CHAPTER 1 INTRODUCTION

1.1 Background of Study

The capital, Lima, which accommodates a population of over 7 million, about 30% of the national total in the area of coastal dry land, has always grappled with the problem of primary water supply to meet domestic and industrial demand. The Government of Peru therefore made a request to the Government of Japan for technical assistance to study an integrated water resources development of the Cañete river basin by paying due consideration to the conveyance of water from the basin to the capital Lima. The Japan International Cooperation Agency (JICA) and the Potable Water and Sewerage Service of Lima (SEDAPAL) agreed on the Scope of Work for the Study on the Integrated Water Resources Development in the Cañete River Basin in the Republic of Peru on November 22nd, 1996.

The scope of work for the Study on the Integrated Water Resources Development in The Cañete River Basin in The Republic of Peru (the Study) has been agreed upon between the Japan International Cooperation Agency (JICA) and the Potable Water and Sewerage Service of Lima (SEDAPAL) in November 22nd, 1996, with objectives;

(1) to formulate an integrated master plan for the development of water resource in the Cañete River Basin in the Republic of Peru up to the year 2020 (PHASE I),

(2) to conduct a feasibility study of priority project(s) to be identified and agreed upon by the two sides based on the master plan up to year 2003 (PHASE II), and

(3) to transfer technology to the counterpart personnel in the course of the Study.

The details of the scope of work and study area are shown in the Inception Report.

The Study area is shown on the map “The Study Area” and is composed of the area of the Cañete river basin for water resources development, the coastal corridor to the south of Lima for water conveyance, and the southern area of the capital Lima for domestic and industrial water supply.

1.2 Implementation of the Study

JICA has entrusted the Study to the joint venture of Nippon Koei Co., Ltd and Pacific Consultants International (the Study Team) in March 1999.

The Study was commenced in March 1999 by preparing an Inception Report in Japan. The Study Team dispatched the first mission to Peru in April 1999 for the initiation of the PHASE I work. An agreed Minutes of Meeting was prepared on May 26th, 1999. It is noted that the Study horizon (the year 2020) for the PHASE I is extended to the year 2030 to be consistent with that in the studies of

SEDAPAL. The words “up to year 2003” in the second objective (2) is also deleted.

The Study was carried out in Peru in collaboration with officials of SEDAPAL and by holding Joint Meetings among the parties concerned including the Consultative Group.

On February 22, 2000, the Study Team submitted Interim Report, the output of Phase I, Master Plan Formulation executed from March to December 1999.

SEDAPAL and JICA discussed about possibility of implementation of [PHASE II] based on Interim Report as stipulated in the Scope of Work signed on November 22nd, 1996, and agreed on implementation procedure of PHASE II as described in item 2 of the Minutes of Meeting signed on March 1, 2000, in which:

(1) SEDAPAL requested the work procedure in Phase II as illustrated in the attached diagram, and

(2) JICA proposed that it would like to proceed with the supplemental investigation of water use and water loss in the Rimac river at first to clarify uncertain supply capacity of raw water at La Atrjea intake, but it would like to determine the implementation of Phase II and the content of its TOR based on the result of the supplemental investigation.

The Study Team commenced the Supplemental Investigation on August 7, 2001, and the scope of the study was agreed upon between SEDAPAL and JICA as stipulated in the Minutes of Meeting signed August 27, 2001. The results of the Supplemental Investigation was submitted as Progress Report (2) on September 28, 2001.

SEDAPAL and JICA discussed implementation of Phase II based on the Interim Report of Phase I and Progress Report (2).

Accordingly, JICA has decided not to implement Phase II, the F/S for Cañete River water management (Alternative-4) in the near future with agreement of SEDAPAL in the Minutes of Meeting signed on October 19, 2001.

On December 13th, 2001, upon the acceptance of the Draft Final Report, JICA and SEDAPAL agreed that the Final Report would be submitted as soon as possible after obtaining comments of SEDAPAL by January 10th, 2002.

1.3 Contents of Report

The draft Final Report presents the master plan for the integrated water resources development in the Cañete River Basin, and the result of the supplemental investigation of the Rimac River Basin.

CHAPTER 2 SOCIOECONOMIC AND NATURAL BACKGROUND

2.1 Socioeconomy

2.1.1 National Socioeconomy and Government Policies

(1) Socioeconomic Features in Peru

According to the Population Census conducted in 1993, the country had a population of 22,639,443 that had been growing at a rate of 2.0% per annum since 1981. It is estimated that the country's population has amounted to 24,801 thousand in 1998. And, the proportion of the urban population in the same year was estimated to touch 72%, which was remarkably increased from 60% in 1972, implying a continuos trend of rural-urban migration.

In conformity with the topographic and climatic condition, the country is categorized into three large regions: "Costa" (Coastal strip alongside the Pacific Ocean, "Sierra" (Mountain area) and, "Selva" (Amazon jungle), and more than half of the nation's population is concentrated in the "Costa" region, which represents no more than 10% of the territorial extension of the country.

Judging from UNDP's human development index (HDI) in 1997, Peru is categorized as nation of medium human development being ranked at 80^{th} (HDI: 68.3) among 174 nations of the world. HDI is calculated on the basis of four indicators and Peru's value for respective indicator is as follows: life expectancy at birth (68.3 years), adult literacy rate (88.7%), gross school enrollment rate (78%) and real GDP per capita (US$4,680 in PPP).

(2) Structural Reform Program and Recent Economic Performance

Starting in 1990, under the leadership of the present President Fujimori, the Peruvian government has launched a bold economic and social structure reform agenda to restore long-term and sustainable economic growth of the country, aiming at: (a) improving incentive policies to reflect prices their opportunity costs, (b) reducing government subsidies so as to control budget deficit and inflation, (c) deregulating to promote private investment; and (d) defeating terrorism and fighting drug trafficking. To materialize these agenda, the government has liberalized an interest rate, an exchange rate and an international capital flows; it has established the independence of the central bank and eliminated credit from the central bank to the government; it has increased the competition by opening the economy to trade with the rest of the world and eliminating public monopolies and price controls; and it promoted private ownership of land and promoted a vast privatization program.

As a consequence of the said actions, the government has succeeded to achieve high economic growth (GDP's average growth of 6.2% per annum for the period

1993-98), to subdue an intractable hiper-inflation (an annual inflation was plummeted from 7,650% in 1990 to 6.0% in 1998) and to alleviate poverty (poor population has decreased from 55.3% in 1991 to 37.6% in 1997). In 1998, the macro-economic performance of Peru was severely affected by the phenomenon of "El Niño" together with the financial crisis taken place in Asian countries and the GDP's growth rate was thereby declined remarkably to 0.7%/year - the lowest for the last six years. Nevertheless, the Peruvian economy was able to muddle through this diversity, and is anticipated to restore around 2%/year of GDP's growth for the year of 1999.

Major macroeconomic indicators of Peru in recent years is as summarized hereinafter.

Major Economic Indicators in Peru 1994-98

Items	1994	1995	1996	1997	1998*
GDP Growth (%/year)	13.1	7.3	2.5	7.2	0.7
Current account balance (US$ x 10^6)	- 2,648	- 4,306	- 3,626	- 3,408	- 3,789
Trade balance (US$ x 10^6)	- 997	- 2,165	- 1,988	- 1,738	- 2,477
- Exports in FOB (US$ x 10^6)	4,598	5,589	5,898	6,814	5,723
- Imports in FOB (US$ x 10^6)	5,596	7,754	7,886	8,552	8,200
Net international reserves (US$ x 10^6)	6,025	6,693	8,862	7,982	7,114
External public debt (US$ x 10^6)	23,980	25,652	15,196	18,787	19,562
Inflation (%/year)	15.4	10.2	11.8	6.5	6.0
Exchange rate (Annual average)	2.20	2.25	2.45	2.66	2.93

* Preliminary estimation
Source: Banco Central de Reserva del Perú, "Memoria, 1997"

(3) Government's Development Policies and Strategies

The national development plan to cover the period of 1995 – 2000, has not been forged, and it is thus not easy without such plan to pinpoint the government's central policies and strategies on development. Albeit such constraint, there would not wide of the mark to mention that a sustainable socio-economic development and an alleviation of poverty are the major concerns to have been tackled with by the present government.

In 1998, the budget for the public sector amounted to about US$10,076 millions, which was distributed by type of services in the following manner: Economic services (12.8%), social services (42.3%), debt and subscription of share of stocks (19.8%) and general services (25.1%). And, 18.8% of this public finance, equivalent to US$1,897 million, was earmarked to investment of public works; this finance to public works was distributed by ministry as follows: 47.6% for Ministry of Presidency (In charge of development of water supply and sewerage systems, water resources, etc.), 26.1% for Ministry of Transportation, Communication, Housing and Construction, 6.4% for Ministry of Education, 5.2% for Ministry of

Agriculture, 3.1% for Ministry of Energy and Mining, 11.6% for the rest of ministries. On the other hand, to materialize their concern on poverty alleviation, the government had allocated close to 9% of the public finance to the relevant program.

Within the context of the structural reform program, the Peruvian government is proceeding with privatization for the purpose of consolidating bases for development of competitive economy and re-composition of the role of state and the private sector. Until February 1997, the national revenue stemmed from privatization efforts reached US$7,022 million, which is broken down by sector as follows: Telecommunications (37.7%), Electricity (22.4%), Petroleum (11.2%), Mining (11.1%) and Other sectors (17.6%). In line with the policies for privatization, the government has created the Commission for Promotion of Private Concessions (PROMCEPRI) with functions of planning, design, implementation and regulation of concession process. PROMCEPRI makes promotion for concession of public infrastructure in eight specific fields (highways, electric infrastructure, port facilities, communications, airports, hydraulic structures, railways and tourism), so that public finance may be focused on development of infrastructures with less financial returns but high social returns (The percentage of the public finance for social development against GDP had increased from 4.0% in 1994 to 6.4% in 1998, while that for economic development had declined from 2.2% to 1.9%) until May 1998, and then its functions have been transferred to the Commission for Promotion of the Private Investment (COPRI).

2.1.2 Socioeconomic Condition of the Study Area

(1) Administrative Division and Demographic Feature

The Study area consists of three sectors: the Cañete River Basin, the Corridor Lurin-Cañete (Proposed route for installation of the water conveyance facilities from the Cañete River to Lima Metropolitan Area) which comprises the Axis Chilca-Cañete and Lima South Zone and the Pampas Concón-Topará and Chincha Alta. The Cañete River Basin is located within the provinces of Cañete, Yauyos and Huarochiri (very small portion only) and the Corridor Lurin-Cañete pass through the province of Cañete and encompasses 10 districts of 12 districts located in the south zone of the province of Lima. In addition, the proposed benefitable area of irrigation system to be contemplated in the Master Plan is prolonged to the District of Grosio Prado, Province de Chincha, Department of Ica. In sum, the Study area is extended over four provinces of the Department of Lima and one district of the Department of Ica, comprising 51 districts in total. The table below indicates the evolution of population in the Study area from 1981 to date.

Evolution of Population in the Study area

Provinces	No. of Related Districts	Population			Annual Growth (%/1981-98)
		1981[1/]	1993[1/]	1998[2/]	
Cañete	15	122,520	152,964	169,187	1.9
Yauyos	24	27,822	23,190	21,567	- 1.5
Huarochiri	1	1,854	1,771	1,786	- 0.2
Lima	10	539,154	881,314	1,023,520	3.8
Chincha (Depto. de Ica)	1	12,011	14,912	16,108	1.7
Total	51	703,361	1,074,151	1,232,168	3.4

Source: 1/: INEI, Censos Nacionales de Población y Vivienda, 1918 y 1993
2/: Estimated by the Study Team based on projection of INEI

Due to suburban sprawling of the population in Lima Metropolitan Area, the population in its south zone has been burgeoning at a rate of 3.8% for the period of 1981-98, outstripping remarkably an average rate of Lima Metropolitan Area (2.3%).

By contrast, the exodus of inhabitants in the Province of Yauyos is of significance causing decline of its population by more than 30% for the last 17 years (1981-1998). Owing to geographical advantage to be easily accessible to Lima Metropolitan Area as well as being endowed with favorable conditions for agricultural development, the population in the Province of Cañete showed a sound growth to catch up with the national average. Because the great majority of its population is represented by the province of Lima, the growth of the population in the Study area in general has attained such higher rate as 3.1%, in comparison with the national average (2.0%).

(2) Social Conditions and Coverage of Social Services

Similar to other rural-predominant provinces in Peru, the provinces of Yauyos and Cañete are less developed socially in comparison with the Province of Lima. The table below indicates an evidence of this disparity.

Some Social Indicators

Items	Provinces		
	Lima	Cañete	Yauyos
Adult illiteracy rate (%)	3.7	7.5	10.2
Primary school enrollment rate (%)	92.3	92.3	90.2
Average years of school attendance (years)	11.1	8.8	7.4
Population without any school education (%)	3.6	7.2	9.8
Population who has learned language(s) other than Spanish as mother language (%)	10.7	7.6	7.7
Rural population (%)	0.4	26.9	39.8
Share of the primary sector within EAP (%)	2.2	45.7	76.6

Source: INEI, Perfil socio-demográfico del Departamento de Lima, January 1999

It is worth while to point out that the proportion of population who has learned language(s) other than Spanish as mother language is higher in Lima than other two provinces. This phenomenon may be attributable to the fact that Lima has received many immigrants from departments or provinces in which such dialects as quechua, aimara, jíbaro, etc are predominantly spoken.

As for distribution of electricity, 7 of 33 districts (21%) in Yauyos had no access to this service in 1997, meanwhile none of district in Lima and Cañete was reported to be without any electric services. Districts with coverage rate of electric service more than 75% are: 70% in Lima, 33% in Yauyos and 25% in Cañete.

Except for one district (Tupe) in Yauyos, all districts in three provinces in question had some coverage rate of water supply. Nevertheless, as of 1997, there were a number of districts with coverage rate of water supply inferior to 50%: 7 of 16 districts (43%) in Cañete, 8 of 33 districts (24%) in Yauyos and 10 of 43 districts (23%) in Lima. Water resources to be available for domestic water supply are not abundant in these provinces, so rationing of water supply is carried out in many districts, standing at 54% of districts in three provinces on average.

Sewerage system is far under-developed in Yauyos and in Cañete; in case of the former, close to 40% of its districts had not been provided this system as of 1997, meanwhile in the case of the latter, even though all of its districts had any coverage of the service, the coverage rate remained low (districts with coverage rate more than 50% were less than half – 7 of 16 districts). By contrast, the situation had been improved in Lima with the coverage rate of sewerage services almost equal to that of the water supply.

An outstanding imbalance is observed among provinces with respect to development of road network; almost 80% of roads (total length: 4,839 km) in Lima are paved with asphalt, meanwhile only 1 km of road in Yauyos (1,311 km in total) has such improvement. Development of roads also lags behind in Cañete, with as low portion as 45% in total length.

(3) Economic Activities

The Province of Lima together with the Constitutional Province of Callao makes up Lima Metropolitan Area – the capital city in Peru, so is the center of the economic activities of the country with contribution of the Gross Regional Product (GRP) of the Department representing 47% of the GDP in Peru in 1997; in particular, the region's contribution to the GDP becomes higher in such sectors as manufacturing (59%) and services (57%). In Lima Metropolitan Area, the primary sector represents as small portion as 5.2% of its total GRP.

On the other hand, the agricultural and livestock sector constitutes the mainstay in the provinces of Cañete and Yauyos. In the Province of Cañete, owing to endowment with fertile soil and consistent availability of surface water from the Cañete River, crop production represented mainly by cotton, yellow corn, sweet potato, potato and grapevine has been prosperous under irrigation system. Recently, the production of asparagus has expanded as a consequence of inauguration of related canning factory. Agricultural products of the province play an important role in the wholesale market of Lima Metropolitan Area; sweet potato occupies more than three-fourth of the supply in this market and apple, grape, pumpkin, cassava and potato also make a significant contribution in supply of foodstuff there. According to the Population Census in 1993, the economically active population (EAP) of the province is distributed by sector as follows: primary (45.7%), secondary (11.4%) and tertiary (42.9%).

Economic activities of the Province of Yaunos are extremely concentrated in the primary sector, which accounted for 76.6% of the EAP in 1993. Nevertheless, unlike the Province of Cañete, the importance of the agriculture (crop production) sector is reduced and, by contrast, livestock and mining sectors contribute more dynamically to the regional economy. In value terms, the relation between livestock and crop production is estimated to be 57:43; about 65% of the livestock production is produced by cattle, which is followed by sheep (16%), mean while nearly half of crop production is represented by two traditional crops (potato and yellow corn). In the Province of Yaunos, agro-industry is limited to processing milk to produce cheese, butter, etc.

2.1.3 Tourism

(1) Tourism-oriented Resources in the Cañete River Basin

Frankly, speaking, tourism attraction is very scarce in the Cañete River Basin. The city of Lunauaná may be the only spot which may call attention of tourists from Lima Metropolitan Area, other departments of the country and foreign countries owing to its geographical position within the basin to give tourists opportunities for enjoying river adventures by canoe, boat, raft, etc. Lunahuaná has also some prestigious hotels and good restaurants, and the road from Lima to the town is completely paved including the stretch of the Pan American Highway which occupies mayor portion to the destination.

Although the basin has other tourism-oriented resources such archaeological ruins (Ñaupahuasi, Huashuaao, Tupina Chaca, Turpa, etc.), hot spring at Ocro (District of Yaunos), natural lakes and lagoons, water fall, panoramic view of the valley and so on, poor transportation means combined with an absence of adequate lodging facilities and other infrastructure has constrained the basin from development of tourism.

Some zones belonging to five districts (Alis, Huancaya, Miraflores, Tanta and Vitis) of the Province of Yauyos located upper basin of the Cañete River together with three districts of the Province of Jauja, Department of Junin have been included in "Tourism-oriented Reserve Zone" denominated as "Cañete y Conchas-Pachacayo", which by general law for tourism are required to forge action plans for preservation, control and use of their tourism-oriented resources.

(2) Tourism Development Prospects

At national level, there are fourteen tourism-oriented reserve zones which are designated as such provisionally. This means that these zones are eligible zones to be upgraded to the national park (8 in total nationwide) or the national reserve (8 in total nationwide) within the context of the natural protected areas in Peru , provided that an adequate measures and actions on preservation, control and use of their fauna and flora should be taken. In this regard, it is critical that local governments should formulate action programs aiming at proper management and preservation of natural resources (implementation of measures to conserve soil, water and vegetation, establishment of ecological monitoring system, undertaking of training for responsible persons and enlightenment of rural inhabitants, etc.) with participation of local population.

Tourism development is one of few proposals which attribute to decelerating exodus of population in the upper basin of the Cañete River as well as to vitalization of the basin's regional economic activities. For attaining this development it is prerequisite that, apart from measures mentioned above, to improve related infrastructures such as transportation, lodging facilities, restaurants and water and sewage treatment systems and, at the same time, to incorporate tourism information and promotion center of the basin in Lima Metropolitan Area.

Finally, the construction of dam proposed in the Cañete River Basin is anticipated to contribute to an expansion of tourism related with river water to have been developed at Lunahuana and its surrounding area, because river flow will be maintained at such level as to make it possible to navigate boats, canoes and other means even at dry season.

2.2 Topography

The Cañete River is the second largest among the rivers which flow into the Pacific Ocean in Peru. Its length is approximately 230 km and its catchment area is 6,189 km^2. The Cañete River basin shows an abrupt morphology with youthful V-shaped valley, which is being vigorously deepened at present. The average slope of the basin is 16.7%, whereas that of the riverbed is 1/53 (approximately 2%). In view of the physiographic characteristics, the basin can be divided into three units; upper, middle and lower reach. A general characteristic for each unit is shown in Table 2.2.1.

The lower reach extended from the river estuary to 70 km upstream (nearby San Jerónimo bridge) is occupied by Andean ridges, plain area and shore area. Andean ridges show hilly feature with slope inclined between 17.6% and 57.7% to the river channel. Some geodynamic phenomena occur on the slopes and along the tributaries. Plain area consists of fluvio-alluvial plains such as river terraces, alluvial cones, riverbanks, flood plains subject to inundation, etc. In this section, the width of the riverbed varies from 50 m to 200 m, and slope of the river ranges from 0.7% (1/14) to 4.2% (1/24). Riverbed gradient is steeper in the upper stream, whereas steep and gentle slope varies alternately in some section. Fairly large terraces situated in the both margins of the river are utilized for agricultural uplands. Shore area is distributed along the coastal zone and formed by marine erosion and sedimentation.

In the middle reach situated in 70 km to 170 km from the river estuary (nearby Huancaya village), continuous high mountain ranges and gouges with V-shaped deep valley are predominant. The height increases progressively from the west to the east and high lands become eroded steep and deep ravine in this reach. Major geodynamic phenomena such as slope failure, debris flows and unstable slope occur on the slopes and along the tributaries. Agricultural uplands are distributed in man-made stepped terraces on rather gentle slopes and alluvial cones. Generally, however, hillsides facing the river channel are very steep and eroded. The elevation difference between the riverbed and the top of the hills ranges from 500 m to 1,300 m.

The upper reach situated in 170 km to 230 km from the river estuary consists of alpine areas and glacial areas. Both areas range at an elevation higher than 4,000 m (elevation of the river rise, Ticliacocha lake, is approximately 5,800 m). Physiographically, the alpine area is formed by glacial and fluvio-glacial action showing U-shaped valley, cirque, swampy plain, glacial lakes, drumlins, etc. Moraine and fluvio-glacial deposits are main overlying sediments. This area occupies 58% of the total surface basin. Slope of the riverbed largely vary ranging between 0.5% and 100% according to glacial erosion and sedimentation at the elevations from 4,000 m to 4,800 m. There are also some natural reservoirs created along the rivers, which were dammed up by the sedimentation of glacial and fluvio-glacial deposits, talus deposit of collapsed weathered rocks and/or eroded limestone outcrops. Number of glacial lakes and reservoirs is 447, and the total surface area is estimated at approximately 4 km^2, which contribute to store and regulate river water in the basin. Extensive livestock is practiced in gently sloped lands and river valley. Farming is practiced sporadically on man-made terraces.

2.3 Meteorology

2.3.1 Rainfall

The location of gauging station and the isohyet of the basin is shown in Figure 2.3.1.

In the lower basin of the Cañete River of which elevation is lower than 2,000 m, monthly rainfall records are available at two stations located at an elevation 150 m and Pacaran at 700 m. Annual mean rainfall recorded at the Cañete station is as little as 16.9 mm, and that at the Pacaran station is 15.6 mm. Contribution of rainfall to river discharge is not expected in the lower basin.

In the reach between elevations 2,000 m and 3,000 m, monthly rainfall records are available at two stations, Huangascar situated at an elevation 2,550 m and Yauyos at 2,850 m. Annual mean rainfall recorded at the Huangascar station is 271.3 mm, and that at the Yauyos station is 356.0 mm, which indicates that quantity of rains increases as altitude goes up.

In the reach between elevations 3,000 m and 4,000 m, monthly rainfall records are available at six stations, Huantan, Colonia, Siria, Vilca, Carania and Sunca. Annual mean rainfalls recorded at these stations ranges from 545.3 mm to 917.0 mm. The fact indicates that there is high pluvial potential and that contribution to the river runoff is effective.

In the upper reach higher than 4,000 m, monthly rainfall records are available at two stations, Tanta located at an elevation 4,300 m and Yauricocha at 4,522 m. Annual mean rainfall recorded at the Tanta station is 795.0 mm, and that at the Yauricocha station is 949.5 mm, which indicates that this section of the basin possesses the highest pluvial potential and contributes effectively to river runoff.

Table 2.3.1 shows annual mean and monthly mean rainfall at above stations. The rainfall records at Pampas, Catahuari, Picamara and Callangas were not collected because of their limited record period.

2.3.2 Temperature

Temperature in the Cañete River basin has been observed at three stations at elevations ranging from 100 m to 2,850 m. Table 2.3.2 compares the monthly mean temperature at three stations of Imperial located at an elevation 104 m, Pacaran at 700 m and Yauyos at 2,850 m.

It is understood from the table that the monthly mean temperature at the respective stations varies moderately throughout the year, and that is largely influenced by altitude. However, there is an exception in monthly mean temperature between the Imperial and Pacaran stations during the months from June to November. Despite the fact that the Imperial station is lower than the Pacaran station in elevation by about 600 m, there is no significant difference in temperature, rather records at the Imperial show smaller values than those of the Pacaran in some months. This may be attributed to the fact that the dense cloud (mist) prevails in the coastal lowland areas during the said period.

2.3.3 Wind

The Cañete station is the only one in this basin which records wind velocity, direction and frequency. According to the records, southwest wind prevails in the area but its velocity is not so high. During spring, summer and winter, it is called as “slight breeze” (7 to 12 km/hr) according to the Beaufort and in autumn as “weak wind” (2 to 6 km/hr) according to the same scale. The maximum absolute velocity was recorded for a southwest wind, with 22.2 km/hr in August 1986.

2.3.4 Evaporation

Data on evaporation in the Cañete River basin are collected from three meteorological stations. Table 2.3.3 compares the annual and monthly mean evaporation recorded at the Cañete station at 150 m, the Pacaran station at 700 m and the Yauyos station at 2,850 m.

The table indicates that there is a clear trend as far as the three stations are concerned. The annual mean evaporation increases as elevation rises, in spite that the temperature goes down as elevation rises. The fact implies that there may be more important factors which influence the value of evaporation, such as sunshine hour, wind velocity, relative humidity, etc.

It is also seen from the table that there is a reverse phenomenon between the records observed at stations situated at lower elevation in coastal area (Cañete and Pacaran) and those observed at Yauyos station located at rainy catchment. The records at the former stations show high evaporation during the months from December to March and low evaporation in the months of June to August, whereas those at the latter station show high evaporation during the period of July to October. This may also be attributed to the fact that the sunshine hour is very short in the coastal areas during the period of June to August.

2.3.5 Sunshine Hour

The Cañete station is the only one in this basin which records information on sunshine hour. Table 2.3.4 shows annual mean and monthly mean sunshine hours at the Cañete station. According to the table, annual mean sunshine hour is only 1,524 hr or 4.19 hr/day. Although it is not possible to compare with any other elevated areas, the sunshine hour in the higher areas in elevation may be much longer.

2.3.6 Relative Humidity

Relative humidity in the Cañete River basin has been observed at two stations. Table 2.3.5 compares the annual and monthly mean relative humidity records at the Cañete station located at an elevation 150 m and the Yauyos station at 2,850 m.

There is a notable difference in relative humidity between the two stations of Cañete and Yauyos. The annual mean relative humidity at the Cañete station is as high as 83%, whereas that at the Yauyos station is only 53%. Monthly mean relative humidity at the Cañete station varies moderately throughout the year. On the other hand, there is a significant variation from month to month at the Yauyos station.

2.4 Hydrology

2.4.1 Introduction

The hydrological aspects of the river basin have been studied by reviewing the previous study reports and available hydrological data. The results of the previous study reports are elaborated by use of additional up-to-date data and information.

(1) River Basin

The Cañete River basin is located at the latitude 11°55'S to 13°15'S, the longitude 75°30'W to 76°30'W and the altitude 0 m to 5,900 m. The basin boundary of the major tributaries and specific areas, and the longitudinal profile of the Cañete River are examined based on the 1:100,000 topographic map. The catchment area at the Socsi station is 5,890 km^2. The total length of the Cañete River mainstream is approximately 230 km and the average slope is 1/53. Longitudinal profile of the Cañete River and the catchment area at major points are shown in Figure 2.4.1.

(2) Data Collection

Hydrological observations of rainfall and river water level in the Study Area have been operated by the following agencies:

- SENAMHI: Servicio Nacional de Meteorología e Hidrología
- ELECTROPERU: Empresa de Electricidad del Peru

- SEDAPAL: Servicio de Agua Potable y Alcantarillado de Lima
- Cementos Lima S.A.

Available records of monthly rainfall at seven stations, daily rainfall at another eight stations and daily discharge at seven stations are collected. All collected data are stored in digital medias to use for detailed analysis. Location of the gauging stations is shown in Figure 2.3.1

(3) Measurement of Water Level and Flow Velocity

Additional water level and flow velocity measurement was commenced by the Study Team at five stations in the selected three sites along the Cañete River. General location of three measurement sites is shown in Figure 2.4.2. The results of these measurements will be utilized in PHASE II Study to calibrate the discharge records and to examine the hydro-geological conditions of the infiltration flow areas in the upper stretch of the Cañete River basin.

2.4.2 Rainfall Analysis

(1) Available Daily Rainfall Data

Daily rainfall records from 1964 to 1997 at eight stations (Tanta, Vilca, Carania, Yauyos, Huantan, Colonia, Huangascar and Pacaran) in the Cañete River basin are collected. The conditions of missing records are summarized in the following table.

Daily Rainfall Records (34 years: 1964 ~ 1997)

Station	Sample (days)	Missing ratio
Tanta	12,054	2.9%
Vilca	12,263	1.3%
Carania	12,034	3.1%
Yauyos	9,190	26.0%
Huantan	8,631	30.5%
Colonia	8,764	29.4%
Huangascar	11,961	3.7%
Pacaran	8,299	33.2%

Missing data in this period are filled with estimated daily rainfall by means of correlation method on close stations. Table 2.4.1 shows summary of correlation formula and coefficient on each station.

(2) Probability Analysis

Probability analysis of annual rainfall and annual maximum daily rainfall at the above eight stations are examined by means of Gumbel method (extreme value distribution) and those results are summarized in Table 2.4.2. Probable value on any return period can be calculated regardless of that sample size, but the accuracy of results and the limits of application depend on those sample sizes. These results can be applied for further study on probable design rainfall in consideration of those application limits.

(3) Areal Daily Rainfall

Basin average daily rainfall that is an average depth of rainfall over a specific area is estimated by means of the Thiessen method with the estimated complete daily rainfall series from 1964 to 1997. Figure 2.4.3 shows Thiessen polygon based on the available eight stations and those effective areas at hydrological stations in Cañete River basin. Calculated basin average daily rainfalls from 1964 to 1997 at five hydrological stations (Tanta, Aguas Calientes, Tinco de Alis, Chavin and Socsi) are utilized as a basic input for runoff calculation mode.

2.4.3 Runoff Analysis

(1) Available Daily Discharge Data

Discharge records at following seven water level stations in the Cañete River basin are available within the period shown in the following table.

Summary of Water Level Station in the Cañete River Basin

Station	River	Catchment (km^2)	Operation	Observation Period
Imperial	Cañete	5,900	SENAMHI	1-Jan.-1926 ~ 30-Apr.-1968
Socsi	Cañete	5,890	SENAMHI	1-Jan.-1965 ~
Chavin	Cañete	3,265	ELECTROPERU	1-Jun.-1985 ~
Tinco de Alis	Cañete	930	ELECTROPERU	8-Feb.-1986 ~
Aguas Calientes	Cañete	352	ELECTROPERU	1-Jul.-1986 ~
Tanta	Cañete	172	ELECTROPERU	1-Jul.-1986 ~
Tomas	Alis	142	ELECTROPERU	12-Feb.-1986 ~

Missing data of daily discharge records from 1986 to 1997 at five stations (Tanta, Aguas Calientes, Tinco de Alis, Chavin and Socsi) are filled with estimated daily discharge by means of correlation method on close stations. The condition of missing records is summarized in the following table.

Daily Discharge Record (12 years: 1986 - 1997)

Station	Sample (days)	Missing ratio
Tanta	3,578	18.4%
Aguas Calientes	2,969	32.3%
Tomas	4,036	7.9%
Tinco de Alis	3,805	13.2%
Chavin	3,413	22.1%
Socsi	4,382	0.0%

Adopted correlation formulas and coefficients on each station are summarized in Table 2.4.3. Monthly discharge compiled from the complete data series of daily discharge from 1986 to 1997 is applied to the water balance study. Figure 2.4.4 shows the duration curve of daily discharge from 1986 to 1997 at five stations.

(2) Probability Analysis

Probability analysis of annual maximum daily discharge, annual maximum peak discharge, annual mean discharge and annual seasonal mean discharge, are examined for planning and design purpose.

(3) Runoff Calculation

The daily discharge records before 1985 are available only at the Imperial (1926 – 1968) and Socsi (1965 – 1997) stations. The records at Socsi are adopted as the basic daily discharge records for 34-year period (1964 –1997). Unrecorded data at Socsi are interpolated by the following method and priority:

Priority	Method
1	Daily discharge estimated by a correlation method
2	Daily discharge simulated by the Tank Model

The Tank Model method is applied as a daily runoff simulation model. Available daily discharge records at each station are utilized to calibrate the each basin model, and the complete data series of basin average daily rainfall from 1964 to 1997 are employed as the model input. Each parameter of five basin models (Tanta, Aguas Calientes, Tinco de Alis, Chavin and Socsi) is calibrated through trial and error presses, and summarized in Table 2.4.4.

The simulated daily discharge by the Tank Model did not agree with the recorded data due to insufficient number of rainfall stations, in particular, in the mountain area along the basin boundary higher than 3,000 m.

The Study Team initially intended to utilize the 34 year simulated daily discharge records for the detailed water balance analysis, but application of the simulation result is limited to the Socsi station only in this stage. Simulation by the Tank

Model will be elaborated if several reliable rainfalll records at mountain areas are made available during PHASE II period.

(4) Balance of Rainfall and Runoff

The balance of rainfall and runoff of the Cañete River basin is approximately estimated at Socsi station (catchment area 5,980 km^2) by use of the daily rainfall data (1964-1997) and daily discharge data (1965-1997).

	MCM/ year	m^3/s
Mean annual basin rainfall	2,576 (437.3 mm)	81.7
Mean annual runoff	1,385	43.9
Maximum annual runoff	2,672	81.6
Minimum annual runoff	600	19.0
Evaporation and groundwater	1,191	37.8
Runoff ratio	0.54	-

2.4.4 Flood Discharge

(1) Relationship between Daily Discharge a Peak Discharge

Instantaneous flood peak discharge data in Cañete River basin were not made available in this study phase except discharge hydrographs from 1986 to 1999 at Chavin station. Relationship between daily discharge and peak discharge is studied to clarify characteristics of flood peak discharge at specific points. Using the results of probability analysis of annual maximum daily mean discharge and annual maximum instantaneous peak discharge at Chavin station, the relationship between probable specific daily discharge ($q_{day}(n)$) and probable specific peak discharge ($q_{peak}(n)$) is examined. The relationship is plotted in Figure 2.4.5 and is generalized by following formula.

$$q_{peak}(n) = 1.42 \times (q_{day}(n) - 0.01) \qquad (q_{day}(n) > 0.034)$$

(2) Probable Daily Discharge

Annual maximum daily mean discharges at six stations (Tanta, Aguas Calientes, Tinco de Alis, Chavin Socsi and Imperial) are available in Cañete River basin. Using the results of probability analysis of these six stations, studies are made on probable specific daily discharge ($q_{day}(n)$). Results of probable specific daily discharge at each station are shown in Figure 2.4.6. In consideration of accuracy and availability of data, results of probability analysis at Socsi+Imperial (combination of data at Socsi and Imperial) are utilized for planning and design. Probable specific daily discharge at Socsi+Imperial is summarized below. These are applied to the middle and lower Cañete River basin.

Probable Specific Daily Discharge ($m^3/s/km^2$)

T	2	5	10	20	50	100	200	500
$q_{day}(n)$	0.0541	0.0791	0.0956	0.1115	0.1320	0.1474	0.1627	0.1829

(3) Probable Peak Discharge

Probable specific peak discharge at any point on the middle and lower Cañete River is assumed as in the following table, by adopting the results in the foregoing paragraphs.

Probable Specific Peak Discharge ($m^3/s/km^2$)

T	2	5	10	20	50	100	200	500
$q_{peak}(n)$	0.0626	0.0981	0.1216	0.1441	0.1732	0.1951	0.2168	0.2455

2.4.5 Drought Discharge

(1) Available Data

The record period of the mean discharge at Socsi (1926 – 1968) and Imperial station (1965 - 1997) is different, but those data can be combined as one set because the catchment area and the location of both stations are considerably same. Combined daily mean discharge at Socsi+Imperial (combination of data at Socsi and Imperial) from 1926 to 1997 is made for historic discharge analysis.

(2) Probability Analysis

Probable drought discharge is examined by use of log-extreme value distribution on annual mean discharge of hydrological water year instead of calendar year. The hydrological year is set as a period of one year from September to August. The annual seasonal mean discharge in drought period is also examined for the period June to September, July to October and July to September. Results of the probability analysis are listed in the following table.

Probable Daily Mean Drought Discharge (m^3/s)

Period	Statistical Parameters			Return period (year)					
	N	Mean	ST-DV	2	5	10	20	50	100
Hydrological year	63	48.6	17.9	48.2	34.2	27.2	21.9	16.5	13.3
Jun - Sep	66	13.4	2.7	13.6	11.2	9.9	8.8	7.5	6.7
Jul - Oct	66	11.8	2.3	12.0	9.9	8.8	7.8	6.7	6.0
Jul - Sep	66	11.7	2.2	11.9	9.9	8.7	7.8	6.7	6.0

The 1960 and 1992 seasonal mean discharges during the specified months are assumed to be the droughtiest year within the available records. The drought return period is estimated to be approximately 20 to 30-year in 1960 and 30 to 50-year in 1992.

2.4.6 Sediment Load

Sedimend yield in the Cañete river basin varies from 300 m^3/km^2/year (upper reach) to 600 m^3/km^2/year (middle reach) depending on vegetation, topography, geology and rainfall.

El Platanal report in 1987 provides measurement record of sediment load at Chavin in 1986, with an estimate of annual volume of sediment load at 1.7 million tons, which suggest a specific yield at Chavin (3,265 km^2) to be 430 m^3/km^2/year ($1m^3$=1.2 ton).

2.5 Geology and Hydrogeology

2.5.1 Geology

(1) Regional Geology

The Cañete River basin is made up of marine and continental sedimentary rocks, granitic and volcanic rocks and overlaying soft sediments in order of the old. The morphology attained its elevation through granitic intrusion of batolith type, mountain-building processes (Andean orogenesis) and epeirogenesis, which involved faults, folds and recumbent folds, etc. Stratigraphic classification is shown in Table 2.5.1. The regional geological map is shown in Figure 2.5.1.

The sedimentary formations are distributed in the upper reach from the locality of 3 km downstream from Magdalena with a structural orientation parallel to the Western Cordillera of the Andes. These formations range in age from upper Triassic to lower Tertiary. The older formation tends to distribute in the upstream of the basin. Geological structure generally trends northwest and steeply dips with anticlines/synclines and sporadically recumbent anticlines. Sedimentary component consists of limestone, marl, dolomite, mudstone, shale, sandstone, conglomerate, quartzite and rarely interbeded with volcanic rocks. Taking karst features of the carbonate rocks such as swallow-holes, sinkholes, dry valley and springs into consideration, there might be locally causing caves and faults.

The granitic rocks have a large exposure principally in the middle and lower reaches and form a part of Andean Batholith. The intrusion of these rocks occurred from lower Tertiary to upper Cretaceous and perhaps during later phases of the Andean orogenesis. The granitic rocks consist of granodiorites, tonalities, diorites and granites. The granitic outcrop forms a peculiar morphology such as gouge, “bottle neck” and steep slope in the river channel because of its hardness, low weathering and massiveness, etc.

The Tertiary continental/volcanic rocks are distributed filling the topographic concavity to the downstream from the imaginary line linking Tanta - Lalaos. These rocks include lavas, breccias and tuff breccias that range in composition from rhyolite to andesite with rarely interbeddings of sandstone and conglomerate. All volcanic rock at the surface is disintegrating and decomposing in various processes of weathering.

The Quaternary deposits consist of soft sediments such as glacial and fluvio-glacial deposits, old fluvial deposit, terrace deposit, talus deposit, alluvial cone and present fluvial deposit from Pleistocene to Holocene. These deposits have a large and thin exposure principally at the foot of the mountains, rather gentle slope and river valley in the all basin area and compose of various particles in size. Principally water and glacial agent formed the deposits. Some of them caused geodynamic phenomena such as landslide, slope failure, debris flow and damage to social infrastructures, agricultural lands and housings during the heavy rain.

(2) Geodynamic Issue

The Cañete River basin is one of the rivers with geodynamic problem, which flow into the Pacific Ocean. From an engineering point of view, the pre-quaternary formations and granitic rocks do not bring on critical problems because of favorable lithologic character and geological disposition, and low weathering and alteration, etc. On the other hand, the overlaying quaternary deposits are generally soft/heterogeneous, and unstably accumulated on the steep slopes and ravines. Therefore the deposits tend to flow/move down. Some geodynamic phenomena have occurred from many centuries ago, whose principal figures are; ①debris flows coming from the tributary, ②large landslides, ③slope failures of old fluvial and fluvio-glacial deposit located on the slopes,④failures of under-cut slope in meander and ⑤buried valley. The characteristics of each phenomenon are shown in Table 2.5.2. These geodynamic phenomena commonly occur in the dry basin located less than 2,500 m.a.s.l. and distribute in the stretch between Lunahuana – Yauyos - Alis. The phenomena are closely connected with the factors of heavy rainfall, large annual mean discharge, weathering, fracturing, erosion of rock mass, faulting, folding, poor vegetation and aridity.

The debris flows and large landslides are important geodynamic features. Large filling sedimentation along the Cañete River is believed to have occurred partly as the result of a large landslide located on the right bank in Vibora pampa, 1.5 - 6.5 km upstream of Catahuasi, which dammed up to create a natural reservoir upstream. Alluvial terraces and remnants of alluvial cones suggest this portion of the Cañete River valley was filled with alluvium to a depth of an additional 200 to 300 m at some time in the past. These remaining sediments cause the slope failures and debris flows.

Therefore it's necessary to identify and diagnose these phenomena previously for each proposed site to take countermeasures against sedimentation and the slope stability before the beginning of the river engineering works,

(3) Dam Geology

Study of water resources development project of the Cañete River basin was initiated in 1980s. Electro Perú proposed 43 possible reservoir sites to be studied in the following project. Recently Cementos Lima S.A. is promoting the similar project through reviewing and analyzing the existing reports and data, and has made up a plan of the Paucarcocha seasonal regulation dam in the upper reach, Morro de Arica large dam and Capillucas intake dam in the middle reach. Based on the topographic and geological studies by means of cartographic maps, aerial-photographs and existing reports, the Study Team carried out field survey at 18 possible dam and intake dam sites; 8 sites proposed by Electro Perú, 8 sites proposed by the Study Team and 1 site by Cementos Lima S.A. and 1 site by SEDAPAL. Location of the dam site is seen on the map of the Study Area.

As the result of meticulous comparison and engineering check of each site, the Study Team selected Auco and San Jerónimo as possible new dam site, in addition to those of Paucarcocha, Morro de Arica and Capillucas which are under examination by Cementos Lima S.A., moreover, Zuñiga and Socsi as possible intake structure sites for the mountain and coastal route, respectively, to convey the D/I water to Lima. Characteristics of these proposed dams and intake sites with regard to topography/ geology and issues are summarized in Table 2.5.3.

Cementos Lima S.A has actively performed various studies on the engineering geology at the mentioned three dam sites including borehole drilling, materials testing and geophysical/chemical exploration, etc. Even though some detailed tasks still remains, these proposed dam sites are believed to have high priority.

General characteristics of the two dam sites (Auco and San Jerónimo) proposed by the Study Team are commented as follows:

Auco dam site:

a) General condition

The Auco dam axis (see location in general on the map of the Study Area and in detail in Figure 5.1.4) will be located about 600m upstream from Puente Auco village, where shows almost V-shaped valley with both abutments ranging in angle from 40 to 60^{o} from horizontal. The riverbed width is about 160m. Owing to gentle river gradient, the reservoir area shows wide aspect. The present river channel is located along the right margin. The alluvial cones, which were formed by debris flows, overlay on fluvial terrace in the left bank. The bedrocks have wide exposure in both abutments consisting of granitic rocks. Old fluvial and fluvio-glacial deposits thinly overlay on the lower part of the left abutment.

The bedrock consists of hard, slightly weathered granodiorites, tonalities with many semi-vertical joints. The old fluvial deposits show heterogeneous composition consisting of gravels, large boulders, sand and silt that may be alluvial deposit origin. The fluvio-glacial deposits are distributed on the left slope and plain hill raising about 220 m above the riverbed. The lithological composition is also heterogeneous and consists of gravels and silty matrix with slightly bedding planes.

The debris flow deposits exist at the mouth of the Pampa River, which is a tributary situated 500m upstream from the dam site. These sediments were largely deposited in March 30 and April 2, 1972. According to the information obtained from local people, the debris flow buried agricultural land and temporary dammed up the Cañete River channel. These debris flows were formed by slope failure of subsurface deposits on the slope of Mt. Huamanripa, located in the beginning of the tributary.

b) Evaluation

From topographic and geological point of view, it's possible to propose the dam site, if strict countermeasures against debris flow and slope unstability would be done. The soft deposits on the left abutment may be treatable. It's assumed that alluvial and fluvial deposit filled in the valley will be thick.

<u>San Jerónimo dam site</u>:

a) General condition

The San Jerónimo dam axis (see location in general on the map of the Study Area and in detail in Figure 5.1.6) will be located approximately 1.3km downstream from the Puente San Jerónimo, where shows V-shaped valley with both abutments ranging in angle from 40 to 50^{o} from horizontal. The riverbed at the dam site is about 85m wide. Terrace and alluvial deposits fill the valley. The left abutment consists of granitic bedrock covered by old fluvial and colluvial deposits, on the other hand the right abutment composes of granitic rocks completely free of surface deposits on the spur morphology. Fractured volcanic rocks of the Tantará Formation, alluvial and colluvial deposits sporadically outcrop in and around the reservoir area. The debris flow deposits were identified at the mouth of the Cacra and Tupe tributary rivers located upper end of the proposed reservoir area.

The bedrock consists of hard, slightly to no weathered granodiorites and diorites with some low-angle joints. The old fluvial deposits consisting of gravels, boulders, sand and silt overlay intermittently in 35 - 45 m relative high from the riverbed. The colluvial deposits principally consist of angular gravels and have the extensive exposure. Judging from the distribution of bedrocks, these soft sediments can be estimated about 10m or something more in thickness.

b) Evaluation

Topographic and geological condition is relatively suited. Fluvial and terrace deposit may fill thickly. The old fluvial and colluvial deposits on the left abutment are subject to be removed. It is assumed that alluvial and fluvial deposit filled in the riverbed will be thick. The study on the slope stability and permeability character will be important issues.

2.5.2 Hydrogeology

The hydrogeological study has been made principally based on available information in the lower basin of the Cañete River, which comprises the districts of Quilmaná, Cerro Azul, San Luis, Imperial, Nuevo Imperial and San Vicente from north to south.

(1) Well Inventory and Groundwater Utilization

In these districts, 90 wells, 27 tubular wells and 63 open cut wells, were identified. The tubular wells are mechanical dug made. The wells vary from 20 m to 121 m deep and from 0.3 m to 0.5 m of well diameter. On the other hand, the open cut wells are hand-dug made. These wells ring from 2 m to 21 m deep and vary between 0.8 m and 3.0 m of diameters. The operation is done by means of electric/diesel pump for tubular wells and small electric pump/bucket for open cut wells.

The total pumping volume by wells is estimated at about 4.4 MCM/year; 4.0 MCM/year (90.5 %) by 19 tubular wells and 0.4 MCM (9.5％) by open cut wells, for use of drinking (65％)、irrigation and livestock (23.5％) and industries (11.5％). Yields of tubular wells are from 15 l/s to 60 l/s. Groundwater developing areas excels in Quilmaná and San Vicente districts, where occupies about 82% of the total pumping volume.

In addition to the total volume (aprox. 4.4 MCM/year), the Cañete Water Supply Company (EMAPA Cañete S.A.) operates 2.8 MCM/year (1998) of groundwater by means of 3 filtering galleries and provides to the Cerro Azul, San Luis, Imperial and San Vicente districts.

(2) Aquifer Characteristics and Groundwater Table

The aquifer is composed of alluvial deposits, which fill the Cañete River valley. Aquifer is distributed in the area of rather thick quaternary deposits consisting of boulders, gravel, sand and clay. Some aquifers are identified in the alternating layers of different granularity. Judging from the geological logs of boreholes, results of aquifer test, etc. this aquifer is classified into unconfined type. The potential of the groundwater varies depending on the thickness of the quaternary deposits, particle size and precipitation, etc. The thickness of quaternary deposit varies to 450 m in maximum.

The hydroisobath map was drawn based on the water levels measured in August of 1999. The study result reveals that the hydraulic gradient shows 1.7% and groundwater flows from East to West direction. The groundwater recharge is presumed to be from the Cañete River and irrigation canal through infiltration. The deepest groundwater level is encountered at 86.6m from the ground surface in Quilmaná district and the highest level at 1.6m in San Luis district. It trends to raise progressively the water level from East to West. It is noticed that the groundwater fluctuation has no considerable variation up to 5 m from 1972 to 1999.

(3) Aquifer Hydraulic Characteristics

15 aquifer tests, including 2 tests for 2 same boreholes, were carried out from 1969 to 1971 by means of drawdown and recovery method. However, the well locality is restricted only Quilmaná, San Vicente, Imperial and Nuevo Imperial districts and detailed methodology remains unknown, the general notion on aquifer hydraulic characteristics became clear.

Transmissivity varies from 1.4×10^{-3} to 1.3×10^{-1} m^2/s. Aquifer with over $1.5 \times 10^{-2} m^2/s$ of transmissivity is generally presumed as suitable for exploitation, for that reason the mentioned values are evaluated as good or mediocre.

Storage coefficient varies from 1.5×10^{-1} to 5.0×10^{-2}, but the representative value of the study area is to be 1.5×10^{-1}. Since confined aquifer shows from 1×10^{-3} to 1×10^{-5} of the coefficient, these values probably indicate a characteristics of the unconfined aquifer.

Specific capacity indicates from 2.79 to 24.4 l/s/m and 12 l/s/m on the average. High values have been registered in Quilmaná and Imperial districts.

Radius of influence shows from 43 to 394 m after 24 hours continuous aquifer test.

Permeability coefficient varies between 3.3×10^{-4} and 3.3×10^{-3} m/s which corresponds to good or mediocre aquifer.

(4) Groundwater Quality

The water quality analysis of 62 samples obtained from tabular wells reveals the water type; Calcic/sodium bicarbonated, chloric and sulfated. Electric conductivity and hardness indicate low values in the recharge area and meanwhile high in the western and northern plain, where is polluted by the evaporation and saline soil. The values of pH shows between 7 and 8 which is slightly alkaline. The appearance of nitrate ions may indicate the intermixture of fertilizer and/or organic materials.

(5) Groundwater Balance

Based on 3 meters of the piezometric head fluctuation, 1.5 x 10^{-1} of the storage coefficient and 310 km^2 of the surface area of aquifer in the study area, the groundwater recharge volume is roughly estimated to be about 150 MCM/year. The other approximation also shows from 120 to 160 MCM of exploitable groundwater volume without the deterioration of resources (INADE, 1990). The total infiltrated volume in the study area, which is obtained by the total infiltrate volume of the basin wide divided by area proportion, is about 165 MCM. After all, the potential pumping volume is approximately evaluated at about 150 MCM/year (equivalent to 4.75 m^3/s) in this stage.

(6) Area of Groundwater Exploitation

The groundwater recharged from the infiltrated surplus water of irrigation might be contaminated because of the existence of nitrate ion. Development of unconfined groundwater preserved in the subsurface layer, which is presently utilized by collector wells of the Cañete water supply company, will be the first priority.

(7) Consideration

Though groundwater development started in the Cañete River basin many years ago, hydrogeological background data are not sufficient to grasp hydrodynamic characters and potentiality of aquifer with appropriate accuracy. Some of the available hydraulic data are inaccurate for the estimation of the groundwater balance. Therefore, in addition to exhaustive data collection, some data should to be checked and updated. Moreover, continuous measurement of water table is indispensable.

It is tentatively assumed in this stage that development potential of groundwater is about 130 MCM/year (about 4 m^3/s).

The safe yield of the groundwater development must be determined through stepwise development with careful monitoring of groundwater level, water quality, effect of sea water intrusion and other expected adverse effects.

2.6 Land Use

The Cañete River basin covering an area of approx. 618,900 ha is divided into five (5) categories in terms of present condition of land, namely (i) irrigated agricultural lands with an area of approx. 33,400 ha (5.4%), (ii) non-irrigated agricultural lands of 2,100 ha (0.3%), (iii) grass lands for shepherding of 113,700 ha (18.4%), (iv) desert/dune of 116,500 ha (18.8%), (v) exposed rock of 353,200 ha (57.1%), and in addition, some forests with an area of 200 ha exist (Source: Inventario, Evaluacion y Uso Racional de los Recursos Naturales de la

Costa Cuenca del Rio Cañete prepared by ONERN in June 1970. See Figure 2.6.1.).

In view of agricultural land use of (i) and (ii) above, the basin is divided into three (3) areas, namely, Valley area, Caltopa-Zuñiga area and Andino area based on the topography, soil, climate, etc. as discussed in the following paragraphs.

Valley area is located downstream the Nuevo Imperial intake covering a total area of 35,800 ha. Irrigation is practiced for an area of 24,100 ha or 67% of the area, which is divided into small pieces for private farms of large and middle extension. It is observed that the extensive cultivation of cotton, maize and potato occupies an area of 17,200 ha or 71% of the net agricultural land.

Caltopa- Zuñiga area embraces the agricultural land located upstream the Nuevo Imperial intake up to Zuñiga locality with a total area of 1,600 ha. The cultivation distribution in this area is not so different from that of Valley area. However, there is a predominance of orchard as it occupies an area of 670 ha, while cotton does 280 ha and pasture, 260 ha. It should be noted that forests with an area of approx. 200 ha are situated in this area.

Andino area pertains to the upper and middle reaches of the Cañete River basin. Most of the agricultural lands are scattered along the Cañete River and its tributaries. The agricultural activity is limited to the wet season lasting from October to March. Total agricultural lands are estimated at approx. 9,800 ha, out of which 2,100 ha are non-irrigated and 7,700 ha are supplementarily irrigated. The crops which prevail in the area are alfalfa, maize, potato and other kinds of forage (Source: Inventario y Evaluacion de los Recursos Naturales de la Microrregion de Yauyos prepared by ONERN in 1989).

Table 2.2.1 Physiographical Units in the Cañete River Basin

	Unit	Altitud (m. a.s.l.)	Proportional area	Slope gradient	Characteristic
Upper Reach	Glacial area	4,800-5,800	3.0%	35-50^o	Mountains are covered with snow/glacial and glacial lakes. The slope gradient is very steep. Continuos ascent of snowline shows a process of snowmelting.
Upper Reach	Alpine area	3,500-4,800	58.0%	0-30^o	Topographic feature was formed by glacial and fluvio-glacial action showing U-shaped valley, cirque, swampy plain, glacial lakes, drumlins, etc. Glacial and fluvio-glacial deposits are largely distributed. Slope stability is generally good.
Middle Reach	Andean ridge, River valley and Gouge area	1,000-3,500	31.5%	30^o-50^o	Continuous mountain ranges increase progressively the height from the west to the east and are eroded by weathering, heavy rainfall, etc. V-shaped deep valleys and gouges are predominant. The mayor geodynamic phenomena are occurred such as slope failure, landslide, debris flow, unstable slope, etc.
Lower Reach	Andean ridges	400-1,000	2.7%	10^o-30^o	Transitional area Geodynamic phenomena such as river erosion, debris flow, landslide and slope failure are broken out during the rainy season.
Lower Reach	Plain area	10-400	4.3%	0^o-10^o	Plain and some hilly area with talus, alluvial cones and flood plains. Erosion and inundation are prominent phenomena. The principal physiography are: terraces, river channels, flood plains, alluvial plains, etc.
Lower Reach	Shore area	0-10	0.5%	<1^o	The physiographycal unit is formed by marine erosion and sedimentation.

Table 2.3.1

MONTHLY MEAN RAINFALL

(Unit: mm)

Station	Altitude (m)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Cañete	150	0.4	0.8	0.4	0.3	1.6	3.8	1.8	2.3	2.6	1.1	1.1	0.8	16.9
Pacaran	700	5.5	3.1	4.0	0.2	0.1	0.1	0.0	0.0	0.1	0.6	0.4	1.6	15.6
Huangascar	2,550	63.5	72.9	90.2	8.0	0.7	0.3	0.0	0.3	0.6	2.6	6.5	25.6	271.3
Yauyos	2,850	69.2	87.4	90.9	20.8	3.6	0.6	0.2	1.2	4.4	15.1	18.6	44.0	356.0
Huantan	3,300	190.9	229.7	193.9	69.9	10.1	1.0	2.0	2.1	2.7	50.5	62.9	91.4	907.0
Colonia	3,350	84.6	109.7	127.0	27.4	3.1	0.3	0.8	0.5	3.9	15.4	19.4	65.6	457.8
Siria	3,650	121.5	130.6	126.7	58.9	24.1	5.7	15.4	6.9	34.4	49.1	62.0	76.9	712.0
Vilca	3,800	180.0	184.4	173.0	77.8	17.5	6.0	4.3	11.8	27.4	61.4	67.0	106.5	917.0
Carania	3,850	117.0	109.1	115.8	37.8	13.6	4.9	3.9	6.3	12.2	27.7	28.9	68.2	545.3
Sunca	3,850	134.6	143.0	144.4	62.4	17.6	5.8	4.4	3.6	29.0	51.1	73.4	97.7	766.9
Tanta	4,300	139.5	137.8	139.7	84.1	25.5	9.7	7.1	12.7	28.3	51.7	67.8	91.2	795.0
Yauricocha	4,522	175.3	176.3	162.7	75.9	24.2	9.3	9.3	9.4	41.7	66.5	84.0	114.9	949.5
(Stations closed to Cañete basin)														
San Juan de Castrovirreyna	1,670	53.4	53.4	56.7	3.5	0.5	0.1	0.1	0.3	1.2	1.0	2.4	18.0	190.4
San Juan de Yanac	2,550	20.7	29.8	45.8	4.0	0.3	0.0	0.0	0.0	0.0	0.3	0.1	7.2	108.2
San pedro de Huacarpana	3,189	82.3	108.0	157.8	22.0	1.7	0.5	0.3	3.0	6.0	18.6	23.0	50.8	474.0

Table 2.3.2

MONTHLY MEAN TEMPERATURE

(Unit: ℃)

Station	Altitude (m)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Imperial	104	23.8	24.6	24.5	22.8	20.5	17.8	17.0	16.9	17.2	18.6	20.0	22.0	20.5
Pacaran	700	22.6	23.0	23.2	21.8	19.6	17.6	16.8	17.4	18.7	19.6	20.5	21.2	20.2
Yauyos	2,850	14.2	14.1	13.8	14.6	15.0	14.6	14.7	15.0	15.3	14.6	14.6	14.0	14.5

Table 2.3.3

MONTHLY MEAN EVAPORATION

(Unit: mm)

Station	Altitude (m)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Cañete	150	137.6	133.8	141.7	128.8	90.3	54.4	53.7	59.8	73.4	96.8	109.4	132.1	1211.9
Pacaran	700	121.5	120.0	137.4	117.4	103.0	79.0	81.0	92.1	106.6	120.0	121.3	130.5	1329.7
Yauyos	2,850	79.9	61.7	65.9	90.3	122.0	139.7	154.6	158.2	147.7	140.7	133.1	114.4	1408.2

Table 2.3.4

MONTHLY MEAN SUNSHINE HOUR AT CANETE STATION

(Unit: hr)

Station	Altitude (m)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual/ Mean
Cañete	150													
Monthly mean		184.2	177.7	200.3	205.5	145.0	63.5	55.1	48.7	59.6	102.3	120.6	161.3	1523.8
Daily mean		5.94	6.35	6.46	6.85	4.68	2.12	1.78	1.57	1.99	3.30	4.02	5.20	4.19

Table 2.3.5

MONTHLY MEAN HUMIDITY

(Unit: %)

Station	Altitude (m)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Cañete	150	81	80	80	81	84	85	86	86	86	85	82	81	83
Yauyos	2,850	48	49	42	46	52	58	62	61	59	56	56	51	53

Table 2.4.1 Summary of Correlation Formula and Coefficient

y \ x	Tanta	Vilca	Carania	Yauyos	Huantan	Colonia	Huangascar	Pacaran
Tanta		- y=0.5962x r=0.6077	1 y=1.1613x r=0.7564	- y=1.5657x r=0.6835	- y=0.3686x r=0.3159	- y=1.1467x r=0.6432	- y=1.3243x r=0.4880	- y=15.5640x r=0.4675
Vilca	1 y=1.0872x r=0.6077		2 y=1.3717x r=0.5757	- y=1.6979x r=0.4189	- y=0.4993x r=0.5568	- y=1.3131x r=0.6054	- y=1.6371x r=0.4203	- y=16.6960x r=0.2317
Carania	2 y=0.6782x r=0.7564	- y=0.4482x r=0.5757		1 y=1.1635x r=0.7808	- y=0.3378x r=0.5259	- y=0.8987x r=0.6987	- y=1.1301x r=0.6446	- y=11.8410x r=0.4243
Yauyos	- y=0.4507x r=0.6835	- y=0.2870x r=0.4189	1 y=0.6770x r=0.7808		- y=0.2859x r=0.4654	2 y=0.7511x r=0.7595	- y=0.8242x r=0.6042	- y=7.5752x r=0.3861
Huantan	- y=1.1308x r=0.3159	2 y=1.1443x r=0.5568	1 y=1.6039x r=0.5259	- y=1.6519x r=0.4654		- y=1.6689x r=0.4663	- y=1.9972x r=0.4634	- y=16.0690x r=0.3094
Colonia	- y=0.6126x r=0.6432	- y=0.5092x r=0.6054	3 y=0.8153x r=0.6987	1 y=1.0366x r=0.7595	- y=0.3006x r=0.4663		2 y=1.0035x r=0.6973	- y=9.9058x r=0.3826
Huangascar	- y=0.4149x r=0.4880	- y=0.3014x r=0.4203	- y=0.5768x r=0.6446	- y=0.7412x r=0.6042	- y=0.2389x r=0.4634	1 y=0.6898x r=0.6973		2 y=9.9014x r=0.6601
Pacaran	- y=0.0326x r=0.4675	- y=0.0209x r=0.2317	- y=0.0402x r=0.4243	- y=0.0610x r=0.3861	- y=0.0274x r=0.3094	2 y=0.0488x r=0.3826	1 y=0.0663x r=0.6601	

(yellow) : adopted for estimation of missing records
The nubmer 1 - 3 identifies priority order.

Table 2.4.2 Results of Probability Analysis

Probability Analysis of Annual Rainfall (mm/year)

Station	Statistical Parameters			Return period (year)					
	N	Mean	ST-DV	2	5	10	20	50	100
Tanta	31	799.2	276.7	756.9	1038.0	1224.1	1402.6	1633.7	1806.8
Vilca	29	909.8	556.1	825.1	1393.6	1770.0	2131.1	2598.4	2948.6
Carania	28	545.2	171.4	519.2	695.1	811.5	923.2	1067.8	1176.2
Yauyos	22	356.4	173.1	330.6	513.0	633.8	749.7	899.7	1012.1
Huantan	15	656.2	318.3	610.6	964.1	1198.1	1422.6	1713.2	1931.0
Colonia	20	453.5	146.5	431.9	588.1	691.5	790.8	919.2	1015.4
Huangascar	29	272.2	143.6	250.3	397.2	494.4	587.6	708.3	798.8
Pacaran	18	14.9	11.5	13.2	25.7	34.0	41.9	52.2	59.9

Probability Analysis of Annual Maximum Daily Rainfall (mm/day)

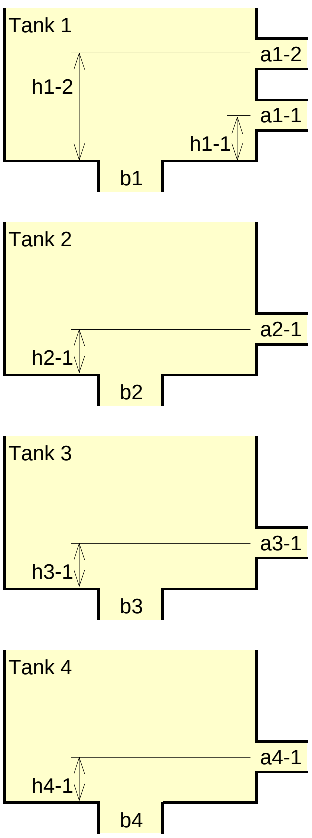
Station	Statistical Parameters			Return period (year)					
	N	Mean	ST-DV	2	5	10	20	50	100
Tanta	31	21.2	8.2	20.0	28.3	33.8	39.1	46.0	51.1
Vilca	29	26.0	9.6	24.5	34.4	40.9	47.1	55.2	61.3
Carania	27	18.8	4.9	18.1	23.1	26.4	29.6	33.8	36.9
Yauyos	22	21.0	6.3	20.1	26.7	31.1	35.3	40.7	44.8
Huantan	15	28.5	7.9	27.4	36.2	42.0	47.6	54.8	60.2
Colonia	19	22.3	11.5	20.6	33.0	41.2	49.1	59.2	66.9
Huangascar	28	22.0	8.6	20.7	29.5	35.3	40.9	48.1	53.5
Pacaran	17	3.8	2.4	3.5	6.1	7.9	9.6	11.8	13.4

Table 2.4.3 Summary of Correlation Formula and Coefficient

y \ x	Tanta	Aguas Calientes	Tomas	Tinco de Alis	Chavin	Socsi
Tanta		1 $y=0.8428x^{0.801}$ r=0.9455	- $y=2.9824x^{0.4929}$ r=0.6695	2 $y=0.2348x^{1.0203}$ r=0.8978	3 $y=0.1204x^{0.9076}$ r=0.8075	4 $y=0.2133x^{0.6861}$ r=0.7310
Aguas Calientes	1 $y=1.3473x^{1.1161}$ r=0.9455		- $y=5.1479x^{0.6738}$ r=0.7453	2 $y=0.2058x^{1.2783}$ r=0.9448	3 $y=0.0726x^{1.2093}$ r=0.8871	4 $y=0.1391x^{0.958}$ r=0.8404
Tomas	- $y=0.2238x^{0.9094}$ r=0.6695	- $y=0.1714x^{0.8245}$ r=0.7453		- $y=0.0302x^{1.2652}$ r=0.8158	- $y=0.0077x^{1.3003}$ r=0.8577	- $y=0.0.109x^{1.125}$ r=0.8689
Tinco de Alis	3 $y=4.7019x^{0.79}$ r=0.8978	1 $y=3.7474x^{0.6984}$ r=0.9448	- $y=12.584x^{0.526}$ r=0.8158		2 $y=0.495x^{0.9043}$ r=0.9159	4 $y=0.7788x^{0.7248}$ r=0.8846
Chavin	- $y=13.327x^{0.7184}$ r=0.8075	- $y=10.438x^{0.6507}$ r=0.8871	- $y=35.636x^{0.5657}$ r=0.8577	1 $y=3.1587x^{0.9276}$ r=0.9159		2 $y=1.8938x^{0.762}$ r=0.9158
Socsi	- $y=14.682x^{0.7789}$ r=0.7310	- $y=10.746x^{0.7372}$ r=0.8404	- $y=45.482x^{0.6711}$ r=0.8689	- $y=2.6413x^{1.0797}$ r=0.8846	1 $y=0.8361x^{1.1005}$ r=0.9158	

: adopted for estimation of missing records
The number 1 - 4 identifies priority order.

Table 2.4.4 Summary of Tank Model Parameters



Station	Tanta	Aguas Calientes	Tinco de Alis	Chavin	Socsi
Evaporation (mm/day)					
Non-rainy day	0.30	0.80	1.60	1.30	0.70
Rainy day	0.15	0.40	0.80	0.65	0.35
Catchment Area(km^2)	172	352	930	3265	5890
Tank 1					
Initial storage height (mm)	0	0	0	0	0
a1-1	0.060	0.080	0.010	0.080	0.100
h1-1(mm)	10	10	10	10	10
a1-2	0.080	0.150	0.010	0.100	0.200
h1-2(mm)	35	30	30	20	20
b1	0.2000	0.1100	0.2000	0.2000	0.1500
Tank 2					
Initial storage height (mm)	0	0	0	0	0
a2-1	0.0400	0.0450	0.0500	0.0120	0.0350
h2-1(mm)	0	10	0	0	0
b2	0.0500	0.0300	0.2000	0.0300	0.0600
Tank 3					
Initial storage height (mm)	0	0	0	0	0
a3-1	0.0200	0.0030	0.0050	0.0020	0.0020
h3-1(mm)	0	0	0	0	0
b3	0.0500	0.0150	0.0080	0.0050	0.0050
Tank 4					
Initial storage height (mm)	1200	700	2800	2000	500
a4-1	0.00020	0.00030	0.00010	0.00010	0.00030
h4-1(mm)	0	0	0	0	0
b4	0.0003	0.0001	0.0000	0.0000	0.0000

Note) ax-x, bx : multiplier of model hx-x : Storage height (mm)

Table 2.5.1 Stratigraphic Classification of the Cañete River Basin

Era	Period	Series	Stratigraphic Unit	Symbol	Thick-ness(m)	Lithology
Cenozoic	Quaternary	Holocene	Present fluvial deposit & Alluvial cone	Qh-pf Qh-ac		Soft deposit located along the river channel composing of boulder, gravel, sand and silt.
			Talus deposit	Qh-td		Semi-soft heterogeneous material composing of rockfall block, sand and silt on the gentle slope.
		Pleistocene	Terrace deposit	Qp-td		Semi-hard to soft deposit composing of boulder, gravel, sand and silt with regular alterating beds.
			Old fluvial deposit	Qp-of		Semi-hard to soft deposit composing of boulder, gravel, sand and silt with graded bedding.
			Fluvio-glacial and glacial (moraine) deposit	Qp-fg Qp-g		Semi-hard heterogeneous material composing of block with striation, gravel, sand and silt.
			Caudalosa Formation	Ts-c	400	Rhyoritic tuff and rhyodacite with alternating beds of tuffaceous sandstone.
	Tertiary	Upper	Astobamba Formation	Ts-a	200	Andesitic lava and breccia with variable tonality.
		Middle	Sacsaquero Group	Tm-s	300	Volcano-sedimentary sequence. Andesitic breccia, lava, tuff with alternating beds of sandstone.
		Lower	Tantará Formation	Ti-t	500	Dark gray andesitic lavas and violet volcanic breccias with rhyorite and rhyodacite layers.
			Casapalca Formation	KsTi-c	600	Red shale and sandstone with good stratified beds of conglomerate and limestone.
Mesozoic	Cretaceous	Upper	Celendín Formation	Ks-c	400	Stratified siliceous shale with thin beds of limestone and yellowish gray marl.
			Jumasha Formation	Ks-j	300	Yellowish gray limestone with alternating beds of marl and chert.
		Lower	Machay Group (Chulec/Pariahuanca, Pariatambo Frms)	Ki-m	300	Gray limestone with layers of marl and sandstone. Fossil bearing formation.
			Goyllarisquizga Group (Oyon/Chimu, Santa y Carhúaz frms)	Ki-g	350	Quartziferous sandstone with regular alternating beds of shale and siltstone. Limestone and dolomite of Santa Frm.
	Jurassic	Upper	Chaucha Formation	Js-ch	250	Gray limestone with good stratified layers of marl and dolomitic sandstone.
		Middle Lower	Cercapuquio Frm.	Jim-c	400	Dark gray sandstone with good stratified layers of siltstone.
	Triassic	Upper	Pucará Group	TrJ-p	400	Gray limestone alternating with layers of marl, calcareous sand-stone and shale.

Rocas Intrusivas

Age	Unit	Symbol	Lithology
Lower Tertiary～ Upper Cretaceous	Andean Batholith	KT-I	Granodiorite, diorite and granite

Table 2.5.2 Geodynamic Issues in the Cañete River Basin

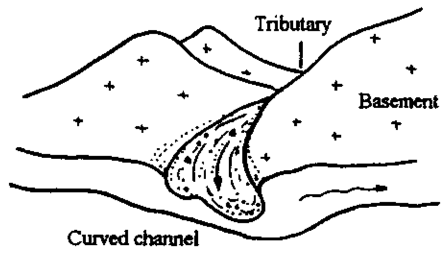
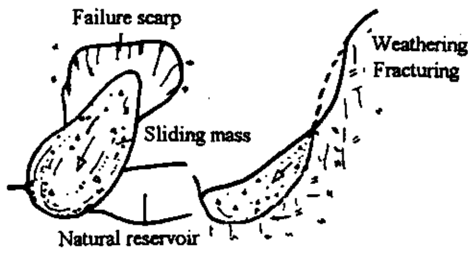
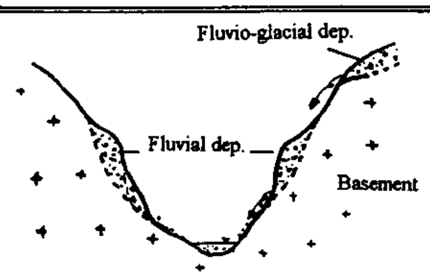
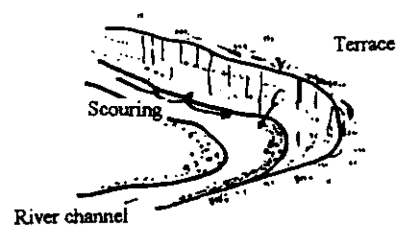
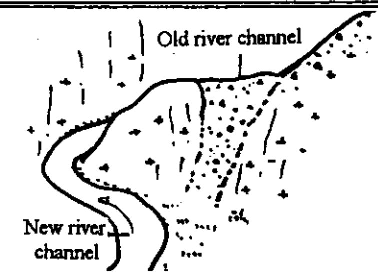
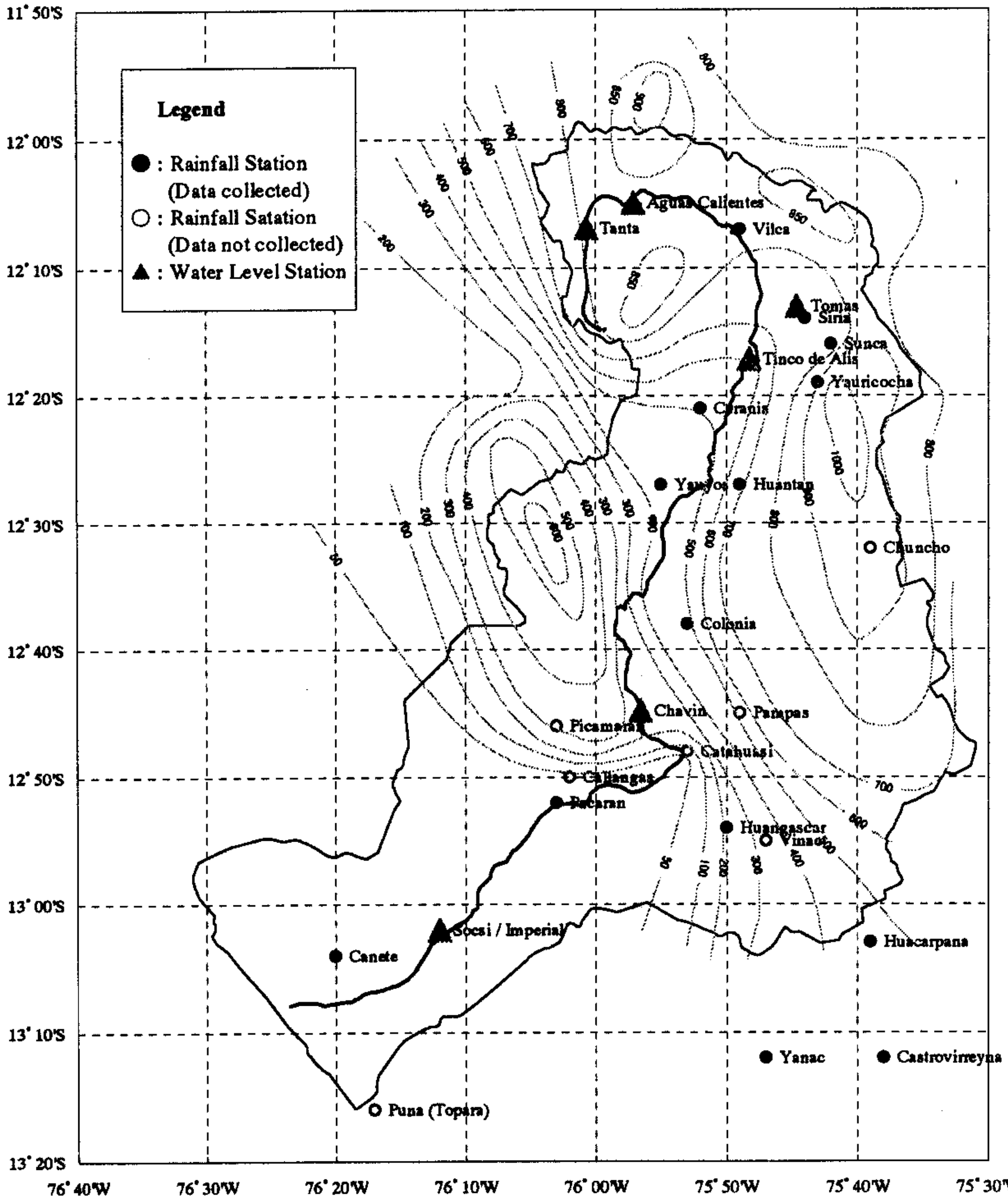
Geodynamic phenomenon	①Debris flow	② Landslide	③Slope failure	④ Riverside failure	⑤ Buried valley
Schematic figure					
Characteristic	The heterogeneous particles of various size carried by debris flow are discharged unexpectedly and are deposited in cone shaped form in tributary riverbed and confluence between the Cañete River and tributary.Debris flow occurs temporary in the rainy season. Rapid and voluminous flows cause a serious problems. Some alluvial cones stem the Cañete River to build a temporary reservoir.	A large scaled landslide occured on the NE facing slope in kp. 86.5 and 88km many years ago.Consequently, sliding mass stemed the Cañete River and dammed up to creat a natural reservoir upstream. This dam body has existed for long time because of large deposit of lacustrine sediment in the ex reservoir area.	Many slope failures fail in the steep ravine on the slopes. Major failures occur near of the base of the slope on which unstable old fluvial and fluvio-glacial sediments overlies. The fluvial sediments are deposited in the form of terrace in the lower reach and hanging in the middle. The fluvio-glacial sediments are accumulated extensively on the gentle slopes in the upper and middle reach.	Riverside failures are shown in the curvilineal channel of wide Cañete valley between San Jerónimo and Zuñiga. The failures are formed by erosion at under cut slope of river terrace along the channel through the scour during the flooding.	At present, the old river channels exist with almost straight alignment filled of fluvial and possibly fluvio-glacial materials through gravity, sliding and geodynamic phenona. After interruption of the river current, a new river channel was formed aside the old one with curved and narrow aligment by means of river erosive action on its riverbank.
Physiography	The phenomenon occurs along the tributary of 15-45° gradient and stops less than 10° gradient.	V-shaped valley with both slopes of 35-40° gradient. Landslide surface shows 20-25°gradient. Slinding scarp is located at 800-900m high from the riverbed.	Slope failures occur along the ravine of 30-40° gradient. There are many rills and gullies around of the slope failures.	River channel is generally meander form. Eroded slope shows almost vertical. Original deposits are mainly terrace and alluvial cone.	Appearance of break-line on a slope along the old river channel and narrow riverbank eroded by the new one.
Geology	Debris flows are distributed mainly in the stretch between Lunahuana and Magdalena where volcanic, non-carbonated sedimentary rocks and granitic rocks are exposed.	Soft volcanic formation consisting of pyroclastic rocks with large boudlers. Lacustrine sediment composing of fine materials are distributed upstream in Chavin, Capillucas, etc.	The old fluvial sediment shows bedding composed of gravel, sand, silt and clay. The fluvio-glacial sediments show slightly bedded strata composed of heteogeneous materials.	Soft sediments composed of gravel, sand and silt. Some materials may be deposited at the base of the slope or carried directly into a main stream.	The fluvial, colluvial and possibly fluvio-glacial deposits buried the concavity of the old river channel. Buried materials consist of unsorted boulder, pebble, cobble, gravel, sand and silt.
Frequency	Frecuent	Few	Frecuent	Moderate	Moderate
Sediment supply	Abundant	Abundant	Abundant	Normal	—
Remarks	Debris flow do large damage to the infrastructures, agricultural crop and human life during the summer of El Niño year. Debris flow is called Huayco in Perú.	Few landslide occurred in the basin, but its magnitude was large. Clayish lacustrine material shows a continuous distribution such like band on both slope sides.	This type of failure is common in the basin. These sediments are intermittently distributed on the both slopes as far as Magdalena. Particles of these sediments continuously fail.	This type of failure causes agricultural damage on the river terrace.	The old river channels become a engineering problem due to a weakness, high permeability, etc. in some proposed dam sites such as Capillucas, Santo Domingo and Calachota.

Table 2.5.3 Characteristics of the Proposed Dam and Intake Dam

		Proposed Dam/Intake Site	Paucarcocha Dam	Morro de Arica Dam	Auco Dam	San Jerónimo Dam	Capillucas Intake Dam	Zuñiga Intake Structure	Socsi Intake Structure
Dam Plan		Altitude of river bed (m.a.s.l.)	North EL 4,216m South EL4,235m	EL2,787m	EL1,950m	EL1,000m	EL1,522m	EL775m	EL330m
		Efficiency of reservoir	Good	Relatively good	Good	Relatively good	Relatively good	Good	Good
		H.W.L (Crest height)	EL4,254m (38m) EL4254m (19m)	EL2,987m (200m)	EL2,100m (150m)	EL1,150m (150m)	EL1,565m (43m)*	EL785m (10m)	EL340m (10m)
		Volume (Crest length)	(350m) (280m)	(150m)	(420m)	(550m)	(100m)	(150m)	(200m)
				EL2,997m (210m)	EL2,150m (200m)	EL1,200m (200m)	EL1,560m (38m)**		
				(151m)	(505m)	(650m)	(93m)		
Topography		Limit of crest height	Nothing	Lower than SWL3,060m	Lower than SWL2,200m	Nothing	Lower than SWL1,565m	Lower than SWL795m	Lower than SWL340m
		Riverbed width	35m 80m(Low part)	aprox. 20m	155m	85m	70m	20m	40m
		Slope gradient	L: 7-22° R: 20° / L: 20° R:2-25°	L: 60-80° R: 70-85°	L: 60° R: 70°	L: 40° R: 50°	L: 60° R: 50°	L: 55° R: 5°	L: 55° R: 5°
		Landslide at dam site	No present	No present	No present	No present	No present	No present	No present
	Landslide	Near of dam	No present	No present	No present	No present	No present	No present	No present
		Reservoir	Small scale	Isolated rock falls, rock slides and landslides.	Remove of alluvial cones in small scale	Remove of alluvial deposits in small scale	Remove of alluvial deposits in small scale	No present	No present
		Remarks	Drumlin separates two embankmen located downstream of the Paucar-cocha lake.	Narrow gouge between very steep walled canyon	Flat topography in the top of the left abutment. Relatively, gentle and wide river channel.	Rocky spur form the right abutment.	Rocky hill 47m high form the riverbed and paleo-channel behind the hill.	Steep rocky slope in the left bank and very gentle slope in the right.	Wide valley filled by fluvial and alluvial deposits.
Geology	Dam site	Bedrock	Andesite, dacite of the Tantará Frm is restricted in the upper part of the right abutment.	Oyón/Chimú Frm.(quatzite, meta sandstone and silicified shale)	Andean Batholith (granodiorite, diorite and tonalite)	Andean Batholith (granodiorite, diorite and tonalite)	Andean Batholith (granodiorite, tonalite and granite)	Goyllarisquizga Group (quartzife-rous sandstone with alternating beddings of shale and siltstone)	Andean Batholith (granodiorite, diorite and tonalite)
		Quaternary sediment	Qp-g, Qp-fg and Qh-pf	Qh-pf	Qh-td, Qh-ac and Qh-pf	Qp-of, Qp-td, Qh-td, Qh-ac and Qh-pf	Qh-pf including lacustrine deposi Qh-td at the bottom of the slope.	Qh-pf	Qh-pf
		Thickness of fluvial sediment	more than 100m	aprox. 35m	Thick	Relatively thick	Thick (more than 50m)	Thin	Thick
		Faults	No present	No major fault is present	No major fault is present	No major fault is present	No present	No present	No present
		Fractures	—	Open fracture trends north-north-west direction	Many semi-vertical joints, some-times opened.	Patially semi-vertical jand semi-horizontal joints	Widely jointed in an angle of medium degree and semi-vertical	Many fractures parallel to the bedding planes	Sporadic fractures
		Alteration	—	Slight	No present	No present	No present	No present	No present
		Remarks	Glacial moraine deposit (Qp-g) is compact.	Tight fold structure near of the dam axis. Limestone outcrops are over 3060m at dam site.	Distribution of soft sediments on the basis of left abutment.	Distribution of soft sediments on the basis of left abutment.	Paleo-channel filled with fluvial materials caused by debris flows and aluvial deposits	Terrace, alluvial and fluvial deposits accumulated in the right margin.	Granitic outcrop is located near of the proposed intake weir in the right abutment.
	Reservoir	Bedrock	—	Ki-g (alternating beds of carbo-nate and non-carbonate rocks)	Andean Batholith (granodiorite, diorite and tonalite)	Tantará Formation (Andesite, dacite, rhyorite and rhyodacite)	Andean Batholith (granodiorite, granite), Tantará Frm. (andesite)	Principally quartziferous sand-stone	Principally Andean Batholith
		Quaternary sediment	Qp-g, Qp-fg, Qhtd, Qh-ac	Qh-td, Qh-ac, Qh-pf	Qp-fg, Qp-of, Qp-td, Qh-td, Qh-ac and Qh-pf	Qp-of, Qp-td, Qh-td, Qh-ac and Qh-pf	Qp-of, Qh-td and Qh-ac possibly Qp-fg	Qp-of, Qp-td, Qh-td, Qh-ac and Qh-pf	Qp-td, Qh-td, Qh-ac and Qh-pf
		Faults	No present	No major fault is present	No major fault is present	No major fault is present	No major fault is present	No major fault is present	No major fault is present
		Possible large leakage	Possibly insignificant	Possibly insignificant	No present	Possibly insignificant	Possibly insignificant	—	—
		Remarks		Landslides and small debris flows are present.	Relatively gentle and wide reservoir.	Wide distribution of terraces and talus slopes.	Relatively gentle and wide river channel.	Debris flows are located up-stream.	
Borrow Materials		Aggregates	Alluvial cones and talus deposit (colluvial type)	Andesite lava, alluvial and talus deposits and quarried bedrock	Fluvial deposit and alluvial cone	Talus deposit colluvial type and Tantará Formation (andesitic lava)	Alluvial cones and fluvial deposit	Alluvial cones and fluvial deposit	Fluvial and alluvial deposit
		Rock material	Alluvial cones and talus deposit (colluvial type)	—	Fluvial deposit and alluvial cone	Talus deposit colluvial type and Tantará Formation (andesitic lava)	Alluvial cones and fluvial deposit	—	—
		Earth material	Talus deposit and lacustrine deposit	—	Talus deposit	Talus deposit	Lacustrine deposit	—	—
Integrated Evaluation			Taking into considerations of similar engineering works near a this site, it's possible to construct a low fill type dam.	Narrow gouge consisting of hard and compact bedrock is suited fo the high dam. Reservoir area is relatively small.	Hard bedrock and wide valley are suited. Alluvial cone deposit may be thick.	Narrow river width and hard bedrock is suited.	Fill or RCC type will be appro-priate because of thick fluvial deposit accumulated.	Topographically surficial deposits is suited to conduct the intaked water in the right margin.	Topographically, terrace distri-bution is suited to conduct the intaked water in the right margin.
Issues			Groundwater behavior in the dam site soft deposits, subsurface pro-perties and sedimentation in the Paucarcocha lake. Reservoir rim stability study. Study of borrow materials.	Detailed grasping of the distribu-tion of the carbonated Santa Frm. and karst conditions. Distribution and behavior of fractures, open joints and bedding planes. Reservoir rim stability.	Grasping of the magnitude and properties of the soft sediments located on the valley and left slope. Exhaustive study on the debris flow. Permeable property **of the bedrock.**	Understanding of the magnitude and properties of the soft sedi-ments located on the left abutment Slope stability on the talus slopes.	Reservoir rim stability and seriou seepage studies by geological and soil mechanical data obtained. Material testing.	Grasping of soil mechanics and properties.	Grasping of soil mechanics and properties.



Note) Isohyet is cited from the "El Platanal Hydroelectric Power Plant Feasibility Study, 1987", ELECTROPERU

STUDY ON INTEGRATED WATER RESOURCES DEVELOPMENT IN THE CANETE RIVER BASIN IN THE REPUBLIC OF PERU	**Figure 2.3.1**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Location of Meteorological and Hydrological Station**

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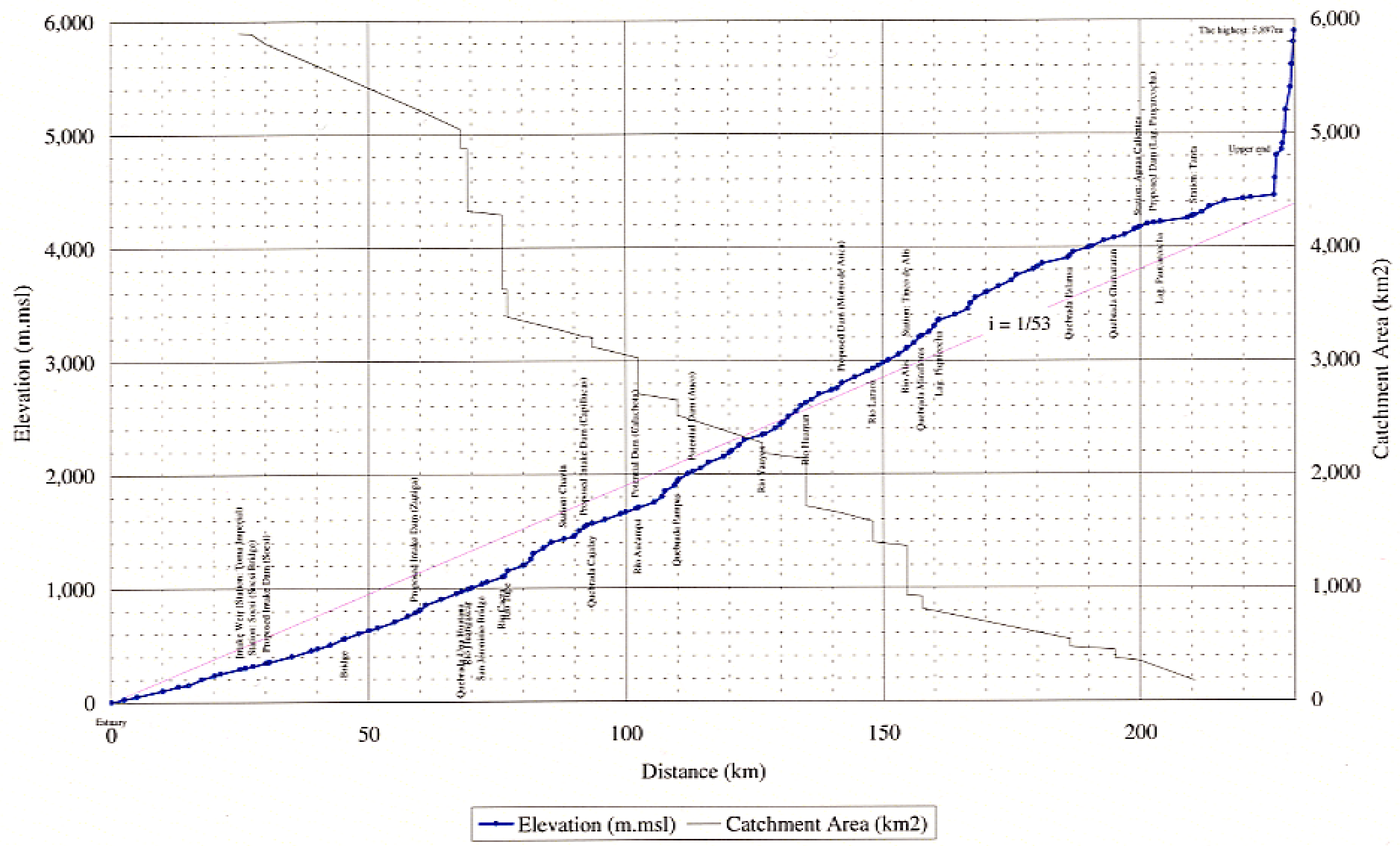
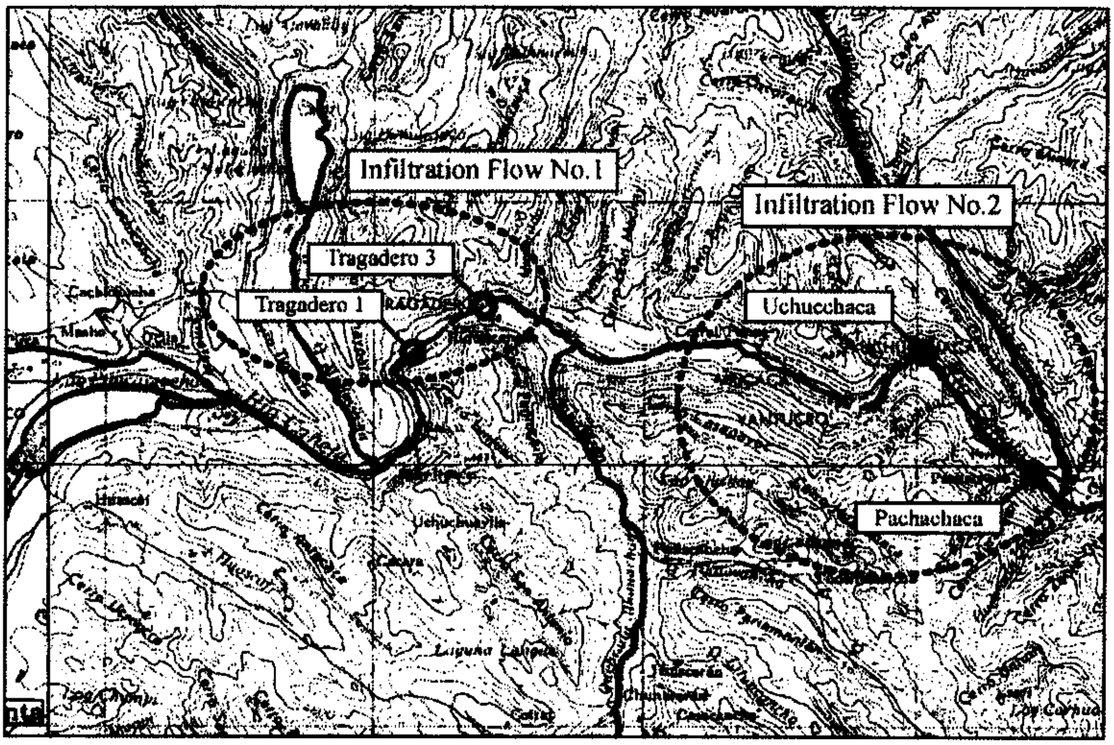
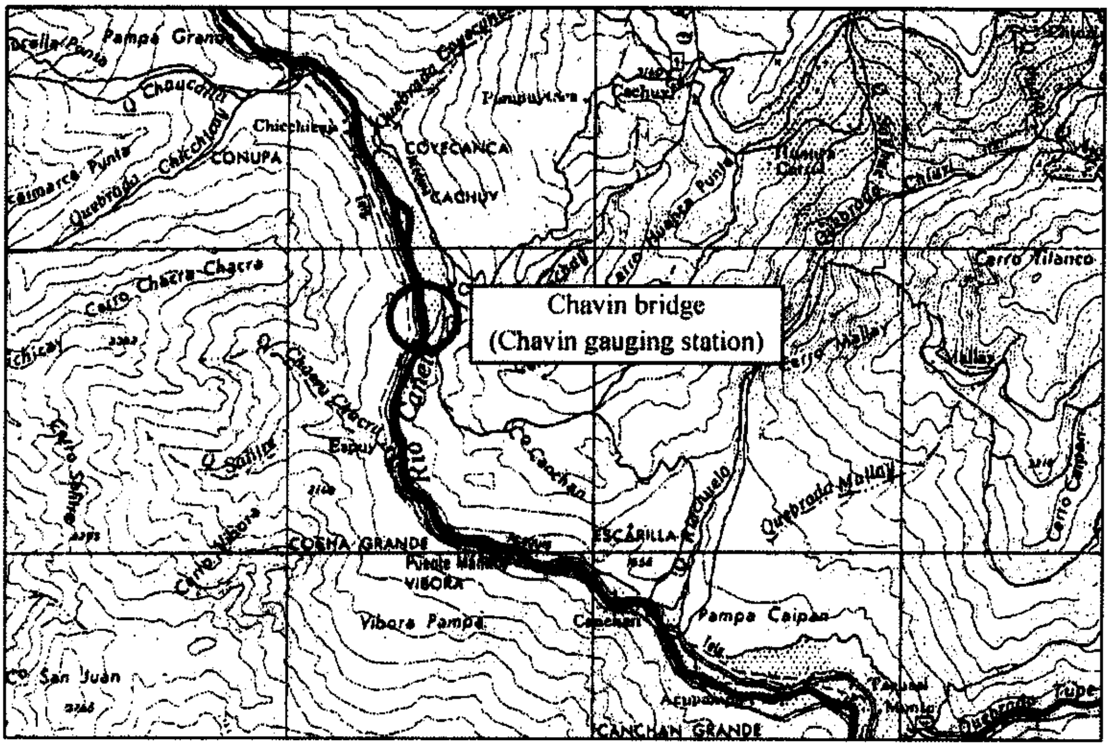


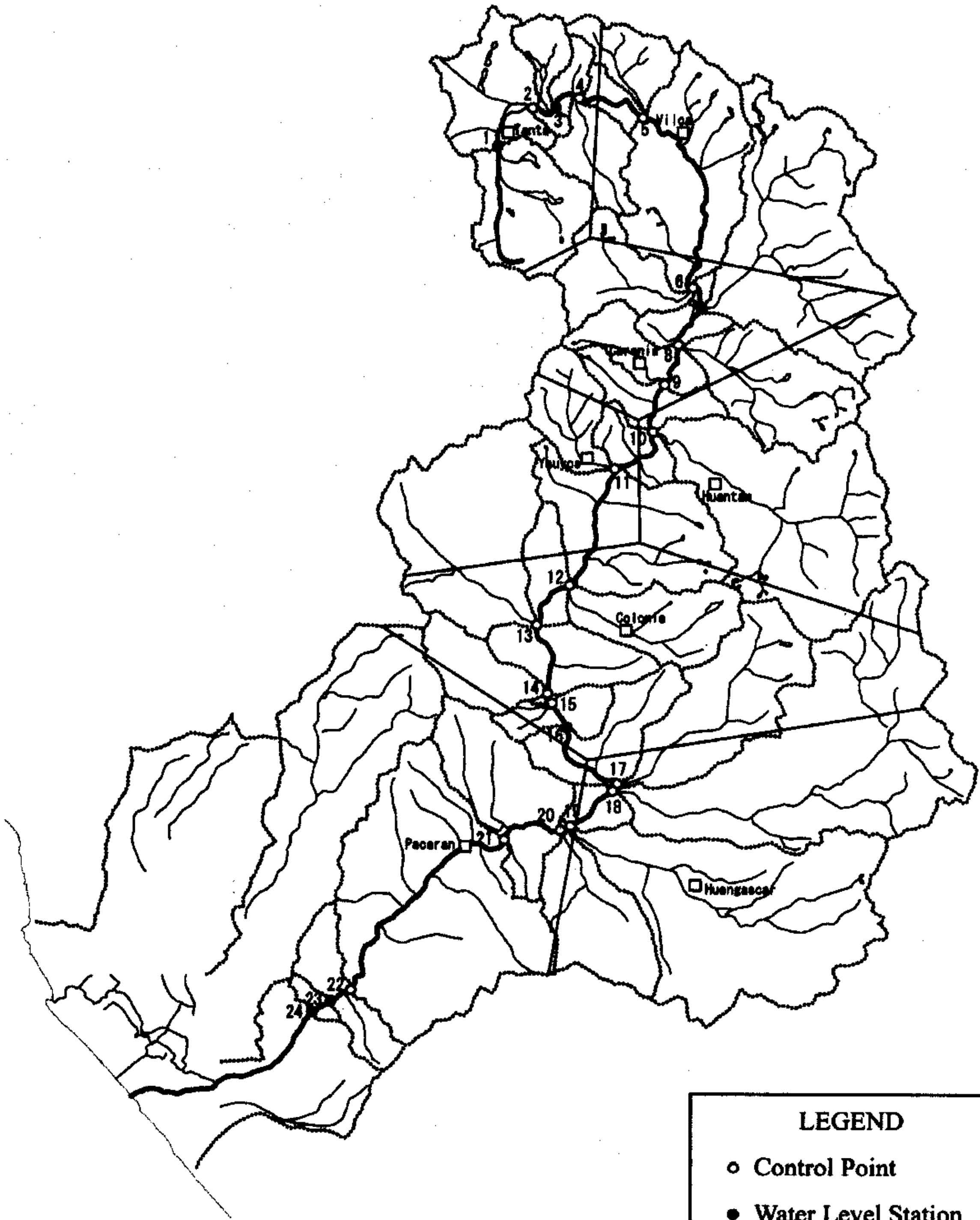
Figure 2.4.1

Longitudinal Profile of Cañete River





STUDY ON INTEGRATED WATER RESOURCES DEVELOPMENT IN THE CANETE RIVER BASIN IN THE REPUBLIC OF PERU	**Figure 2.4.2** **Location of Measurement Site**
JAPAN INTERNATIONAL COOPERATION AGENCY	



LEGEND

- o Control Point
- • Water Level Station
- □ Rainfall Station

No.	Station	Catchment Area(km²)	Effective Area(%)							
			Pacaran	Huangascar	Colonia	Tanta	Vilca	Huantan	Yauyos	Carania
1	Tanta	172	-	-	-	96.9%	0.6%	-	-	2.5%
3	Auas Calientes	352	-	-	-	98.5%	0.3%	-	-	1.2%
7	Tinco de Alis	930	-	-	-	46.6%	40.6%	-	-	12.8%
16	Chavin	3265	0.6%	-	18.2%	13.3%	20.0%	20.1%	13.9%	14.0%
23	Socsi	5890	15.7%	20.7%	17.9%	7.4%	11.1%	11.8%	7.7%	7.7%
24	Imperial	5900	15.8%	20.7%	17.9%	7.3%	11.0%	11.8%	7.7%	7.7%

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Figure 2.4.3

Thiessen Polygon

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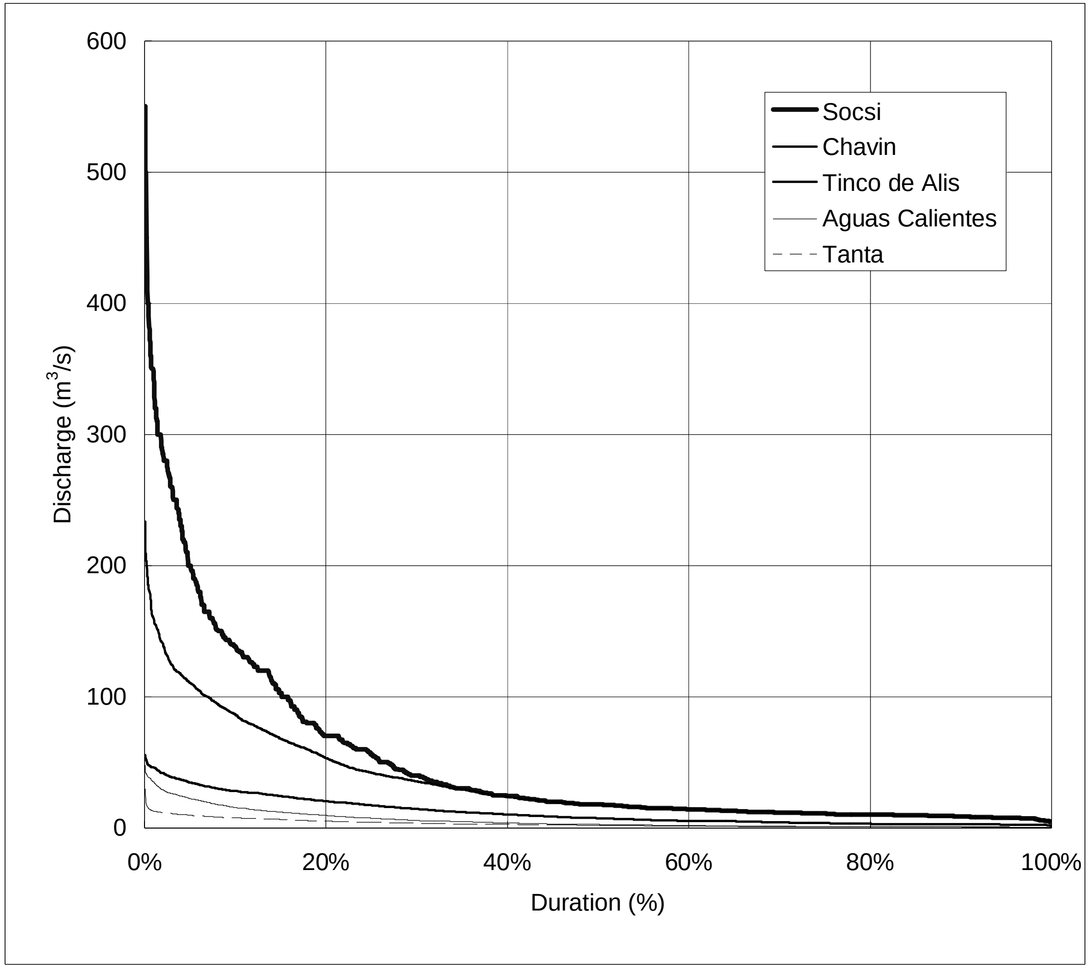
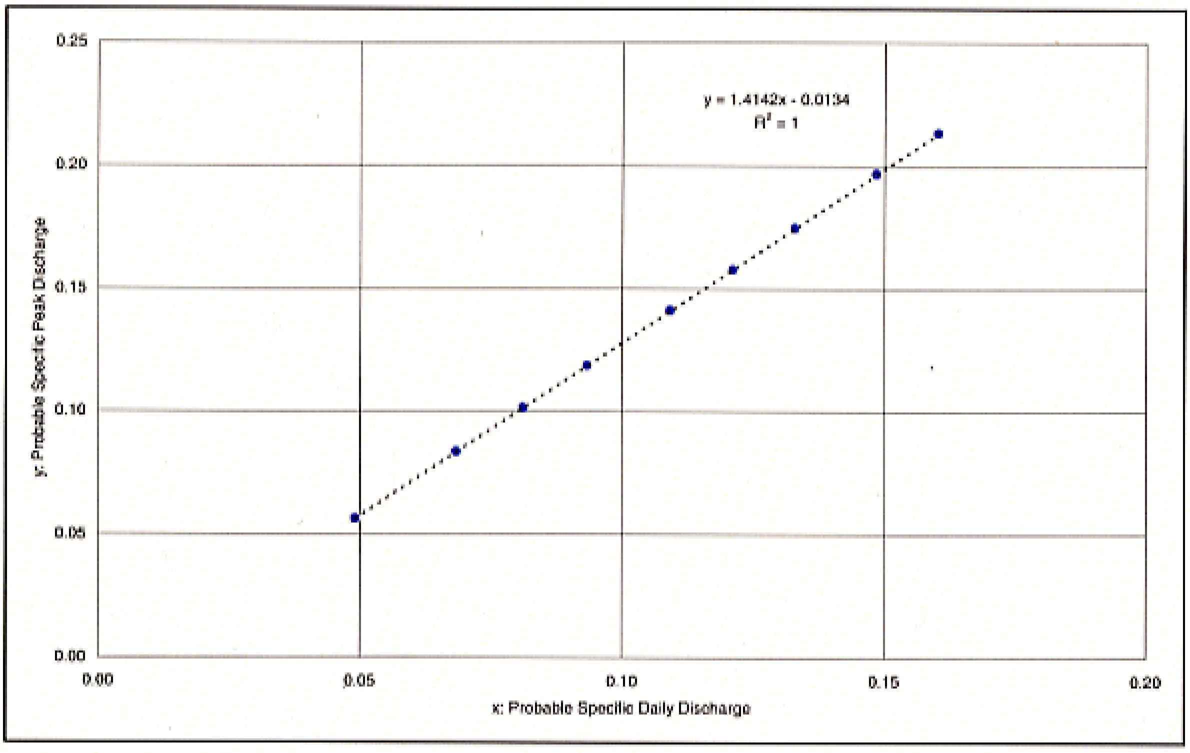
Figure 2.4.4
Flow Duration Curve at the Gauging Stations in the Cañete River Basin



Duration (%)	Discharge (m^3/s)				
	Socsi	Chavin	Tinco de Alis	Aguas Calientes	Tanta
0.02%	550.0	233.8	55.5	47.8	29.9
5%	200.0	110.7	34.7	22.3	9.5
10%	138.0	86.7	28.1	15.6	7.6
15%	103.0	68.0	24.3	12.0	6.5
20%	70.0	53.1	20.4	9.4	5.1
25%	56.0	42.2	17.2	7.4	4.3
30%	40.0	35.4	14.4	5.7	3.7
35%	30.0	29.4	12.0	4.7	3.0
40%	24.5	23.7	10.3	3.8	2.6
45%	20.0	20.0	8.7	3.1	2.3
50%	18.0	17.6	7.4	2.6	2.0
55%	15.5	15.7	6.3	2.2	1.7
60%	14.0	14.5	5.5	1.8	1.4
65%	13.0	13.0	5.0	1.5	1.2
70%	11.7	12.2	4.3	1.3	1.1
75%	11.0	10.8	3.7	1.1	0.9
80%	10.0	9.9	3.2	1.0	0.8
85%	9.5	9.1	2.9	0.8	0.7
90%	8.8	8.5	2.8	0.7	0.6
95%	7.8	7.5	2.5	0.6	0.5
100%	4.6	5.4	1.2	0.2	0.2



STUDY ON INTEGRATED WATER RESOURCES DEVELOPMENT IN THE CANETE RIVER BASIN IN THE REPUBLIC OF PERU	**Figure 2.4.5**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Relationship between Probable Daily Discharge and Peak Discharge**