

BEYOND THE NORM



ECUADOR OIL PIPELINE RIVER CROSSINGS

The route traversed by the 500 kilometre, 24-36" OCP oil pipeline is daunting. Commencing in the jungles of the Amazon River basin, the route tortuously winds through narrow river valleys fringed by raging rivers and steep, unstable mountain slopes to reach an oxygen-depleted elevation of 4000 metres near Quito from whence it follows a knife-edged ridge for 8 kilometres before plunging to the Pacific Ocean.

In March 1987, a 6.9 magnitude earthquake, following a month of torrential rains, caused ruptures and damage to 70 kilometres of the existing parallel SOTE oil pipeline, the most extensive pipeline failure ever in the world. In June 2001, landslides caused 46 fatalities in the Rio Papallacta Valley and spillage of the SOTE oil line into the Rio.

Relative Magnitude of May 5, 2003 Rio Reventador Flood

1:100 Year, Standard Alberta Criteria

1:1000 Year, OCP Criteria

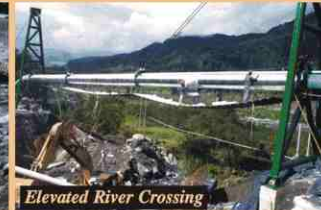
May 5, 2003 Equivalent Peak

On November 3, 2002, Volcan Reventador, in a massive eruption, transformed steep stable mountainous rivers to moonscapes of erosion and deposition. Then on May 5, 2003, after construction of the OCP line was nearly completed, a 100 year rainfall mobilized the newly deposited material from the upper slopes of the volcano generating a combined water/debris flow nearly 10 times the 1000 year flood.

In the Rio Papallacta valley, the landslides necessitated a significant realignment of OCP resulting in 11 river sections in less than 14 kilometres. In the shadow of the active volcano, fast-tracked redesigns and reconstruction of the river crossings were required to ensure completion of the OCP pipeline on schedule.

The combination of design, scheduling, logistical and construction challenges faced by the Owner, EPC Contractor and River Engineering Consultant required innovative solutions, truly "Beyond the Norm".

Impact of Debris Flow on SOTE



Oleoducto de
Crudos Pesados
Owner



Techint
EPC Contractor



Hydroconsult

Hydroconsult
River Crossing Consultant



Oleoducto de Crudos Pesados

Firm: Hydroconsult

Project: Oleoducto de Crudos Pesados

Client: Techint, Argentina, SA

Location: Ecuador, South America

Owner: Oleoducto de Crudos Pesados;
Craig Day, Tim Zboya

EPC Contractor: Techint; Ron Curle,
Ignacio Viboud

The US\$1 billion, 500 km, 24"-36" OCP export oil pipeline in Ecuador winds its way through some of the most rugged terrain imaginable anywhere in the world. In its route from the Amazon River basin, across the 4000 m high Andes to the Pacific Ocean, it crosses 70 major river crossings. These required practical, unique, innovative, and fast-tracked designs and construction techniques particularly in the Rio Papallacta and Rio Quijos valleys, which experienced major landslides and massive volcanic-generated debris flows during construction.

The integrated approach applied to route evaluation, design, construction, and operation will enhance the safe and sound operation of the line and yield long-term economic dividends to all Ecuadorians.



Judges' Comments:

"Often engineering is thought to be on large complex projects, however the OCP Pipeline challenge steps beyond the normal boundaries of engineering. The organization, risk, value, and benefit elements of this project are unique and require specialized engineering thinking — sometimes that which cannot be handled in a computer model."

"The demonstrated technical difficulty, innovation, and the benefit to society make this project #1. Extreme and dynamic project parameters were met in a challenging timeframe."

"The OCP Pipeline project was very complex and had a high level of risk. Hydroconsult was able to apply innovative solutions, managed the risk appropriately, and deliver the project on schedule."

1.0 THE PROJECT

The Oleoducto de Crudos Pesados (OCP) in Ecuador is a 500 km long, 24" – 36" heavy crude oil pipeline to transport up to 450,000 barrels per day from the jungles of the Amazon River basin across the Andes past Quito to an export terminal near Esmeraldas on the Pacific Ocean. Three stations are required to push the heavy crude, made pumpable via heating, to a peak elevation of 4000 m. Then on its drop from the Andes, pressure reducing stations and smaller pipe sizes are used to safely deliver the crude into the sea-level terminal.

The U.S. \$1.1 billion pipeline will more than double the crude oil exported from Ecuador. A further U.S. \$2.0 billion is expected to be invested in the field facilities to expand production and construct delivery lines to the OCP pipeline. The construction of the pipeline and field facilities is projected to result in a 3.5 to 4% national economic growth and generate more than 50,000 jobs during construction.

2.0 HYDROCONSULT'S ROLE

In its tortuous route up and down the Andes, the OCP crosses over 160 rivers ranging from several metres to more than 400 m in width. Detailed engineering designs were prepared for 70 crossings as well as 6 instream sections where the line is located immediately parallel to or in the riverbed. Five suspension bridges were constructed with the remainder of the river crossings buried.

TECHINT, a large Argentina based Contractor, was responsible for the design, construction and initial operation/maintenance of the line. The EPC role involved close coordination with OCP's Owners especially in developing

solutions to significant challenges that arose during construction.

"Hydroconsult was the principal engineer in designs and decisions associated with all river crossings. Hydroconsult completed numerous field visits to each of the engineered river crossings on the project. These field visits were followed up by post-construction visits to ensure the crossings had been installed as per design." (OCP Reference letter) TECHINT's Reference letter added that *"Hydroconsult was required to study, design and monitor the construction of an incredible array of works to accommodate the pipeline within the river systems of Ecuador."*

The design and construction challenges posed by the river crossings were unique, at times unforeseen and in the case of the aftermath of the eruption of the Volcan Reventador, *"Beyond the Norm."*

3.0 DESIGN AND CONSTRUCTION

3.1 History of the SOTE Line

In 1972 the first crude oil pipeline was completed from the Orient to the Pacific Coast. SOTE follows the Rio Quijos and Papallacta valleys in its eastern approach to the peak of the Andes. SOTE's operational performance for 30 years was an important consideration in the route selection and design of the OCP line. But as detailed later, even its history was not an adequate mirror for the challenges to be faced by OCP.

In March 1987 earthquakes of magnitude 6.1 and 6.9 occurred along the SOTE alignment in the Quijos/Reventador area. Preceding rains of 600 mm resulted in massive slope failures and landslides, some of which entirely blocked the 300 m wide Rio Quijos for short periods of

time. The subsequent overtopping and washout of the river blockages caused devastating flooding and major river changes downstream. Nearly 70 km of the SOTE line was ruptured and destroyed primarily at river crossings and where the line was close to and parallel to the Rio Quijos.

Five months were required to repair the line representing the most extensive naturally induced outage ever experienced with any pipeline in the world. The earthquake event also caused an estimated 1000 deaths and a total economic loss in excess of U.S. \$1.0 billion.

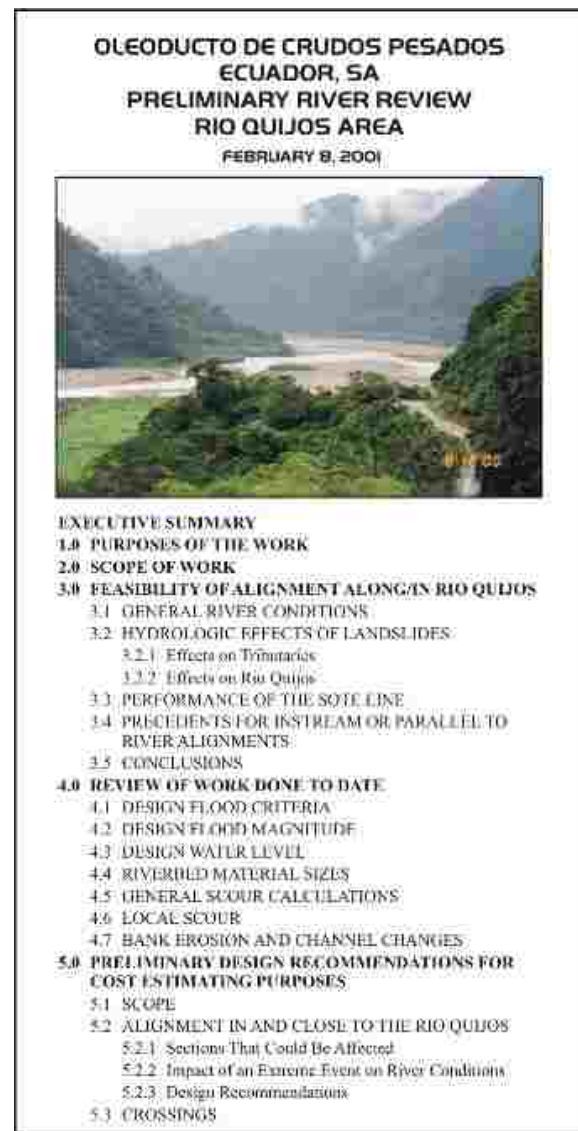


Trans-Ecuadorian pipeline (SOTE) severed by flood water, east bank of the Aguarco River. ("The March 5, 1987, Ecuador Earthquakes, Mass Wasting and Socioeconomic Effects". Natural Disaster Studies, National Research Council, 1991).

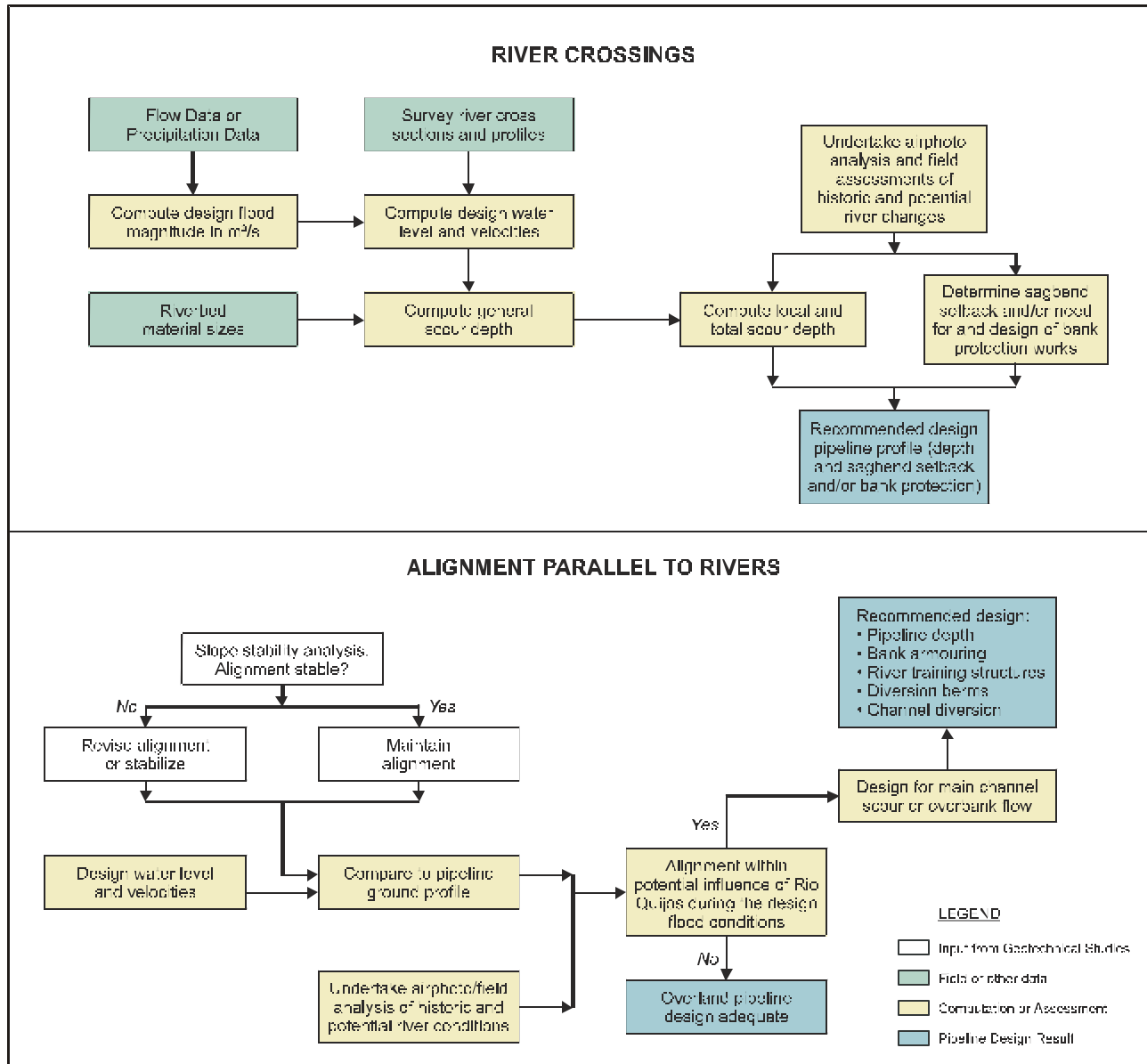
3.2 Parallel the SOTE line in the Reventador area and Quijos Valley?

To construct SOTE, a road was built to the Orient which has since become the main and essentially only highway to the oil field's center at Lago Agrio. Utilizing this existing infrastructure and pipeline corridor was an obvious first choice for OCP for economical and environmental reasons – away from the Quijos valley, the terrain is extremely rugged and virtually non-accessible.

Hydroconsult's first assignment in late 2000 as part of the route selection process was to assess the feasibility and soundness of the design along the Rio Quijos and across the rivers at the base of Volcan Reventador. From Hydroconsult's assessment of the impact of the 1987 event, a design and construction approach was developed in early 2001.



Hydroconsult's Alignment Review in Rio Quijos Valley.



Overall Design Approach.

Deep burial, up to 6 m of cover, was recommended for segments where the OCP would be located within the potential zone of influence of a 1000 year flood on the Rio Quijos or where blockage and subsequent flash floods would cause inundation and channel changes upstream and downstream respectively. SOTE's experience with buried and elevated

river crossings was also evaluated in selecting the mode and design criteria of the river crossings.

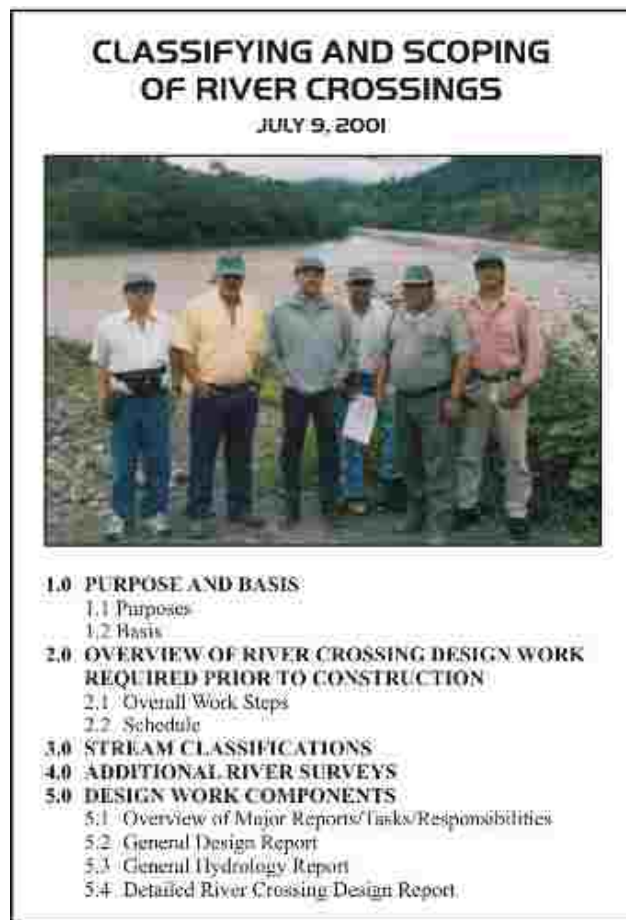
This assessment combined with OCP's and TECHINT's pipeline, economic and environmental considerations, resulted in selecting an alignment essentially paralleling the

SOTE line in the Reventador, Rio Quijos and Rio Papallacta valleys.

3.3 Design and Construction Steps

Utilizing Ecuadorian hydrologic and river engineering expertise for the individual river crossing surveys, assessments, designs and government submittals was considered essential.

- classify the crossings as Major, Minor and Typical. The mode, buried or elevated, was also recommended at this time.
- scope out the required detailed work to be done by the local Ecuadorian hydrologic firm,
- review the results of the detailed work.



Hydroconsult's Scoping Report following a Multi-discipline field review of all the crossings.

Consequently Hydroconsult was tasked by TECHINT to:

- field review all significant river crossings with their routing, pipeline design and construction specialists,



Guards are a common necessity in eastern Ecuador near the Columbian border.

Pipeline bending and excavation requirements, particularly at steep banks next to river crossings, required an interactive review and design and construction approach by TECHINT and Hydroconsult. The right bank at Rio Salado illustrates this:

- the extent of the pipeline into the steep and high bank was recommended by Hydroconsult following field assessments and a review of the impact of the 1987 events,
- from this TECHINT developed pipeline profiles and excavation depths (up to 10 m), for various field or factory bends,
- recognizing schedule implications – factory bends require months for delivery – and construction practicalities, a design with the sagbend (the point where the pipeline starts

to rise) within the zone of influence of the river was selected.

- Hydroconsult then designed a gabion-armored dike to protect the sagbend.
- due to high flows during construction, the gabion protection was modified to a steel pipe/plate and rock riprap structure to facilitate instream construction. Hydroconsult reviewed the design changes and subsequent as-built conditions.

3.4 Alignment and Design in Rio Papallacta Valley

In June 2001 heavy rains triggered debris flows in several relatively small tributaries to the Rio Papallacta. Residents of two homes provided overnight shelter to bus passengers stranded by the slides. In the night, a massive debris flow into the homes resulted in the death of 46 people. The SOTE line was ruptured in several locations.



Fatal Slide Area.

As a result of these events, TECHINT's geotechnical and geologic specialists field reviewed a 15-km long segment in detail. The steep slopes precluded alignments away outside the influence of the Rio.



Rio Papallacta, Field Assessment Methodology

The initial OCP alignment involved three (3) crossings of the Rio Papallacta. The final route selected required seven (7) crossings and three (3) instream sections where the line was located parallel to and within the influence of the Rio.



Instream section in upper reaches of Rio Papallacta. Pipeline protected by cover depth and riprap.

In reviewing the impact of the June 2001 slides, which triggered short term blockage of the Rio Papallacta, Hydroconsult recognized the general natural stability of the steep massive boulder-paved streambeds. The boulders, transported and deposited into the river valleys by extreme events, like March 1987 and June 2001, dissipate the high energy inherent in these mountainous streams. This delicate balance between the force of the river and the resistance

provided by the large boulders can be upset by construction due to the impact of excavation, blasting and backfilling.



Boulder sizes in Rio Papallacta.

Recognizing this, Hydroconsult:

- developed excavation and backfilling procedures and specifications for different bed material conditions,
- field-reviewed the as-built conditions of the pipe profile and the restoration of the streambed and banks and made recommendations for modifications or additional work where necessary.

3.5 November 3, 2002 Eruption of Reventador Volcano

The OCP alignment passes within 10 km of the Volcano and crosses the Azuela, Reventador, Montana, Marker and Piedra Fina Rios which drain its eastern flank. The November 3 eruption blanketed Quito in volcanic ash forcing an almost total shutdown of the capital city for several days. The eruption resulted in massive lahar flows (a mixture of ash, lava, rock and water), primarily in the Rio Montana and Marker watersheds. Montana, a steep stable mountainous river at its pipeline alignment, was transformed into a virtual moonscape due to

erosion or deposition across its alluvial delta into the Rio Quijos.



Rio Montana, Before the Eruption.



Rio Montana, After the Eruption.

In the area of the Marker River crossing, the main highway bridge was completely buried by the deposited material.



Rio Marker after the Eruption. Bridge deck below the concrete abutment marker.

A fast-tracked re-assessment of the alignment and design of the OCP – the pipeline already welded up in preparation for its burial was damaged by the impact of the debris flow – was necessary.

Burial depth criteria were established by Hydroconsult to ensure the OCP line was placed a minimum of 3 metres into the pre-eruption ground elevation. This provided the necessary pipeline cover in the event of scour – zones of deposition and scour in an alluvial fan are variable from event to event and even within the timeframe of a single event – but excavation depths up to 10 m required multiple passes of large excavation equipment.



Rio Marker, Excavation for the Pipeline Ditch.

3.6 Impact of May 5, 2003 Rains on Rio Reventador

The influence of the November 3, 2002 eruption on Rio Reventador at the OCP crossing was truly *"Beyond the Norm"*. It was not affected by the initial eruption however a moderate rain in December 2002 and 200 mm in 5 hours on May 5, 2003, nearly a 100 year event, revealed the long lasting impacts of the material deposited by the Volcano. The rains mobilized the volcanic-deposited material at the top of its

watershed and transported it to the OCP alignment. The moderate rains in December 2002, moved -3 m sized boulders which destroyed several pile supports for the adjacent elevated SOTE line. The OCP design was reviewed in January 2003 and the Rio Reventador crossing was constructed in April 2003.



Construction of Rio Reventador crossing complicated by proximity of existing high pressure lines.



Erosion of Main Highway as a result of overflow from Rio Reventador. Note man at left for scale.

The May 5, 2003 lahar flows on Rio Reventador resulted in the complete disappearance of the highway bridge, the erosion of a 30 m deep canyon into the highway approaching the bridge

and the inundation and severing of the elevated SOTE line. Initial inspection and assessment of the newly completed OCP, located immediately upstream of the SOTE line, indicated 6m of deposition on the buried line and minor exposure of the line up its right bank. However a subsequent inspection of the line revealed severe damage to the pipeline near the right bank.



Rio Reventador, Damaged OCP Pipe due to May 5, 2003 Flood

Hydroconsult attributed the pipe damage to extreme initial scour, created by flow patterns generated by a sharp, high rock point upstream. This theory was supported by no evidence of pipe exposure in the remainder of the crossing. In conjunction with TECHINT and OCP, Hydroconsult evaluated alternative designs and alignments from technical and construction viewpoints – the proximity of the SOTE oil line and a gas pipeline made construction in this steep walled valley very difficult.

The uncertainties associated with the influence of the rock point on scour resulted in a realignment and reconstruction of OCP downstream. The redesign was done concurrent with construction in order to meet the overall schedule of the OCP line.

4.0 MONITORING AND MAINTENANCE

An integral component of the sound operations of major pipelines is the development of site specific monitoring and maintenance plans which recognize the uniqueness of the river crossings. Hydroconsult is presently developing detailed monitoring plans for about 50 major river crossings.

5.0 CLOSURE

The OCP line faced numerous topographic and geologic challenges all within a fast-tracked EPC environment. The history of the SOTE line and particularly the large-scale failures it experienced in 1987 required innovative river designs for the OCP. The fatal landslides and failures in June 2001 required numerous additional river crossings and instream sections in the Rio Papallacta valley. Then the unprecedented magnitude of the eruption of Volcan Reventador, near the end of construction, generated unimaginable debris flows, fourteen times the magnitude of a typical design flood.

“Hydroconsult has provided solid technical and innovative solutions to the numerous engineered stream and rivers on the OCP project” (OCP’s Reference letter) and developed “unique and practical solutions for the river engineering in a very complex project within a fast-track EPC program” (TECHINT’s Reference letter).

The OCP line is a key component of the economic growth necessary to improve the living conditions in Ecuador. The river crossings were one of many challenges faced by TECHINT and OCP. The occurrence of major landslides and a volcanic eruption during construction magnified those challenges especially within the framework of a fast

tracked EPC environment. Hydroconsult was honoured to be entrusted to assist OCP and TECHINT in solving challenges, *"Beyond the Norm"*.



Hydroconsults "Local Expert", a resident on the banks of the Rio Quijos for over 80 years.