.58 **Erosion Map in Cañete basin**

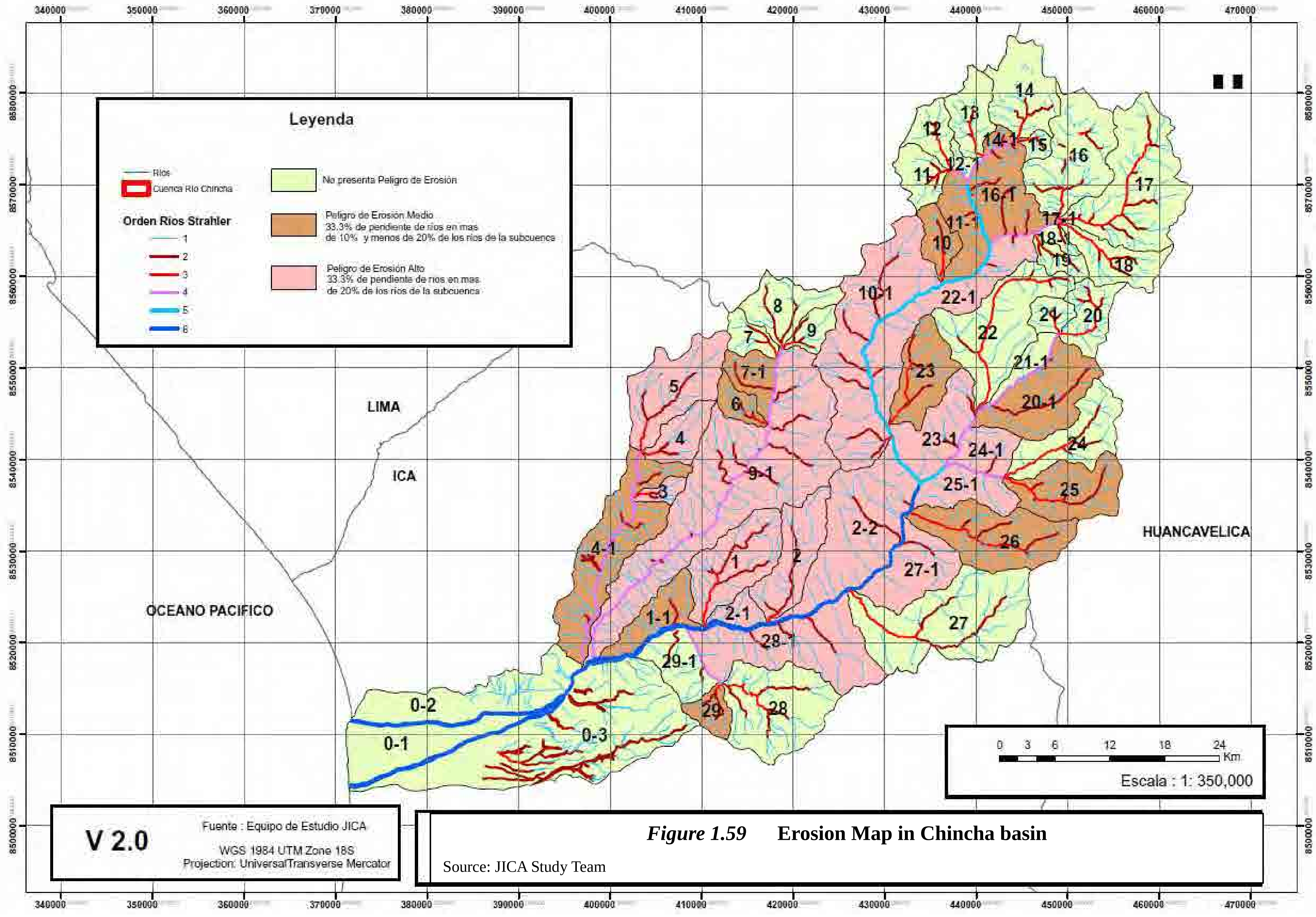


Figure 1.59 **Erosion Map in Chincha basin**

Source: JICA Study Team

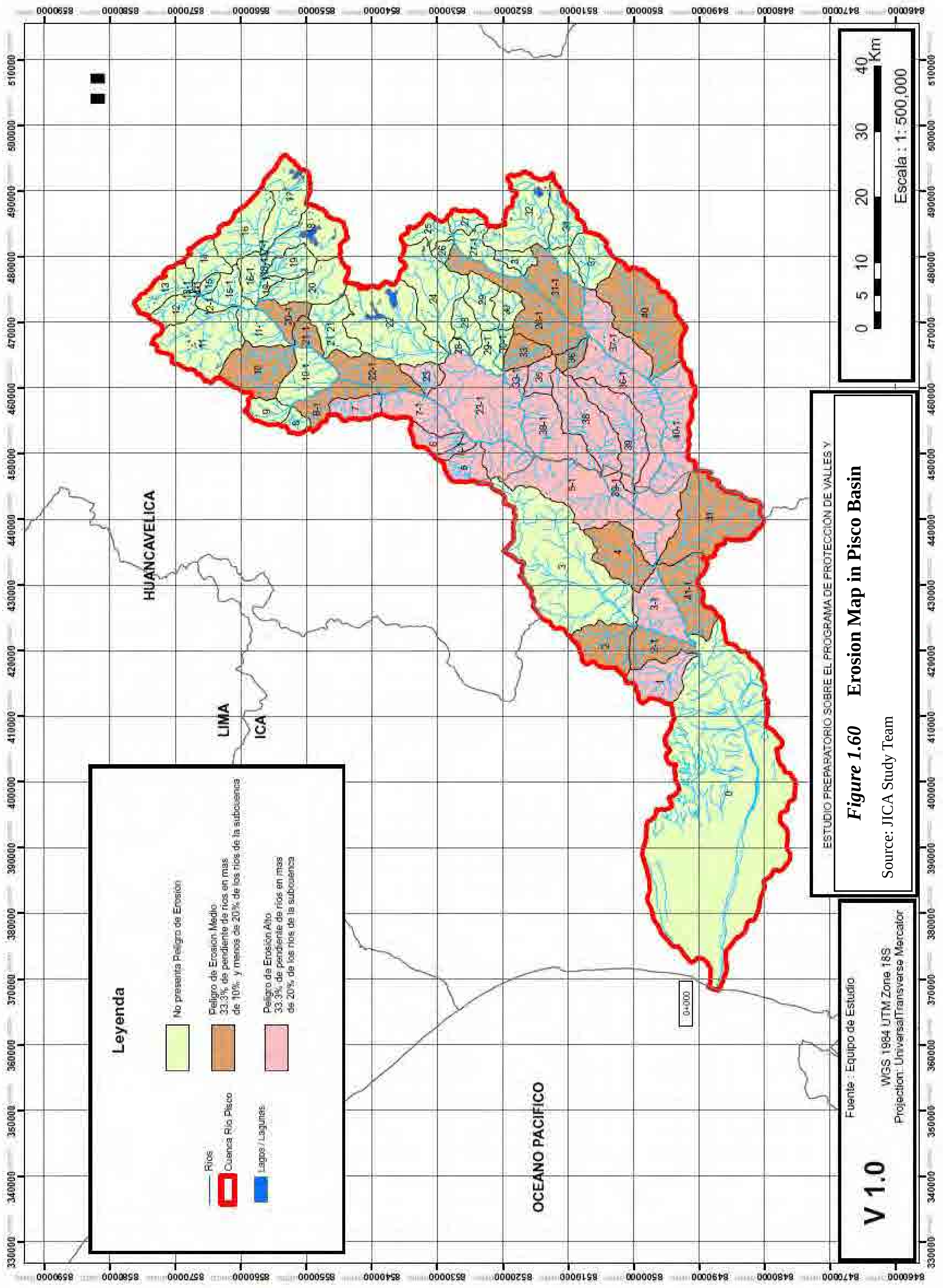
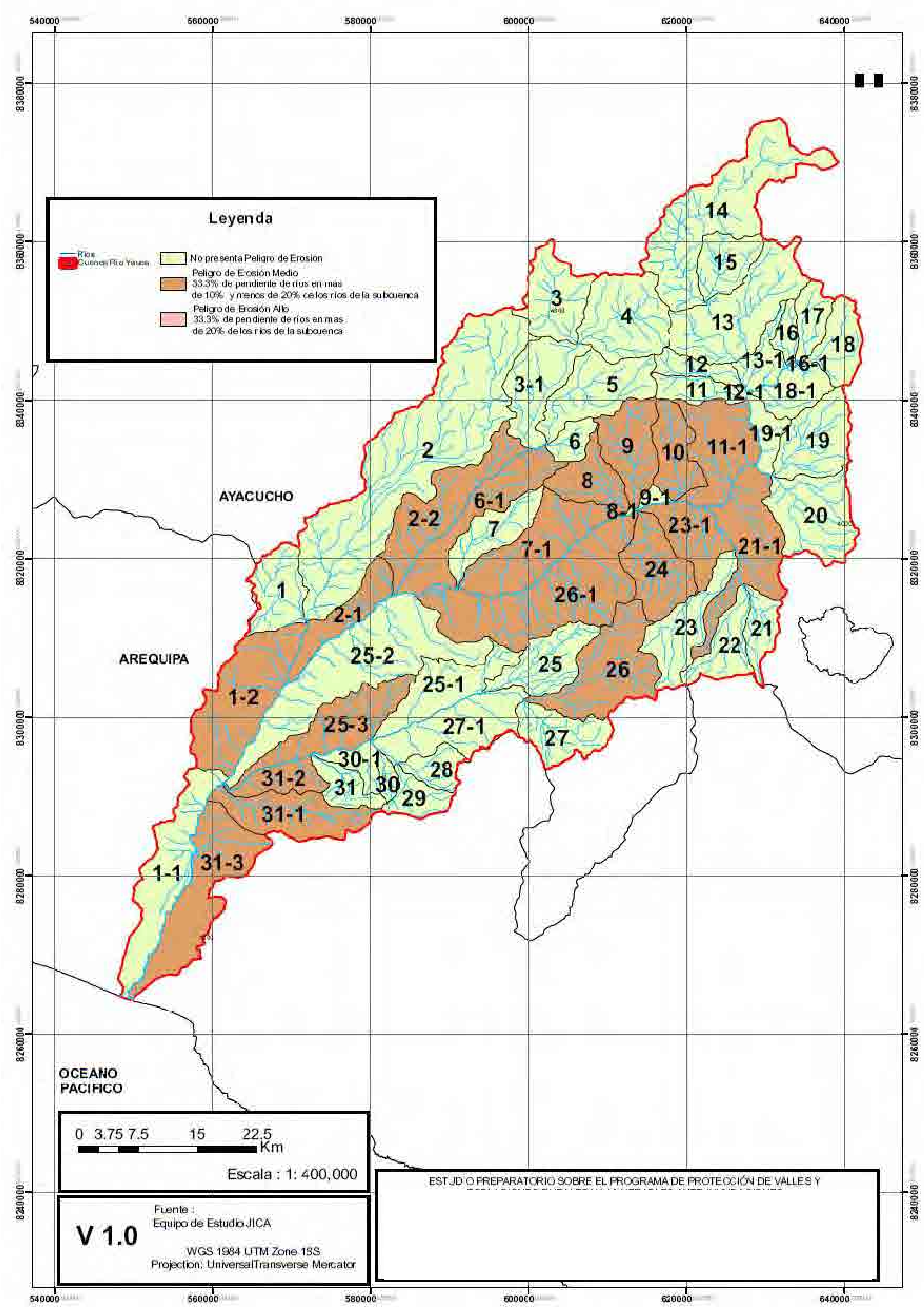


Figure 1.60 **Erosion Map in Pisco Basin**

Source: JICA Study Team



Source: JICA Study Team

Figure 1.61 **Erosion Map in Yauca Basin**

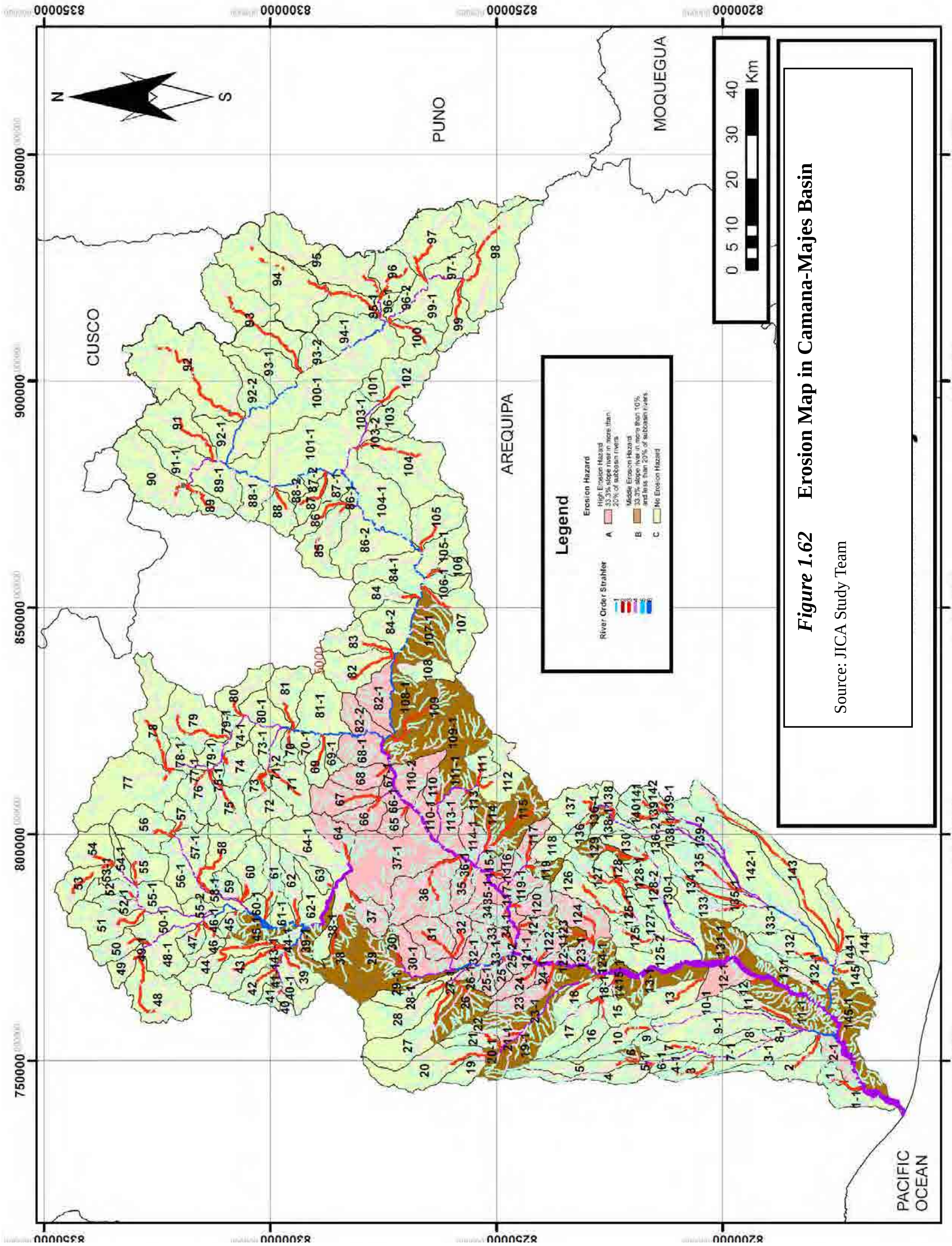


Figure 1.62 **Erosion Map in Camana-Majes Basin**

Source: JICA Study Team

CHAPTER 2 SEDIMENT CONTROL PLAN

2.1 Basic policy

Basic Policy is below:

(1) Relationship of Rainfall and Sediment Transport

- Sediment transport in lower rainfall rather than with return period of 50 years are caused by erosion of the banks and riverbed evolutions (regular year).
- The sediment production from the slopes and debris flows occur in exceptional years by rainfall like El Niño, with a return period of 50 years.

(2) Countermeasures for Ordinary years

It is efficient countermeasures that revetment works that prevent the bank erosion, Groundsel and Bed hill that control riverbed evaluation. It is possible to control sediment discharge that flow in ordinary years by settlement of riverbank and riverbed.

Control regulation of outflow and sediment control by training dike and revetment work should be conducted in the alluvial fans. Also sediment control for downstream should be conducted by settlement flow path that caused by the Groundsel, Bed hill and stream prevention works, and decrease of flow rate

(3) Countermeasures for Rainfall Return Period of 50 years

As countermeasures for rainfall with return period of 50 years, sediment control in the flood season by the check dams that allocated in the erodible areas should be conducted. It is effectual Is more effective to implementation by two methods.

(a) Control of Sediment Production

In flood season, Slope failure that composed by weathered soil occurs by the rainfall. So due to the prevention of slope failure Conservation works on the hillside should be mainly implemented and due to determent of sediment discharge transected structure that settle riverbed should be mainly implemented.

(b) Acquisition and control of sediment

Sediment discharge to the downstream should be prevented by settlement of riverbed and acquisition of sediment discharge by construction of dams in the valley.

Table 2.1 **Components of Sediment Control**

Condition	Ordinary years	Rainfall with return period of 50 years
Condition of Sediment Flow	Bank erosion and riverbed evolution	Bank erosion and riverbed evolution Debris Flow from small valley
Countermeasures	Erosion control: Revetment works Prevention of riverbed evolution : Groundsel, Bed hill	Erosion control: Revetment works Prevention of riverbed evolution: Groundsel, Bed hill Prevention for debris flow: Check dam

Source: JICA Study Team

2.2 Component of Sediment Control

(1) Sediment Control Countermeasures

The control of sediment discharge to downstream that keep the river cross section enable the flood control. The countermeasures for sediment control shown in ***Figure 2.1*** enable sediment control.

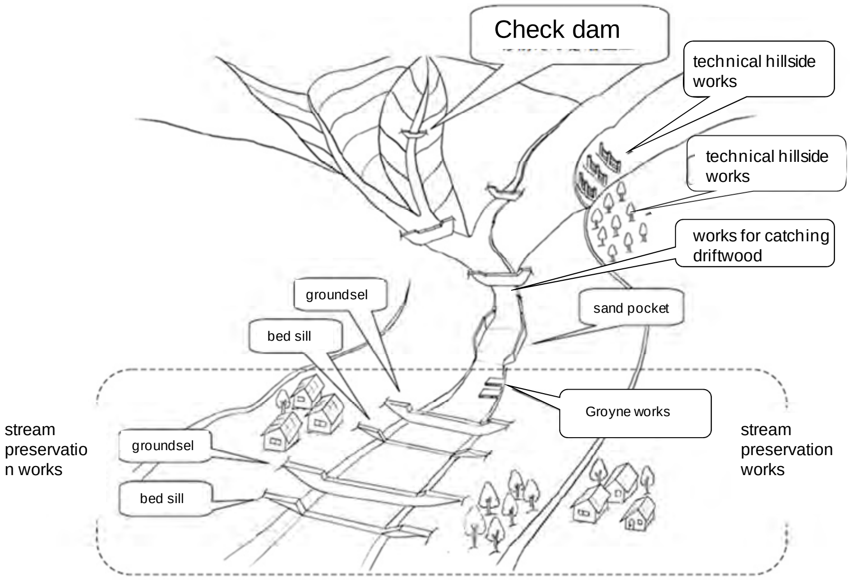


Figure 2.1 **Concept of the Sediment Control**

Source: JICA Study Team

Countermeasures against sediment control are classified as production facilities for sediment control and sediment control in accordance with the objectives. ***Table 2.2***, shows each target and the type of work.

Table 2.2 **Classification of Countermeasures against Sediment Control**

Works of sediment product control They are works which protect mountain slope, river bank and river bed to reduce sediment product in generation source.	Conservation works on the hillside Planting works on the hillside Technical hillside works
	Check dam
	Groundsel
	Bed hill
	Revetment works
	Stream prevention works
Works of sediment flow control They are works which control the sediment that rundown in traction area	Check dam
	Groundsel
	Bed hill
	Groyne works
	Revetment work
	Sand pocket
	Stream preservation works
	Training dike

Source: JICA Study Team

(a) Works of sediment product control

Works of sediment product control are works that protect mountain slope, river bank and river bed to reduce sediment product in generation source.

(2) Conservation Works on the Hillside

Works of sediment product control are classified into three below. The purpose of this works is to control sediment production by implementation of these works independently or in combination.

a) The technical hillside works are that stabilize slopes and prevent erosion on the slopes.

b) The hillside seeing is that installation of vegetation mitigating the surface erosion and surface slope failure in the slope failures and devastated areas.

c) Reinforced earth methods are that reinforce the slopes by the construction of concrete retaining walls and rock bolts.

The technical hillside works are works that stabilize the slope after the cutting and prevent surface erosion due to rainfall by construction of drainage of mountain areas. Also this function is helpful for invitation of vegetation ***Figure 2.2*** shows typical countermeasures.

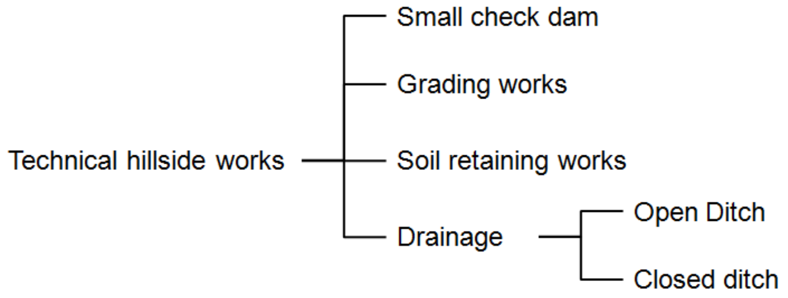


Figure 2.2 **Typical Structures of Technical Hillside Works**

The hillside seeing are works that prevention of erosion and weathering of surface, and recover the vegetation by the installation of the vegetation directly. The hillside seeing seldom grows until prospective figure by the initial construction. So the soils are improved by the installation of an indigenous plant and function of prevention is upgraded gradually.

Figure 2.3 shows typical countermeasures.

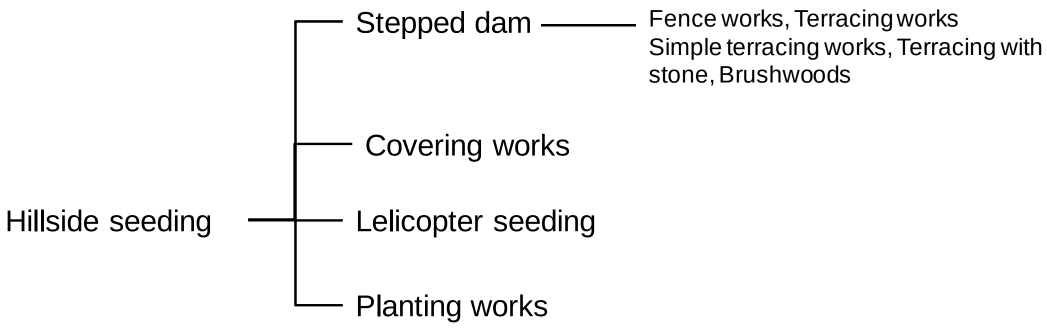


Figure 2.3 **Typical Structures of Hillside Seeding**

(3) Check dams

The purpose of sediment control dams classified sediment product control is below:

a) Prevention and mitigation of the spread and occurrence of slope failure due to settlement foot of the slope
b) Prevention and mitigation erosion of the riverbed length
c) Prevention and mitigation sediment discharge on the riverbed.

In the plan, dimensions suited to the purpose of the allocation of the dams should be selected.
Allocations of the check dams should be determined in condition of expected effect for check dams ,the topography, geology and sediment condition. Allocation of the check dams should be determined below:
The check dams are allocated at downstream of anticipated place of slope failures
The check dams are allocated at downstream of areas with longitudinal erosion
The check dams are allocated at downstream of areas with unstable sediment on the river bed.

(4) Groundsel

Groundsel have the purpose that prevention and mitigation bank erosion and slope failure and stabilization the sediment on the riverbed due to removal of the sediment. Also They have the function to protect the base of revetment. Allocation of Groundsel should be planned in consideration with below:

- ✓ The place that erosion of the bed
- ✓ The purpose is to protect the foot of the structure, downstream of the works
- ✓ In erodible, landslides and slope failure areas, the location should be downstream of their areas.

(5) Bed hill

They have the purposes that prevent erosion, stabilize the riverbed and regulate the flow. The difference between Bed hill and Groundsel is presence or absence of drop. Bed hill do not have the drop and do not have function of mitigation for gradient.

(6) Revetment works

The Revetment works have the purpose that prevent bank erosion and slope failure.
These works should be located at the area needed the protection for erosion and the settlement of the foot of slope, and where there is a high possibility of the landslide and slope failures.

(a) Stream prevention works

Stream prevention works have the purposes that prevent the bank erosion and slope failure due to control of water flow and the riverbed gradient. Stream prevention works consists of combination of Groundsel Bed hill, Revetment works and Groyne works. Stream prevention works should be planned to conserve the landscapes and ecosystems.

(b) Works control sediment transport

Works control sediment transport have the purpose that control the sediment discharge in the traction areas.

(7) Check dam

The check dams as Works control sediment transport have the purpose as below:

- ✓ Control and regulation of sediment discharge
- ✓ Acquisition and mitigation of debris flows

There are two types that are open type and closed type. For planning, types of the check dam, dimensions and structures should be selected with consideration for the purpose of the check dam. The allocation of check dams as Works control sediment transport should be planned at the area where is narrowed area that have wide areas in upper stream and confluence.

(8) Groyne works

Groyne works are structures to prevent bank erosion and slope failure by control of flow and fixation of the river. They have the functions to protect the revetment works by sedimentation on the base of revetments. Groyne works should be planned at downstream areas of mountain streams and turbulent flow areas in alluvial fan.

(9) Sand pockets

Sand pockets are structures to control the bed load by widening the valley and turning down the flow rate. Sand pockets are planned that have the place to sedimentation around the downstream.

(10) Training dike

Training dikes are the structures that guide the debris flows to the safety areas not to do harm the object to be conserved. The debris flows should be acquired at the upper stream. If it is difficult to acquire the debris flows and there are the spaces for sedimentation of debris flows safety, Training dike can be planed. Training dikes are principally artificially-excavated types. And Training dikes have the check dam and sand pocket for acquit ion of the debris flows. If it is difficult to take on the artificially-excavated type, training dike can be planned for guide the debris flows.

The applicability of these measures for this project is as shown in ***Table 2.3***.

Table 2.3 **Applicability of Sediment Control Measures in the this Study Area**

Works of sediment product control		determination
Conservation works on the hillside	In the study area, there are not water and it is difficult to grow the vegetation. For water supply, huge irrigation facilities are needed. Therefore, this is not an appropriate measure.	×
Check dam	These have effects for sediment control. But only after sedimentation, they produce effects. So it takes too long for production effects.	△
Groundsel	These have effects for sediment control. However, effects are limited in the production area.	△
Bed hill	These have effects for sediment control. However, effects are limited in the production area.	△
Revetment works	These have effects for sediment control. However, effects are limited in the production area.	△
Stream prevention works	These have few effects for sediment control. Effects are limited in the production area.	△
Works of sediment flow control		determination
Check dam	These have effects for debris flow.	○
Groundsel	These have effects for sediment control and are suitable.	○
Bed hill	These have effects for sediment control and are suitable.	○
Groyne works	These have effects for sediment control. but location areas are limited.	○
Revetment works	These have effects for sediment control and are suitable for this project.	○
Sand pocket	These have effects for sediment control and are suitable in the alluvial fans.	○
Stream preservation works	These have effects for sediment control. but location areas are limited.	○
Training dike	It is inappropriate because debris flows do not occur in the alluvial fans.	×

Source: JICA Study Team

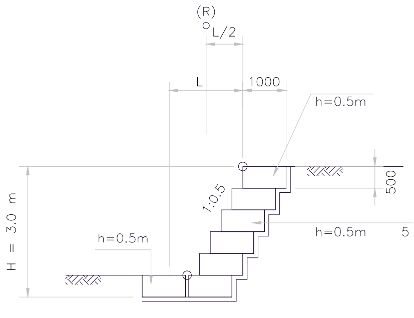
2.3 Quantity and cost for sediment control in this project

Outline designs of revetment works, bed hill and check dams. The plan of location and drawing of the check dams are attached in appendix.

(1) Reventment works and Bed hill

(a) Revetment works

The revetment works are planned at the area where Cenozoic sediment distribute. And approximate quantity and cost are estimated. (Refer to ***Table 2.4***). ***Figure 2.4*** shows the cross section of revetment works. Also ***Figure 2.7*** to ***Figure 2.12*** show the plan of location.



Source: JICA Study Team

Figure 2.4 **Cross Section of Revetment Works**

Table 2.4 **Approximate Quantity and Cost of Revetment Works**

(b) Bed hill

The bed hills are planed every 5km. Approximate quantity and cost of Bed hills are estimated. (refer to ***Table 2.5***). The dimensions of the Bed hill are as follows: Length 40m, Height 3m, Width 0.5m and Volume60m3. (Refer to ***Figure 2.5***).

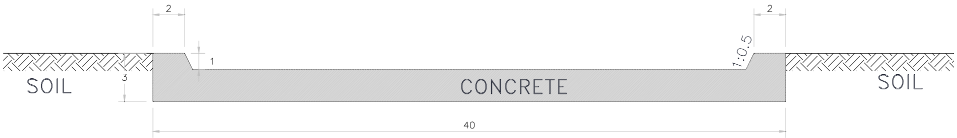


Figure 2.5 **Cross section of Bed sill**

Source:JICA study team

Table 2.5 **Estimated cost of bed girdles**

(2) Check dams

(a) Estimation of design sediment volume

The conditions for estimation the sediment volume is as shown in ***Table 2.6***.

Table 2.6 **Estimation conditions for sediment volume**

Item	Conditions
Design Specifications	Output third-order basin
Layout Size	Rainfall with return period of 50 years Calculation for each small watershed (estimated by the hydrology specialist)
Design sediment volume	Sediment Volume can be transported It is clear that movable sediment volume is larger than Sediment Volume can be transported.

Source: JICA study team

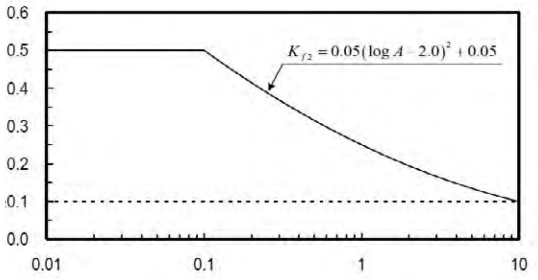
(b) Estimation of sediment volume can be transported

Sediment volume can be transported by the design debris flow is estimated by equation below:

$$V_{dy2} = \frac{10^3 \times P_p \times A}{1-K_v} \times \left(\frac{C_d}{1-C_d} \right) K_{f2}$$

Where;

Vdy2 : Sediment volume can be transported by the design debris flow (m3)
PP : Design volume of precipitation (rainfall with return period of 50 years)
A : Watershed area (km2)
Kv : Porosity (= 0.4)
Cd : Density of debris flows
Kf2 : Discharge coefficient correction
0.05・(log A－2.0)2＋0.05 〔Kf2:Threshold 0.1 Celling 0.5〕



Horizontal axis: The basin area (km2)
Vertical axis: Discharge coefficient

Source: Basic Methodology Guide Project Planning Sediment Control

Figure 2.6 **Outflow Correction Factor**

Density of debris flows (Cd) is estimated by the equation below.

$$C_d = \frac{\rho \tan\theta}{(\sigma - \rho)\ (\tan\phi - \tan\theta)}$$

Where;

Cd : Density of debris flows〔If Cd≧0.9C*is Cd＝0.9C* and If Cd≦ 0.3 is Cd＝0.3〕
C* : Density of the sediment on the river bed(＝0.6)
σ : Density of the gravel (2,600kg/m3)
ρ : Density of the water (1,200kg/m3)
Cd : Internal friction angle (°)〔Generally 35°〕
θ : Riverbed inclination (°) Inclination is measured by GIS

(c) Plan of location of check dams

Detentions and quality of check dams needed for estimated sediment volume are estimated. Meanwhile, it is prerequisite that the sedimentation in the check dams are taken away. Regulation of rivers for sedimentation are calculated on ten % of all. And it is without target that inclination of riverbed is under two degrees. Sediment volume of one check dam is estimated by equation below. In Camana Majes rivers only classification of erosion A and B (Refer to ***Table 1.33***) is target. Because catchment area is large and landform of upper stream is gentle.

$$\text{Sediment volume} = W \cdot H \cdot H \cdot N$$

Where:

W : Average width of sediment
H : height of check damt
1/N : Riverbed inclination sediment length L=H・N

(d) Estimation of the approximate cost

It is assumed that the check dams are constructed by concrete, volume of concrete are estimated, and the approximate cost are estimated.(Refer to ***Table 2.7***) And classification of erosion are conducted, two it is estimated for two cases. One case is target for all area and Two case is target for erodible area. Plans of location are as shown in ***Figure 2.7*** to ***Figure 2.12***. It is assumed that Secondary dam and apron protection are not planed. If they are planed, the approximate cost is 1.5

times. Temporary works such as temporary road are not planed.

Table 2.7 **Quality and the Approximate Costs of Check Dams**

Table 2.8 **Production Sediment Volume and Plan of the Check Dams in Chira Basin**

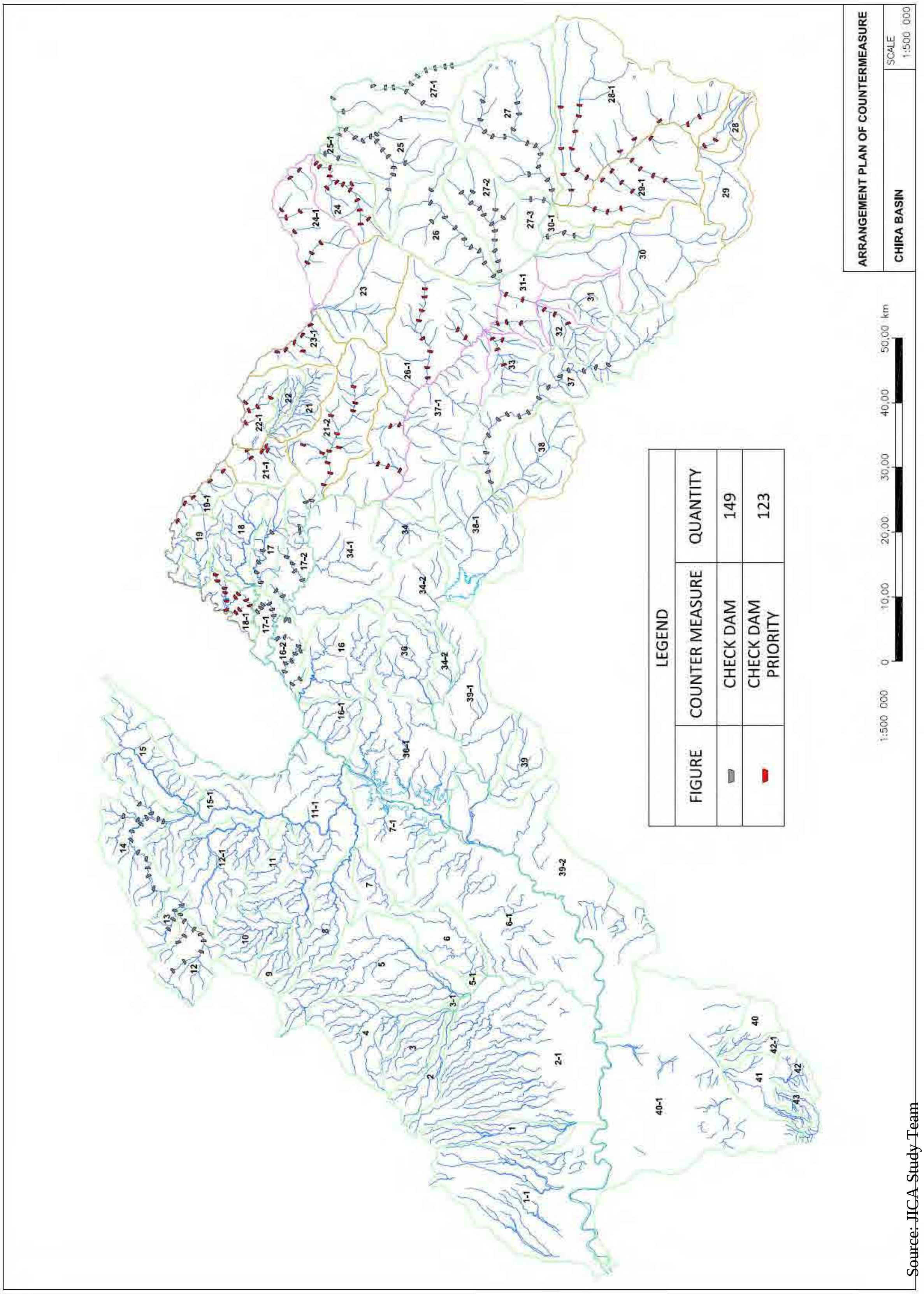
Table 2.9 **Production Sediment Volume and Plan of the Check Dams in Cañete Basin**

Table 2.10 **Production Sediment Volume and Plan of the Check Dams in Chincha Basin**

Table 2.11 **Production Sediment Volume and Plan of the Check Dams in Pisco Basin**

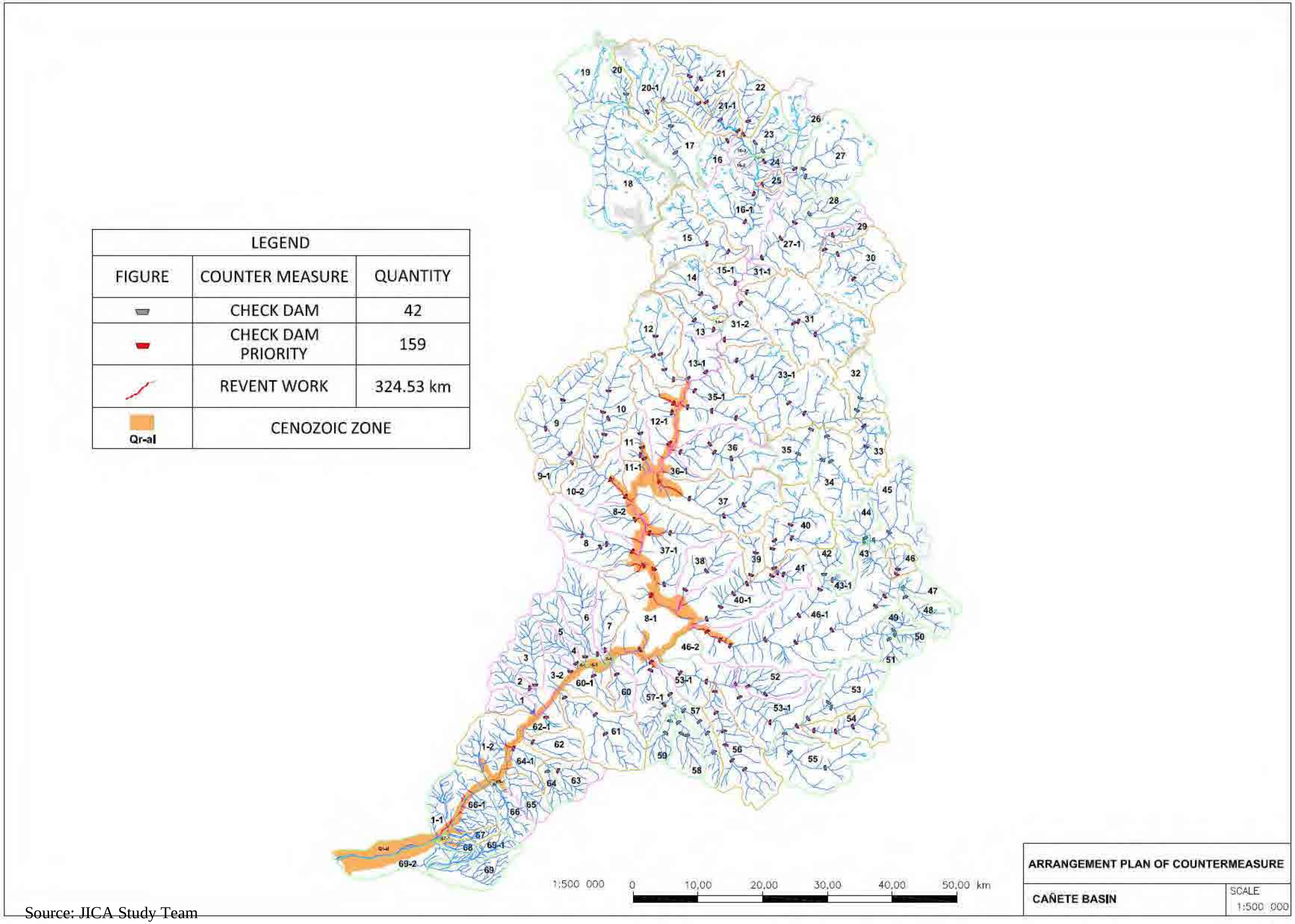
Table 2.12 **Production Sediment Volume and Plan of the Check Dams in Yauca Basin**

Table 2.13 **Production Sediment Volume and Plan of the Check Dams in Camana-Majes Basin**



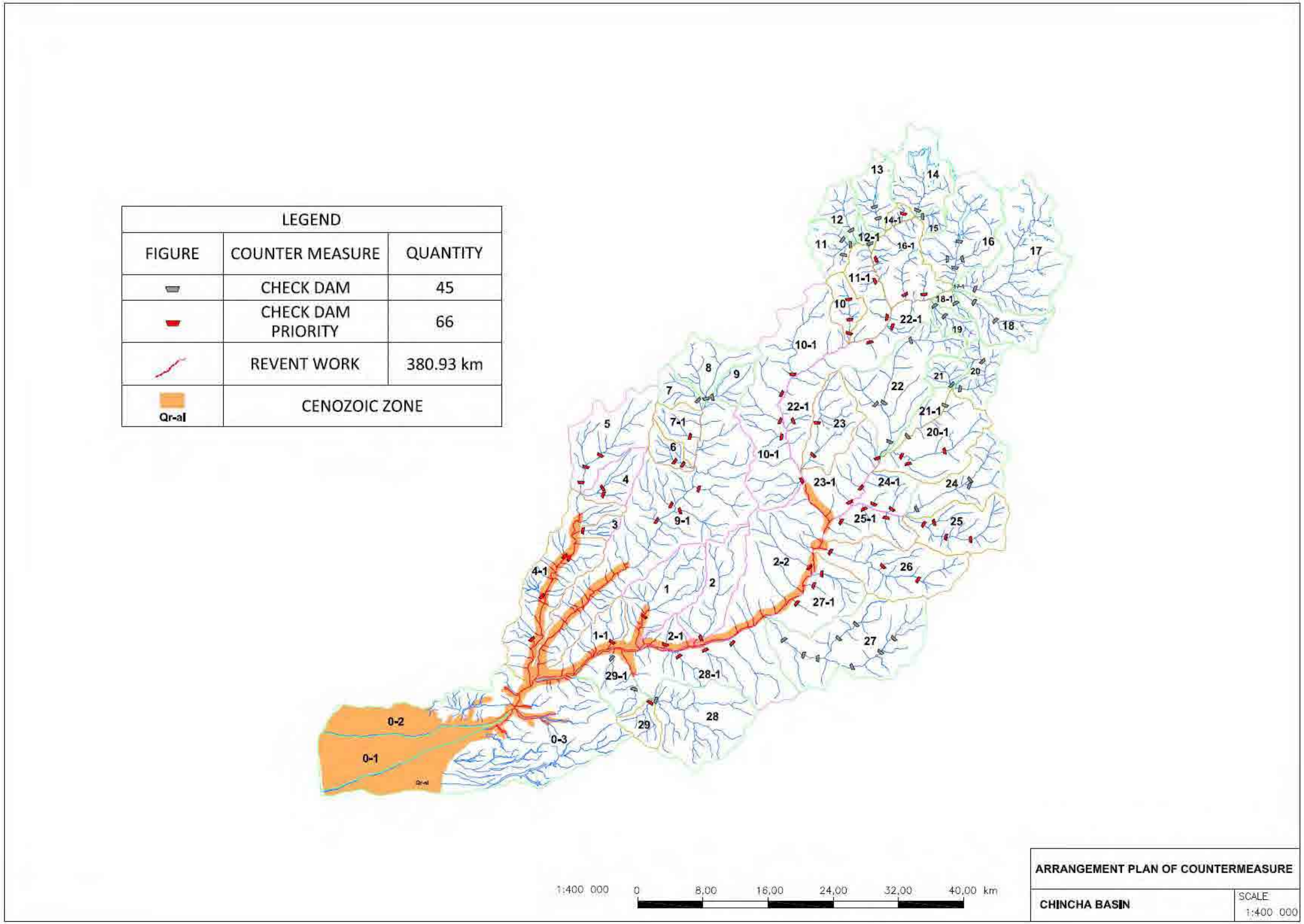
Source: JICA Study Team

Figure 2.7 **Plan of Countermeasure Works in the Chira Basin**



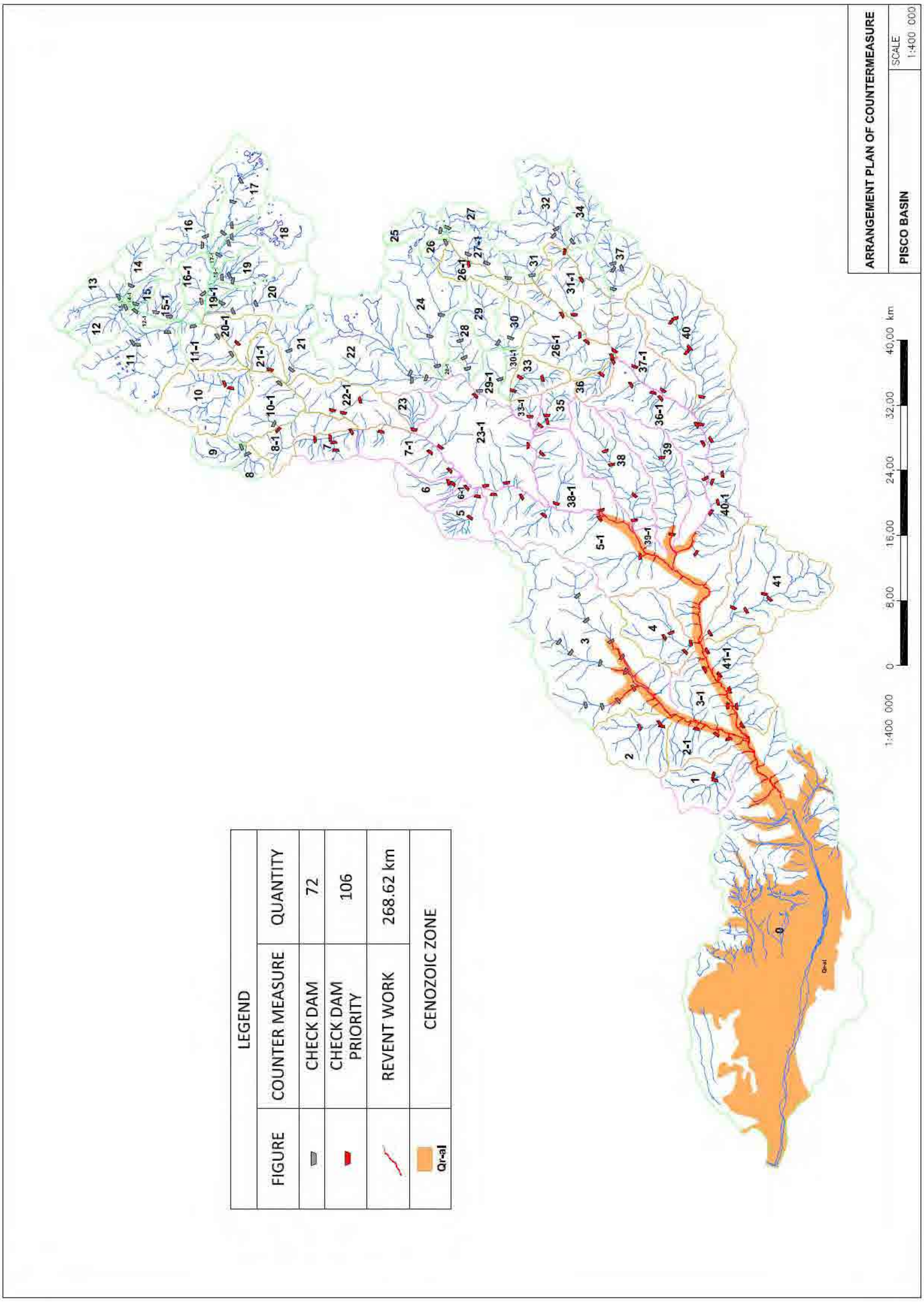
Source: JICA Study Team

Figure 2.8 **Plan of Countermeasure works in the Cañete Basin**



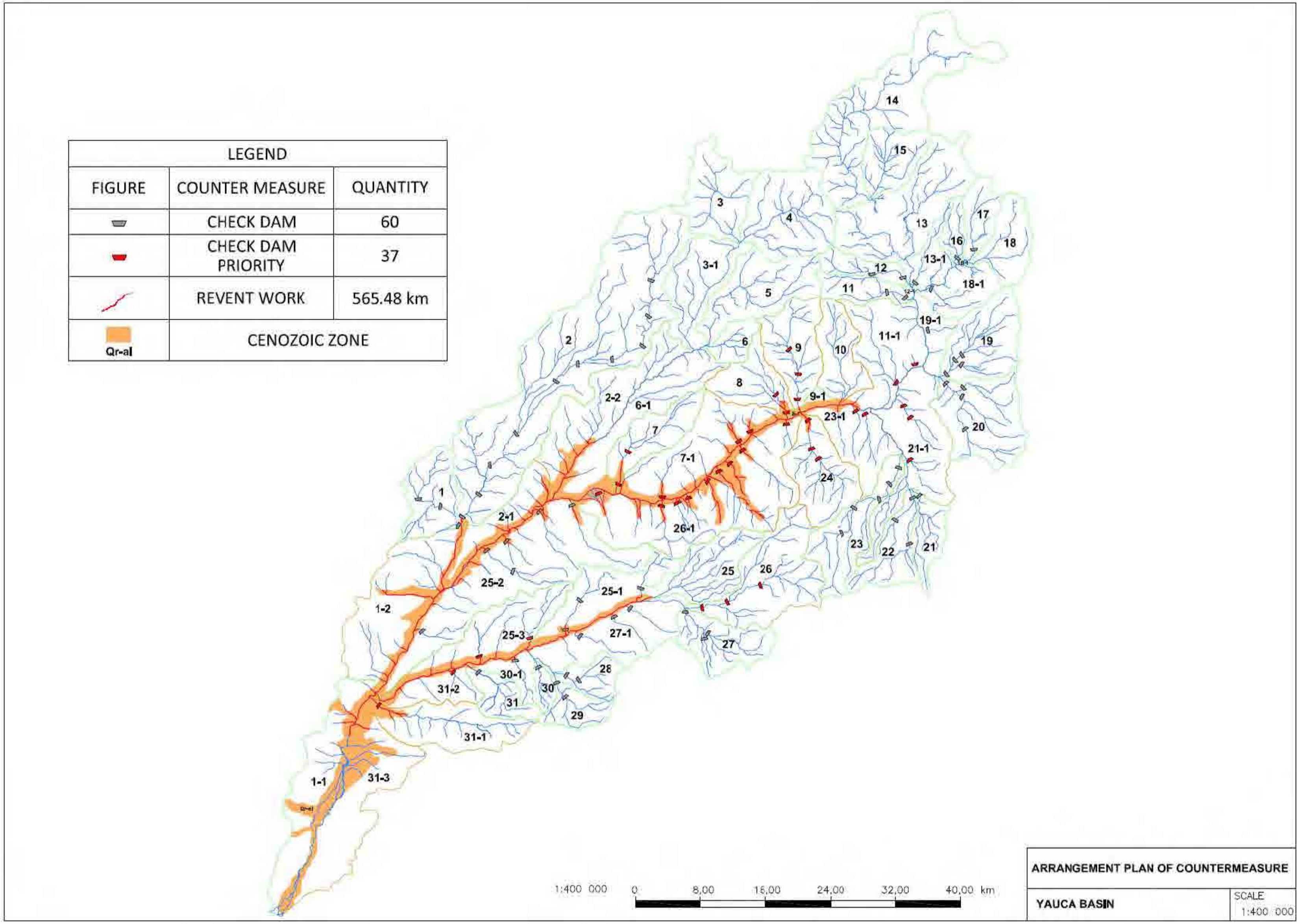
Source: JICA Study Team

Figure 2.9 **Plan of countermeasure works in the Chincha Basin**



Source: JICA Study Team

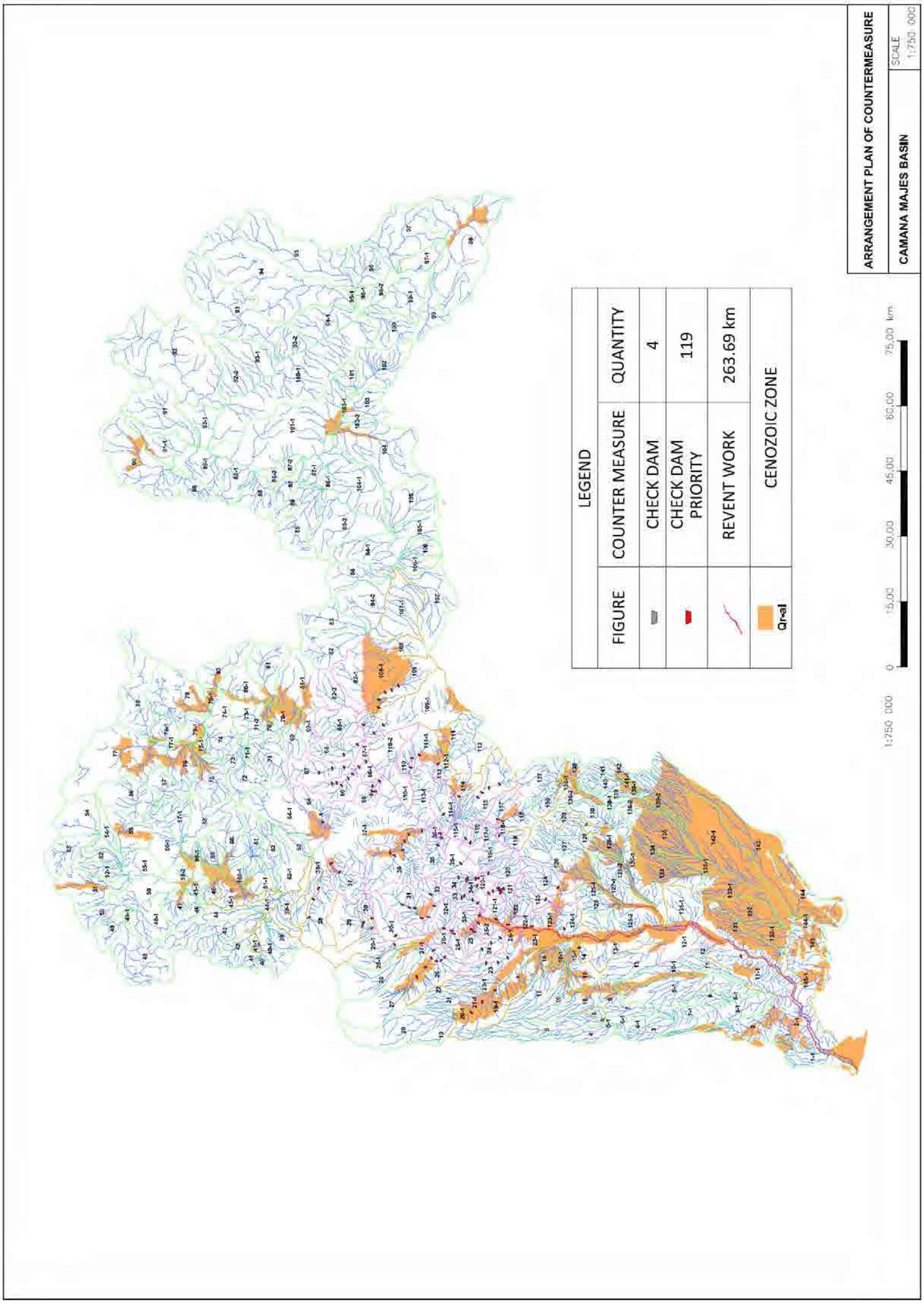
Figure 2.10 **Plan of Countermeasure Works in the Pisco Basin**



LEGEND		
FIGURE	COUNTER MEASURE	QUANTITY
▬	CHECK DAM	60
🟥	CHECK DAM PRIORITY	37
⁄	REVENT WORK	565.48 km
🟧 Qr-al	CENOZOIC ZONE	

Source: JICA Study Team

Figure 2.11 **Plan of countermeasure works in the basin Yaura**



Source: JICA Study Team

Figure 2.12 **Plan of countermeasure works in the Camana Majes Basin**

(3) Sediment Countermeasure in the alluvial fan

It is clear that sediment control works for the all basin need huge investment costs. So it was considered that sediment control works which covers only the alluvial fan. In this process, the results of the analysis of variation of riverbed that are conducted in this study are considered.

(a) Results of the analysis of variation of riverbed

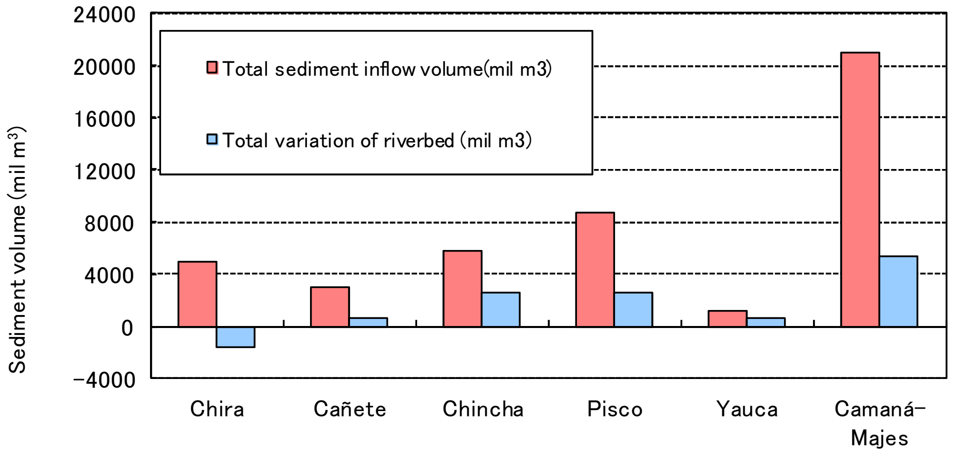
Table 2.14 and ***Figure2.13*** shows t Results of the analysis of variation of riverbed. According to these results, sedimentation in Chincha, Canete, Pisco and Camana&Majes is high. In these rivers sediment control works in alluvial fans should be planned in alluvial fans. However sediment disaster occur gustily and locally, so countermeasure for keeping the river channels suited for monitoring of river variation should be planned for a total extent of the rivers. In Canete basin the Plantanal dam, which is electric-generating dam, were constructed last year (Refer to ***Figure 2.14***). Due to the small reservoir capacity, the dam will be filled with sediment soon, but the control function of sediment will be keeping up. Due to this function, inpact of sediment to the river will be estimate to be diminished.

- The total income sediment volume and of sediment carried to the total amount of variation in bed are higher in rivers Chincha and Pisco, Cañete and compared with Yauca. Consequently, the volume of bed variation is also high in Chincha and Pisco rivers.
- It was estimated that the average height of the riverbed in 50 years will be high in all four rivers except the Chira basin. In particular, the average height of the riverbed in the Chincha basin is 0.5 meters relatively high.

Table 2.14 **Results of Analysis of the Variation in Bed**

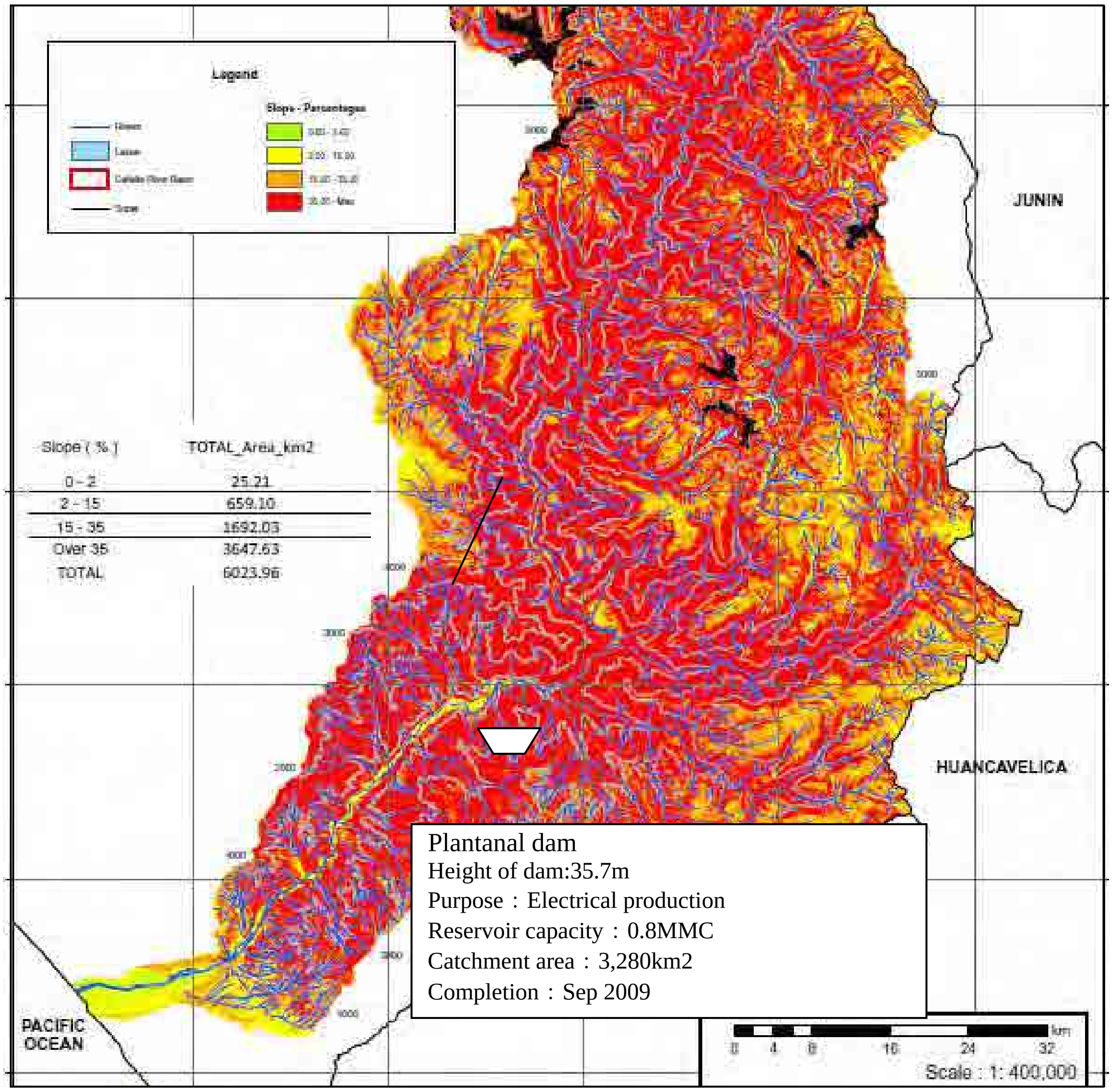
Basin	Total income sediment volume （Mil m3）	Total variation volume variation （Mil m^3）	Average height variation of bed (m)	Interval length （km）
Chira (Total)	5,000	-1,648	-0.01	49
Cañete	3,263	673	0.3	32
Chincha（Chico）	5,759	1,131	0.4	24
Chincha（Matagente）		1,479	0.5	25
Pisco	8,658	2,571	0.2	45
Yauca	1,192	685	0.1	46
Camana Majes	20,956	5,316	0.2	120

※ 1:Caluculation periods is 50 years   Source: Annex 3



Source:JICA study Team

Figure 2.13 **Results of Riverbed Analysis**



Slope (%)	TOTAL_Area_km2
0 - 2	25.21
2 - 15	659.10
15 - 35	1692.03
Over 35	3647.63
TOTAL	6023.96

Plantanal dam
Height of dam:35.7m
Purpose : Electrical production
Reservoir capacity : 0.8MMC
Catchment area : 3,280km2
Completion : Sep 2009

Figure 2.14 **Location Map of Plantanal Dam**

(b) Sediment Control Works in the alluvial fan

As sediment control works in the alluvial fan, there are Sand pocket, groundsel, bed hills, groyne works and Stream preservation works that combinate with them. There are function for not only sedimentation works but also river structure. The river structures that planed in this study, in Pisco basin flood control basin is planned at the 34.5K, Flood control basin have function of sand pocket. Also in Chincha basin diversion weir is planned. This diversion weir have channel works and training levee that have function to control the sediment. In the Camana Majes basin, There are river width area with narrowed areas in the upper stream that width is 600m at the 107K. This area have the function of sand pocket. So removal of stone in this area enable to keep the function to control the sediment. These works are economical and investment effect of them is high. If the cost of stone removal are calculated on, it is judged that these structures have higher investment effects by far than the works targeted for all basin.

In the Pisoco and Chincha basin, the river structures are plan that have the function to control the sediment, approach route for stone removal and space for O&M should be planned.

2.4 Problems for Implementation of Sediment Control Plan

Problems for implementation of sediment control plan are below.

(1) Project Schedule and Project Costs

Every one of the basin in this project is varsity, if revetment woks and Check dams would be implemented, the project need not only construction costs but also periods until project completion. So it is supposed that a great deal of time are taken until project effect would present itself. In addition, the frequency of debris flows in the upper streams is 1 per 50 years, in consideration of this matters, it is supposed that economic effects of the check dams are lower.

Table 2.15 **Construction Cost in Each Basin**

(a) Population in the mountainous area

The population in the mountainous area that are directly object to be conserved from debris flows are researched. The population in the mountainous area are few and it is clear that economic effects at the view of sediment control that are radical function for sediment control works.

1) Population in intermediate and mountainous area

The population in the mountainous area in this project are as shown in ***Table 2.16***. Without Yauca and Chira basin, the population in the mountain area is smaller than the population in the alluvial fans. The population density in the mountains is quite few, less than a ten peoples per one km2. The objects to be conserved in the mountain areas are few, and Cost-benefit performance of the sediment control works is low.

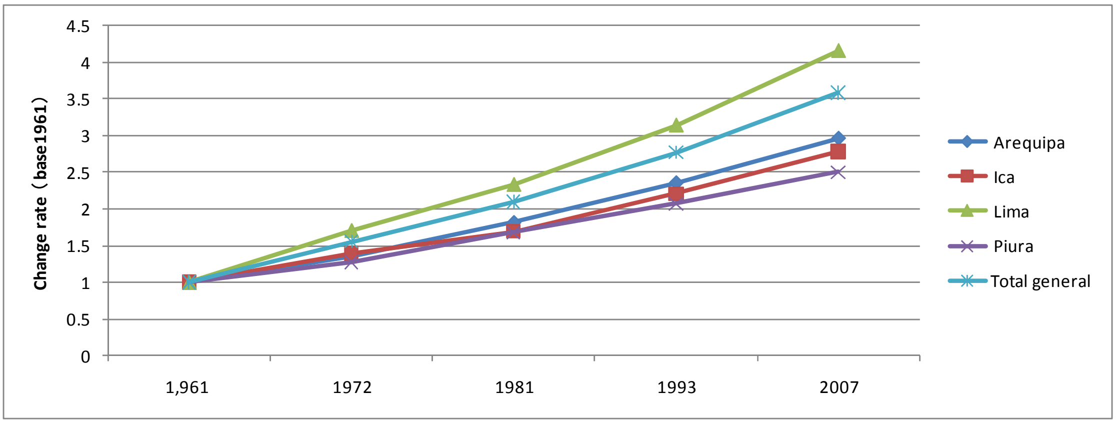
Table 2.16 **Population in the Mountains and on the Alluvial Fans**

Basin	Area	Mountain area	Alluvial fan	Total
Chira	Population(persons)	116,716	3,975	120,691
	Area (km2)	337,766	668,339	1,006,105
	Population density (persons/km2)	0.35	0.01	0.12
Cañete	Population(persons)	29,987	50,133	80,120
	Area (km2)	5,939	110	6,049
	Population density (persons/km2)	5.05	455.84	13.24
Chincha	Population(persons)	12,665	83,602	96,267
	Area (km2)	3,140	165	3,304
	Population density (persons/km2)	4	507	29
Pisco	Population(persons)	18,269	84,220	102,489
	Area (km2)	3,907	367	4,274
	Population density (persons/km2)	5	230	24
Yauca	Population(persons)	26,253	3,171	29,424
	Area (km2)	4,053	269	4,323
	Population density (persons/km2)	6.48	11.77	6.81
Camana Majes	Population(persons)	47,764	41,517	89,281
	Area (km2)	12,403.14	4,646.37	17,049.51
	Population density (persons/km2)	3.85	8.93	5.23

Source: JICA Study Team based on data from the INEI (2007)

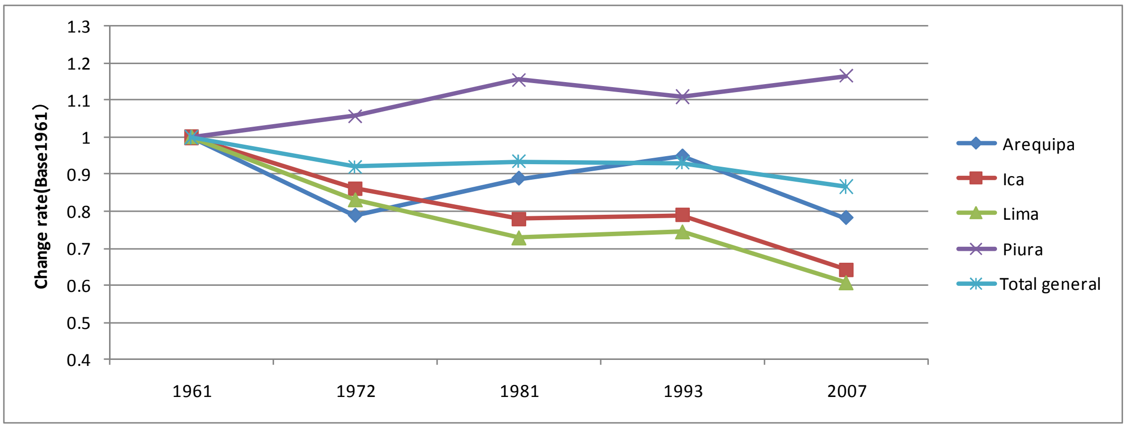
2) Process of the population

The process of the population and agricultural population in the study areas are as shown in ***Figure 2.15*** and ***Table 2.16***. In four area without Chira basin, agricultural population decrease. In Chira basin, climate condition and landform are favored by comparison with other four basin and agriculture is main industry and agricultural populations increase. On the other hand in four basin climate condition and landform are severe, agricultural populations decrease. Especially decrease of the agricultural population in the mountainous area are continuing. So directly objects to be conserved from debris flows are decrease, Cost-benefit performance of the sediment control works becomes lower.



Source: JICA Study Team based on census data

Figure 2.15 **Process of the Provinces Population in each Relevant Pref**



Source: JICA Study Team based on census data

Figure 2.16 **Process of the Rural Population in the Relevant Pref**

(2) Land acquisition

The revetment works are structure in the river and land acquisition is not required. However check dam need the land acquisition. Land Expropriation Act (Law No. 27117) （Ley General de Expropiaciones (Ley No. 27117) set down proceeding of expropriation in the Public works. We must obey this law.

Before implementation of new project, the contents of the project should be applied for Ministry of the Environment (Ministerio de Ambiente, Sevicio Nacional de Areas Naturales Protegidas por el Estado), it must be confirmed that there are no natural reserve in the project site. Natural protection is classified by manager, that is National management, Regional Government management and Private and Company Management as shown in ***Table 2.17***. In the Natural protection of National management, Prohibited matter are established.(Refer to ***Table 2.18***) In this study area there are only National forests in the downstream of Canete and there is no Natural protection that regulate the project implementation.

Many digs are dotted about in the Peru. For this reason, before implementation certification of no digs (Certificación de Inexistente de Restos Arqueológicos: CIRA) must be taken out in the Ministry of the culture（Comision Nacional Tecnica de Arqueologia).

Table 2.17 **Classification of Environmental Protective Areas**

ANP	National management (Sistema Nacional de Areas NaturalesProtegidas-SINANPE)
ACR	Regional Government management (Management by Regional Government and Provincial Government)
ACP	Private and Company Management (After coordination with MINAM / MINAG)

Table 2.18 **Prohibited matters in Environmental Protective Areas**

	Name	Characteristics	Prohibited Matter
Indirect Utilization	National Parks	Protection area of diverse ecosystems	Immigration and extraction of resources for commercial

Area			purposes
	National Shrines	Protection zone of specific flora and fauna. It allowed the collection of the flora and fauna that is used to maintain the life of the people who lived from the beginning.	Immigration and extraction of resources for commercial purposes
	Historical Shrines	Areas where cultural heritage, also have areas that are valuable in the aspect of nature.	Immigration and extraction of resources for commercial purposes
Direct Utilization Area	National protective zone	Protection zones of Ecosystem and forest areas. Deforestation is prohibited. However, gathering plants and hunting animals are allowed (including commercial use) provided to ensure the sustainability of species. (according to in Ministry of Environment)	Immigration
	Protection zones of Landscapes	Protection zones of Landscapes. If you want to exploit the resources must seek permission from the Ministry of Environment. According to the zoning in Ministry of Environment is possible to immigrate.	Extraction of resources without permission of the Ministry of Environment.
	Protection zones for specific flora and fauna	Protection zones for specific flora and fauna. The exploitation of flora and fauna that is not included in specific can be done provided with the regulations of the Ministry of Environment. (including commercial use)	Immigration and extraction of resources for commercial purposes
	Communities protective zone	Protection of areas inhabited by indigenous people. Priority permission for the extraction of resources necessary for the survival of purple. Extraction for non-residents are also allowed provided it is in accordance with the regulations in the Ministry of Environment.	Immigration and extraction of resources for commercial purposes
	National forests	Group of trees that serve to prevent erosion on river banks and hilly areas.	Immigration and extraction of resources for commercial purposes
	Game area	Hunting is only permitted with permission by the Ministry of Environment.	Immigration and extraction of resources for commercial purposes
Investigation Area	protective zone (ZR)	Research areas that would be recorded, areas under the research for extensions and classification	

(3) Sediment control in this project

Cost for sediment control plan for all basin is expensive, in addition project need long term periods. So it is clear that it would take long time before effective appearance and cost-benefit performance is low. Main purpose in this project is mitigation of the flood disaster. With the view to this purpose, it is judged that sediment control works in the alluvial fans is most effective. It is judged that implementation of the river structures that have the functions of sediment control in Chincha and Pisco basin that have a profound effect of the sedimentation would be most effective.

(4) Schedule of project implementation

The schedule should follow the components of river structures (Refer to the annex of river structures).

2.5 Recommendations

(1) Measures for the structures

Cost for sediment control plan in the mountainous area is expensive, in addition project need long term periods. There are no objects to be conserved in the mountainous area, so cost-benefit performance is low. Main purpose in this project is mitigation of the flood disaster. With the view to this purpose, it is judged that sediment control works in the alluvial fans is most effective. It is judged that implementation of the river structures that have the functions of sediment control in Chincha and Pisco basin that have a profound effect of the sedimentation would be most effective.

(2) Formulation of the monitoring system for the behavior of the river channel and sedimentation.

To manage the optimal preservation method of river channel, river channel change in the tandem with rainfall should be figured out. The understanding of the river channel change clarify the places needed for countermeasures and O&M terms and frequency. The understanding of the river channel change enable optimal preservation method of river channel. Currently Formulation of the monitoring system for the behavior of the river channel and sedimentation is not established, actual rivet channel change are not figure out. For this reason Formulation of the monitoring system for the behavior of the river channel and sedimentation should be established, periodic the river cross section survey should be conducted and river channel change in the tandem with rainfall should be figure out.

(3) Climate change

The design sediment volume are be proportionate to rainfall. So rainfall increased the sediment volume increase, the numbers of the check dams increase and project cost increase. Rain fall volume depend on Climate Change Prediction, so precision Climate Change Prediction should be required.

(4) Non-structural measures

Despite being distinct from the project purpose, in Peru sediment disasters have occurred frequently. So Non-structural measures to mitigate the sediment disasters below would be suggested. These Non structural measures are more economical than structural measures and have function to prevent the human life and minimum property from the sediment disaster.

- Regulation of agricultural areas and residential areas
- Setting the alert rainfall for each region and establishment early warning Systems.
- Collect sample of sediment disaster and raise awareness of disaster prevention through education and patrimony of disaster prevention

1) Legislation

In Peru, except in urban areas, there are no large towns near mountain stream or in the exits of mountain stream. And rainfall is little, also direct damages due to sediment disaster are few. From the point of view of heritage protection, it is necessary to regulate cultivation in disaster-prone area.

2) Rainfall observation and configuration of caution rainfall, establishment an early warning system

In Peru there is few precipitation station, it is difficult to establish early warning System by rainfall gauges. However, it is possible to establish an early warning system using radar rain gauge system (RRGS) that cover wide areas. RRGS are effective against flood alert as well. However due to the topography is steep, it is necessary to carefully evaluate to install.

3) To raise awareness of disaster prevention through education and patrimony

Table 2.5.1 shows the occurrence of disasters during the period 1995-2010 in Peru. During the period 1997-2002 occurred several floods and sediment disasters. It is necessary to raise awareness about disaster prevention, building on past experiences as lessons to be learned.

Table 2.19 **Number of Disasters in Peru (sediment disasters, floods）**

year	type	Total	Total of 4 districts	Arequipa	Ica	Lima	Piura
1995	sediment disasters	51	15	6	2	7	0
	floods	30	9	3	4	2	0
1996	sediment disasters	38	6	2	0	3	1
	floods	53	7	1	4	2	0
1997	sediment disasters	74	12	7	2	3	0
	floods	224	48	42	0	1	5
1998	sediment disasters	182	39	15	0	21	3
	floods	358	93	6	13	23	51
1999	sediment disasters	89	28	4	5	19	0
	floods	292	88	44	14	21	9
2,000	sediment disasters	131	13	5	2	5	1
	floods	208	15	2	1	9	3
2001	sediment disasters	116	15	6	0	5	4
	floods	239	37	15	2	15	5
2002	sediment disasters	64	18	2	0	15	1
	floods	136	22	3	0	5	14
2003	sediment disasters	265	45	4	2	27	12
	floods	470	17	1	0	13	3
2004	sediment disasters	175	19	3	3	12	1
	floods	234	19	2	1	11	5
2005	sediment disasters	223	36	11	3	19	3
	floods	134	16	2	1	7	6
2006	sediment disasters	396	53	4	1	40	8
	floods	348	27	3	0	10	14
2007	sediment disasters	248	29	1	3	20	5
	floods	272	23	0	4	11	8
2008	sediment disasters	251	40	0	2	30	8
	floods	242	33	1	6	4	22
2009	sediment disasters	285	30	10	0	15	5
	floods	219	8	3	1	4	0
2010	sediment disasters	258	44	7	1	33	3
	floods	229	4	3	0	0	1

Blank cells no information

Source: Compiled by JICA Study Team based on data from INDECI