FINAL REPORT

VOLUME III SUPPORTING REPORT

B. GEOLOGY AND HYDROLOGY

STUDY
ON
INTEGRATED WATER RESOURCES DEVELOPMENT
IN THE CAÑETE RIVER BASIN
IN
THE REPUBLIC OF PERU

FINAL REPORT
VOLUME III
SUPPORTING REPORT

B: Geology and Hydrogeology

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Chapter 1 Geology

1.1 Regional Geology of the Cañete River Basin

1.1.1 General geology

The Cañete River basin originally formed a depression in which deposited marine and continental sediments. Subsequently, these geological units have been deformed by orogenesis and epeirogenesis movements, which is Andean mountain-building processes including faulting, folding and recumbent folding, etc. in the Andean Cordillera sector.

Lithological components of the basin are fine sedimentary rocks with intercalation of volcanic (andesites, dacites, etc), limestone, sandstones, shale, etc., moreover igneous rocks of granitic composition and volcanic effusions, which covers partial or totally the old structures and older rocks. The units show from Upper Triassic to present Quaternary.

1.1.2 Stratigraphy

The Mesozoic stratigraphic units are principally marine, in other hand, Tertiary units are volcanic / non-marine origin. The older sedimentary formation ranging in age from upper Triassic to upper Cretaceous outcrops principally in upstream of the basin and its banded sequence trends parallel to the Western Cordillera of the Andes. The newer deposits have on the western coastal zone. The intrusive and extrusive rocks show large distribution in the central sector of the basin. Regional geological map and stratigraphic succession in the Cañete River basin are shown in Fig. S.2.4.1.1 and Table S.2.4.1.1., respectively. Characteristics of each stratigraphic unit are mentioned in the following paragraph:

(1) Upper Triassic to Lower Jurassic: Pucará Group (TrJ-p)

Pucará Group consists of thin beds of light gray limestone, slightly alterated, with some interbedding marl, calcareous sandstone and shale. Few outcrops are distributed in the Northeast corner of the basin.

(2) Lower-Middle Jurassic: Cercapuquio Formation(Jim-c)

Cercapuquio Formation is composed mainly of gray sandstones, well sorted. Its distribution is restricted in the northern limit of the basin; near of the Parpococha Lake and 2km south from the Chaucha Station. This Formation overlay concordantly on the Pucará Formation.

(3) Upper Jurassic: Chaucha Formation (Js-ch)

Chaucha Formation consists of yellowish dolomite sandstones in the base and gray limestone well stratificated, alternating with marls in the top of the

Formation. These carbonate rocks show small exposure near of Chaucha and Parpococha Lake, orienting the Southeast-Northwest. The stratigraphic relations with upper/lower formation are shown as concordant.

(4) Lower Cretaceous: Goyllarisquizga Group (Ki-g)

Goyllarisquizga Group composes of interbedded quartzite and silicified shale and sandstones partially carbonate rocks. This group has an extensive distribution from the around of Yauyos to Tinco de Alis including Morro de Arica dam site with concordant relation respect to neighbor formations. Goyllarisquizga Group is correlative with the Oyón-Chimú, Santa and Carhuaz Formations.

(5) Lower Cretaceous: Machay Group (Ki-m)

Machay Group consists of gray limestone with alternated marls and sandstones containing many marine fossils. This group has an extensive distribution from around of Paucarcocha Lake to Chucllahuacta village with an orientation Northwest - Southeast. This group shows a concordant relation with other formations.

(6) Upper Cretaceous: Jumasha Formation (Ks-j)

Jumasha Formation composes of gray limestone with alternating beds of marl and cert, with strong folding. The distribution is elongated in band with an orientation Northwest – Southeast between Minabamba- Thomas- Pumacocha. This Formation overlay on the Machay Group in concordant relation.

(7) Upper Cretaceous: Celendín Formation (Ks-c)

Celendín Formation consists of stratified siliceous shale with thin limestone and yellowish gray marl. This Formation corresponds with last marine sequence of the Mesozoic and has an exposure in the Northeast sector of the basin between Ranahuanusa Hills and Mancacocha with an Northwest – Southeast direction.

(8) Upper Cretaceous-Lower Tertiary: Casapalca Formation (KsTi-c)

Casapalca Formation composes of principally continental deposits: red shale and sandstone with good stratified conglomerate and limestone. This Formation is distributed in around of Yauricocha mine, Huancaya and Papacocha Lake in the Northwest-Southeast direction. The relation with the lower Celendín Formation shows clear discordant.

(9) Lower Tertiary: Tantará Formation (Ti-t)

Tantará Formation consists mostly of continental volcanic rocks; extrusive andesite and dacite flows, with some interbedded tuff and breccias. The flow consists of gray to reddish, aphanitic, porphyritic, and agglomerate rocks in thin to massive beds. The tuff is usually pink to white, sandy, and friable, which was deposited in thin to thick discontinuous beds. Bedding in the volcanic rocks usually ranges from horizontal to about 15^{o}. These extrusive andesites are distributed filling the topographic concavity to the downstream from the imaginary line linking Tanta - Lalaos.

(10) Lower Tertiary: Sacsaquero Group (Tm-s)

Sacsaquero Group composes of andesitic breccias, tuff and lavas with alterated sandstone. The distribution is shown extensively in the highland from the southern limit of the basin to the Huantán River. Folding and faulting are commonly made by principally plutonic intrusions.

(11) Upper Tertiary: Astobamba Formation (Ts-a)

Astobamba Formation consists of andesitic lavas and breccias. This Formation is distributed in the Ticlla Cordillera and oriental sector from Condorjaja Hills to Ancoripa Hill.

(12) Upper Tertiary: Caudalosa Formation (Ts-c)

Caudalosa Formation consists of rhyolitic tuff and rhyodacite with alternating beds of tuffaceous sandstone. This Formation has an exposure in southern sector from Poroncancha River to the Pampa Coral River.

Quarternary formations are principally soft deposits made by water, glacial and wind agents and distributed filling on the concaved topography and gentle slopes. From engineering point of view, these deposits frequently make some inconvenient problems due to its geological instability.

(13) Quarternary Pleistocene: Fluvio-glacial (Qp-fg) and Glacial Deposits (Qp-g)

Fluvio-glacial and glacial deposits have been formed by glaciation during Pleistocene. Fluvio-glacial deposits were mapped in the bottom of the Cañete River valley. These deposits consist mostly of alluvium that was deposited as streams reworked portions of the glacial material and ground moraine deposited along the valley bottom. The fluvio-glacial deposits consist of interbedded and stratified sands and gravels, with cobbles and boulders. The clasts almost entirely of volcanic rock fragments. Also included in the fluvio-glacial deposits are peat deposits and silty clay lacustrine deposits.

Glacial deposits, including glacial till and moraine, were mapped in large areas over 3,500m.a.s.l. Most of the glacial deposits consist almost entirely of volcanic rock fragments. The percentage of gravel to boulder-sized material varies. The surface of the glacial deposits often contains a high percentage of large boulders. The glacial sediments were deposited in lateral, medial, terminal, and ground moraines. In the area around the valley glacial processes produced a number of drumlins, which are small hills composed of material similar to the other glacial moraine deposits. Portions of the glacial deposits were overridden by ice resulting in material that is compact and hard. According to the filed observation realized by the Study Team, glacial traces can be seen up to Capillucas intake dam site.

(14) Old fluvial deposits (Qp-of)

There are many old fluvial deposits on the both slope sides along the Cañete River in the stretch between Zuñiga and Tinco, which is a distinctive feature of geodynamic phenomenon. These deposits are formed by a large landslide and debris flows, which dammed up to create a natural reservoir upstream. Actually, these deposits are located more than 100m upper level from the present riverbed. After disappearance of the natural dams, the deposits were vigorously eroded and remained on both slopes. These deposits consist of interbedded and stratified sands and gravels, with cobbles and boulders and show an instable condition to be fragile.

(15) Terrace deposits (Qp-td)

Terrace deposits are distributed widely on both riversides varying 10-30m relative height from riverbed in the lower reach and sporadic/narrowly from dozens meters to over 100m high in the middle reach.

Stratification composing of gravel, cobble, boulder and fine material layers are seen clearly. Sometimes peat and plant are also included.

(16) Talus deposits (Qh-td) and Colluvial deposits

Talus deposits, consisting of gravel to large boulder sized rock fragments, are seen on some of slopes. These deposits often overlie and interfinger with colluvial, fluvial and alluvial deposits.

Colluvial deposits consist of silty sand with gravel to large boulder size rock fragments. These deposits usually cover valley slopes at the base of bedrock outcrops and at the base of steep slopes composed of alluvial deposits. The colluvium may interfinger with alluvium on slopes. The colluvium also contains slide soil and slopewash soil deposits. The colluvium has low moisture content, is weakly cemented, and forms slopes up to 45^{o}.

In this study, both deposits are considered as talus deposits because two deposits are always distributed overlapped.

(17) Fluvial deposits (Qh-pf)

The fluvial alluvium deposits at the Capillucas dam and reservoir area cover large areas along the valley slopes and valley bottom. These deposits consist of silty sand with gravel to large boulder sized rock fragments. The fluvial alluvium was mapped as three levels of fluvial () deposits, based on geomorphology, and in some cases based on composition. The Qf1 terrace represents an older stream fluvial deposit along the Cañete River valley, which in some places are over 250m above the river level. The Qf2 terrace deposits are located above the flooding terrace along this portion of the Cañete River valley. The Qf3 alluvium includes areas in the recent flooding portion of the Cañete River channels.

(18) Alluvial cones (Qh-ac)

Alluvial cones are made by the debris flows up to 100m thick. These huayco deposits form many of the nearly vertical cliffs along the reservoir rim. The Qaf_2 alluvium was deposited as a large huayco deposit up to 75m thick that originated in Quebrada Cajalay and Quebrada Chicchicay.

The Qaf_2 alluvium is somewhat gray-green in color and contains a high percentage of light colored granodiorite rock fragments.

1.1.3 Granitic intrusive rocks

Granitic rocks are widely distributed in both large and small masses of different epoch from the Tertiary to the Cretaceous in principally lower and middle reach up to around Yauyos. These granitic rocks are exposed in two belts running in the North-Northwest to South-southeast direction; one belt along the Cañete River channel and another between south of Huantán and Cacra. The lithologic composition varies diorites, granodiorites, tonalities and merely granites. The granitic rocks have contact metamorphic and folding/ faulting effect on the surrounding rocks. Due to the hardness and fractured character, steep slopes and gouges are commonly seen.

The granitic rocks consist of gray fine to medium grained rock with feldspar phenocrystals and are generally strong, hard, and widely fractured. The color and texture of the rock is variables and related to mineralogical variants.Generally, this intrusive rock contains widely spaced and filled fractures and dipping 30^o to 60^o. Fracture density increases near shear/faults zones.

1.1.4 Structural Geology

The technical movement of the Western Cordillera of the Andes formed structural geology of the basin. Structural phases are divided into two phases: Strong deformation, close folding with reverse faults in the north area from

Yauyos, and weak deformation, open folding, block movement along the faults. The folds and faults trend, in general, the Northwest-Southeast direction and dip approximately vertical.

Geotectonic stresses make longitudinal faults, which have a Northwest-Southeast and Northeast-Southwest direction and a Southwest dip. These structures have a close association with folding and mineralization such as Yauricocha ore deposit.

Recumbent folds are distributed principally in northern area from Yauyos between Alis and Tomas, around Huancaya, etc.

The prominent close folds have an association with the recumbent folds in the northern area of the basin, which shows various kilometers long with Northwest-Southeast orientation and 45-60^{o} inclinations.

1.2 Geodynamic Issues of the Cañete River Basin

The Cañete River basin is one of coastal rivers, which have the geodynamic problems. With regard to geological aspect, the Cañete River valleys are formed by erosion relatively recently in terms of geological age. Erosion causes upward tension fracture in the bedrock by unloading. Usually, open cracks and closed joints have been formed in this process. Extensive rock weathering through fissures causes susceptibility to slope failures. It is unusual to have ground susceptible to foliation that has not already been eroded. However, the gentle slope located above the steep slope at the proposed dam site and the bedrocks around the reservoir may be easily affected by weathering, so that there are generally quite a few areas with unstable ground.

Geodynamic phenomenon generally has a relation with meteorological/ hydrological agents, topographic/geological conditions and vegetation, etc. Moreover, geological agents such as fractures, erosion of the rock mass, intense faulting and folding; poor vegetation and aridity, etc. are also important factors.

Principal geodynamic phenomena (Table S.2.4.1.2) are debris flows (Huaycos), alluviums, floods, unstable slopes, etc. Debris flows and alluviums occur principally between Lunahuana and Yauyos, floods from Zuñiga to estuary and unstable slope between Yauyos and Alis.

1.2.1 Debris Flows (Huaycos)

The heavy precipitation concentrate to the principal drainage channel from January to March and causes the violent discharge of surface water in short duration. Commonly this water mass drags the heterogeneous materials of different composition and granularity including vegetable residues.

Mudflows transport a large amount of the solid materials of different size and weathered rock fragments in rapid velocity of de 60 to 80 km/h. The transported materials along tributary accumulate at the confluence with the Cañete River in fan form of variable thickness.

The characteristics of debris flows vary clearly in accord with lithological component of riverbed, topographic gradient, volume of accumulated materials, etc. This phenomenon has occurred in various tributaries and rivers and sometimes damage to social infrastructures and agricultural lands.

1.2.2 Alluviums

Few alluviums have been detected, however this phenomenon should be occurred frequently in the upper sides of tributary. The following process forms the alluviums: The slope failure commonly originates through the removing of subsurface deposits on mountain slopes. This removed mass creates frequently barriers such as natural dam along the tributary, which are destroyed by water pressure.

1.2.3 Floods

Floods frequently occurred during January and March in the Cañete River valley and flood plain of the lower reach due to insufficient flow capacity. The physiographic figure shows steep slopes with poor vegetation, which causes rapid discharge of the precipitation to the rivers. The principal damages are erosion of agricultural land located near of the riverbed and destruction of irrigation facilities.

1.2.4 Unstable Slopes

Unstable slopes are formed by the land failures, landslides, falling of rock fragments, etc. These mass movements are relocation of the surface formations and rock fragments under the mixed influence of gravity and water saturation. This phenomenon has a close association with slope gradient, intensity of joints and fractures, rock type, structural dip, type and depth of subsurface deposit and inter-action of them with the agents of climate, seismic movement, etc.

The most prejudicial agent must be water coming from precipitation, filtration of groundwater and leakage of irrigation channels. The saturated water actuates as lubricant in the unconsolidated materials in the slopes.

1.3 Dam Geology

Based on the topographic and geological studies by means of cartographic maps, aerial- photographs and existing reports, the Study Team carried out field reconnaissance at 18 possible dam and intake sites; 8 sites (Paucarcocha Lake, Huachacara, Pampa, Vitis, Morro de Arica, Churchura, Santo Domingo, Casa Vieja) proposed by Electroperú, 8 sites (Paruco, Humuchaca, Auco, Calachota, San Jerónimo I&II, Zuñiga I&II) proposed by the Study Team and 1 site (Capillucas) by Cementos Lima S.A. and 1 site (Socsi) by SEDAPAL. The location of each proposed site is plotted in Fig. S.2.4.1.2. summary of topographic / geological characteristic and evaluation of each site in particular are shown in Table S.2.4.1.3, and S.2.4.1.3 (1/18~18/18).

As the result of meticulous comparison and engineering check of each site, the Study Team preliminarily 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 sites for the mountain route and coastal route, respectively, to conduct the drinking water to Lima. General conditions with regard to topography/geology and issues of these sites are summarized in the following:

1.3.1 Paucarcocha dam site

(1) General condition

The Paucarcocha dam and reservoir areas are located at the upstream end of the Cañete River, surrounded by glacial / fluvio-glacial deposits exposed in hills with relative relief of maximum 30m at the mouth of the Paucarcocha Lake and volcanic- sedimentary mountains. Regional elevations vary from 4,216 to approximately 5,700m.a.s.l. These mountains have undergone intense glacial scouring giving origin to numerous lakes and wide U-shaped valley. The Paucarcocha dam site is completely covered by superficial deposits, including glacial, fluvio-glacial, fluvial and alluvial cone deposits. The glacial deposits have an extensive exposure around the lake and consist of silty sand with glaciated clasts. The fluvio-glacial deposits are restricted to distribute in the entrance and exist way of the lake. Most of these deposits came from the glacial materials that have been removed by the streams. The fluvial deposits are encountered at the bottom of the moraine. Glacial deposits have low permeability and compact as a result of the glacial ice loading.

(2) Issues

Detailed hydrogeological investigations will be required, because artesian head in the glacial deposit is present. Nevertheless, ARPL/Cementos Lima S.A. has performed 13 boreholes in addition to those of Electroperú and has monitored the artesian phenomenon for several months during 1998.

Survey of inflow sediment to the Paucarcocha Lake is necessary due to the advance of sediment front in relatively flat valley.

1.3.2 Morro de Arica dam site

(1) General condition

The Morro de Arica dam site is located in a very steep, ranging in angle from 60 to 70^o from horizontal, narrow gorge and raise 200-500m above the level of riverbed. The canyon bottom is less 20m wide. Bedrock is equivalent to the Oyón-Chimú Formation composed of massive, hard-very hard siliceous sandstone, quartzite and siliceous shale. Limestone outcrops of the Santa Formation are at the upper mouth of the Morro de Arica gorge and over 3060m elevations at the dam site on the left abutment. Bedrock outcrops are predominant in the dam site and reservoir showing only thin (less than 5m thick) covers of talus (colluvial) deposits. The dam site and reservoir areas contain anticlinal and synclinal structure that are closely folded, structures with nearly vertically oriented to overturned limbs. The fold axis is oriented in a general northwest-southeast direction.

A notorious spring is identified at the syncline of the sandstone interbedding in the left bank, about 230m downstream from the dam axis. It is possible that the leakage comes from karst cave conditions in the limestone or the contact between siliceous rock and limestone, which then filters through cracks of bedding joints in the syncline. However, according to ARPL/Cementos Lima S.A. after recent detailed geological investigations of this area, the leakage path is far enough from the influence area of the left abutment, in such a way that the security of the dam would not be compromised.

(2) Recommendations and issues

Considering the possibility of leakage through karst cave condition in limestone of the Santa Formation, the dam height should not exceed the contact with limestone of the Santa Formation.It’s necessary to grasp exactly the distribution of the Santa Formation and karst cave condition, moreover detailed hydrogeological study shall be required.

1.3.3 Auco dam site (Fig.S.2.4.1.3)

(1) General condition

The Auco dam site is located in almost V-shaped valley with both abutments ranging in angle from 60 to 70^o from horizontal. The river bottom is about 155m wide. Owing to gentle river slope, the reservoir shows wide aspect. The present river channel is located along the right margin. The alluvial cones (alluvium deposits) overlay on fluvial terrace in the left margin. The bedrocks have wide exposure in both abutments consisting of granitic rocks of the Andean Batholith.

Old fluvial and fluvio-glacial deposits thinly overlay the concavity of the left abutment (Fig.S.2.4.1.4).

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

At present, the alluvium cone deposits exist at mouth of the Pampa River, which is a tributary, situated about 500m upstream from the dam site. The debris flows have occurred in March 30 and April 2, 1972. Information obtained from local people reveals the appearance of temporary natural dam in the Cañete River channel. Large natural dams distributed in the beginning of this tributary, which were formed by slope failure of subsurface deposits on the Mt. Huamanripa, broke down at once and caused this phenomenon.

(2) Issues

Grasping of thickness and properties of the superficial deposits such as alluvial cone, old fluvial and fluvio-glacial deposits.

Study on the slope stability and debris flow along the Pampa River.

1.3.4 San Jerónimo dam site (Fig.S.2.4.1.5)

(1) General condition

San Jerónimo Ⅰ dam is called as San Jerónimo dam, which is located in V-shaped valley with both abutments ranging in angle from 40 to 50^{o} from horizontal. The valley bottom at the dam site is about 85m wide. Terrace and talus (colluvial) deposits overlay the valley. The left abutment consists of granitic bedrock covered by old fluvial and colluvial deposits, on the other hand the right abutment consists of granitic rocks completely free of superficial deposits (Fig.S.2.4.1.6). The Tantará Formation composed of andesites and dacites is predominant in the reservoir area. These volcanic rocks are widely fractured. Colluvial deposits are sporadically distributed in and around the reservoir area. The debris flow deposits are identified at the river mouth of the Cacra and Tupe Tributary River 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 boulders, cobbles, gravels, sand and silt overlay intermittently in 35-45m relative high from the riverbed. The colluvial deposits principally consist of angular gravels and have the extensive exposure. Judging from the distribution of the bedrock, these soft deposits are estimated to be about 10m or something more deep.

(2) Issues

Grasping of thickness and properties of the superficial deposits such as the fluvial and colluvial deposits.

Survey on the distribution of joints and fractures of the bedrocks and its permeability.

Survey on the slope stability around the reservoir area.

1.3.5 Capillucas dam site

(1) General condition

The Capillucas dam is located in relatively narrow (70-100m) valley, and nearly vertical left and right abutments approximately 50m high. There are fluvial and alluvial fans filled in deep and narrow intermittent old river channel in the southern part of the site. The steep wall valley was originally cut into hard granitic bedrock and had a V-shaped; however the bottom of the valley has been filled with lacustrine, fluvial and alluvial cone deposits about 120m in maximum thickness. An old river channel over 70m in depth is present in the southern part of the Cañete River channel, which is filled by the fluvial (alluvial) and partially colluvial materials. The bedrocks are overlain by thick accumulations of superficial deposits in the dam site and reservoir area, the reasons for which will be suitable for low rockfill type embankment.

(2) Recommendation and Issues

Considering the extensive and deep distribution of unconsolidated deposits and old river channel, there could be concerns regarding slope stability and seepage. Nevertheless, ARPL/Cementos Lima S.A. informs that as a result of recent geological investigations which include 24 boreholes with a total length of 1800m, they conclude that for the selected size and function of the reservoir, slope stability or serious seepage problems are not envisaged.

1.3.6 Zuñiga intake structure site

(1) General condition

Zuñiga Ⅰ is called as Zuñiga intake structure site, which is located in narrow portion and attains a width of about 20m. The left steep abutment is composed of hard quarziferous sandstone with interbedding planes of shale; on the other hand, the right gentle slope is made of terrace, fluvial and alluvial deposits (Fig.S.2.4.1.7).

(2) Issues

Grasping of thickness and properties of the soft subsurface deposits in the right margin.

1.3.7 Socsi intake structure site (Fig. S.2.4.1.8)

(1) General condition

The Socsi intake structure site is located in wide valley of the Cañete River channel. The riverbed is about 50m in width. The left bank is composed of alluvial river terrace, and the right bank also of terrace overlaying the granitic bedrocks (Fig.S.2.4.1.9). Present river deposits and alluvial terrace are distributed in and around the river course.

(2) Issues

Grasping of thickness and properties of the soft subsurface deposits.

1.4 Detailed Survey and Tests for Dam Geology

1.4.1 Future Detailed Survey and Test

From a hydrological and geological point of view, the Study Team put higher priority on San Jerónimo dam site in comparison with Auco site and made plans of following geological survey items. The ultimate objective of geological investigations at the dam site during planning and basic design stages is to ascertain the possibility of dam construction and estimate rough construction costs. For this objective, studies on the following items are to be made.

1) Whether loading capacity of foundation ground is adequate for the necessary dam scale and proposed dam site,
2) Preliminary selection of foundation cut lines for dam body and spillway (if necessary),
3) Preliminary planning of foundation treatment work,
4) Availability of borrow materials at quarry site in quality and quantity, and
5) Slope stability of around reservoir.

Items and procedures for dam geological investigations are shown in Table S.2.4.1.4.

The geological survey area of San Jerónimo dam can be divided into dam site, around reservoir and quarry site, and the survey items consist of surface geology, subsurface geology and foundation test.

Based on the Topo-maps of adequate scale, aerial photos and existing geological maps, surface geological survey will be carried out to grasp the topographical, stratigraphy, structural features, lithologic character and hydrogeology. The most important items for the dam site and reservoir area are to know potential and stability of the unconsolidated deposits located on riverbed/both abutments and permeability of bedrocks.

After compliment of the surface geological survey, the following subsurface geological survey items will be conducted at dam site:

- Seismic prospecting

  3 lines along dam axis and 3 lines in cross sectional direction in the river bottom and foot of the left slope.

- Drilling

3 drilling along the dam axis (1 in the riverbed 150m in depth, 1 in the left abutment 50m deep and 1 in the right abutment 30m deep). These drilling works have to include the permeability test, Lefranc test for the unconsolidated deposit and Lugeon test for the bedrock every 5m depth, lateral loading test every 3m depths and borehole VTR filming. In addition to those investigations, logging and seismic tomography will be recommended.

Based on the result of these surveys, elaboration of geological map and profile (1/500 - 1,000) including groundwater levels, permeability values, seismic wave velocity and proposed foundation excavation will be made.

In around reservoir, analysis of seepage and stability of natural ground are the most important study items. The distribution of pervious area should be clarified on 1/5,000 scale geological map elaborated by surface geological investigation, and quantity of seepage should be estimated. Elaboration of landform classification map at 1/5,000 scale and natural ground stability classification is carried out for the preliminary design considering impact of dam construction.

Quarry site should be encountered a few kilometers around the dam site. Type of materials and distribution will be clarified through surface geological survey, seismic prospecting and drilling. The result of these surveys will be elaborated in the geological map in adequate scale with a description of material classification and approximate quantity.

Quantity of dam geological investigation and laboratory tests are shown in Table S.2.4.1.5.

1.4.2 Recommendations of new survey methods

The abutment of proposed dam sites shows generally steep, which make quite difficult or impossible to carry out the surface geological investigation for filed geologist. Moreover, temporary works such as drillings and gallery excavation are neither easy. However, detail/accurate geological observation of the outcrops and geo-engineering works are very important and will influence the fluidal implementation of the dam construction and the construction cost. For this reason, VTR filming by radio-controlled helicopter shall be one solution method. Detailed information will be done verbally.

Some bedrock of the proposed dam sites shows various open fractures, which may cause leakage and/or slope stability problems. To grasp the distribution and hydrogeological characteristics of these fractures, it's ideal to observe the boring cores in-situ condition. To get the panorama vision of 360^{o} angle in the borehole, it's recommendable to use the VTR borehole camera, which indicates exactly the problematic point.

Chapter 2 Hydrogeology

2.1 Existing Groundwater Utilization

Methodology applied by Ministry of Agriculture has been followed as for the nomenclature used for the wells so as to be identified with their historical data in files kept in above-mentioned institution.

Thus, for instance, well No. 8 of Quilmaná district is identified with number 15/03/14-08, which from left to right means: 15 Lima department, 03 Cañete province, 14 Quilmaná districts, 08 number of well pertaining to district. Wells that were not identified in former inventories have been appointed with letter J followed by the number of well assigned in correlative order 15/03/14/J-8. Elevations corresponding to the Inventory of Groundwater from the Ministry of Agriculture have been considered in order to standardize this information with the studies taken as references.

Number pertinent to their identification number has identified filtering springs and galleries with letter M followed. Well Inventory and location map are shown in Table S.2.4.2.1. and Fig. S.2.4.2.1, respectively.

From the inventory made of total 90 wells in the valley (Table S.2.4.2.2), 27 are tubular wells: 19 are used, 4 are usable which are without any equipment by the time being or with an equipment that does not work, 2 under drilling, 1 buried and 1 abandoned. Motors, most of which are electrical with power ranging from 20 to 130 HP, operate wells. These wells were constructed from 1956 up to 1999; the years where most of drillings were made were between 1960 and 1969, with the construction of 10 wells, and between the years 95 and 99, 6 wells, which account for 22% from all existing tubular wells in the valley, have been drilled.

63 are open-cut wells, with depths ranging from 2.09 m up to 21.36m. Diameters of drillings range from 0.80m up to 3.0m; most of these wells have been hand-made. Exploitation is carried out by means of buckets and in other cases with small suction centrifugal pumps operated by electrical motors that carry the water into small reservoirs from 1 to 1.5 m^3 of capacity, which are taken for human consumption purposes and, in general, for a domestic use.

Table S.2.4.2.2 Distribution of Wells (August, 1999)

District	Tubular	Open-cut	Total
San Vicente	4	29	33
Quilmaná	15	17	32
Imperial	4	11	15
Nuevo Imperial	3	2	5
San Luis	1	4	5
Cerro Azul	-	-	-
Total	27	63	90

From the inventory of 90 wells, 48 of them are equipped (27 tubular and 21 open cut) which account for 53% of wells; 34 wells are exploited hand-operated by means of buckets which account for 38% and the remaining, which are not in use, 9% (Table S.2.4.2.3).

Table S.2.4.2.3 Well Equipments

District	With pump			With motor			Without equipment	
	V.T.	S.C.	S	D	G	E	With Bucket	Non-usable.
Quimaná	9	8	1	2	-	16	11	3
San Vicente	3	11	1	-	-	15	16	2
ImpeialL	2	5	1	1	-	8	4	3
Nuevo Imperial	-	3	2	-	-	5	-	-
Cerro Azul	-	-	-	-	-	-	-	-
San Luis	-	2	-	-	-	2	3	-

(note) V.T.: Vertical Turbine, S.C.: Suction Centrifugal, S: Submergible, D: Diesel, G: Gasoline, E: Electrical

Yields of wells have been measured and obtained information about them. These values only show the runoff value exploited by users and not the optimal runoff value. In case of the open cut wells, domestic consumption has been calculated based on information from the uses and on calculations of 50 litters per person per day (Table S.2.4.2.4).

Table S.2.4.2.4 Yield of Tubular Wells (1999)

District	Runoff (l/s)	No. of Wells
Quilmaná	10 - 20	-
	20 - 40	2
	40 - 60	6
San Vicente	10 - 20	2
	20 - 40	–
	40 - 60	1
Imperial	--	--
Nuevo Imperial	10 - 20	2
	20 - 40	-
	40 - 60	-
San Luis	--	--

The whole exploitation volume by means of inventoried wells in the Cañete River valley is of 4,362, 426m^3/year, which is utilized for domestic, livestock, irrigation and industrial use purposes. At present, 65% the total exploitation volume is intended to use for domestic purposes, the 23.5% for agriculture/livestock use and the 11.4% for industrial use. San Vicente district is the one where most of groundwater resources are exploited, followed by Quilmaná and together the 82% from the total water mass is obtained. Annual exploitation mass by means of wells according to use and districts is shown in Table S.2.4.2.5.

Table S.2.4.2 .5 Annual Exploitation by Use (1999)

(m^3/year)

District	Domestic Use	Agriculture Use	Industrial Use	Total / year
San Vicente	1,917,525	-	58,400	1,975,925
Quilmaná	592,795	1,021,824	912	1,615,531
Imperial	251,630	-	438,000	689,630
Nuevo Imperial	79,205	-	-	79,205
San Luis	2,135	-	-	2,135
	2,843,290	1,021,824	497,312	4,362,426

From the total production of 19 tubular wells used, a volume of 3,949,561 m^3/year is exploited and from the open cut wells, a volume of 412,865 m^3/year that accounts for 90.5% and 9.5%, respectively.

According to the information collected from the organization that administers drinking Water in the Cañete valley, EMAPACSA, it is known that the water supply through galleries for domestic use is of 2,835, 336 m^3/year, which complements drinking water demand of Cerro Azul, San Luis, Imperial and San Vicente districts, accounting for an additional 65% from what is exploited in the valley by means of wells (Table S.2.4.2.6).

Table S.2.4.2 .6 Exploitation Mass by Filtering Galleries (1999)

(m^3/year)

District	Source	Exploitation Mass
San Vicente	Filtering Gallery	551,880
Cerro Azul	Filtering Gallery	751,680
San Luis	Filtering Gallery	1,103,616
Imperial	Filtering Gallery	428,160
Total		2,835,336

Source: EMAPACSA. 1999

Total annual exploitation mass in the Cañete River valley including tubular wells, open-cut wells and filtering galleries is of 8,097,762 m^3 / year.

Inventory belonging to year 1990 (INADE, 1990), is the one which contains more information, making the inventory up to 246 wells in the valley. Distribution of wells which inventory was made in 1990 is shown in Table S.2.4.2.7. There are most wells (90) in San Vicente district, and 58 and 56 in Imperial and Quilmaná districts, respectively. These wells account for 83% from the collection. Tubular wells are distributed among districts as follows: Quilmaná 10, Imperial 8 and San Vicente 7, accounting for 86% from total existing tubular wells.

Table S.2.4.2. 7 Distribution of Wells per District (1990)

District	Tubular	Open-cut	Total
San Vicente	7	83	90
San Luis	1	22	23
Quilmaná	10	46	56
Nuevo Imperial	3	13	16
Imperial	8	50	58
Cerro azul		3	3
Total	29	217	246

According to information sources, exploitation volume does not vary considerably with the time, that is, mass varies between 5.0 MCM (1969) and 3.2 MCM (1991). Valley did not consume more than 5.0 MCM/year according to 30-year records. Exploitation mass from 1969 to 1999 according to well type, well number and district is shown in Table S.2.4.2.8.

Table S.2.4.2.8 Annual Exploitation Mass per District and Well Type

(m^3/year)

District	Year Type	1969		1971		1991		1999	
		No.of well	Volume	No.of well	Volume	No.of well	Volume	No.of well	Volume
San Vicente	TA	21	68,388	43	2,329	53	103,158	29	160,123
	T	2	415,000	1	1,000,000	4	444,848	4	1,815,802
San Luis	TA	9	15,210	14	135,710	14	19,093	4	1,861
	T	0	0	1	32,900	1	12,096	1	273
Quilmaná	TA	6	18,942	15	403,754	44	326,676	17	3,685
	T	5	3,032,650	6	1,686,263	7	2,161,426	15	1,611,846
Nuevo Imperial	TA	3	48,360	4	86,000	10	6,451	2	364
	T	1	26,000	2	46,176	2	31,095	3	78,840
Imperial	TA	11	204,863	20	187,922	48	90,738	11	246,831
	T	4	1,225,300	3	1,091,570	2	20,736	4	442,798
Total		62	5,054,713	109	4,672,624	185	3,216,317	90	4,362,426

TA: Open-cut well , T: Tubular Well

2.2 Aquifer Characteristics

From geological and topographical evaluations as well as lithological profile analysis, it is determined that the aquifer is composed of alluvial deposits that fill the Cañete River valley, forming a reservoir where groundwater runs. Such unconsolidated deposits pertaining to the Quaternary in geological age are originating from accretions of materials carried by rivers consisting of boulders, cobbles, gravel, sand, silt, and clay, etc,

These materials may form layers of different thickness interbedded in the alluvial fan. Maximum depths which could be identified through well drilling was only 80m in depth, although recent drilling (1999) reach 120 m in depth in Quilmaná district.

Pre-quaternary rocks may be found on the borders of aquifer of the Cañete River valley. Borderlines are known in depth by means of geophysical prospecting made in former surveys, reaching at 450 m in depth. The side borderlines consist in rocks, which are present prior to the alluvium that filled the valley. Candela hill is isolated and sticks out of the central part of the valley, being part of the side borders.

2.3 Groundwater Tables

A isobath map has been elaborated from measurements taken in-situ (Fig. S.2.4.2.2). Historical variations of water tables per districts from 1969 up to 1999 are shown in Table S.2.4.2.9. Comparing the isobath maps of 1972, 1991 and 1999, it is noticed that the groundwater tables have no considerable variations up to 5m. In the isobath map, it is observed that the depth of groundwater table fluctuates between almost 0 and 10m in the greater part of the valley although the depths increase gradually up to reach 80 m to the north of Quilmaná district. Drains and irrigation channels that cross the valley longitudinally, standing out in inflections that are present in curves, especially in the vicinity of San Vicente district, affect levels of groundwater table.

Based on measurements made in August 1999, Hydroisohipsas Curves was established. According to the shape and intervals of curves, we come to the following conclusions:

- Groundwater flow is mainly oriented from East to West direction, according to the runoff direction of the Cañete River and from Northeast to Southeast towards the far north of valley, north boundary of Imperial and San Luis districts.
- Hydraulic gradient is of 1.7%
- High groundwater tables are located in the west direction, in the vicinity of the boundary with the coastal line and all along the valley.
- Feeding axis rises in the Cañete riverbed and receives apparently the contribution from Pocoto stream.

Fluctuation of groundwater tables from 1971 up to date is shown in Table S.2.4.2.10.

Monthly mean runoffs higher than 900 m^3/year are in the years 1932, 1955, 1973, and 1984. The drier seasons have been identified in the years 1931, 1940, 1958, 1968, 1980 and the period between the years 1987 – 1992. Basically it is given by seepage of the Cañete River and due to the irrigation facilities by means of about 150 km of channels.

2.4 Hydrodynamics

According to pumping tests made in the representative tubular wells in the area, underground hydraulic characteristics of aquifer may be identified, permitting to deduct the productivity of wells.

Pumping tests were made under transitory regime and values both in descend and recovery were obtained. transmissivity values, general characteristics and conditions on which every test was made are shown in Table S.2.4.2.11. Descend phases had duration between 11 and 28 hours, while those of recovery between 3 and 50 hours. Permeability values and records obtained from pumping tests are shown in Table S.2.4.2.12.

Table S.2.4.2.12 Permeability Values

Well Code N°	Thickness of Aquifer	Permeability k (m/s)
15/03/06-05	38	3.35×10^{-4}
15/03/06-06	30	5.00×10^{-4}
15/03/06-11	35	8.00×10^{-4}
15/03/11-01	45	21.00×10^{-4}
15/03/11-07	15	33.00×10^{-4}
15/03/11-09	62	20.30×10^{-4}
15/03/11-11	35	10.30×10^{-4}
15/03/14-08	17	3.70×10^{-4}

2.5 Groundwater Quality

Physical-chemical quality is known by trials made between the years 1969 and 1991, obtaining an overall view of chemical quality of waters in the Cañete River valley. Source of first analysis with records is the inventory made by the General Directorate of Waters of the Ministry of Agriculture (1969, 1971, 1972) and the study made by INADE (1990).

62 physical-chemical analysis made during the inventory campaign carried out by above-mentioned institutions (Table S.2.4.2.13); the following families may be there observed: calcic/sodium bicarbonated, calcic/sodium chlorated; calcic/sodium sulphated.

Electric conductivity expressed in milimhos/cm at + 25°c of the waters from inventory of wells and springs was measured. These conductivities indicate the global concentration of salts contained in the water. Measurements were made with a portable conductivimeter and values vary from 0.5 to 1.5 milimhos / cm at + 25ºC, being the highest values in the wells of Essalud 15/03/11-3 San Vicente de Cañete district; towards the lateral boundaries of aquifer, Cuiva area 15/03/11/J-3 and towards the line of the coast in San Luis district, well 15/03/13-5.

Analysis of historical data shows that main characteristics of waters of wells are the same with the time. Lower values are found in the vicinity of feeding source of aquifer and they increase downstream and show better chemical characteristics near to the main source of feeding.

Area of large salinity is in the lower parts of valley and towards the north (Cerro Azul) due that the lands are in lower position from the topographic point of view, giving rise to evaporation process and salinization of soils. Other area that stands out due to its large conductivity is Candela hill and the land around it.

It is expressed in French degrees which values are determined by presence of Calcium and Magnesium. In the study area the hardness varies from 5 to 77° F, which higher values show from San Luis and San Vicente districts (lower areas) and towards the vicinity of the coastal line. Water which is above 20° F may be considered whether soft water or hard water.

Collected pH data indicate that the values are higher than 7.0 classified as slightly alkaline water, which would bear relation to their chemical composition. Presence of Nitrate ion noticed in physical-chemical analysis of groundwater would have an organic origin due to the bacterial decomposition and in other cases due to the washing of soils, which have received lots of nitrogenous fertilizers that cause existing concentrations. Findings of chemical analysis of groundwater from former investigations where presence of Nitrate ion is noticeable and where most frequent concentrations are between 1.0 and 5.0 miliequivalent/litter considered as medium to high concentrations.

2.6 Tentative Groundwater Balance

In order to know the possible groundwater volume to be exploited, exploitable reserves based on regular reserves, which are represented by the quantity of free water stored in aquifer for the inter-annual variations of rainfalls in the basin, are intended to be calculated. These volumes of flow and renewals are shown in variations of piezometric levels which values are partially known in the time from former investigations.

Available and scattered information does not permit to obtain a sustained calculation, however the option was to analyze it in terms of piezometric level variations, pursuing to gather the more information possible so as to elaborate hydrographs. If 310 km^2 of the extension of the Cañete River valley is considered, only 3.0m of variation of the piezometric levels and a coefficient of storage of 15% are being included, having:

V = Ah x S x A

V = Volume of storage water

Ah= Variation of piezometric levels

S = Storage coefficient (storativity)

A= Surface of considered aquifer

Given that surface (A) and variation of piezometric levels (Ah) are not constant for all the piezometric surface of valley, there is a margin of error that is not significant for calculations by approximation. In general piezometric variations in the valley are not considerable. Adjustment of these variations in the valley level may be achieved by establishing mass of iso-piezometric curves, which match the different flood and low water seasons.

Then if it is considered:

Ah = 3.0m

S = 15%

A = 310 km^2

Volume of storaged water in aquifers (Q)

Q = 3.0 m x 310 km x 15%

Q = 150 millions of cubic meters(MCM)

In other hand, INADE's survey result said that "Aquifer reservoir of the valley is at its maximum level and that the volume of stored water in the aquifer is 3,800 MCM, that the annual exploitable mass only considering the 10% of this volume would be of about 380 MCM" It is also proven according to the same survey that if it is obtained from aquifer between 8 and 10 m^3/s, a mass of about 120 and 160 MCM is, without exhaustation danger, assured.

Taking into account that the Cañete River has 6,189 km^2 and that the rainfall is of about 830 mm/year and that the annual discharge volume of the Cañete River in the last 10 years is 42.0 m^3/s = 1,324'512,000m^3 , it is established that the runoff coefficient is as follows:

1,324/5,136 = 0.26

If 10% of losses due to infiltration is considered

5,136,870,000 m^3/year x 10% = 513,687,000 m^3

Then, the seepage would be:

513'687,000 m^3 + 1,324'512,000 m^3 = 1,838'199,000 m^3

513'687,000 m^3 + 1,838'199,000 m^3 = 3,298'671,000 m^3

3,297 MCM

If it is considered that the valley only stands for the 5% of the total area of basin, seepage of about 165 MCM may be estimated.

TABLES

Table S.2.4.1.1 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	Cercapuquio Frm.	Jim-c	400	Dark gray sandstone with good stratified layers of siltstone.
		Lower				
			Pucará Group	TrJ-p	400	Gray limestone alternating with layers of marl, calcareous sand-stone and shale.
	Triassic	Upper				

Rocas Intrusivas

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

Table S.2.4.1.2 Geodynamic Issues in the Cañete River Basin

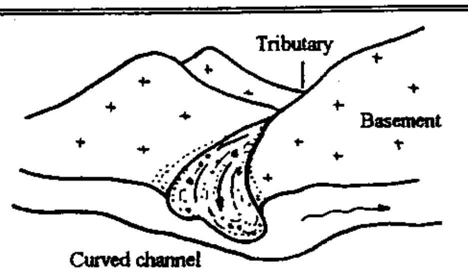
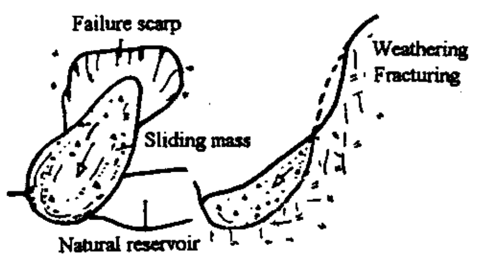
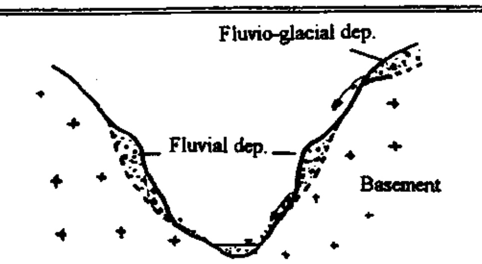
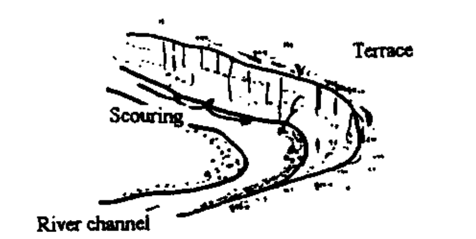
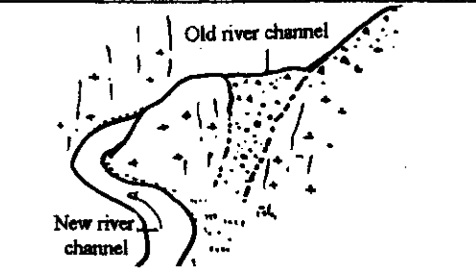
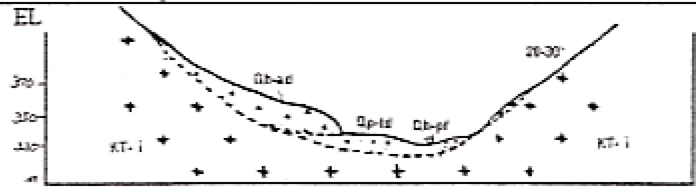
Geodynamic phenomenon	①Debris flow	② Landslide	③Slope failure	④ Riverside failure	⑤ Buried valley
Schematic figure					
Characteristic	The heterogeneous particles of various size carried by debris flow are discharged unexpectedly and are deposited in cone shaped form in tributary riverbed and confluence 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. Sliding 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 infra-structures, 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 S.2.4.1.3 General 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) EL2,997m (210m) (151m)	(420m) EL2,150m (200m) (505m)	(550m) EL1,200m (200m) (650m)	(100m) EL1,560m (38m)** (93m)	(150m)	(200m)
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 Paucarcocha 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 (quartziferous 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, sometimes 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 carbonate 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 sandstone	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 upstream.	
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 for 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 appropriate because of thick fluvial deposit accumulated.	Topographically surficial deposits is suited to conduct the intaked water in the right margin.	Topographically, terrace distribution is suited to conduct the intaked water in the right margin.
Issues			Groundwater behavior in the dam site soft deposits, subsurface properties and sedimentation in the Paucarcocha lake. Reservoir rim stability study. Study of borrow materials.	Detailed grasping of the distribution 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 sediments located on the left abutment. Slope stability on the talus slopes.	Reservoir rim stability and serious seepage studies by geological and soil mechanical data obtained. Material testing.	Grasping of soil mechanics and properties.	Grasping of soil mechanics and properties.

Table S.2.4.1.3 General Characteristics of Proposed Dam and Intake Site (1/18)

Site	Socsi	Department : Lima	Province : Cañete	District : Lunahuana	River : Cañete
Topography	Riverbed width	Approximately 50 meters			
	Characters	Wide valley varied by fluvial and alluvial deposits.			
Schematic section		Qh-pf: Present fluvial deposit Qh-ad: Alluvial deposit Qh-td: Talus deposit Qp-td: Terrace deposit KT-i: Andean Batholith			

Geology			Left bank	River bed	Right bank
	Geology of Basement		No present	No present	No present
	Condition of Basement	Fault	—	—	—
		Fracture	—	—	—
		Alteration	—	—	—
		Weathering	—	—	—
	Overlying Sediment		Fluvial and alluvial deposits	Fluvial deposit	Fluvial, alluvial and talus deposits
	Landslide and/or Failure		No present	No present	No present
	Remarks		Present fluvial deposit including flood plain and low terrace is distributed around the river channel. Granitic outcrop is located near the right margin.		

Dam site	There seems to be thin fluvial deposit in the right margin.
Reservoir	Wide valley with extended terrace and alluvial deposits.
Evaluation	It's possible to construct low intake structure. Topographic feature is suited for the driving canal without major problems.
Issues	Grasping of thickness and properties of the subsurface deposits.
Site photo	 Negative No.16-12