PACIFIC HYDRO CHILE'S

Chacayes Hydroelectric Generating Station

Generating hydropower in the Andes

For the Association of Consulting
Engineering Companies | Canada

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ACEC Submission
Table of Contents

Introduction and Summary

Pacific Hydro is a leading renewable energy company, producing clean power from natural resources with hydro, wind, solar and geothermal power projects in Australia, Brazil and Chile. In 2004, Pacific Hydro Chile, S.A. (PHC) acquired the Coya and Pangal hydroelectric stations in the Cachapoal basin from Codelco, the state-owned copper producer. The Pangal River is a tributary of the Cachapoal River with the power flow from the Pangal generating station feeding directly into the forebay of the Coya generating station.

With the purchase of these generating stations, PHC also obtained an option to purchase the water rights of the upper Cachapoal River basin. PHC therefore commissioned an prefeasibility study of the Cachapoal River basin with the objective of identifying the "optimal" development sequence in a phased approach. The study resulted in the recommendation for a development of the Cachapoal River basin in a total of four projects. With the viability of the development of the plants upstream confirmed, PHC exercised the option and purchased from Codelco the water rights.

PHC subsequently retained Hatch, formerly Acres International, to provide consulting services for the basic and definition engineering and the preparation of tender documents for an Engineering, Procurement and Construction Management (EPCM) contract for the Chacayes project.

The Chacayes project consists of the following components:

- Chacayes diversion weir and intake at elevation 1111 m above sea level
- Cipreses River diversion weir and intake at elevation 1134 m
- Combined design flow from the two intakes of 72.5 m^3/s
- Desander downstream of the Chacayes intake for the combined flow from the two intakes
- Sections of canals, tunnels, culverts and penstock to connect the intake, regulation pond and powerhouse, and a
- Two-unit surface powerhouse with an installed capacity of 111 MW.

Project Background

The Chacayes hydroelectric project is set in the mountainous terrain of the Chilean Andes in an area characterized by rain and glacier-fed streamflow. Chacayes is the first in a series of planned greenfield developments on the Cachapoal River to be undertaken by PHC. The project includes diversion weirs, a daily-regulation pond, a desander, canals, tunnels and a surface powerhouse.

Hatch prepared the basic design, definition designs, the owner's technical requirements, including drawings and specifications for civil structures, and mechanical and electrical systems. The project was constructed under an EPC contract with Constructora Astaldi Fe Grande Cachapoal Ltda, a consortium made up of Astaldi SPa from Italy and Fe Grande, a Chilean construction company. Hatch was also Owner's Engineer, responsible for reviewing the EPC contractor's detailed design documentation and drawings for civil works, mechanical and electrical systems and equipment supply. The project poses a number of logistical challenges. The development is in a seismically active region of Chile, and one of the two diversion intakes is located in a national reserve. Careful attention was given to the visual impacts on the unique development.

The Cachapoal River has been recognized as an important resource for electric power in central Chile for more than 100 years. The Coya and Pangal hydroelectric stations have been operating since 1911 and 1921, respectively. The Coya and Pangal stations were purchased by PHC from the Chilean state-owned copper company CODELCO in April 2004, and included the associated transmission lines and an option to purchase the upstream water rights. They have a combined installed capacity of 76 MW, and uniquely provide both 50 and 60 Hz power to Codelco's El Teniente mine.

In the Cachapoal Basin Pacific Hydro Chile saw an opportunity to develop run-of-river hydroelectric plants to feed into the national grid, with attractive returns, especially with a a 6% annual growth in electrical demand in the country. In 2005, PHC commissioned a feasibility study of the Cachapoal River basin with the objective of identifying the "optimal" development sequence in a phased approach.

This study resulted in the recommendation for a development of the Cachapoal River basin in six run-of-river projects with the Chacayes Project being located just upstream of the existing Coya project. PHC subsequently retained Hatch to provide consulting services for the basic and definition engineering and the preparation of tender documents for an Engineer, Procurement and Construction (EPC) contract for the Chacayes hydroelectric project.

Chacayes Hydro Project

The Chacayes project is developed in the Alto Cachapoal River basin between 1111 and 924 metres above sea level. The project included diversion dams, a daily regulation pond, a desander, canals, tunnels, and a surface powerhouse.

The delivery of this run-of-river hydro project in October 2011 was needed to meet the 6% growth in the electrical market in Chile and to reduce reliance on energy from imported fossil fuels.

Chacayes will generate 558GWh per annum of renewable energy for Chile's power market, which is enough electricity to supply enough energy for more than 300,000 Chilean homes. This project will also abate approximately 340,000 tonnes per annum of greenhouse gas pollutants.

Chacayes was given environmental approval by COREMA VI Region in July 2008. In October 2008, Chilean President Michelle

Bachelet unveiled the first stone to mark the commencement of advance-works construction.

Chacayes is the first of six hydro power projects in the US$2 billion development pipeline in the Cachapoal Valley. The six will add more than 600MW of renewable energy capacity to Chile's national grid.

Hatch prepared the basic design and definition designs for the project as well as the Owner's technical requirements, including drawings and specifications for civil structures, and mechanical and electrical systems. Hatch also acted as Owner's Engineer, responsible for reviewing the EPC contractor's detailed civil design and drawings, and equipment supply. The work was done in two phases:

- Phase 1, preparation of an inception report including the review of a previous feasibility study. Development of basic engineering, sufficient to define the structure for permit applications to the relevant authorities
- Phase 2, refinement of basic engineering to a definition stage, preparation of drawings and specifications required so that the EPC construction contract for the project works could be tendered.

Design of the Chacayes hydroelectric development takes into consideration the seismically active geology of the region.

The Chacayes project is the first in a series of potential greenfield developments on the Cachapoal River with upstream projects being studied by Hatch including the Nido de Aguila and Las Leñas hydroelectric projects

The Cipreses diversion and intake is located in a national reserve and this required careful consideration of the visual impacts of the diversion structure on the area. Construction access to this site was limited to be only through the diversion tunnel to reduce the impact on the Reserve, but a small access road is being constructed for operations for routine maintenance and inspection. Any major maintenance works will be carried out through the tunnel.

Chacayes is one of six hydro projects in Chile

Chacayes has 6.5 km of tunnels and 6.4 km of canal

In the end there were:

- 6.5 km of tunnels
- 6.4 km of canal
- 2 million cubic meters of earthworks
- 154,000 m^3 of concrete
- 25,500 m^3 of shotcrete
- 10.7 million man-hours

Clean energy generated at Chacayes is supplied to Chilectra, the largest electricity distributor in the country, under a long-term Power Purchase Agreement.

The plant is co-owned by Italian construction company Astaldi, which was responsible for delivering the project under an Engineering, Procurement and Construction (EPC) agreement. Astaldi holds a 27.3% stake in Chacayes.

Even though the run-of-river Chacayes projects did not cause inundation or require relocation of communities affected by the project, PHC does take into account the legitimate concerns that the community has on the way that the construction or long term operation of the project will affect their environment. One of the ways PHC facilitates community growth is through its Creciendo Junto (Growing Together) community fund. The aim of this initiative is to improve the quality of life of the communities living in the Alto Cachapoal Valley, in Chile's O'Higgins Region. Creciendo Juntos encourages community members to identify their needs and develop and submit proposals for projects in the areas of health, environment, education and community development. These submissions are assessed and selected by an expert panel which includes Pacific Hydro executives, community members and authorities from the O'Higgins Region. Funds are awarded annually to projects selected by the panel.

Mountainous terrain of the Chacayes project

Cipreses Diversion Weir and Intake

The Cipreses Diversion is located on the Cipreses River within the boundaries of the Rio de Los Cipreses National Reserve. The remote location coupled with the low profile of the diversion structures will limit visual or other impacts that the structure will have on the use of the Reserve. The diversion weir is constructed of reinforced concrete with a width of 20 m and a 3-m high rubber dam to increase the operating level. The top of the concrete weir has been set at el 1131.5 m and the top of rubber dam is set at el 1134.5 m. The weir is designed for a flood discharge equivalent to the 1-in-250-yr flood, and has been checked for a flood equivalent to the 1-in-500-yr flood.

An upstream apron has been provided to control seepage under the foundation. Consolidated rockfill was provided in the apron downstream from the structure to protect against erosion and scour. The diversion weir is constructed of conventional concrete, with a layer of granite paving stones provided to resist abrasion from river bed-load material transported during floods. An access gallery is provided within the body of the weir to provide access between the two banks of the river. A degraveller/sediment sluice is provided on the right bank adjacent to the intake structure. The sediment sluiceway has a hydraulically operated radial gate 3 m wide x 3 m high. The degraveller floor has a slope of 5% in keeping with the apron and general slope of the river. Stop log slots are provided upstream of the radial gate. The sluice has a width of 11 m at the upstream end and 3 m at the gate section. A 26-m long divider/acceleration wall with a top at el 1136.7 m was provided to separate the degraveller sluice from the main weir section. An apron was provided downstream of the sluice to tie into the apron downstream of the weir.

The intake is a reinforced concrete structure located on the right side of the diversion weir upstream of the sediment sluicing bay. It consists of two openings leading to the upstream end of the tunnel which conveys the flow to the

Chacayes diversion weir. Trashracks are located at the upstream end of the intake, immediately upstream of the tunnel entrance. Material which collects in the upstream area is flushed through the 3 m x 3 m degraveller radial gate.

The water is drawn off into two intakes located on the face through two openings. Each intake passage is equipped with sloping trashracks. The intake floor slopes toward the tunnel entrance and the sides converge to the tunnel width of 3 m. A 3.1 m high by 3 m wide slide gate is provided at the entrance to the tunnel to control the flow. An underground cavern contains the gate hoist to operate the slide gate. This allows the gate to be lifted fully above the deck level for ease of servicing. The cavern allolws contains all of the auxiliary electrical equipment.

The 5-m diameter tunnel is free flow and was constructed using a Tunnel Boring Machine (TBM). This method was selected by the EPC contractor in order to accelerate the construction and provide access to the Cipreses intake, in order to meet the overall construction schedule. The tunnel has a total length of 2520 m with no major bends. No construction audits were required for the construction of the tunnel.

The tunnel leads to a short outlet canal that conveys the flow from the tunnel outfall to the upstream end of a drop structure that empties into the pond upstream of the Chacayes Diversion weir. The canal and drop structure are constructed of conventional concrete The canal has a bottom width of 3 m and side slopes of 1.5H:1V. It was constructed of granular fill and has a concrete lining. The drop structure dissipates the energy in the water as it discharges into the Chacayes intake headpond

Chacayes Diversion Weir

The diversion weir is constructed of reinforced concrete and has a width of 55 m. It is designed for a flood discharge equivalent to the 1-in-250-yr flood and was checked for a 1-in-500-yr flood. The diversion weir has five radial gated bays of 8-m width and a degraveller sluice. The bays of the diversion weir are constructed of conventional concrete, with a layer of high-strength granite rock on the floor of all bays in the weir to resist the abrasion of bedload transported in flood conditions. An impervious apron comprising of concrete slab together with an impermeable membrane, covered with layers of silts, sands, gravels topped with large boulders has been provided immediately upstream from the structure to control seepage under the foundation. The upstream apron has a slope close to the river gradient to maintain, as far as possible, the natural regime of the river.. Large rock pieces in-filled with concrete to produce a consolidated rockfill have been provided in an apron downstream from the structure to protect against erosion and scour.

The diversion weir has a non-overtoppable section having a length of approximately 32.5 m. The non-overtoppable section is composed of concrete with the top of the section set 1112.0 m. There are no drainage galleries in the structure. The main spillway gates are radial 8 m wide x 5.5 m high and are made of structural steel. The sediment sluiceway has a hydraulically operated radial gate 4 m wide x 4 m high.

Intake

The intake is a reinforced concrete structure located on the northern (right bank) side of the diversion weir upstream of the sediment sluicing bay. It consists of four openings leading to the upstream end of the channels which convey the flow to the desanders. Trashracks are provided immediately upstream of the canal intakes. Sediment collection and flushing facilities have been provided immediately upstream of the trashracks in the most northerly (right side looking downstream) bay of the diversion weir. Material which collects in the upstream area is flushed through the 4-m x 4 m radial gate located in this bay of the diversion structure.

The water is drawn off into four conduits located on the intake face through four openings. Each intake sill is located at an elevation of 1106.85 which is a minimum of 2.5 m above the floor of sediment sluicing bay.

Desanding Chambers

The four desanding chambers each have a design flow of 18.13 m3/s. The desanding chambers have been designed to be flushed intermittently depending on the sediment load in the river. The channels which connect the intake to the desanders will act as diffusers to decelerate and spread the flow gradually over the full cross-section of the chamber prior to entering the principal settling section of the structure. The sedimentation chambers are open structures having a length of 50 m and an inside width of 10.4 m, constructed of reinforced concrete. Water is decanted off the top at the downstream end of the chamber by a weir prior to entering the canal. A gate to facilitate the intermittent flushing of each chamber of the desander is provided at the downstream end. This gate has a width of 2 m and is operated by a hoisting mechanism which is located on the deck. The desanding facilities conclude with a transition to convey the clean water that exits over the overflow weir into the diversion canal.

Surface runoff is directed under the canal

Water Conveyance and Chupallal Pond

The Chacayes water conveyance system conveys water from the downstream end of the desander to the Chupallal regulating pond and runs down the right bank of the river. The design discharge for the canal is 72.5 m3/s. The canal is made up of a combination of structures, including:

- a trapezoidal cross-section when the canal is constructed in alluvium or in fill, with a bottom width of 3 m and side slopes of 1.5H:1V,
- rectangular, when in rock, with 1:6 side slopes and the bottom width increases to 7.8 m.
- two free flow tunnels (La Isla and Peralitas, 7m horsehoe shaped with shotcrete linings
- Rectangular reinforced concrete channels where sides slopes were too steep for the regular trapezoidal canal
- Four reinforced concrete culverts where streams and outwashes must be passed over the canal
- Four reinforced culvert bridges for road crossings
- Transition sections between the different cross sections
- Cross drainage works and side ditches to capture surface runoff and direct it under the canal.

The Chupallal regulating pond provides the storage required by the project for potential peaking operation and to earn firm capacity benefits. The regulating pond is located at the downstream end of the Chacayes diversion canal and was created by gradually enlarging the canal section. The dykes were designed with side slopes of 2.5H:1V on the pond side and 2H:1V on the dry side.

The pond has a total volume of approximately 1,078,700 m3 with a surface area of approximately 168,750 m2. The embankments are composed of granular rock fill with proper compaction to facilitate the installation of an impervious lining consisting of a sandwich of geomembrane, geotextile and geodrain. The pond slopes from the upstream end toward the power intake. The pond is equipped for dredges which will remove material which is too fine to deposit in the desander but may deposit in the regulating pond.

Power Canal and Culvert

A power canal abstracts water from the northwest end of the regulating pond and conveys it to the headworks where it enters the power culvert. The headworks consists of a bell mouth and gate structure which transitions into the 5.25 m diameter reinforced concrete culvert leading to the power tunnel and subsequently to the powerhouse.

Power Tunnel

The Chacayes power tunnel transfers the flow from the power culvert to the powerhouse. The initial section of the low pressure tunnel has a 5 m D-shaped cross section, while the lower part where swelling pressures were high (see below) was ovoid in cross section.

Two issues that had to be addressed were hydrojacking where there is insufficient confining pressure surrounding the tunnel to contain the water pressure that can then jack open the rock with a resulting loss of flow. This was addressed through an in situ testing to determine the confining pressure. The risk of hydrojacking was addressed by providing a steel liner from the powerhouse to the bottom of the drop shaft, and from there to just upstream of the surge shaft, providing an impermeable membrane sandwiched between the initial shotcrete support and the concrete liner.

Another phenomenon observed in the Chacayes power tunnel was the existence of minerals in the rock mass that were subject to swelling when they got wet. The initial geotechnical investigation did not identify this issue and extensive testing using ethylene glycol had to be done in the tunnel to identify the areas most susceptible to swelling. The observed swelling pressures of 1.2 Mpa resulted in the need for a heavily reinforced concrete liner in the affected areas,

At the downstream end, the tunnel bifurcates into two penstocks which carry the flow to each of the two units in the powerhouse. Each of the penstocks has turbine inlet valves.

Chacayes power tunnel flows to the powerhouse

The powerhous eis 56m long and 21m wide

During the basic and definition design serious consideration was given to installing one or two by-pass valves so that water could be diverted to the downstream Coya I and future Coya II generating stations even when the Chacayes generating station was off-line. Ultimately PHC took the decision to eliminate the by-pass valves from the scope of the EPC contract but made provision through a preliminary design and a stub connection for their installation in the future.

Generation Facilities

The surface powerhouse is a mass concrete structure to enclose the generating units and auxiliary services. A structural steel superstructure is used to enclose the area above the main operating floor. The powerhouse is 56 m long and 21 m wide and contains the two Francis units coupled to vertical shaft generators. The main transformers are located adjacent to the powerhouse and have isolate phase bus bars to bring the power from the units. The transformers have a security fence, blast wall and containment pit.

The primary equipment will consist of two vertical Francis turbines, each with a rated output of 55.4 MW at a rated net head of 168.6 m and a rated discharge of 36.25 m3/s. It is anticipated that the firm capacity for the station will be 82 MW and a base annual energy of 557 GWh/yr will be generated. The runners, wicket gates and discharge rings are of modern design and have a ceramic coating on the runners for maximum sediment erosion and cavitation resistance.

The moving parts of the wicket gate operating mechanism operate using self-lubricated materials in order to minimize the loss of lubricants to the environment.

The main element related to the environment is the potential for loss of oil used to lubricate the bearings and to operate the hydraulic system that controls the wicket gates, etc. The powerhouse sump system collects any leakage of oils or other potentially hazardous materials and an oil-water separator protects against any material being discharged to the outside environment.

To maximize plant/unit reliability, a dedicated appropriately rated 3-phase main transformer is provided for each generator unit. The rating of the main transformer is capable of handling the maximum generator output capability. The power is evaculated through a conventiaonl air-insulated switchyard connected to a double circuit 220kV transmission line.

The Environmental and Social Benefits

Considerations in the development of the optimal hydropower scheme and development sequence for the Cachapoal River basin relates to the existing downstream users and water rights that pose a constraint on hydropower operations in the basin. Being a run-of-river plant, the operation of the Chacayes hydroelectric project cannot affect the water rights or operation of existing downstream hydropower plants or irrigation needs.

One of the primary concerns at the start of the project was the construction of the Cipreses diversion as this area is located inside a national reserve. To mitigate the impacts of the diversion PHC agreed to construct a diversion structure which was as low and inconspicuous as possible. In order to avoid any major disruption to the reserve during construction it was also agreed that construction access to the diversion site would only take place through the diversion tunnel constructed to convey water from the intake to the Chacayes headpond. To facilitate the rapid construction of the diversion tunnel so that access to the diversion could be obtained, the contractor proposed to use a 5.0 m diameter Tunnel Boring Machine (TBM). The TBM progressed well with the exception of when it encountered two buried valleys along the route in-filled with large boulders.

To further minimize the environmental effects and visual impact on the National Reserve the electrical and fibre optic lines to the Cipreses

A run-of-river power-plant in the Cachapoal river basin

Diversion works were installed inside the diversion tunnel instead of a surface powerline through the National Reserve lands.

The main aspect related to the environment associated with the powerhouse was the presence of oil in the transformers. A containment system will collect any oil leakage from the transformer. This drainage would then be sent to the oil-water separator to remove any oil or other contaminants for disposal at a licensed facility. A deluge system has been provided to limit the risk associated with fire at the transformers. The containment system is sized to hold the oil from the transformer plus the discharge from the deluge system so that it could be treated by the oil-water separator.

PHC has created positive outcomes for the local communities. At the peak of its construction, the project created approx. 2,000 direct and 3,000 indirect jobs. Pacific Hydro also developed an annual training program for the community and created an ongoing community fund called Creciendo Juntos to sponsor projects in education, health and the welfare of the local communities.

Technology Transfer

Hatch's activities covered a period commencing in Oct 2006 and going through to completion of the project in 2011. Throughout the basic and definition design, the specification preparation and the tendering process Hatch sent specialists in the major disciplines, either individually or as a team to work in Chile on a short term basis. Hatch has two offices in Chile that specialize in mining and at the outset of the project they had limited capability in hydroelectric generation technology.

As a key part of the execution of the work Hatch undertook to actively recruit local Chilean staff with experience in the design of hydroelectric generating stations. Hatch also sent staff from Canada to work in the Santiago office in some cases for periods of several years. The staff that was recruited into the Santiago office had enough experience to undertake the normal technical review of the design being carried out by the Chacayes Contractor.

When required to address specific technical issues, staff from Canada would be brought in to provide comments on an as-required basis. The project had deliverables that included 2000 drawings and roughly 4000 submissions and 750 documents in roughly 1200 submissions. The procedure that was followed in providing the technical review is outlined below.

Complexity and Risk Identification

The following geological risks had to be considered in the project area:

Debris flows and/or floods, develop in the upper reaches of the main rivers Cachapoal and Cipreses and in the tributary stream valleys, e.g., Qdas. Potrerillos del Medio, Tinajon, Peralitas and Retamal. These debris flows carry large amounts of sediment up to boulder (>0.30 m) and block size (>0.30 m). These debris flows are initiated in periods of unusually high rainfall as valley slopes become saturated and fail, depositing their debris into the river or stream. These phenomena can cause considerable damage. Frequency of occurrence is relatively high with the frequency estimated to range from 1-in-1 to 1-in-20 years.

Bank overflow occurs in the upper parts of the alluvial fans which have developed at the base of Qdas. Potrerillos del Medio, Tinajon and Peralitas. These overflows are diversions of flow from the main tributary flow path. These phenomena cause relatively little damage. They are rainfall-induced with frequencies ranging from 1-in-20 to 1-in-50 years.

Debris falls include cobble and boulder-size material falling from steep slopes onto the upper part of the alluvial fans or colluvial deposits (talus) at the base of the bedrock cliffs, either in the main river valleys or the tributary stream valleys. Sometimes the fallen material rolls downslope a considerable distance. These are often caused by freezing and thawing action and can cause local damage. Frequency of these events is estimated to range from 1-in-20 to 1-in-50 years.

Landslides have been identified in a few locations in the project area. Where the volume of material involved has been generally small, local damage can result. Frequency of this type of phenomena is estimated to range from 1-in-20 to 1-in-50 years.

Bank erosion occurs in many areas along the Cachapoal River. This phenomenon is most prevalent during the flood periods. Frequency of this event is estimated to range from 1-in-1 to 1-in-20 years.

Swelling occurs in the volcanic formations in the project. The rock contains minerals such as zeolites or montmorelinites which deteriorate and swell upon exposure to water, or possibly even humidity. In tunnels, the deterioration may be manifested during or shortly after excavation or some time later during operation. Deterioration, if left untreated, may result in sloughing/slabbing or even tunnel collapse.

Technical Challenges and Innovation

Chile is one of the most seismically active areas in the world as demonstrated by the 2010 earthquake which occurred off the coast of central Chile on 27 February 2010 with a magnitude of 8.8 on the moment magnitude scale. It ranks as the sixth largest earthquake ever to be recorded by a seismograph. The off-shore location of the quake reduced the violence of the shaking at the site in comparison with such cities as Arauco, Coronel and particularly Concepción, which experienced the strongest shaking. The shaking was still violent at the Chacayes Project site and PHC reported that a resurvey indicated that the entire area had been shifted to the north-east by about 0.5 m.

Hatch had undertaken a seismic assessment of the Chacayes site as part of the basic and definition engineering and had developed the seismic ground accelerations to be used in the design of the civil structures. This was based on the records of large historical earthquakes in the region. It applied both deterministic and probabilistic approaches to derive a suitable design basis event which was then transposed to the site using a number of attenuation formulae which are widely accepted as applicable to this region including some developed specifically by Chilean seismic experts. Based on the design parameters developed from these studies the Chacayes civil structures were not damaged during the 2010 earthquake event.

Another important aspect of the basic and definition design was the sediment management aspects of the project. The sediment being carried by the Cachapoal River was estimates based on field measurements carried out over a range of discharges. The sediment load in the river has to be flushed out through the gated spillways in the diversion during floods or flushed through the sediment sluice during periods of lower discharge. Finer material that enters the intake will travel through the desanders in which the coarser fraction will settle out. The material finer than 0.25 mm will be transported to the regulation pond where additional material will settle out. The very finest material will pass through the regulating pond and reach the generating units. To guard against damage the units have a ceramic coating to minimize the wear and tear on the blades.

Hatch considered the installation of dredging equipment in the regulation pond to maintain the storage. An optimization study was carried out to balance the costs of buying and operating the dredging equipment versus the capital cost of the desanders to limit the sediment reaching the regulation pond and having to dredge it out.

Another technical challenge was the design of the diversion structures and more specifically the design of the sediment sluicing arrangement for the two intakes. PHC recognized this as a key activity and undertook the construction and testing of two physical hydraulic models in a laboratory near Santiago. This work began prior to the award of the construction contract and the models were maintained to allow the contractor to make use of the models in carrying out the construction design.

The main issue that was examined was the flow through both intake structures during flood events and the operation of the dividing walls between the main spillway sections and the sediment sluice adjacent to the intakes. Refinements to the upstream dividing wall in the Cipreses diversion included an extension of the wall to improve the alignment of the flow. In the Chacayes intake the divide wall was lowered to improve the flow distribution entering the four intake bays.

The diversion conveyance system is composed of a mixture of trapezoidal and rectangular canals, culverts and tunnels which is approximately 7600 m from the downstream end of the desander to the entrance to the Chupallal Regulation Pond. The rated discharge in the conveyance system is 72.5 m3/s. This created as concern in the case where there was a sudden shutdown of the units at the powerhouse due to such things as the

Construction of the hydro power plant

loss of the transmission line. The water that was already in the canal could not be stopped so it would have to be stored in the regulation pond or spilled.

To allow for this spill an emergency spillway was added at the lower end of the canal where it crossed the Tinajon Quebrada. A free overflow spillway was considered but the width of the spillway to control the rise in water level would be excessive. It was decided to construct a siphon spillway. This spillway has a conduit which goes over the side of the canal such that when the water level in the canal rises a specified amount it primes the siphon which give a greater discharge than a free overflow spillway. This spillway was tested after construction was complete and it was found to have significant scour downstream if the full powerhouse flow was discharges so an operating strategy was developed by PHC to limit the flow through the spillway by reducing the flow at the intake should a sudden station shutdown occur.

To accomplish this ambitious project, a number of innovative ideas were adopted by the project participates. A feasibility level study was undertaken in 2005– 2006 to establish the basic concepts for the projects in the valley. This was followed up with Basic Engineering to define the project structures and sizing undertaken by Hatch from 2006 – 2007. This resulted in 60 to 70 drawings that were used for the preparation of the Environmental Impact Assessment (EIA). This level of design could also have been used to prepare an Engineering, Procurement and Construction Management (EPCM) tender, however, an innovative idea from PHC let them to ask Hatch to conduct a Definition Engineering level of design to lock down project arrangement before going out to tender. This work resulted in approximately 180 drawings and reduced the time for tendering as bidders did not have to undertake design of project. In addition the information was used to refine the EIA submission.

Meet Clients Schedule

In 2006 PHC requested technical and financial proposals to select the consultant that would undertake the Basic and Definition design for the Chacayes project. Hatch was judged to offer the best combination of technical skills and cost of service of the consultants who participated in the competition.

The design that was developed by Hatch during the Definition design phase formed the basis for tendering of the EPC contract for the project. The EPC contractor made changes to the arrangement / design, but the overall concept developed by Hatch was carried through to implementation. Therefore the work met the overall goals of the Owner which was to take the design to a higher (definition) level prior to award of the EPC contract, so that the resulting project would be closely aligned with their expectations.

The Owner was satisfied with the work as indicated by the fact that they awarded a contract for Owner's Engineer services to Hatch on a sole-source basis to review the final design of the Chacayes project prepared by the EPC contractor.

The Owner also retained Hatch on a sole source basis to provide the Basic and Definition design services for the Nido de Aguilas hydroelectric project located upstream of the Chacayes Project on the Cachapoal River.

The schedule for the Basic and Definition phases called for the completion of the design and specifications in approximately 40 weeks. Slow progress in the geotechnical field work by the investigation contractor and additional effort to address regulatory requirements pushed the completion date out to approximately 50 weeks. The scope of the services was modified through change orders which were agreed by the Client to address technical issues identified during the execution of the work.

The project went into operation in October 2011 and has been successfully generating revenue for the Owner since that time. Hatch was also recently selected by the Owner to carry out an optimization study of the conjunctive operation of the Chacayes Project with the downstream Coya project, owned by PHC, and the hydroelectric projects owned by Endesa. Following on from this the Owner has the option to request Hatch set up an hourly model for the Cachapoal water resource system to assist in the long term and short term operations of the projects.