

## **ALTO MAIPO HYDROELECTRIC PROJECT**

### **STUDY OF EFFECTS OF WATER INTAKE AND DISCHARGE WORKS IN THE FLUVIAL AND SEDIMENTOLOGICAL HYDRAULIC-MECHANICAL BEHAVIOR OF THE RIO MAIPO.**

#### **1. BACKGROUND INFORMATION**

AES Gener SA needs to address the questions asked by the CONAMA about the Environmental Impact Study of the Alto Maipo Hydroelectric Project (PHAM), specifically the sedimentological component of that study.

A review of the background information provided by AES Gener SA (the Owner) to the Consultant reveals that the concerns that have been expressed about the sedimentological component come mainly from the Hydraulic Works Department of the MOP (DOH). The following aspects are among the main observations the reviewing entity has made to the Owner:

- The definition of the direct and indirect area of influence of the project. This is the area that might be affected by changes in the sedimentological condition created by the works of the project.
- Objective technical elements that make it possible to establish and characterize the effect on the river bed of the discharge work in the Las Lajas sector, whose operating flow will be 65 m<sup>3</sup>/s. This effect could mean possible degradation of the river bed, local scouring, and a reduction in the contribution of sediments to the section downstream from the work. The lack of background information also prevents a definition of the area of influence of the project.
- Complementation of background information to determine the specific effect on the dragging of solids caused by a reduction in flows in sections downstream from the water intake works located on the Colorado and Yeso rivers, as well as the Colina, La Engorda, Las Placas and Morado streams.
- Formulation of a monitoring plan whose basis takes the information generated in the specific analyses described above into account.

In order to properly address the concerns mentioned, the Owner has deemed it advisable to develop the specific studies that will enable the DOH of the MOP to have the technical elements necessary to corroborate that the magnitude of the impacts of the works of the project is insignificant in regard to the sedimentological component of the Maipo river and the main affluents directly related to it. Notwithstanding that, a request has been made to establish a monitoring plan and the mitigation measures that are deemed necessary in order to obtain the technical approval of the PHAM project.

As part of the work prior to the execution of the studies in reference, it is appropriate to consider the technical interaction of this Consultant with the DOH in order to reach preliminary agreements about the definition of the specific objectives and scopes of the studies that must be developed to resolve the questions about the sedimentological behavior of the Maipo river.

This report contains the scopes and methodological aspects the Consultant proposes be applied in the execution of the studies required, which would be submitted for the approval of the DOH of the MOP so the Owner has technical approval before starting the studies. This proposal intends for the reviewing institution to be involved in the process of defining the requirements for the study and in the review of the study so that once the study has been finished there will be full agreement on its results, conclusions and recommendations.

## **2. OBJECTIVES OF THE STUDY**

The objectives of the study are, first, to make a characterization of the Baseline of the sedimentological component in the areas of influence of the intake and discharge works of the PHAM, considering the information available and generated for the Environmental Impact Study presented by the Owner, and then, to make an identification and characterization of the possible effects on that component when considering the start-up of the project.

Specifically, the current situation of the river with regard to the sedimentological regime of the Maipo River and its affluents, the Colorado and Yeso Rivers, and the Colina, La Engorda, Las Placas and Morado streams, and the conditions of existing infrastructure that might be affected by the PHAM will be characterized.

Based on the characterization of the areas possibly affected by the project, an analysis will be made of the potential impact of the extractions and discharge of waters on the fluvial and sedimentological hydraulic-mechanical behavior of the Maipo River and tributaries, particularly with regard to eventual phenomena involving degradation of the river bed (depth and extension). The effect that the reduction of contributions of sediments to the sections located downstream of the works, in the Maipo river and directly in affluents where the works of the PHAM will be located, might have on those phenomena will also be analyzed.

Based on the results and conclusions of the study, a Monitoring Plan shall be proposed for the fluvial and sedimentological hydraulic-mechanical component, including eventual the mitigation measures and follow-up that is deemed necessary to complement the measures proposed originally in the EIS.

### 3. SCOPES

As stated, the study will include first a detailed characterization of the waterways that will be intervened by the works, which correspond to the following:

- Colorado River in area where the intake work will be located
- Yeso River in the area where the intake work will be located
- Colina Stream in the area where the intake work will be located
- La Engorda Stream in the area where the intake work will be located
- Las Placas Stream in the area where the intake work will be located
- Morado Stream in the area where the intake work will be located.
- Maipo River in the Las Lajas sector where the discharge work is located and area downstream, in a section of about 2 to 5 km, which is deemed sufficient to establish the effect of the discharge on the sections downstream.

In each case, the characterization of the hydro-topographic, geomorphological, granulometric-fluvial aspects and any other element that makes it possible to define the current properties (natural or intervened) of each section in particular shall be carried out. Finally, the current fluvial and sedimentological hydraulic-mechanical behavior of the river beds will be characterized to establish the Baseline of the fluvial system. The existing infrastructure in the river beds in the area being studied that might be affected by the PHAM will be characterized, defining the specific characteristics of each work and the current condition of its environment.

The foregoing will make it possible to describe in sufficient detail the initial condition of the river beds and existing works in order to evaluate the effects that might be expected in each sector as a result, which might be:

- o The reduction of flows generated in the sections downstream of the area where the intake works will be located.
- o The increase that flows would experience in the sections of the Maipo River downstream of the discharge, due to the concentrated contribution of clean water with a maximum flow of 65 m<sup>3</sup>/s in the Las Lajas sector.

### 4. EXECUTION SCHEDULE OF THE STUDY

The study will be developed in 6 stages which have been defined with regard to durations and scopes in a document presented by AES GENER and approved by the DOH of the MOP. The period of the study is 300 days, and it shall be subdivided into the stages described below:

#### **STAGE 1: COMPILATION AND ANALYSIS OF INFORMATION AND CADASTERS**

This includes the compilation and analysis of information, field reconnaissance, and the execution of the cadasters and monographs of works. The hydrological study of sites of interest will be started, as well as the campaigns involving granulometric samples.

The execution period is 45 calendar days. It is thought the DOH will require a review period of 10 calendar days, as will the Consultant to answer any possible questions about the report.

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**STAGE 2: COMPLEMENTARY FIELD WORKS AND BASIC STUDIES**

It includes the preparation of complementary works corresponding to cadasters of works, granulometries (delivery of final information), and topography aimed at obtaining transverse profiles of the river beds in all areas where that information needs to be completed or added. It also includes delivery of the final hydrological study and basic studies aimed at characterizing the fluvial hydraulic and mechanical behavior of the river beds of interest.

The execution period is 60 calendar days from the end of Stage 1 of the study. It is estimated that the DOH will require a review period of 10 calendar days, as will the Consultant to answer any possible questions about the report.

**STAGE 3: ANALYSIS OF THE PHENOMENA AND EFFECTS OF DEGRADATION DOWNSTREAM FROM THE INTAKE WORKS ON AFFLUENTS**

This includes the preparation of a diagnosis to establish the effect that reductions of the volume of flow would have on sections downstream from the place where the intake works would be located on the Colorado and Yeso rivers, as well as the Colina, La Engorda, Las Placas and El Morado streams. The diagnosis will be made on the basis of a simulation of fluvial and sedimentological hydraulic-mechanical behavior in order to cover the broad spectrum of possibilities and establish the magnitude of the effects of the works on the environment.

The execution period is 45 calendar days as of the end of Stage 2 of the study. It is estimated that the DOH will require a review period of 10 calendar days, as will the Consultant to answer any possible questions about the report.

**STAGE 4: ANALYSIS OF THE PHENOMENA AND EFFECTS OF DEGRADATION DOWNSTREAM AND OF LOCAL SCOURING OF THE DISCHARGE WORK IN THE MAIPO RIVER – LAS LAJAS SECTOR**

In this stage the effects shall be defined that would be generated in the Maipo river in the area downstream of the concentrated discharge of 65 m<sup>3</sup>/s in the Las Lajas sector, on the sedimentological and fluvial hydraulic-mechanical behavior and the eventual local scouring or degradation that the river bed could experience.

As indicated for the sectors affected by the intake works, simulations will be made of the fluvial and sedimentological hydraulic-mechanical behavior of the Maipo River, considering different scenarios as well as other factors whose incorporation is deemed necessary. Local scouring of the discharge and environment will also be analyzed, considering the possible effects on the river banks and their stability.

The execution term is 75 calendar days as of the end of Stage 3 of the study. It is thought that the DOH will require a review period of 10 calendar days, as will the Consultant to answer any possible questions about the report.

**STAGE 5: PROPOSAL OF MITIGATION MEASURES AND MONITORING PLAN**

Based on the identification of the eventual negative effects associated with the operation of the intake and discharge works on their environment, as well as the characterization of their magnitude, established on the basis of simulations of the sedimentological and fluvial hydraulic-mechanical behavior of the river beds, the need will be assessed to implement works or mitigation actions to reduce or eliminate the adverse effects that might be detected such as local scouring or degradation processes, erosion of river banks or others.

On the basis of the characterization of the expected effects, a monitoring plan will be proposed that will make it possible to follow up on the intake and discharge works during their operation phase. The plan will make it possible to corroborate the results of the study or eventually introduce, if applicable, corrective measures to eliminate undesired effects on the environment.

The execution period shall be 45 calendar days from the delivery of Stage 4. It is thought that the DOH will require a review period of 10 calendar days, as will the Consultant to answer any possible questions about the report.

#### **STAGE 6: FINAL REPORT**

The preparation of the final report of the study is included in this stage, with an executive summary and the report on the study as such.

The execution period is 30 calendar days from the end of Stage 5 of the study. It is thought the DOH will require a review period of 10 calendar days, as will the Consultant to answer any possible questions about the report.

It is necessary to consider that the periods indicated for each one of the stages exclude the review times of the DOH.

## **5. PROPOSED METHODOLOGY**

### **5.1 Preparation of Terms of Reference of the Study**

In order for the objectives, scopes, and development of the proposed study to be shared completely by the DOH and the Consultant mandated by AES GENER, we propose as a starting point of the consultancy that the proposed Terms of Reference (TR) of the study be approved by the DOH. On the basis of that technical framework, the study will be developed, and its different stages will be submitted for the consideration and approval of that Department, following a review procedure similar to the procedure for studies that the Department customarily carries out with its consultants. It is understood that this review procedure for each stage will conclude with the official approval of the DOH.

To achieve the foregoing, the Consultant will initially prepare a proposal to be discussed with the DOH and after it has been agreed, the study will be developed according to the timetable defined in the work plan specified in the TR. The timetable will make it possible to define the total period of the study.

As stated, during the development of the study the Consultant shall submit progress reports for the consideration of the DOH, to be discussed jointly. After they have been agreed on with regard to criteria, interpretations of results, and conclusions on progress, the Consultant shall continue with the next stage of the study.

An important aspect of the study will be the field works. In that regard, an integral part of the study will be the joint visits made by the engineers from the DOH and the Consultant. This proposal shall include, among other points, the complementary field works that are deemed necessary to improve the characterization of the river and accuracy of the studies to be developed, mainly in regard to the identification and characterization of the natural

conditions of each river bed and the infrastructure that might be affected by eventual degradation processes generated by the project.

## **5.2 Scopes and Works Proposed in order to conduct the Study**

### **5.2.1 Basic Background Information**

#### **a. Review of Previous Studies**

The studies, projects, plans, publications, statistics and cartography available shall be compiled and reviewed in order to achieve a precise idea of the information that can be used for the study.

The review shall also include a critical analysis of the basic information available in the PHAM project, considering the characterization of information associated with the hydrological, topographic, fluvial hydraulic and mechanical studies that are relevant to the analysis that needs to be made. An aspect that will also be incorporated in the analysis refers to the water rights granted in the area of the project, in accordance with official information available at the DGA (Water Authority) of the MOP.

The review shall address two main aspects: the first related to a critical analysis of the information with special attention to the validity and limitations of the scopes and quality of the information collected and/or processed previously; and a second aspect related to the characterization of the main problems and/or conflicts detected.

The most recent information with updated data associated with the Maipo River is available in the following studies:

Estudio de Impacto Ambiental Proyecto Hidroeléctrico Alto Maipo. 3119-0000-MA-INF-001. ARCADIS GEOTECNICA para AES GENER.

Estudio Sedimentológico en el Río Maipo. Departamento de Ingeniería Civil de la U de Chile para AES Gener, 2008.

Diagnóstico Plan Maestro Río Maipo y sus Afluentes. AC Ingenieros Consultores Ltda para Dirección de Obras Hidráulicas del MOP, 2008.

Estudio Sedimentológico Central Guayacán. IRH Ingenieros Consultores Ltda, 2008.

As a result of the review, a summary and discussion of the specific issues that each study contributes to the current analysis shall be delivered.

#### **b. Review and compilation of Available Basic Information**

A thorough review shall be made of the information contained in the studies identified above to determine which ones have a higher degree of validity and, therefore, which ones are more useful to the development of the study. If there is information that is no longer valid and, therefore, is not directly usable, it shall be updated and adapted for the purposes that are required.

In particular, the following information shall be collected that is necessary to conduct the study.

- Works of the PHAM and operating conditions
  - Arrangement of the intake and discharge works that are proposed in the PHAM for the collection of flows in the Colina, La Engorda, Las Placas, and Morado streams, as well as the Colorado and Yeso rivers, and the delivery work on the Maipo river in the Las Lajas sector.
  - Operation of the PHAM in regard to flows and expected pattern of collection and discharge of flows in the Maipo River.
- Characteristics of the river beds of the Maipo River and Affluents
  - Pattern of flows at monthly, daily, and flood levels, in the beds of the Colina, La Engorda, Las Placas, and Morado streams, as well as the Colorado, Yeso, and Maipo rivers.
  - Representative integral granulometric curve of the sediments constitutive of the bed in the sections of river beds that will be affected by intake and discharge works of flows. Fundamentally, the information generated in the study of the U. of Chile in 2008 will be used, which presents the results of the integral granulometric characterizations in the rivers Maipo in Las Melosas and San José de Maipo, Volcán near Baños Morales, Yeso in confluence with the Maipo, and Colorado between Alfalfa and Maitenes. The streams indicated above have surface samplings, so the validity of that information will be reviewed.

The information generated in that study may be complemented with information included in the study of the DOH of the MOP in 2008, where data related to sediments in the Maipo River were provided.

- Hydro-topographic characterization of the river beds in the area where the works will be located and the sections that would be affected by the works of the PHAM. Topographic surveys were made in the U. de Chile study, but they were local, covering sections of no more than 500 m in the environment of the intake and discharge works. An analysis should be made to decide whether it is possible to use this information for the study to be carried out or whether it is necessary to expand it.
- Cadaster of works on the Maipo River and affluents, focusing fundamentally on elements that might be relevant regarding the effect of the PHAM works on the behavior of the river beds. In particular, they should keep information in the study of the DOH of the MOP of 2008 in mind, which provided information about a cadaster of works on the Maipo River, from the El Ingenio Bridge downstream.

## 5.2.2 Complementary Field Works

### a. Field Reconnaissance

The river beds will be visited to collect detailed information in the field about their principal geomorphological, hydraulic, mechanical-fluvial and sedimentological characteristics, as well as uses with constructed works. Special importance shall be given, in particular, to the visit to sectors where the PHAM works will be carried out. A complete, detailed monograph of the visit shall be prepared through photographic documentation, which will be complemented by descriptive reports on the different sections with homogeneous characteristics, singular points, etc.

The visit shall be organized and coordinated with professionals from the DOH, as joint excursions are envisaged. The visits will make it possible to characterize and visualize the characteristic details and aspects of the entire bed and banks of the waterways. The team shall contact the institutions and users of the waterways to make a preliminary identification of the critical sectors and typical or more frequent problems that might arise during the operation of the PHAM works.

A set of recent aerial photos shall be available for the visit, which will make it possible to make up a suitable cartographic base to identify relevant geomorphological aspects or aspects of interest for the characterization of the river beds. Aerial photos shall be used from prior dates in order to have information about the most relevant changes in the river beds located in the areas to be intervened by the PHAM works.

The main objective of the visit shall be to detect the existence of critical sectors that might be visualized from the marks or traces left by the passage of runoffs in previous floods. Special interest shall be paid to the identification of sectors with a tendency toward erosion or depositing sediments in the river bed after relevant flood events, types of granulometry, and degree of armoring of the sediments, areas of meanders and tendency toward wandering of runoff, section with low river banks or with a tendency toward erosion due to the direct or indirect action of the current.

Each problem or relevant situation detected shall be analyzed in a context of integral behavior of the river beds in order to permit visualization of the origin or effect that caused it so a baseline can be established that can be used to measure the eventual effects that might be generated by works of the hydroelectric project.

This visit will be used to review the granulometric characterization of the sediments made for the U. of Chile study, verifying the degree of representativeness of those samples with regard to changes in the sizes of sediments in the river beds in the sections downstream of the works, which would be affected by reductions or increases in flow generated in the intake and discharge works, respectively.

The review of the characterizations in the Colorado and Yeso rivers and the Las Placas, El Morado, Colina and La Engorda streams will be given special importance because, in the case of the Maipo river, there is data from the DOH study of the MOP in 2008 in the sectors of El Manzano and San Ramón that can be used to verify the data used as a basis for the U. of Chile study.

If changes are detected in sections of interest of the river beds, integral granulometric samples shall be taken to complete the characterization of the sections of interest, permitting, in accessible sectors, the availability of data for a better approximation to the size of the sediments and tendency toward armoring of the river bed. With regard to the latter, it should be taken into account that the  $D_{50}$  of the surface armor corresponds approximately to the  $D_{84}$  of the integral granulometry.

**b. Works Cadaster**

The works cadaster available in the study of the Maipo River, made for the DOH of the MOP in 2008, shall be complemented. This information will make it possible to have a complete characterization of this course from the sector of the El Ingenio Bridge downstream. Therefore, it is thought that it will not be necessary to make a new cadaster in this river bed in order to identify the works that might be affected by the discharge in the Las Lajas sector.

However, in the location areas and downstream of the intake works of the PHAM, there is no information about existing works so the execution of cadasters in those sectors that might be affected by the operation of the works shall be envisaged.

The cadaster shall include the characterization of existing works in the river beds, identifying their main characteristics and location on a general drawing at a scale of 1:50,000. The works include fluvial defenses, bridges, fords, footbridges, storm water discharges, sewage and liquid industrial waste discharge, permanent and temporary water intakes, etc.

A descriptive sheet shall be provided for each one of the identified works, including aspects related to the geometric and construction characteristics and aspects related to their condition of conservation. Relevant aspects about their location and arrangement in the river bed shall also be included in order to have the most complete information possible about the works. The works shall be located on the drawings with coordinates (DATUM WGS 84), which shall be obtained in the field by using precision GPS satellite positioners.

**c. Integral Granulometry**

As indicated in letter a, samples shall be defined (test pits at least 1.5 meter deep) that need to be made on the basis of the results obtained from the visits and reconnaissance of the river beds that are carried out for the study. The number of samples required is not known a priori so this item shall be paid at unit prices to allow sufficient flexibility for their execution based on the real needs of the study.

The execution schedule in regard to location, distribution, and amount shall be agreed upon previously with the professionals of the DOH in charge of the supervision of the study.

**d. Topography**

In order to have topographic information to represent some specific sectors of the natural river beds, the information generated by the Owner shall be used as a base. That information came from a high-resolution topographical survey made with an air-transported laser scanner over an area of 16,176 hectares in March 2006 (Base PSAD 56). On the basis of that survey, topographical drawings are available at scales of 1:1,000 and 1:10,000 with level curves at 1 and 10 meters.

On the basis of the information mentioned, transverse profiles of the river beds to be studied will be obtained. The sectors to be represented correspond to the following:

- Maipo River in the sector downstream of the discharge in Las Lajas for 5.5 km, starting 500 m upstream of the location of the discharge (including up to about 100 meters downstream of the Independent Water Intake). The transverse profiles shall be obtained with a maximum distance of about 200 meters.
- Colorado and Yeso Rivers from 100 meters upstream and up to 1 km. downstream of the location of the intake work. The transverse profiles shall consider a maximum distance of about 100 meters.
- Colina, Las Engorda, Las Placas, and El Morado Streams from 100 meters upstream and up to a length of 1 km. downstream of the location of the flow intake work. The transverse profiles shall be obtained at a maximum distance of about 100 meters.

The set of transverse profiles shall be delivered including the following information:

- Mileage at the planimetric axis.
- No. of profile.
- Accumulated distances and elevations of all points of the profile.
- Reference elevation of each profile.
- Zero referring to the planimetric axis.

If it is necessary to include details that are not properly represented by available topographic information, a topographic survey shall be made to complement the air-transported Laser Survey available in the Project. It shall be carried out based on UTM coordinates and a WGS-564 system of reference, which shall be materialized in each survey by means of Topographic Bases measured with double-frequency geodesic GPS.

To carry out the topographic survey Type A current closed polygonals shall be built. A Topographical Base of 2 PRs that is visible to one another shall be built in each sector.

The vertexes of the polygonals or the Topographical Bases (PRs) shall be arranged on monoliths as indicated in the instructions of the DOH, and they shall be placed at a distance of no more than 400 meters from one another so there is visibility between them. Their location shall be selected so they are not affected by the river bed or vehicular traffic.

The monoliths shall be Type PR. The respective monograph shall be delivered according to the format indicated in ETT-DOH.

As part of the works of the topographical survey as such, files of “raw” (not manipulated) data on the survey from the total stations, polygonal spreadsheets, geometric leveling of PR, spreadsheets with data on transverse profiles (mileage, accumulated distances, elevations), plant drawings, drawings of transverse and longitudinal profiles shall be delivered to the IF.

### 5.2.3 Basic Studies

#### a. Historical Evolution of the River Beds

Initial Definition Element of the Fluvial and Sedimentological Hydraulic-Mechanical Baseline of the Fluvial System influenced by PHAM.

An analysis shall be made to characterize the historical evolution of the river beds of the Colorado, Yeso, and Maipo rivers as well as the Las Placas, El Morado, Colina, and La Engorda streams.

The analysis shall be made on the basis of a review and study of aerial photographs obtained on different dates, complemented by reconnaissance visits to the field and basic information on flood hydrology available in recent studies, in order to characterize the past behavior of rivers and streams, and on that basis obtain a better view of the status of the current situation as a result of the historical evolution of these river beds.

The analysis will provide basic information that will be useful for the characterization and identification of current or natural phenomena (without influence of the PHAM) associated with the fluvial hydraulic and mechanical behavior of the river beds and how they have shaped the zones that would be affected by the operation of the works of the PHAM. It will also make it possible to establish the conditions that characterize the baseline of the river beds as well as possible future scenarios in which past situations may be repeated after the hydroelectric project has started operating.

In preparing the analysis the professionals should take advantage of the existence of aerial photographs that cover a broad period of information. Stills of the following flights should be obtained for that purpose.

- Hycon of the IGM on a scale of 1:70,000 from 1955
- OEA of the IGM on a scale of 1:30,000 from 1961
- FONDEF of the SAF on a scale of 1:20,000 from 1994
- GEOTEC of the SAF on a scale of 1:70,000 from 1997
- REGIONAL GOVERNMENT on a scale of 1:20,000 from 2006

The stills shall be digitalized on the same graphic scale by means of a process of planimetric cartographic rectification, considering control points obtained from the regular charts on a scale of 1:50,000 of the IGM.

The information generated may be represented graphically based on available stills, providing information that will be useful to define possible scenarios for the development of fluvial and sedimentological hydraulic-mechanical simulations of the river beds.

#### b. Hydrological Study

A review of the hydrological information available for the development of the study shall be made, analyzing fundamentally its quality, validity, and representativeness with regard to the zones of interest to the study.

In particular, the information and data generated in the following studies shall be analyzed:

Estudio Sedimentológico en el Río Maipo. Departamento de Ingeniería Civil de la U de Chile para AES Gener, 2008.

*Sedimentological Study in the Maipo River. Department of Civil Engineering of the U. of Chile for AES Gener, 2008.*

Diagnóstico Plan Maestro Río Maipo y sus Afluentes. AC Ingenieros Consultores Ltda para Dirección de Obras Hidráulicas del MOP, 2008.

*Diagnostic Master Plan Maipo River and its Affluents. AC Ingenieros Consultores Ltda. for Department of Hydraulic Works of the MOP, 2008.*

Estudio Sedimentológico Central Guayacán. IRH Ingenieros Consultores Ltda, 2008.

*Sedimentological Study. Guayacán Power Plant. IRH Ingenieros Consultores Ltda., 2008*

Based on this information the series of average daily and flood flows in periods of snow and rain shall be generated in order to have the appropriate information available for an analysis of the sedimentological behavior of the flows.

In that context it is important to emphasize that an analysis was made in the U. of Chile study with the series of monthly average flows, which limited the characterization of the real variations of the flows (at a daily and hourly level the approximation should be better), leading to a conclusion that, although consistent with that approach, gives more relevance to the impact of the PHAM in terms of volumes of material mobilized. On this basis, it is necessary to include the generation of the series of flood and daily average flows in this study.

### **c. Fluvial Hydraulic Studies**

The analysis to be made will envisage the calculation of the hydraulic axes along the sections of each river bed of interest, for the representative flows of the monthly and/or daily pattern, as well as in floods, evaluating speeds of runoff, slopes, local water levels, normal and critical levels, and hydraulic demands on the riverbanks and on structures in the case of existing works.

As basic information for the analysis of the fluvial and sedimentological hydraulic-mechanical behavior of the river, a hydraulic study will be done for daily average flows of determined probabilities obtained from the duration curve that will be generated for this analysis. A study of the hydraulic axes for floods that are relevant to the fluvial and sedimentological mechanical phenomena will also be included.

The analysis will be made using Hec-Ras software that evaluates hydraulic axes in natural river beds considering a one-dimensional analysis. Data files will be created for this purpose that will contain all the information about the transverse profiles of the river bed, longitudinal slope, and integral granulometric curve representative of each section of the area of study.

### **d. Fluvial and Sedimentological Mechanical Studies**

A calculation of the bottom scouring along sections of interest in the beds of the Colorado, Yeso, and Maipo rivers will be made, as well as in the Las Placas, El Morado, Colina, and La Engorda streams for flow series of interest to the study. Only the component associated with bottom dragging will be evaluated. That component corresponds to the fraction of sediments that might be affected by operation of the PHAM works.

Calculation ratios with the best technical foundations will be used for the analysis, as well as applicability to the rivers in the Chilean Andes. An analysis will be made of the different results generated with the calculation expressions used, defining representative values for the river beds being studied.

The analysis will focus first on establishing the magnitude of the dragging capacity of river beds in the sections of interest, as well as their relative importance with regard to the different hydrological scenarios representative of the current situation that, as stated above, would be evaluated on the basis of the hydrological series of average daily flows available in base studies for the hydroelectric project. This will make it possible to define the threshold value of flows for which eventual modifications in the fluvial and sedimentological hydraulic-mechanical behavior generated by the PHAM would have some future relevance and the time scale of the flow series, which is of interest to the analysis. An analysis will also be included of floodwaters that generate relevant episodes of fluvial dragging.

The analysis will include an estimate of scouring in suspension in order to obtain estimates of total scouring for every point of interest in the river beds being studied.

### **5.2.3 Analysis of the Phenomena and Effects of Degradation Downstream of the Water Intakes in Affluents**

The fluvial and sedimentological hydraulic-mechanical behavior of the Colorado, Yeso rivers and the Colina, Las Placas, El Morado and La Engorda streams in the sections downstream and upstream of the location area of the intake works of the PHAM project shall be evaluated.

Mathematic simulations shall be made to estimate the volume of bottom dragging for different hydrological conditions and/or scenarios to characterize and quantify the volumes of sediments associated with the current regime (without presence of the PHAM works), as well as eventual future changes in that volume generated as a result of the start-up of the PHAM.

The foregoing will be used as a basis for establishing the possibilities of degradation/aggradation in the beds of the rivers and streams whose flows will be reduced because of the operation of the water intakes. That would be the result of the imbalance that volumes of contribution of sediments would experience in sections downstream of the location of the water intakes.

The above will make it possible to define the relevance that a reduction in flow might have on contributions of sediments generated in sections affected by the reduction of flows and its effect on the contributions of affluent sediments to the Maipo river. In particular, the possibility will be evaluated of that phenomenon's having some influence on sectors of confluence of the Volcán, Yeso and Colorado rivers, as well as areas of major exploitation of sediments located downstream of the Pirque bridge.

In the latter case, the joint effect of the reduction and the increase in bottom dragging that the concentrated discharge of 65 m<sup>3</sup>/s in the Las Lajas sector might generate should also be taken into account, notwithstanding the collection of those flows in the Independent Intake and the La Sirena Canal. This aspect is analyzed individually in the following point.

#### **5.2.4 Analysis of the Phenomena and Effects of Degradation Downstream of the Discharge Work in the Maipo River – Las Lajas Sector**

The concentrated discharge of a 65 m<sup>3</sup>/s flow in the Las Lajas sector is expected to produce a local increase in the capacity to transport bottom scouring in the section downstream of that discharge and, along with it, the degradation of the bed as a result of the relative higher dragging capacity of passing flows.

As indicated for sections downstream of the water intakes, mathematical simulations will be made for the Maipo river to estimate the volume of bottom dragging, for different hydrological conditions and/or scenarios including the current regime, as well as eventual future changes generated as a result of the start-up of the PHAM.

The analysis shall also establish the length of the river where that phenomenon will extend in order to determine the direct area of influence of the hydroelectric project with objective technical information.

The analysis shall take into account the existence of the intake works of the La Sirena canal as well as the Independent Intake of Aguas Andinas and the San Carlos Canal, located about 400 m and 5 km downstream of the discharge, respectively. The importance of these works lies in the fact they both extract flows of the same order of magnitude as the one to be delivered in the future by the discharge from the PHAM project, which could neutralize the effect on alterations in the sedimentological regime of the discharge in the section downstream of the Las Lajas sector.

Another relevant point to be considered in the analysis of possible degradation of the Maipo river bed is the existence of bedrock at a relatively low depth from the surface of the bed in the Las Lajas sector as indicated in the Addenda of the EIS of the project, as well as the tendency to armor of sediments in the river bed, which would limit the possibilities of making the bed deeper in the event of a phenomenon of degradation resulting from an increase in flow.

All of the aspects indicated, plus others that arise during the development of the study, will be incorporated into the analysis of the fluvial and sedimentological hydraulic-mechanical behavior of the river in the section of interest.

#### **5.2.5 Analysis of the Phenomena and Effects of Local Scouring in the Environment of the Discharge Work**

The depth that local scouring could reach in the bed of the Maipo river in the discharge area of the PHAM project, as a result of the concentrated discharge of an estimated flow of 65 m<sup>3</sup>/s, will be determined.

The recommendations described in the Highway Manual of the MOP that are customarily applied in Chile shall be used. In this case it is extremely important because of the limitations that will be caused by the deepening of the scouring, the incorporation of information related to the location of the bedrock, and the tendency to armor of the bed in the discharge area. Possibilities of progression of that phenomenon due to a regressive effect of the scouring will also be evaluated, as it might make the trench extend beyond the specific discharge area.

As part of the local scouring phenomenon an analysis will also be made of the possibility that alterations may be generated in the current of the river as a result of the concentrated discharge, causing the rerouting of the current, which could eventually affect the banks and generate local scouring in some sectors of the river. As part of this analysis, information based on the historical evolution of the river, described in the preceding points, will be kept in mind.

#### **5.2.4 Proposal of a Monitoring Program and Mitigation Measures**

##### **a. Monitoring Program**

Based on the results of the characterization and quantification of the effects that will be generated in the river beds and in the environment of the PHAM works, a monitoring program shall be established with the fundamental objective of carrying out a follow-up of the scouring and degradation phenomena, in both their magnitude and spatial extension, with prior knowledge of the possible scenarios in which those elements may vary, based on information contributed by the study.

Through its future application, the monitoring program shall permit confirmation of the null or negative effects detected and the magnitude and evolution of the phenomena associated with the operation of the PHAM project. Nevertheless, the proposed program shall also make it possible to detect any possible variations that might arise in the phenomena analyzed, making it possible to apply corrective measures, if necessary, in a timely manner with sound, well-founded technical backup.

##### **b. Mitigation Measures**

Based on the results of the characterization of the scouring and degradation phenomena, the need to implement mitigation measures shall be established in order to control the adverse effects detected that are associated with the operation of the works, permitting their elimination or reduction.