INTERNATIONAL COURT OF JUSTICE

DISPUTE OVER THE STATUS AND USE OF THE WATERS OF THE SILALA

(CHILE v. BOLIVIA)

REJOINDER OF THE PLURINATIONAL STATE OF BOLIVIA

ANNEXES 19 TO 23.2

VOLUME 2 OF 6

15 MAY 2019

LIST OF ANNEXES TO THE REJOINDER OF THE PLURINATIONAL STATE OF BOLIVIA

VOLUME 2 OF 6

Annex 19

Minutes of the XIV Meeting of the Bolivia-Chile Political Consultation Mechanism, 5 and 6 October 2005

(Original in Spanish, English Translation)

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REPUBLICA DE BOLIVIA
MINISTERIO DE RELACIONES EXTERIORES Y CULTO

NOTA INTERNA Nº 270/2005
DIRECCIÓN DE AMERICA

PARA : Dra. Yovanka Oliden Tapia
DIRECTORA GENERAL DE ASUNTOS JURIDICOS

DE : MP. Marco Antonio Vidaurre Noriega
DIRECTOR GENERAL DE RELACIONES BILATERALES

REF. : Remisión de Acta y Notas Reversales

FECHA : La Paz, 11 de octubre de 2005

Señora Directora General:

Tengo a bien remitir para fines consiguientes, el Acta de la XIV Reunión del Mecanismo de Consultas Políticas Bolivia - Chile, realizada los días 5 y 6 de octubre de 2005, en la ciudad de Iquique, República de Chile.

Asimismo, las Notas Reversales que intercambiaron los Vicecancilleres de Bolivia y Chile en la misma fecha, por las cuales ambos Gobiernos suscribieron el Acuerdo para permitir la actividad remunerada de personas dependientes del personal consular, administrativo y técnico que presta servicios en las respectivas representaciones consulares en Bolivia y Chile.

Con este motivo, reitero a usted las seguridades de mi distinguida consideración.

DIRECCION GENERAL DE ASUNTOS JURIDICOS
952
14 OCT. 2005
La Paz - Bolivia
MIN. RELACIONES EXTERIORES Y CULTO

M.P. Marco Antonio Vidaurre Noriega
DIRECTOR GENERAL
DE RELACIONES BILATERALES
Min. Relaciones Exteriores y Culto

Edgar Pinto Tapia
VICEMINISTRO DE RELACIONES EXTERIORES Y CULTO a.i.

YAN
Adj / lo citado

Lic. M. Paredes

Republic of Bolivia
Ministry of Foreign Affairs and Worship

Internal Note N° 270/2005
America Directorate

For	:	Dr. Yovanka Oliden Tapia General Director of Legal Affairs
From	:	Minister, 1st Class Marco Antonio Vidaurre Noriega General Director of Bilateral Relations
Reference	:	Remission of Minutes and Diplomatic Notes
Date	:	La Paz, 11 October 2005

Madam General Director:

I kindly refer for consequent purposes, the Minutes of the XIV Meeting of the Bolivia-Chile Political Consultation Mechanism, held on 5 and 6 October 2005, in the city of Iquique, Republic of Chile.

Likewise, the Diplomatic Notes exchanged by the Vice-Chancellors of Bolivia and Chile on the same date, whereby both Governments signed the Agreement to allow the remunerated activity of dependents of the consular, administrative and technical staff that provides services in the respective consular representations in Bolivia and Chile.

With this motive, I reiterate to you the assurances of my distinguished consideration.

(Signature)
Minister, 1st Class Marco Antonio Vidaurre Noriega
GENERAL DIRECTOR OF BILATERAL RELATIONS
Ministry of Foreign Affairs and Worship

ACTA DE LA XIV REUNION DEL MECANISMO DE CONSULTAS POLITICAS CHILE - BOLIVIA

En esta fecha se celebró la XIV Reunión del Mecanismo de Consultas Políticas Chile Bolivia, presidida por el Subsecretario de Relaciones Exteriores de Chile, Sr. Cristián Barros y el Vicecanciller de Bolivia Sr. Hernando Velasco. Esta reunión estuvo precedida por una Reunión del Grupo de Asuntos Bilaterales, efectuada en la misma ciudad en la víspera.

La nómina de las delegaciones y la agenda del Mecanismo de Consultas Políticas se anexan a la presente Acta.

La Delegación chilena dio la bienvenida a la Delegación boliviana y destacó el interés del Gobierno de Chile por avanzar en el fortalecimiento de la relación bilateral de manera de dejar una buena base para los próximos gobiernos de ambos países.

La Delegación boliviana agradeció la bienvenida, destacando las recientes reuniones bilaterales a nivel de Presidentes y de Ministros, y la coincidencia con Chile en cuanto a sentar las bases de la relación entre ambos países para los futuros gobiernos.

Habiéndose acordado el programa y la metodología de trabajo, se procedió al tratamiento de los temas de la agenda.

Tema Silala

En relación a este tema ambas delegaciones intercambiaron ideas acerca de cómo avanzar en materia de recursos hídricos compartidos, los estudios técnicos programados sobre el Silala que se precisarán a la brevedad, y acerca del esquema mediante el cual se acordará su aprovechamiento en mutuo beneficio.

Ambas Delegaciones coincidieron en el interés por encontrar un marco satisfactorio para ambos países sobre este tema dentro de un espíritu amistoso, en el contexto de lo conversado por los Presidentes de ambos países.

Los resultados de los estudios programados deberán constituir un elemento importante para los procesos de decisión gubernamental y para una solución definitiva del tema.

Libre tránsito

Habilitación del Puerto de Iquique:

Minutes of the XIV Meeting of the Bolivia-Chile Political Consultation Mechanism

On this date the XIV Meeting of the Chile-Bolivia Political Consultation Mechanism was held, chaired by the Undersecretary of Foreign Affairs of Chile, Mr. Cristian Barros and the Vice-Chancellor of Bolivia Mr. Hernando Velasco. This meeting was preceded by a Meeting of the Bilateral Affairs Group, held in the same city on the eve.

The list of delegations and the agenda of the Political Consultation Mechanism are attached to this Minutes.

The Chilean Delegation welcomed the Bolivian Delegation and highlighted the interest of the Government of Chile to move forward in the strengthening of the bilateral relationship in order to leave a good basis for the next governments of both countries.

The Bolivian Delegation thanked the welcome, highlighting the recent bilateral meetings at the level of presidents and ministers, and the coincidence with Chile in laying the foundations of the relationship between both countries for future governments.

Having agreed on the program and the work methodology, the topics on the agenda were addressed.

Silala Issue
In relation to this issue, both delegations exchanged ideas about how to move forward in the area of shared water resources, the technical studies scheduled on the Silala that will be required as soon as possible, and about the scheme by which their use will be agreed upon for mutual benefit.

Both Delegations agreed on the interest to find a satisfactory framework for both countries on this issue in a friendly spirit, in the context of what was discussed by the Presidents of both countries.

The results of the programmed studies should constitute an important element for the governmental decision processes and for a definitive solution of the issue.

Free Transit
Enabling the Port of Iquique:

La Delegación boliviana reiteró su interés en que el perfeccionamiento de la habilitación del Puerto de Iquique al régimen de libre tránsito se pueda implementar a la brevedad posible. La Delegación chilena reiteró la voluntad de su Gobierno de habilitarlo al régimen de libre transito. Ambas Delegaciones destacaron el inicio de un ejercicio aduanero, continuo y prolongado, que como parte del Plan Piloto se convino realizar en dicho puerto, en concordancia a los acuerdos alcanzados en las V y VI Reuniones del Grupo de Trabajo de Libre Tránsito y la coordinación realizada por las Aduanas de ambos países.

Para concretar la habilitación de Iquique, la Delegación chilena propuso establecer un cronograma conducente a ese fin que permita resolver con antelación las situaciones complejas que presenta el proceso a nivel interno. La Delegación boliviana expresó su interés por conocer el alcance y contenido de dicho cronograma a la brevedad posible, entendiendo que el mismo conducirá a la plena habilitación del Puerto de Iquique.

La Delegación chilena destacó asimismo, la necesidad de preservar el derecho de opción para el usuario boliviano en cuanto a poder acogerse a la modalidad de transporte en tránsito hacia terceros países prevista en el Acuerdo sobre Transporte Internacional Terrestre de los países del Cono Sur, ATIT.

Por su parte, la Delegación boliviana expresó que el perfeccionamiento de la habilitación del Puerto de Iquique deberá regirse por el Tratado de 1904 y los Acuerdos complementarios que establecen el régimen de libre tránsito y la presencia del Agente Aduanero Boliviano en los puertos chilenos debidamente habilitados. Asimismo, reiteró que la modalidad de transporte prevista en el ATIT es un instrumento compatible con dicho régimen.

Libre tránsito de la carga boliviana:

Ambas delegaciones concordaron en la conveniencia de realizar una nueva reunión del Grupo de Trabajo sobre Libre Tránsito, en la ciudad de Arica, en lo posible dentro del mes de noviembre próximo, a fin de tratar distintos asuntos relacionados con esta materia. La Delegación de Bolivia destacó la conveniencia de establecer en el seno de ese Grupo un Mecanismo de Solución de Controversias. Ambas Delegaciones coincidieron en incluir en la agenda de la reunión la renovación del mandato a la Comisión ad-hoc para la elaboración del nuevo Manual Operativo y el tratamiento de las cargas IMO.

Integración Física

Se acordó que este tema y el de la habilitación del Hito LX, sean tratados en la próxima reunión del Comité de Fronteras programada para los días 17 y 18 de octubre en La Paz.

La Delegación chilena presentará en dicha reunión una evaluación acerca del funcionamiento del ferrocarril Arica - La Paz.

The Bolivian Delegation reiterated its interest that the improvement of the enabling of the Iquique Port for the free transit regime could be implemented as soon as possible. The Chilean Delegation reiterated the will of its Government to enable it for the free transit regime. Both Delegations highlighted the beginning of a customs exercise, continuous and prolonged, which as part of the Pilot Plan was agreed to be carried out in said port, in accordance with the agreements reached in the V and VI Meetings of the Free Transit Working Group and the coordination carried out by the Customs of both countries.

To establish the enabling of Iquique, the Chilean Delegation proposed to establish a timetable conducive to this purpose that allows resolving in advance the complex situations that the process presents internally. The Bolivian Delegation expressed its interest in knowing the scope and content of said timetable as soon as possible, understanding that it will lead to the full enabling of the Iquique Port.

The Chilean Delegation also stressed the need to preserve the right of option for the Bolivian user to be able to benefit from the mode of transport in transit to third countries provided for in the Agreement on International Terrestrial Transport of the Countries of the Southern Cone (ATIT by its acronym in Spanish).

For its part, the Bolivian Delegation expressed that the improvement of the enabling of the Port of Iquique should be governed by the 1904 Treaty and the Complementary Agreements that establish the free transit regime and the presence of the Bolivian Customs Agent in the Chilean ports duly enabled. Likewise, it was reiterated that the transportation modality foreseen in the ATIT is an instrument compatible with said regime.

Free transit of the Bolivian cargo:

Both Delegations agreed on the convenience of holding a new meeting of the Working Group on Free Transit, in the city of Arica, as much as possible within the month of November, in order to address various issues related to this matter. The Delegation of Bolivia stressed the convenience of establishing a Dispute Resolution Mechanism within that Group. Both Delegations agreed to include in the agenda of the meeting the renewal of the mandate to the ad-hoc Commission for the preparation of the new Operating Manual and the treatment of IMO cargo.

Physical Integration

It was agreed that this issue and that of the enabling of Milestone LX, be addressed at the next meeting of the Borders Committee scheduled for October 17th and 18th in La Paz.

The Chilean Delegation will present in said meeting an assessment regarding the operation of the Arica-La Paz railway.

Facilitación Fronteriza

Plan Piloto para la circulación de turistas con Cédula de Identidad:

Ambas Delegaciones coincidieron en la necesidad de formalizar bilateralmente la prórroga indefinida de la utilización de la Cédula de Identidad para la circulación de turistas entre ambos países, acordada por los Presidentes de Bolivia y Chile en la Cumbre Sudamericana de Naciones. Las Delegaciones concordaron en que dicha formalización se haga efectiva de la manera más expedita posible.

La evaluación de esta iniciativa prevista, en el acta de la I Reunión del Grupo Bilateral Chile – Bolivia, se realizará en la próxima reunión del Comité de Fronteras.

Turismo

Ambas Delegaciones acordaron realizar un Encuentro de Operadores Turísticos, con la participación de autoridades de turismo, transporte y de obras públicas de ambos países, en la ciudad de San Pedro de Atacama, los días 17 y 18 de noviembre, cuyo temario será detallado en la próxima reunión del Comité de Fronteras.

Tarjeta Única Migratoria:

Ambas Delegaciones acordaron continuar tratando este tema en la próxima reunión del Comité de Fronteras.

Controles Integrados de Frontera:

Ambas Delegaciones informaron sobre el estado de aprobación legislativa del Convenio de Controles Integrados en sus respectivos países.

La Delegación de Bolivia reiteró su interés en la realización del ejercicio de control integrado de larga duración, que propuso en la Reunión para la Profundización del Acuerdo de Complementación ACE 22, a efectuarse en los meses de octubre, noviembre y diciembre del presente año, de manera simultánea en los pasos Visviri - Charaña, Chungara -Tambo Quemado, Colchane - Pisiga y Ollague - Avaroa. La Delegación chilena concordó con la importancia realizar ejercicios de larga duración, por lo que propone efectuar ejercicios prolongados de dos semanas cada uno, en los distintos pasos en lo que resta de este año, con el fin de probar la eficiencia práctica del sistema.

Asuntos Consulares:

En cuanto a la rebaja de aranceles por visas, la Delegación boliviana informó que existen inconvenientes legales para que se rebajen los aranceles consulares en

Border Facilitation

Pilot Plan for the circulation of tourists with Identity Card:

Both Delegations agreed on the need to formalize bilaterally the indefinite extension of the use of the Identity Card for the circulation of tourists between both countries, agreed by the Presidents of Bolivia and Chile at the South American Summit of Nations. The Delegations agreed that such formalization should take effect as expeditiously as possible.

The assessment of this planned initiative, in the minutes of the First Meeting of the Chile-Bolivia Bilateral Group, will take place at the next meeting of the Borders Committee.

Tourism

Both Delegations agreed to hold an Meeting of Tour Operators, with the participation of tourism, transport and public works authorities of both countries, in the city of San Pedro de Atacama, on November 17th and 18th, whose agenda will be detailed in the next meeting of the Borders Committee.

Single Migratory Card:

Both Delegations agreed to continue discussing this issue at the next meeting of the Boards Committee.

Integrated Border Controls:

Both Delegations reported on the status of the legislative approval of the Integrated Controls Agreement in their respective countries.

The Delegation of Bolivia reiterated its interest in carrying out the long-term integrated control exercise, which it proposed at the Meeting for the Deepening of the [Economic] Complementation Agreement (ACE 22), to be carried out in the months of October, November and December of this year, simultaneously in the crossing points of Visviri-Charaña, Chungara-Tambo Quemado, Colchane-Pisiga and Ollagüe-Avaroa. The Chilean Delegation agreed with the importance of performing long-term exercises, so it proposes to carry out prolonged exercises of two weeks each, in the different crossing points in the remainder of this year, in order to test the practical efficiency of the system.

Consular Affairs:

Regarding the reduction of tariffs for visas, the Bolivian Delegation informed that there are legal disadvantages for the reduction of consular fees in the los trámites de legalización de documentos chilenos ya legalizados por los Consulados bolivianos. Este tema será visto en el Comité de Fronteras.

Asimismo, la Delegación boliviana manifestó su disposición a analizar los mecanismos que permitan la rebaja de aranceles por visas para el caso de estudiantes.

Cooperación Fronteriza

Vigilancia Fronteriza:

En relación a la cooperación sobre vigilancia fronteriza, ambas Delegaciones convinieron en que este tema sea visto en el próximo Comité de Fronteras.

La Delegación de Bolivia informó que ya ha sido nombrada la autoridad competente en materia de lucha contra el narcotráfico y que va a proponer una fecha para realizar la VII Reunión de la Comisión Mixta del Acuerdo sobre Control, Fiscalización y Represión del Tráfico Ilícito de Estupefacientes y Sustancias Sicotrópicas y Productos Químicos Esenciales y Precursores.

Desarrollo Fronterizo

Cooperación entre comunidades fronterizas:

Ambas Delegaciones tomaron conocimiento de que se realizaron los contactos preliminares entre representantes de fondos de inversión social a objeto de establecer una agenda de cooperación en el ámbito de los municipios y comunidades fronterizas.

Temas de Salud:

La Delegación chilena anunció que próximamente visitará Bolivia una misión técnica para explicar el avance del Programa de Pasantías del Ministerio de Salud para profesionales bolivianos del área.

Cooperación en Educación, Cultura, Ciencia y Tecnología

Las Delegaciones de Chile y Bolivia manifestaron su satisfacción y conformidad con los acuerdos alcanzados en la Reunión Técnica de Educación, celebrada en la ciudad de La Paz los días 26 y 27 de septiembre del presente año, con ocasión de la visita del Ministro de Educación de Chile, Sergio Bitar.

procedures for legalization of Chilean documents already legalized by the Bolivian Consulates. This issue will be seen in the Borders Committee.

Likewise, the Bolivian Delegation expressed its willingness to analyze the mechanisms that allow the reduction of tariffs for visas for students.

Border Cooperation

Border Surveillance:

In relation to cooperation on border surveillance, both delegations agreed that this issue be seen in the next Border Committee.

The Delegation of Bolivia informed that it has already been appointed the competent authority in the fight against drug trafficking and that it will propose a date to hold the VII Meeting of the Joint Commission of the Agreement on Control, Oversight and Suppression of Illicit Traffic in Narcotic Drugs and Psychotropic Substances and Essential Chemicals and Precursors.

Border Development

Cooperation between border communities:

Both Delegations learned that preliminary contacts were made between representatives of social investment funds in order to establish a cooperation agenda in the area of municipalities and border communities.

Health Issues:

The Chilean Delegation announced that Bolivia will soon visit a technical mission to explain the progress of the Ministry of Health's Internship Program for Bolivian professionals in the area.

Cooperation in Education, Culture, Science and Technology

The Delegations of Chile and Bolivia expressed their satisfaction and approval with the agreements reached at the Technical Meeting on Education, held in the city of La Paz on 26 and 27 September of this year, on the occasion of the visit of the Minister of Education of Chile, Sergio Bitar.

En particular expresaron su satisfacción con el programa de trabajo acordado en materia de calidad de la educación; educación intercultural bilingüe; ciencia y tecnología y el programa de pasantías y becas.

De igual modo, ambas delegaciones expresaron su valoración y aliento a la iniciativa de historiadores bolivianos y chilenos por desarrollar el proyecto "Chile – Bolivia, Bolivia – Chile 1820-1930".

Convenio sobre Protección y Restitución de Bienes del Patrimonio Cultural:

Ambas Delegaciones acordaron efectuar una reunión técnica antes de fin de año para analizar este tema.

Cooperación e intercambio entre gestores culturales y/o directores de museos:

La Delegación chilena informó sobre la realización de un encuentro de Gestores Culturales de ambos países, el cual se realizaría en Santiago los días 2 y 3 de noviembre. La Delegación boliviana acordó respaldar dicha propuesta.

Programa de Trabajo para la Profundización del Acuerdo de Complementación Económica Nº 22, Promoción Comercial, Económica, de Inversiones y Turismo.

Los responsables de la Administración del ACE 22 de ambos países informaron de los resultados de la Reunión de Trabajo para profundizar este acuerdo efectuada en La Paz, Bolivia, los días 17 y 18 de agosto pasado.

Ambas Delegaciones se congratularon de los avances logrados para dicha profundización siguiendo el principio de una asimetría a favor de Bolivia complementada con acuerdos de cooperación para facilitar el desarrollo exportador boliviano.

Se tomó conocimiento de los acuerdos que se vienen adoptando a partir de la aplicación de un tratamiento asimétrico a favor de Bolivia, el cual, además del tema arancelario, incorporará previsiones para un tratamiento integral (sanitario, fitosanitario, de cooperación, promoción, normas técnicas y otras disciplinas que se acuerden) que promuevan efectivamente el incremento del comercio bilateral.

En esta oportunidad se avanzó en una negociación para la profundización del ACE 22 y se estableció la realización de una reunión el día 12 de octubre de 2005, en Arica, Chile, presidida por el Viceministro de Relaciones Económicas y Comercio Exterior de Bolivia y el Director General de Relaciones Económicas de Chile, con el objeto de avanzar en esta materia.

Educación, Cultura, Ciencia y Tecnología:

In particular, they expressed their satisfaction with the agreed work program on the quality of education; intercultural bilingual education; science and technology and the internships and scholarships program.

Likewise, both Delegations expressed their appreciation and encouragement to the initiative of Bolivian and Chilean historians to develop the “Chile-Bolivia, Bolivia-Chile 1820-1930” project.

Convention on Protection and Restitution of Cultural Heritage Assets:

Both Delegations agreed to hold a technical meeting before the end of the year in order to discuss this issue.

Cooperation and exchange between cultural managers and/or museum directors:

The Chilean Delegation reported on the holding of a meeting of Cultural Managers from both countries, which would be held in Santiago on November 2nd and 3rd. The Bolivian Delegation agreed to support this proposal.

Work Program for the Deepening of Economic Complementation Agreement N° 22, Commercial, Economic, Investment and Tourism Promotion.

Those responsible for the administration of the ACE 22 from both countries reported the results of the Work Meeting to deepen this agreement made in La Paz, Bolivia, on last August 17th and 18th.

Both Delegations welcomed the progress made in this deepening, following the principle of an asymmetry in favor of Bolivia, complemented with cooperation agreements in order to facilitate the Bolivian export development.

We learned about the agreements that have been adopted from the application of an asymmetric treatment in favor of Bolivia, which, in addition to the tariff issue, will incorporate provisions for a comprehensive treatment (sanitary, phytosanitary, cooperation, promotion, technical standards and other disciplines that are agreed) that effectively promotes the increase of the bilateral trade.

On this occasion, progress was made in a negotiation to deepen the ACE 22 and a meeting was set up on 12 October 2005, in Arica, Chile, chaired by the Vice-Minister of Economic Relations and Foreign Trade of Bolivia and the General Director of Economic Relations of Chile, with the aim of making progress in this matter.

Education, Culture, Science and Technology:

Las Partes decidieron constituir una Comisión Bilateral de Educación, Ciencia y Tecnología y una Comisión Bilateral de Cultura. Estas Comisiones serán presididas por autoridades de los Ministerios respectivos y la coordinación de sus actividades se realizará a través de sus Cancillerías.

Mecanismos Institucionales del dialogo bilateral:

Al mismo tiempo, las Partes resolvieron institucionalizar el Grupo de Trabajo sobre Asuntos Bilaterales, creado en junio pasado, en atención a la utilidad que éste ha revelado en el proceso de preparación del Mecanismo de Consultas Políticas establecido entre ambos países.

Convención del Derecho del Mar de Naciones Unidas:

En relación a este tema, teniendo en consideración el interés expresado por Bolivia sobre la participación en actividades de investigación científica oceánica, así como en excedentes en la Zona Económica Exclusiva de Chile, la Delegación chilena expresó su disposición para continuar efectuando las consultas internas y las evaluaciones correspondientes conforme a las disposiciones de dicha Convención.

Tema Marítimo:

En el espíritu de la Declaración de Algarve, de una agenda bilateral sin exclusiones, la Delegación chilena tomó nota de los planteamientos formulados por la Delegación de Bolivia respecto del tema marítimo y coincidió en la importancia de mantener esta materia en la visión de una agenda de futuro.

Otros Temas

Convenio en materia de Seguridad Social:

La Delegación chilena presentó para su análisis un proyecto de Acuerdo en materia de Seguridad Social.

Convenio que permite el Trabajo de los Cónyuges, del Personal Consular, Administrativo y Técnico:

Las Partes expresaron su complacencia por el intercambio de Notas que formaliza este Acuerdo.

Contactos interparlamentarios:

Ambas Delegaciones destacaron la importancia de la reunión de alto nivel que celebrarán Parlamentarios de Chile y Bolivia, durante el mes de noviembre próximo en Bolivia.

The Parties decided to establish a Bilateral Commission of Education, Science and Technology and a Bilateral Commission of Culture. These Commissions will be chaired by authorities of the respective Ministries and the coordination of their activities will be carried out through their Foreign Ministries.

Institutional Mechanisms of the bilateral dialogue:

At the same time, the Parties resolved to institutionalize the Working Group on Bilateral Affairs, created last June, in view of the usefulness that it has revealed in the process of preparing the Political Consultation Mechanism established between the two countries.

United Nations Convention on the Law of the Sea:

In relation to this subject, taking into consideration the interest expressed by Bolivia regarding participation in oceanic scientific research activities, as well as in surpluses in the Exclusive Economic Zone of Chile, the Chilean Delegation expressed its willingness to continue conducting internal consultations and the corresponding evaluations in accordance with the provisions of said Convention.

Maritime Issue:

In the spirit of the Algarve Declaration, of a bilateral agenda without exclusions, the Chilean Delegation took note of the proposals made by the Delegation of Bolivia regarding the maritime issue and agreed on the importance of maintaining this matter in the vision of a future agenda.

Other Issues

Agreement on Social Security:

The Chilean Delegation presented a draft agreement on Social Security for its analysis.

Agreement that allows the Work of the Spouses of the Consular, Administrative and Technical Personnel:

The Parties expressed their satisfaction with the exchange of Notes that formalizes this Agreement.

Interparliamentary Contacts:

Both Delegations highlighted the importance of the high-level meeting to be held by Parliamentarians from Chile and Bolivia, during the month of November in Bolivia.

Situación de los ex trabajadores de AADAA:

Los Directores Jurídicos de ambos países se reunirán en Bolivia en el marco del próximo Comité de Fronteras.

La presente Acta fue suscrita en la ciudad de Iquique, a los seis días del mes de octubre del año 2005.

POR CHILE

POR BOLIVIA

Situation of ex-workers of the Autonomous Administration of Customs Warehouses of Bolivia (AADAA for its acronym in Spanish):

The Legal Directors of both countries will meet in Bolivia in the framework of the next Borders Committee.

This Minute was signed in the city of Iquique, on the sixth day of the month of October of the year 2005.

(Signature)	(Signature)
FOR CHILE	FOR BOLIVIA

Agenda de la Reunión del XIV Mecanismo de Consultas Políticas
Chile – Bolivia

Grupo de Trabajo sobre Asuntos Bilaterales

1. Agenda sin exclusiones Bolivia – Chile
2. Mecanismos institucionales de diálogo bilateral

Libre Tránsito

3. Puerto de Iquique (habilitación al régimen de libre tránsito)
4. Puerto de Arica
5. Manuel Operativo del Sistema Integrado de Tránsito

Comité de Frontera

6. Eliminación de Pasaportes para la circulación de Turistas con Cédula de Identidad entre ambos países.
7. Controles Integrados de Frontera
8. Cooperación Aduanera
9. Grupo Técnico Mixto sobre Infraestructura GTM y ATIT

Educación, Cultura, Ciencia y Tecnología

10. Análisis sobre el establecimiento de una Comisión Mixta sobre Educación, Cultura y Ciencia y Tecnología.
11. Proyecto de Acuerdo sobre protección y restitución de bienes del Patrimonio Cultural.
12. Encuentro de Gestores Culturales Chile – Bolivia.
13. Memorándum de Entendimiento Cultural.

Convenios

14. Convenio para el trabajo remunerado de familiares del personal consular, administrativo y técnica.*
15. Acuerdo para Evitar la Doble Tributación
16. Convenio de Servicios Aéreos (1993)

Temas Económicos y Comerciales

17. Profundización del ACE 22
18. Turismo

Cooperación

Varios

Agenda of the XIV Meeting of the Chile-Bolivia Political Consultation Mechanism

Working Group on Bilateral Issues

1. Bolivia-Chile agenda without exclusions
2. Institutional mechanisms for bilateral dialogue

Free Transit

3. Port of Iquique (enabling for the free transit regime)
4. Port of Arica
5. Operational Manual of the Integrated Transit System.

Border Committee

6. Elimination of Passports for the circulation of Tourists with Identity Cards between both countries.
7. Integrated Border Controls
8. Customs Cooperation
9. Joint Technical Group on Infrastructure of the Joint Technical Group on Infrastructure (GTM) and the Agreement on International Land Transport (ATIT).

Education, Culture, Science and Technology

10. Analysis on the establishment of a Joint Commission on Education, Culture and Science and Technology.
11. Draft Agreement on protection and restitution of Cultural Heritage Assets.
12. Meeting of Chile-Bolivia Cultural Managers.
13. Memorandum of Cultural Understanding.

Agreements

14. Agreement for paid work of family members of consular, administrative and technical personnel.*
15. Agreement to Avoid Double Taxation
16. Air Services Agreement (1993).

Economic and Commercial Issues

17. Deepening of ACE 22
18. Tourism

Cooperation

Various

(*) Respecto al Convenio para el trabajo remunerado de familiares del personal consular, administrativo y técnico, se sugiere efectuar el intercambio de Notas de las conclusiones de la reunión y firma del Acta.

Nómina de la Delegación chilena

Emb. Cristián Barros
Subsecretario de Relaciones Exteriores
Ministerio de Relaciones Exteriores

Emb. Roberto Ibarra
Director de América del Sur
Ministerio de Relaciones Exteriores

Emb. María Teresa Infante
Directora Nacional de Fronteras y Límites
Ministerio de Relaciones Exteriores

Emb. Francisco Pérez Walker
Cónsul General en La Paz

Sr. Anselmo Pommés
Director de Fronteras
Ministerio de Relaciones Exteriores

Sr. Gustavo Vergara
Director Regional Subrogante de la Aduana de Iquique

Sr. Germán Fibla A.
Jefe Departamento Normativo de Aduanas

MC Económico Enrique Soler
Director Oficina Comercial

C. Juan Pablo Crisostomo
Encargado del Escritorio Bolivia
Ministerio de Relaciones Exteriores

Sr. Enrique Ceppi
Jefe del Departamento ALADI
Dirección General de Relaciones Económicas Internacionales
Ministerio de Relaciones Exteriores

SS. Felipe Saéz

(*)Regarding the Agreement for the remunerated work of relatives of consular, administrative and technical personnel, it is suggested to exchange the Notes of the conclusions of the meeting and sign the Minutes.

List of the Chilean Delegation

Amb. Cristian Barros
Under-Secretary of Foreign Affairs
Ministry of Foreign Affairs

Amb. Roberto Ibarra
Director of South America
Ministry of Foreign Affairs

Amb. Maria Teresa Infante
National Director of Borders and Boundaries
Ministry of Foreign Affairs

Amb. Francisco Perez Walker
Consul General in La Paz

Mr. Anselmo Pommes
Director of Borders
Ministry of Foreign Affairs

Mr. Gustavo Vergara
Acting Regional Director of the Iquique Customs

Mr. German Fibla A.
Head of the Customs Regulations Department

Minister Economic Counselor Enrique Soler
Commercial Office Director

Counselor Juan Pablo Crisostomo
Head of the Bolivian Desk
Ministry of Foreign Affairs

Mr. Enrique Ceppi
Head of the ALADI Department
General Directorate of International Economic Relations
Ministry of Foreign Affairs

Second Secretary Felipe Saez

Gabinete Subsecretario
Ministerio de Relaciones Exteriores

Sr. Hernán Acuña
Agencia de Cooperación Internacional

Sr. Patricio Campaña
Gerente General
Empresa Portuaria de Arica

Sr. Sergio Retamal
Gerente de Explotación Comercial
Empresa Portuaria de Antofagasta

Sr. Rolando Varas
Gerente de Operaciones TPA

Sr. Rodrigo Pinto
Empresa Portuaria de Arica

Mariela Fuentes
Dirección de Prensa
Ministerio de Relaciones Exteriores

TS. Andrés Aguilar
Escritorio Bolivia
Ministerio de Relaciones Exteriores

Nómina de Delegación boliviana

Emb. Hernando Velasco Tárraga
Viceministro de Relaciones Exteriores y Culto

MC. William Torres Armas
Director General de Límites y Fronteras

Emb. Edgar Pinto Tapia
Director General de Relaciones Multilaterales

MP. Marco Antonio Vidaurre Noriega
Director General de Relaciones Bilaterales

(Cabinet Undersecretary
Ministry of Foreign Affairs

Mr. Hernan Acuña
International Cooperation Agency

Mr. Patricio Campaña
General Manager
Port Company of Arica

Mr. Sergio Retamal
Commercial Exploitation Manager
Port Company of Antofagasta

Mr. Rolando Varas
Operations Manager TPA

Mr. Rodrigo Pinto
Port Company of Arica

Mariela Fuentes
Press Office
Ministry of Foreign Affairs

Third Secretary Andres Aguilar
Bolivian Desk
Ministry of Foreign Affairs

List of the Bolivian Delegation

Amb. Hernando Velasco Tarraga
Vice-Minister of Foreign Affairs and Worship

Minister Counselor William Torres Armas
Director General of Boundaries and Borders

Amb. Edgar Pinto Tapia
General Director of Multilateral Relations

Minister First Class, Marco Antonio Vidaurre Noriega
General Director of Bilateral Relations

C. Isabel Cadima Paz
Directora de América

MC. Mauricio Dorfler Ocampo
Director General de Integración y Asuntos Comerciales

Dr. Ramiro Prudencio Lizón
Asesor en Política Exterior

MC. Roberto Finot Pabón
Cónsul General a.i. de Bolivia en Santiago

Regina Hennings
Cónsul Adjunto de Bolivia en Santiago

Edgar Choque Armijo
Cónsul de Bolivia en Iquique

TS. Yuri Arce Navarro
Encargado del Escritorio Chile

Counselor Isabel Cadima Paz
Director of America

Minister Counselor Mauricio Dorfler Ocampo
General Director of Integration and Commercial Affairs

Dr. Ramiro Prudentcio Lizon
Foreign Policy Advisor

Minister Counselor Roberto Finot Pabon
Acting Consul General of Bolivia in Santiago

Regina Hennings
Deputy Consul of Bolivia in Santiago

Edgar Choque Armijo
Consul of Bolivia in Iquique

Third Secretary Yuri Arce Navarro
Head of the Chile Desk

Annex 20

Records of the Ministry of Foreign Affairs of Chile, 2009

(Original in Spanish, English Translation)

Ministerio de Relaciones Exteriores

Gobierno de Chile

Memoria del Ministerio de Relaciones Exteriores de Chile
Año 2009

Archivo General Histórico
Ministerio de Relaciones Exteriores de Chile

Records of the Ministry of Foreign Affairs of Chile
Year 2009

Historical General Archive
Ministry of Foreign Affairs of Chile

DIFROL colaboró con otras Direcciones del Ministerio de Relaciones Exteriores y organismos del Estado, en el seguimiento de expediciones científicas marítimas en aguas jurisdiccionales chilenas por parte de naves de terceros países, que se someten a la reglamentación contenida en el D. S. 711 de 1975, así como de investigaciones que se realizarían en zona fronteriza con participación de personas residentes en el exterior.

d. Transferencias de inmuebles situados en zona fronteriza

Autorizaciones al Ministerio de Bienes Nacionales

Títulos Gratuitos	Ventas Directas	Arriendos	Concesiones	Saneamientos
80	66	52	29	97

2. Dirección de Límites (DIRLIM)

a. Departamento de Estudios Limítrofes

Programa especial de fronteras y límites
El Departamento de Estudios Limítrofes continuó las actividades y estudios técnicos del Programa Especial de Fronteras y Límites, el cual comprende los temas de Campo de Hielo Sur, recursos hídricos fronterizos-con particular acento en el río Silala/Silala-, Límites Marítimos y Plataforma Continental Extendida. Este es un Programa de alcance confidencial, sobre el cual ha existido permanente trabajo. Algunos antecedentes de difusión pública, se presentan a continuación:

Tema Río Silala
Se realizaron dos reuniones del Grupo Técnico Chile-Bolivia sobre el río Silala. La V Reunión sobre el tema, y primera del año, se llevó a cabo el 3 de abril, en Santiago. En representación de Chile asistieron delegados de DIFROL y del Ministerio de Relaciones Exteriores, de la Dirección General de Aguas (DGA) y del Servicio Nacional de Geología y Minería (Sernageomin). Por parte de Bolivia, concurrieron representantes de la Cancillería y del Ministerio del Agua. En dicha oportunidad, se continuó desarrollando el programa de trabajo para tratar el tema del río Silala a nivel técnico, así como el proyecto de Acuerdo Inicial.

Posteriormente, se llevó a cabo la VI Reunión sobre el tema, los días 18 y 19 de mayo en La Paz – Bolivia, ocasión en que las delegaciones llegaron a un proyecto de acuerdo que elevaron a sus respectivos Gobiernos. En efecto, el Grupo de Trabajo finalizó la redacción de un proyecto de acuerdo inicial, el que sería sometido a instancias superiores para su consideración y aprobación

[...]

2. Direction of Boundaries (DIRLIM)

a. Department of Border Studies

Special program for borders and boundaries

The Border Studies Department continued the activities and technical studies of the Special Border and Boundary Program, which includes the themes of Southern Ice Field, Border Water Resources –with particular emphasis on the Silala/Silala River–, Maritime Boundaries and Extended Continental Shelf. This is a Program of confidential scope, on which there has been permanent work. Some background information on public dissemination is presented below.

Silala River Issue

Two Chile-Bolivia Technical Group meetings were held regarding the Silala River. The V Meeting on the issue, and first of the year, took place on April 3rd, in Santiago. Delegates from DIFROL and the Ministry of Foreign Affairs, the Directorate General of Water (DGA) and the National Geology and Mining Service (SERNAGEOMIN) attended on Chile's behalf. On the Bolivian side, representatives of the Ministry of Foreign Affairs and the Ministry of Water attended. On that occasion, the work program to address the issue of the Silala River at the technical level, as well as the draft Initial Agreement, continued to be developed.

Subsequently, the Sixth Meeting on the subject was held on 18 and 19 May in La Paz, Bolivia, on which occasion the delegations reached a draft agreement that they submitted to their respective Governments. Indeed, the Working Group finalized the Draft Initial Agreement, which would be submitted to higher instances for their consideration and approval

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respectiva, con miras a su próxima suscripción. Estos trabajos, fueron asistidos por el Servicio Nacional de Meteorología e Hidrología, el Servicio Nacional de Hidrografía Naval, el Servicio Nacional de Geología y Minería de Bolivia, la Dirección Nacional de Fronteras y Límites y la Dirección General de Aguas, de Chile.

En noviembre, en el seno del Mecanismo de Consultas Políticas presididas por los Viceministros de ambos países, concluyó la negociación del acuerdo inicial con los siguientes objetivos:

1. Establecer un acuerdo bilateral para la preservación, sustentabilidad, uso y desarrollo del sistema hídrico del Silala o Siloli, en beneficio de ambos países
2. Conducir estudios e investigaciones para determinar, entre otros fines, la naturaleza, el balance hídrico, la conducta hidrométrica, el registro del agua, los flujos superficiales y subterráneos y la influencia de las obras civiles sobre el volumen del agua. Esto, empleando metodología científica validada de común acuerdo, la que proveería una base para establecer el porcentaje de las aguas de libre disponibilidad de las partes.
3. Establecer un mecanismo para que Bolivia autorice el uso de las aguas de su libre disponibilidad, en su territorio, a fin de que fueran captadas y conducidas hacia Chile, con una compensación. En caso alguno el acuerdo inicial contemplaba el pago del agua por el Estado chileno por el simple hecho de su paso por la frontera.

El Departamento de Estudios Limítrofes continuó en este período con la recopilación y clasificación del material cartográfico y bibliográfico relacionado con el río Silala, y participó en reuniones técnicas con Bolivia, incluso en terreno.

Expediciones científicas y deportivas al sector de Campo de Hielo Norte (CHN), Campo de Hielo Sur (CHS) y zonas englaciadas, durante el año 2009

Expedición CHS
Fecha: 1 Febrero – 30 Julio 2009
Actividades: Esta actividad tuvo como objetivo realizar una travesía deportiva en la zona de CHS, caminata y kayak.
Participantes: Christian Clot, suizo y Mellusine Mallender, británica

15ª Expedición Alemanes, Universidad de Trier
Fecha: 9 Marzo – 16 Abril 2009
Actividades: Expedición científica a la zona del Gran Campo Nevado, Península Muñoz Gamero, en la cual se desarrollaron estudios climáticos y glaciológicos.
Participantes: Rolf Kilian, Sascha Serno, Tobias Sauter, Marco Möller, Frank Lamy, Helge Arz, Gerlinde Castel, de nacionalidad alemana y Marcelo Arévalo de nacionalidad chilena.

with a view to its next subscription. These works were assisted by the National Meteorology and Hydrology Service, the National Naval Hydrographic Service, the National Service for Geology and Mining of Bolivia, the National Direction of Borders and Boundaries and the Chilean Directorate General of Water.

In November, within the Mechanism of Political Consultations chaired by the Vice-Ministers of both countries, the negotiation of the initial agreement was concluded with the following objectives:

1. Establish a bilateral agreement for the preservation, sustainability, use and development of the Silala or Siloli water system, for the benefit of both countries.
2. Conduct studies and research to determine, among other purposes, nature, water balance, hydrometric behavior, water recording, surface and groundwater flows and the influence of civil works on the water volume. This, employing scientific methodology validated by common agreement, which would provide a basis for establishing the percentage of water freely available to the Parties.
3. Establish a mechanism for Bolivia to authorize the use of freely available waters in its territory, in order to collect and transport them to Chile, with compensation. In no case did the initial agreement contemplate the payment of water by the Chilean State for the simple fact of its crossing the border.

The Department of Borders Studies continued in this period with the compilation and classification of cartographic and bibliographic material related to the Silala River, and participated in technical meetings with Bolivia, even in the field.

[...]

Annex 21

El Mercurio, "The Foreign Minister opts for integration", Santiago, 21 October 2001.

(Original in Spanish, English Translation)

☑ ▸ **Domingo 21 de Octubre de 2001**

Canciller apuesta a integración

Soledad Alvear, ministra de RR.EE.

La ministra de Relaciones Exteriores habló sobre los temas contingentes de la región y las auspiciosas proyecciones de integración con los países vecinos

Por Pablo Matamoros A.
Patricio Vega C.

Menuda. De tono suave y amable, pero con innegable poder de convicción. Así es la ministra de Relaciones Exteriores, Soledad Alvear, quien tiene a su cargo las riendas de la política exterior del país.

No es casualidad que esta mujer ocupe una de las carteras más estratégicas del Presidente Ricardo Lagos. Su currículum deja en claro su sello en los dos últimos gobiernos de la Concertación, donde uno de sus "hijos predilectos" es la Reforma Procesal Penal.

Tampoco es un misterio que sea una de las figuras públicas mejor evaluadas y con mayor credibilidad en la ciudadanía, al punto que su nombre suena como presidenciable para las elecciones del 2005.

En medio de su recargada agenda (que incluye por estos días una gira a Singapur), la ministra habló sobre temas de contingencia para la Segunda Región y que han levantado más de alguna polémica, especialmente en el caso de las relaciones internacionales con Bolivia.

El pimpón de la ministra

Amor: Alimento del alma
Hijos: Bendición de Dios
Mujer: Yo soy una y ia mucho orgullo!
Política: Clave para progresar en paz y justicia
Democracia Cristiana: Mi querido partido
Norte: Grande y bello
Pobreza: ¡Debemos eliminarla!
Cobre: Gracias por apoyar nuestro progreso
Inteligencia: Admiro ambas, la racional y la emocional
Periodismo: Clave en una democracia
Injusticia: Me duele y me moviliza para repararla
Cordillera: Me emociona verla nevada
Atentados: Irracionalidad criminal
Reforma Procesal: Haberla encabezado, como ministra de Justicia, junto a un equipo humano con gran mística, es una de mis grandes satisfacciones.

CORREDOR MARITIMO

Existe la posibilidad de un corredor marítimo para Bolivia. En vista de la alternativa de sacar la producción de la minera boliviana San Cristóbal por Tocopilla y una red de gasoducto hacia Mejillones, ¿están avanzados estos proyectos?

- Las autoridades de la Segunda Región, principalmente Obras Públicas, se encuentran estudiando en forma conjunta con la empresa Minera San Cristóbal la coparticipación de esta última en el mejoramiento de la infraestructura caminera para satisfacer las necesidades de dicha empresa para llevar su producción al Puerto de Tocopilla. Estos proyectos están bien encaminados.

El diputado Waldo Mora incluso habla de entregar una franja de terreno para Bolivia cerca de caleta Cobija para que se desarrollen proyectos turísticos, ¿cuál es la posición del Gobierno en este tema?

- Quiero reiterar que el Gobierno de Chile no se encuentra negociando la cesión, a ningún título, de porciones de su territorio.

Un problema pendiente con Bolivia está en la propiedad de las aguas del Silala. ¿Cómo el Gobierno enfrentará el millonario cobro de una empresa altiplánica por el uso de agua?

- Nuestra Cancillería ha seguido el mandato presidencial de celebrar reuniones técnicas, participando en varias sesiones y en una visita conjunta a terreno. La parte chilena ha propuesto que se trabaje una fórmula práctica, que garantice un beneficio económico para Bolivia y sobre la base de que el recurso es compartido, reconociendo una porción del caudal que pasa por superficie para cada país.

Sunday, 21 October 2001

Foreign Minister opts for integration

The Foreign Minister of Foreign Affairs spoke of the issues related to the region and the promising integration projections with neighboring countries

By Pablo Matamoros A.

Patricio Vega C.

Petite, of a soft tone, and friendly, but with an undeniable power of conviction. This is the Minister of Foreign Affairs, Soledad Alvear, who is in charge of the country's foreign policy.

It is no coincidence that this woman occupies one of the most strategic portfolios of President Ricardo Lagos. Her curriculum makes clear her support for the latest innovations of Concertacion [political party], one of her "preferred children" of which is the Criminal Procedure Reform.

Nor is it a mystery that she is one of the public figures best evaluated and with greater credibility among the citizens, to the point that her name as Presidential candidate for the 2005 elections has already been mentioned.

Among the subjects included in her renewed agenda (which includes a tour to Singapore these days), the minister spoke of issues related to the Second Region that have given place to more than one polemic, particularly in regard to international relations with Bolivia.

MARITIME CORRIDOR

Is there a possibility for a maritime corridor for Bolivia? In view of the alternative of shipping production from the Bolivian mine of San Cristobal through Tocopilla and a pipeline network to Mejillones, is progress being made with any of these projects?

- The authorities of the Second Region, mainly those related with Public Works, are studying with San Cristobal mining company the latter's participation in the improvement of the road infrastructure to meet the needs of said company to ship its production to Tocopilla port. These projects are well on track.

Deputy Waldo Mora has even talked of a strip of land for Bolivia near Cobija inlet to implement touristic projects. What is the government's position on this issue?

- I want to reiterate that the Government of Chile is not negotiating the cession, at no cost, of portions of its territory.

A pending problem with Bolivia lies in the proprietorship over the waters of Silala. How will Government face the millionaire request of payment made by the Bolivian company for the use of water?

- Our Foreign Ministry has the presidential mandate to hold technical meetings, participating in several sessions and in a joint visit to the field. The Chilean side has proposed that a practical formula be developed to guarantee an economic benefit for Bolivia and, on the basis of the fact that the resource is shared, to recognize a portion of the flow that passes through each country.

TRATADO MINERO

Chile propicia una política de integración con los países vecinos. ¿Qué importancia le da al Tratado Minero con Argentina y cómo incentivará la actividad económica de la región?

- El Tratado de Integración y Complementación Minera con Argentina es un paso de suma importancia en el proceso de integración binacional. Las proyecciones y potencialidades del tratado, que ya se encuentra plenamente vigente, son enormes y, por tanto, constituye por sí mismo un incentivo importante a la actividad económica de la región. El objetivo esencial se orienta a posibilitar a los inversionistas la exploración, explotación y comercialización de los recursos mineros fronterizos existentes a ambos lados de la cordillera. Se estima que este instrumento generará inversiones superiores a US$ 20 mil millones.

El Mercosur promete convertirse en un gran mercado, ¿Cuál será la oferta que el norte del país brindará en el aspecto comercial y de servicios?

- Tenemos confianza en que el Mercosur, como Unión Aduanera, rápidamente empiece a retomar su dinamismo comercial, una vez que se comience a superar la crisis que viven los países miembros en la actualidad. En este contexto, todo el norte del país deberá intensificar la conexión con el noreste argentino fortaleciendo su vinculación comercial y optimizando la oferta de servicios, especialmente el sector portuario, financiero, telecomunicaciones y de transportes.

MEGAPUERTO

Iquique tiene cierta rivalidad con el proyecto megapuerto de Mejillones porque se dice que ha sido "privilegiado por el Gobierno". ¿La Cancillería apoya la posición que Mejillones sea el futuro puerto exportador para Chile?

- Esta es una decisión del Gobierno en su conjunto, en la que participan varios estamentos con idoneidad en la materia y cuyas decisiones se basan sobre estudios técnicos, medioambientales, jurídicos y otros, y que descansan en el reconocimiento pleno de la capacidad de elegir opciones por parte del sector privado.

La Segunda Región pavimentó el Paso de Jama bajo la administración del ex Presidente Eduardo Frei, ¿qué falta ahora para concretar el intercambio económico con la Zona de Integración del Centro Oeste Sudamericano (Zicosur)?

- Desde 1992 que existe con Argentina un Plan Maestro General de Pasos Fronterizos, eminentemente técnico, que ha priorizado un total de 13 Pasos a lo largo de la frontera. Desde que se inició el proceso de integración binacional, ha sido el interés de ambos países ir mejorando la infraestructura física que los une. El Paso Jama juega un papel fundamental en la integración del Norte Grande con el Noroeste argentino y el Centro Oeste Sudamericano. Cumplido el papel del Estado respecto de dicho paso, la pavimentación corresponde ahora a los beneficiarios de él, es decir, a las personas y sus actividades de concretar el intercambio económico.

ALMACENES FRANCOS

En 1969 se firmó un convenio de almacenes francos entre Chile y Paraguay, pero hasta ahora no se dicta el reglamento para su funcionamiento en el puerto de Antofagasta. ¿Es posible reactivar esta iniciativa de integración?

- Todas las iniciativas de integración son absolutamente prioritarias para el Gobierno de Chile. Este caso específico no constituye en modo alguno una excepción a esa vocación integradora que estimamos prioritaria. Efectivamente, hemos reactivado este convenio que descansó en el olvido durante más de 30 años, y en atención a que se ha hecho necesario efectuar ciertas actualizaciones de carácter administrativo, tributario y otros, se encuentra en funciones una Comisión interdisciplinaria integrada por diversas reparticiones públicas que es presidida por el Ministerio Secretaría General de la Presidencia.

Otro problema que enfrenta la región pasa por los múltiples campos minados que existen en su frontera con Bolivia y Argentina. ¿Existe un plazo para eliminar estas áreas peligrosas?

- El jueves 13 de septiembre, en la Quebrada de Santa Cruz, se llevó adelante la destrucción de más de

MINING TREATY

Chile promotes a policy of integration with neighboring countries. How important is the Mining Treaty with Argentina? And how will economic activities in the region be encouraged?

- The Treaty of Mining Integration and Complementation with Argentina is an important step in the binational integration process. The projections and potentials of this treaty, which is already fully in force, are enormous and it, therefore, constitutes an important incentive to the economic activity of the region. The essential objective is intended to make possible for investors to explore and commercialize the existing border mining resources on both sides of the mountain range. It is estimated that this instrument will generate investments that will surpass the US $ 20 billion.

The Mercosur promises to become a big market, what offer will the country of the north provide in commercial and service provision related aspects?

- We are confident that Mercosur, as a Customs Union, have just begun to resume commercial dynamism, once we have the opportunity to overcome the crisis experienced by member countries at present. In this context, the entire north of the country should intensify the connection with the northeast of Argentina by strengthening its commercial connections and optimizing the provision of services, particularly in regard to the port, financial, telecommunications and transport sectors.

MEGAPUERTO

Iquique has some rivalry with the Mejillones mega-project project because it is said that is has been "privileged by the Government." Does the Foreign Ministry support the position that Mejillones is Chile's future exportation port?

- This is a decision of the Government as a whole, in which several strata are involved with suitability in the matter and whose decisions are based on technical, environmental, legal and other studies, and which rest on the full recognition of the private sector's ability to choose options.

The Second Region paved the Paso de Jama under the administration of former President Eduardo Frei, what is needed now to concretize the economic exchange with the Integration Zone of the Central South American (Zicosur [for its Spanish acronyms])?

- Since 1992 there has been a General Master Plan for Border Crossings with Argentina, eminently technical, which has prioritized a total of 13 passes along the border. Since the binational integration process began, it has been the interest of both countries to improve the physical infrastructure that unites them. Paso Jama plays a fundamental role in the integration of the Norte Grande with the Argentine Northwest and the South American Western Center. Once the role of the State has been fulfilled with respect to this step, the paving now corresponds to its beneficiaries, that is, it is now the role of the people and their activities to concretize the economic exchange.

FREE WAREHOUSES

In 1969 an agreement of free warehouses was signed between Chile and Paraguay, but until now the regulations for its operation in the port of Antofagasta have not been issued. Is it possible to reactivate this integration initiative?

- All the integration initiatives are absolutely priorities for the Government of Chile. This specific case does not constitute in any way an exception to that integrating vocation that we consider a priority. In effect, we have reactivated this agreement that rested in oblivion for more than 30 years, and, in light of the fact that it has become necessary to carry out certain administrative, tax and other updates, an interdisciplinary committee composed of various public agencies is in operation. It is chaired by the Ministry General Secretariat of the Presidency.

Another problem that the region is facing has to do with the multiple minefields that exist on its border with Bolivia and Argentina. Is there a deadline to eliminate these dangerous areas?

- On Thursday, 13 September, in the Quebrada de Santa Cruz, the destruction of more than

10 mil minas antipersonal. Con este acto, Chile mostró su propósito de cumplir en los hechos con el compromiso adquirido cuando suscribió la Convención de Ottawa, sobre Prohibición, Transferencia y Destrucción de Minas Terrestres Antipersonal.

Los atentados en Nueva York demostraron que ningún país puede estar ajeno al flagelo del terrorismo. ¿Cómo Chile enfrentará este problema de seguridad global?
- Nuestro país ha asumido compromisos claros relacionados con el combate contra el terrorismo. Somos parte de la Comunidad Internacional que ha manifestado un rotundo rechazo a los atentados del 11 de septiembre y que considera fundamental adoptar medidas tanto en el ámbito interno como en conjunto con otros países para enfrentar este conflicto. Ahora bien, nuestro aporte al combate contra el terrorismo está vinculado con nuestras reales capacidades.

VOLVER

10 thousand antipersonnel mines was carried out. With this act, Chile showed its intention to comply with the commitment acquired when it signed the Ottawa Convention on the Prohibition, Transfer and Destruction of Antipersonnel Land Mines.

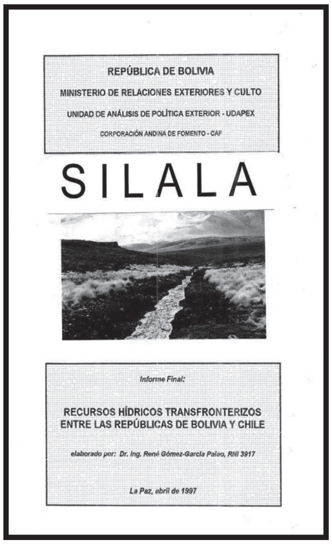
The attacks in New York showed that no country can be unmindful of the scourge of terrorism. How will Chile face this global security problem?

- Our country has assumed clear commitments related to the fight against terrorism. We are part of the international community that has expressed outright rejection to the September 11 attacks and considers it essential to adopt measures both internally and together with other countries to confront this conflict. However, our contribution to the fight against terrorism is linked to our real capabilities.

Annex 22

R. Gomez-Garcia Palao, "Transboundary water resources between the Republics of Bolivia and Chile – Silala", April 1997

(English Translation)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UNIDAD DE ANÁLISIS DE POLÍTICA EXTERIOR - UDAPEX
CORPORACIÓN ANDINA DE FOMENTO - CAF

SILALA

Informe Final:

RECURSOS HÍDRICOS TRANSFRONTERIZOS
ENTRE LAS REPÚBLICAS DE BOLIVIA Y CHILE

elaborado por: Dr. Ing. René Gómez-García Palao, RNI 3917

La Paz, abril de 1997

REPUBLIC OF BOLIVIA
MINISTRY OF FOREIGN RELATIONS AND WORSHIP
FOREIGN POLICY ANALYSIS UNIT – UDAPEX
ANDEAN DEVELOPMENT CORPORATION

Final Report on the Study regarding:

TRANSBOUNDARY WATER RESOURCES BETWEEN THE REPUBLICS OF BOLIVIA AND CHILE

Elaborated by: Dr. Eng. Rene Gomez-Garcia Palao
La Paz, April 1997

Rene Gomez-Garcia Palao
Civil
Engineer
R.N.I. 3917

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7. SILALA CASE

The Silala (Siloli) is a transboundary hydrographic catchment basin, whose upper basin is located in Bolivian territory and at the height of 3,640 meters above sea level, it enters the current Chilean territory.

The area of the basin is of 41 km^2, plus 35 km^2 corresponding to the surface of the Caguana sub-basin, in which water exploitation works are observed in order to transfer a certain volume to the Silala basin. Therefore the concept of successive course is not applicable in the Silala case, basically because there is no flow that generates a current of water through the course. In addition, the concept of contiguous course is not applicable in this case either.

7.1 *Background Information*

In this section we review the actions referring to water exploitation works in the transboundary basins and in the second we make a list of pertinent legal provisions.

May – 1887	The Antofagasta Nitrate & Railway Company sells the railroad to the Huanchaca Mining Company. Mr. Enrique Villegas transfers the right to supply drinking water to the city of Antofagasta for the benefit of the Huanchaca Mining Company.
21 January 1888	Chilean concession for the use of waters from the Loa River basin for the benefit of the Huanchaca Mining Company.
29 November 1888	Concession of the Sub-Prefecture of Porco, Department of Potosi, for the use of waters from the Silala springs for the benefit of the Huanchaca Mining Company for the use of the railroad. Copy registered in archives of documents of the Ministry of Foreign Affairs and Worship.
8 December 1888	The English company "The Antofagasta (Chili) and Bolivia Railway Company Ltd." acquires the Antofagasta-Uyuni railroad from the Huanchaca Mining Company.
25 June 1889	Extension of the Chilean concession to the English company for the use of water in the basins of the Cebollar, Amunaha and Polapi rivers.

1904	The construction of works for the use of Silala waters by the English railway company begins.
1904	Concession to the English company "The Antofagasta (Chili) and Bolivia Railway Company Ltd." for the provision of drinking water to the city of Antofagasta.
6 October 1908	Concession testimony for the use of water from the Silala springs to the Antofagasta and Bolivia Railway Company, located in the Quetena vice-canton, South Lipez Province, with the purpose of feeding the railway machines. There is an unofficial copy issued by the Railways Office of 1940. The management is carried out under the leadership of the manager of the English railway company, Josias Harding, who during the War of the Pacific was an advisor of the Chilean Government, participated in the assault on Antofagasta and was part of the first bi-national commissions to delimit borders.
29 June 1940	Mr. Pablo Boudoin denounces the misuse of the Silala waters. The Permanent Fiscal Commission declines jurisdiction, 18 October 1940.
23 October 1959	The Inter-institutional Study Commission is constituted.
November 1959	The Chancellery, the Army Major Command, plus the National Commission for Coordination and Planning [pronounce] themselves with respect to the arbitrary use of the Lauca River waters.
1962	The Direction of Limits reaffirms that the waters "benefit" Chuquicamata. Complaint by Mr. Augusto Valdivia about expansion of works in the Silala.
1965	The Irrigation Department of the Ministry of Public Works of Chile charges $ 0.20 x m3. Maritime Action denounces the Supreme Council of National Defense.

Regarding the first antecedent of the use of Silala waters, it goes back to 29 November 1888, when the Antofagasta Nitrate and Railway Company signed a contract with the Bolivian State, for the exploitation of saltpeter and was granted the use of the Silala waters.

During that time the legal situation of the Littoral Department was not defined, since the Truce Pact of 4 April 1884 was in force, which according to its Second Article, Chile was in possession of our territories until the signing of a definitive peace treaty that was defined in 1904.

The rights of the Antofagasta Company were acquired by Mr. Aniceto Arce with the company name of Huanchaca Company of Bolivia, which continued with the construction of the Bolivian railway section to Uyuni.

The Huanchaca Mining Company transfers its rights to another company with a predominance of English capital on 21 March 1889. This company completed the construction of the Antofagasta-Uyuni railway on 25 November 1889.

The company named (Antofagasta (Chili) and Bolivia Railway Company Limited) later continued operating the railroads of Bolivia under the name of Bolivian Railway Company which was later nationalized.

7.1.1 Testimony of Concession of Use of Silala Waters

The unofficial copy of the concession document is included in Annex 7 of the study.

As established in Article 217, the Prefect of the Department of Potosi signed the concession for the use of the waters of the Silala springs, whose most significant aspects are indicated below:

Number forty-eight – Deed of concession and consequent adjudication of the use of water, which form some springs called "Siloli" existing in the region of the Quetena vice-canton of the South Lipez Province of this Department. It is granted by the acting Prefect Mr. Rene Calvo Arana, in his capacity as Superintendent of Finance of the Department, in favor of the company "The Antofagasta (Chili) and Bolivia Railway Company Limited," represented in a legal and correct manner by the attorney general, Mr. Theodosius Graz, as recorded by the power constituted, page 10, of the works of the matter, granted by the original legal representative – Benjamin Calderon in the city of La Paz on September 7th of the current year.

"By the previous report given by the President of the Municipal Board of South Lipez it is stated that the water springs of the place called Siloli are located in the Vice-Canton of Quetena in a deserted place, in which any community or property makes use of the water, and with the protest that is made to leave the third part of the water abstracted, for those who want to use it later. Grant the use of the referred waters in merit of Article 217 of the Decree of 8 September 1879, raised to the rank of Law on 28 November 1906."

The aforementioned petitioner company and in its condition of having fulfilled the requirements of the law and in force of this public instrument is further covered with the character of true and only concessionaire and adjudicator of use of the Siloli waters, without any person being able to claim better rights, therefore deed testimony must serve as sufficient title.

"…The Antofagasta (Chili) and Bolivia Railway Company Limited, having informed of this relative deed, accepts in all its parts in favor of the company it represents by ratifying with the same solemnity as the Prefecture of the Department, making the formal denunciation that the concessionaire will comply strictly the prescriptions of the law and regulations that govern the subject in the future. Testimony of this, they said, is granted and signed with me by the Notary Public of the Treasury and the instrumental witnesses of his choice who were the citizens in office Manuel Zubieta and Honorato Vela, Bolivians and able to testify."

"…For being in accordance with the prescriptions to the law of all that I give faith, the signatories are Rene Calvo Arana.-.-.-. Teodosio Graz.-.-.-. Manuel A

Zubieta.-.-.-. Honorato Vela and Francisco lñiguez, Notary Public."
Additionally, we must emphasize that the object of the concession testimony emphasizes the use of springs or water eyes. The document does not specify that the Silala had been known as a river. On the contrary, its name originates from the pampas of the same name, desert plains covered by sand.

7.1.2 Complementary Background Information

The first official complaint known for the use of water –with different uses than the one granted to the railway– is that carried out by Mr. Pablo Baudain G., in June 1940, signed with his lawyer Z. Echeverria, where it is stated that the concessionary "Company" not only used the water for the purpose of the authorization or concession, but negotiated with them for so many years and continues to negotiate, selling drinking water to Antofagasta, meaning that it defrauded the Bolivian State, selling its wealth and monthly receiving more than 500,000 Chilean pesos for this concept. The permanent Fiscal Commission had admitted the denunciation through its Decree of 26 June 1940, with the signature of its President, Rafael Parada Suarez. After almost four months of this legal instance, the Commission decided to decline jurisdiction and competence by means of a Resolution dated 18 October 1940.

On 23 October 1959, the Bolivian Acting Foreign Minister, Dr. Walter Guevara Arce, informed the President of the Republic, Dr.

Hernan Siles Zuazo, of this situation and received instructions to constitute an Inter-institutional Commission to study the matter.

The commission was formed in November 1959 with delegates from the Foreign Ministry, the Army General Staff and the National Coordination and Planning Commission.

In 1962 the then Directorate of Limits of the Ministry of Foreign Affairs informed that the waters granted for the railroad were now "benefiting" Chuquicamata.

In 1965, Acción Marítima (Maritime Action) filed a complaint with the Supreme National Defense Council regarding the 1908 concession, stating that there is no Decree or authorization from the Supreme Government regarding the use of water for drinking water, charging the sum of 0.20 cents per cubic meter, by the Irrigation Department of the Ministry of Public Works of Chile, which exploits this wealth. On 23 November 1965, the Supreme Council of Defense stated that the said use only refers to "the surplus" of said waters.

In May of 1996, civic institutions and some media in the national press reported the existence of infrastructure works for the use of water resources by a Chilean company in Bolivian territory.

7.2 Hydraulic Analysis

Based on hydro-meteorological data read in Bolivia and by the FCAB in Bolivian territory through the precipitation station installed 2 km upstream of the borderline (see photo 56, Annex 6), the Silala is a hydrographic basin whose yield and surface runoff is minimal, 48 liters per second when there is rainfall with a sheet greater than 5 millimeters, whose annual probability is of 0.002. Complementarily, due to the characteristics of volcanic soils and sands in the superficial strata of the basin –which are the cause of high infiltration rates– it is irrational to assume the existence of surface runoff processes of rainfall with minimal incidence in the formation of eventual, seasonal or base flows in the main drainage course, see Plan BC-009.

Therefore, it is incorrect to define the Silala as a river and much less as a river of successive course.

The basic information available about the specific area of study is worryingly poor. Data on hydrology, geology and climate are scarce in Bolivia. The study had to resort to Chilean and North American research sources in order to cover the necessary information.

7.2.1 Location

The upper basin of Silala is registered in Canton Quetena, Province of South Lipez with capital San Pedro de Lipez in the Department of Potosi. Geographically, it is delimited between parallels 21°58' and 22°04' south and meridians 67°57' and 68°05' west. Attitudinally, it varies from 5,600 meters above sea level at the peak of Silala Grande Hill, from 4,280 meters above sea level in the Silala Pampas to approximately 3,600 meters in the current borderline.

Physically, the basin is delimited to the north by the watershed defined between the Grande Silala and Negro hills, to the west by the Inacaliri Hill and the transect between the border milestones LXXIII and LXXIV, to the south by the Silala Chico and Caguana hills and to the east by the pampas of Silala.

7.2.2 Identified Water Sources

The main source of water in the Silala basin is that produced by filtering and transporting underground water from the Eastern Mountain Range of the Andes to cuts of land with lower altitudes. 94 water eyes or springs were counted in the development of this study, (8 and 9 January 1997), which, according to the hydrological analysis –see Annex 4– produces a gross flow on site of 1,470 liters per second.

Water from underground and surface sources originating within the national territory is stored in natural water bodies. These aquifers retain and discharge important volumes of water due mainly to conditions of energy balance in the interior of the earth. The discharged water is transported guided by the gradient or hydraulic slope and due to natural conditions of permeability of the soils. A part of this water crosses trajectories that intersect with the natural cuts of the relief of the land, these cuts are formed from abrupt depressions that form valleys and canyons; the Silala basin is one of these cases.

The description of the previous scenario allows creating areas with atypical humidity conditions for the landscape in general. The bofedales originate from springs, watersheds or water eyes, which in an artesian manner emanate certain water flows to the surface. The characteristics of humidity and saturation of soils allow the formation of vegetation on the surface and basically create conditions that allow a process of natural regulation of the volume of stored water, establishing in this way an ecological balance between each of the elements of nature.

Therefore, we again argue that it lacks technical sense to speak of international waters in the Silala case, when it is verified that these are waters generated and retained in a natural way in Bolivian territory.

The distance of the watercourse from the furthest point where the springs, watersheds or water eyes are located to the borderline is of 18 km at an altitude of 4120 meters above sea level. As well as from the nearest water eye or spring –observed– up to the borderline is 750 meters, at an altitude of 3,740 meters above sea level.

7.2.3 Water Yield and Hydraulic Structure

According to the methodology exposed at the beginning of Chapter 5, of the geophysical and climatic characteristics described in Chapter 2, based on the hydro-meteorological information detailed in Annex 3 and with the analytical sequence expressed in Annex 4, we obtained the estimate of water yields expressed in the following table:

The total area of the catchment basin is of 76 km2, of which 76 km2 corresponds to the upper basin or water exporter basin. The minimum volume of water produced per year is 22.85 million cubic meters. The volume used per year is 9.15 million cubic meters and the annual volume of wastewater available is 13.70 million cubic meters.

Table 7-1. Water Balance, Silala Transboundary Basin

Code	Unit	Minimum flow rate produced l/s	Maximum flow rate produced l/s	Flow Rate Used l/s	Flow Rate Available l/s	Observations
S-4-1	North Silala	584	621	120	464	to Chile
S-4-2	South Silala	865	901	460	405	to Chile
S-4	Silala	1449	1522	580	869	

Source: own elaboration

The infrastructure present in the basin has a hydraulic structure based on obtaining economic efficiencies beneficial to the investor. The spring water catchment works are rustic chambers that allow concentration in the direction of the flow. These small chambers are built with stone and in few cases with stone and mortar masonry. In all the cases observed, the signaling is confirmed with sulfur-based tincture.

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From each water catchment work, channeling networks have been built, dimensioned according to the flow produced by each spring, watershed or water eye. These canals constructed with dry masonry or turf have rectangular or trapezoidal sections respectively, with canal bases that vary in a range of 15 cm to 50 cm, and canal heights that vary in a range of 20 cm to 60 cm.

As primary channeling elements, collector canals have been constructed that converge in a main collinear canal to the main drainage axis of the Silala basin. These collector canals of rectangular section have dimensions –base by height– that vary in a range of 60 cm by 60 cm in the intermediate section up to 1 meter by 60 cm in the current borderline. The base of the canals is consolidated with stone masonry and the walls are sealed with a mortar coating.

The water catchment works not only channel the surface flow. The Silala hydraulic system captures and channels water through open canals and pressurized pipes.

The first hydraulic control work is located 470 meters above the current borderline. This work simultaneously fulfills the functions of loading chamber for the 10 and 12 inch pipes that come out of it; decanter functions or primary water treatment plant; and functions of discharge control dam to the downstream canal system, the construction detail can be seen in the BC-011 and BC-012 plans.

The second work of control has constructive characteristics similar to the first, the discharge speeds are greater due to a greater capacity downstream. The dimension of the canals is 25% higher and there are two 12-inch pipes coming out of the loading chamber.

This system has a central control point in the current Chilean territory, which serves the water catchment works of San Pedro, Inacaliri and Silala. A control dam is built 5.5 kilometers downstream from the current borderline. This work has significantly greater dimensions, 13 meters of elevation and approximately 300,000 cubic meters of control storage. It drifts its waters to a pipe of 24 inches in diameter and a minimum capacity of 650 l/s. This flow of water is channeled to the aqueduct system of the Loa River basin, through the San Pedro River. From this system –owned by the FCAB and administered by the National Irrigation Department of Chile– water is distributed for the following uses in order of distance:

- Agricultural irrigation systems
- Minor populations between the lower basin of Silala and Antofagasta
- The cities of Calama and Chuquicamata

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- The mining center of Chuquicamata
- The cities of Antofagasta, Mejillones and Tocopilla

It should be noted that the network of aqueducts converges in the city of Calama, which functions as a discharge center, which is distributed through a complex network of aqueducts to the cities of Tocopilla, Mejillones and Antofagasta, as well as to intermediate points.

This study has not found evidence of use of water resources for the generation of hydroelectricity by means of micro-centrals, however we consider it reasonable to estimate that the natural fall of 1,500 meters with available flow rates greater than one cubic meter per second has the potential to generate electricity in the current Chilean territory.

7.2.4 The Silala Hydraulic System

The system of catchment, channeling, control and storage of water from the Silala basin has the following dimensions:

- 94 small water catchment works
- 27,000 meters of canals covered with dry masonry
- 2,500 meters of canals covered with stone masonry with mortar
- 17,600 meters of 10-inch pipe laying
- 4,600 meters of 12-inch pipe laying
- 1 combined work, loading, unloading, decantation and control in Bolivian territory.
- 1 combined work, loading, unloading, decantation and control in current Chilean territory.
- 1 storage and control work in current Chilean territory.

7.2.5 Hydraulic Capacity and Efficiencies of the System

There are three channeling systems that transport the volume of water abstracted in the upper basin of Silala; the main open canal, the 10-inch pipe and the 12-inch pipe. Each of them has the following capacity:

- Open canal from 210 l/s to 320 l/s
- 10-inch pipe from 85 l/s to 100 l/s
- 12 inch pipe from 130 l/s to 160 l/s
- Silala Hydraulic System from 425 l/s to 580 l/s

- **Equivalent to an annual yield in the range of 13.4 million cubic meters to 18.3 million cubic meters.**

The estimation of system capacity values from a given range is due to the lack of accurate data on the slope on which the pipeline is laid and the open canal.

The hydraulic efficiency of the constructed works that operate the system is 40%, see Table 5-5. This value is substantially high if we compare it with the referential values of water efficiency in the country, such as 21% of the Tiraque-Punata system, 10% of the Yura system or 4% of the Tacagua system.

7.2.6 Water Requirements of Chile

Studies carried out during the last twenty years by the Catholic University of the North have calculated the water requirements corresponding to the first two Regions of Chile:

First Region:	Arica	7,500 l/s or 236 million cubic meters of water
Second Region:	Antofagasta	11,500 l/s or 363 million cubic meters of water

The first region obtains 45% of its water requirements through surface water catchment works in the Lauca River basin.

The Second Region obtains 20% of its water requirements from the water catchment works in the piedmont of the Andes Mountain Range. We estimate that the waters from the Silala represent between 5% and 6% of the total water required and consumed by the Second Region of Chile.

The volume of remaining water required and consumed by the Second Region, 9,200 l/s, is abstracted through the pumping of underground water from wells drilled in the plains and pampas of the current Chilean territory. This underground water comes from infiltration processes from the Andes Mountain Range and the Altiplano. Studies have shown that the yield of wells has not decreased during the last ten years, the flow rate remains constant, despite the almost zero rainwater recharge of the Chilean desert. This constant flow is due to the conditions of infiltration and transmissibility of waters from Bolivian territory.

7.3 Evaluation of the Investment Made

The first water catchment works in the Silala basin were carried out by the Antofagasta Railway and Nitrate Company in 1888. These works are mainly rustic chambers for collecting water from springs and canals in dry masonry for the channeling of water through a network of collector canals.

The laying of the 10-inch pipe and the construction of the first combined work (loading chamber, decanter and control dam) were developed in 1913 by the Antofagasta and Bolivian Railway Company. Likewise, the main collector canal is covered with cement mortar.

The extension of the adduction system with 12-inch pipe, the transfer works of the Caguana basin and the construction of the two control and storage works in current Chilean territory was developed between 1938 and 1941 by the FCAB. This study has made field measurements of all the relevant works present in Bolivian territory, from this information have been generated plans of built and combined works, as well as location and trace of the water catchment and channeling system. The BC-09, BC-10 and BC-11 plans detail these characteristics.

From this dimensioning we proceeded to quantify the existing works, as well as to estimate unit prices for the site, consequently, this information has allowed us to establish a first monetary estimate of investment volume present in the Silala.

Table 7-2. Estimation of Investment Costs, Silala

ITEM	DESCRIPTION	QUANTITY	PRICE USD
100	REINFORCED CONCRETE	350 M^3	77,000
200	MASONRY WITH CONCRETE	2750 M^3	165,000
300	DRYWALL	31,500 M^3	1,260,000
400	OPEN FLOW CONTROL WORKS	GLOBAL	75,000
500	10-INCH PIPE, CAST IRON	17,600 ML	1,056,000
510	12-INCH PIPE, CAST IRON	4,600 ML	345,000
520	PRESSURE FLOW CONTROL, VALVES	GLOBAL	70,000
600	EXCAVATION, MOBILIZATION, ETC.	30% PARTIAL	893,400
700	OVERHEAD CONSTRUCTION	25% PARTIAL	744,500
	TOTAL		**4,685,900**

Source: own elaboration

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The estimated amount of the investment is four million six hundred and eighty five thousand nine hundred American dollars.

7.3.1 Silala System Management

The Silala hydraulic system is operated, maintained and managed by the Chilean company Antofagasta Railway to Bolivia (FCAB), located in the city of Antofagasta.

This company has a technical department with an "Adduction Directorate" based in the city of Calama. This personnel is in charge of the operation and maintenance of the System.

Engineer Mario Rivera is the Director of the Technical Department, having Engineer Carol Galvez as his assistant, both based in the city of Antofagasta. The Director of Adductions, based in the city of Calama and directly responsible for the Silala System, is Engineer Rene Villalobos. In the area of the project work two turners, in charge of field work, one of Chilean nationality: Santos Gonzalez and the other, recently hired and of Bolivian nationality: Pedro Cortez; the latter is in charge of basic maintenance, in Bolivian territory. Likewise, this Bolivian citizen, originally from Ollagüe and with a strong Chilean accent, is in charge of reading the instruments of control and data collection installed in Bolivian territory.

The Antofagasta Railway to Bolivia Company makes use of the economic benefits derived from the sale of water. This company sells the water coming from the Silala to a central system of discharge of flows controlled by the Irrigation Department of the Ministry of Public Works of Chile. According to information obtained in Antofagasta, the sale price has a range that depends on the weather station: between 16.80 to 21.80 Chilean pesos. Approximately, equivalent to between 4 and 5.2 cents of a dollar per cubic meter measured upon reaching the central aqueduct system of the Second Region of Chile. This aqueduct system distributes the water according to the detail shown in the previous section.

Based on the annual yield developed previously, we can conclude that the gross economic performance of the Silala basin has the following characteristics:

For a minimum of 13.4 million cubic meters of water and an average price of 5 cents of a dollar per cubic meter, the economic return is $ 670,000 per year.

For an estimated average value of 18.3 million cubic meters of water and an average price of 5 cents per cubic meter, the economic return is $ 915,000 per year.

Of the previous economic income, the Bolivian State has never received any tribute or participation during the last 84 years that the Silala Hydraulic System works.

7.4 Recommendations

1. It is not convenient to use the term water diversion, since the waters do not flow to any place, they are stored in a natural way in bofedales registered in the Silala basin in Bolivian territory.

2. Legally, the case should be dealt with initially by the investigating court in the Province of South Lipez, in the context of private law under Bolivian jurisdiction.

3. The concession was granted to the Antofagasta (Chili) and Bolivian Railway Company Limited by the Prefecture of Potosi. The date of 30 September 1908 marks the beginning of the concession. According to the Law of 1906 (Water Regulation) this concession lasts 99 years. Therefore, theoretically this concession ends on 29 September 2007, within ten years.

4. The concession deed must be reviewed by the District Attorney of Potosi, since it offers discrepancies in dates of granting powers after the start of the procedure before the Municipal Council of the South Lipez Province in San Pablo de Los Lipez.

5. The concession is specific and grants water for use in the railroad machines of the Antofagasta (Chili) and Bolivian Railway Company Limited, as of today that company does not exist.

- Its original address in Valparaiso does not exist and was not changed before the national authorities that keep the registry of mining and water concessions.
- The awarded company never paid for the concession, as specified by the Law of 1906.
- The water is sold to third parties, and no taxes are paid to Bolivia for Bolivian water.
- The concession is not valid today. This should be said by a judge in Potosi.

6. It is recommended that the local judge or competent authority notify the Chilean company of the invalidity of the concession of 1908, based on the

absence of legally valid records that legitimize the use of the Silala waters.

7. The claim of a Bolivian legal or natural person must be promoted about the use and exploitation of Silala waters, through the processing of a new concession to a private third party.

8. A historical economic balance of the profit enjoyed by the Chilean company with the value of the existing infrastructure should be carried out. Proceed to the confiscation of its assets for lack of payment of taxes and grant a new concession. Based on this mechanism, the State could have an additional income of approximately 5 million dollars for the collection of the facilities built on the site, as well as tax payments and royalties to the region.

9. It is recommended the immediate installation of instruments that allow the continuous and systematic collection of basic information for the study, evaluation and planning of the use of natural resources in the border areas. The network of hydro-meteorological border stations can be installed based on hydrological research projects and programs with broad support from the international scientific community.

10. Following the previous point, it is recommended that the Bolivian authorities initiate diplomatic efforts to allow academic and operational Bolivian institutions to participate in the "Andean Hydrology Research Program" developed at the Catholic University of the North in Antofagasta under the auspices and financing of the French ORSTOM. Bolivia as a transboundary country has as much right as Chile to participate in this important research effort.

11. It is recommended that research institutions in the country conduct a scientific research regarding the behavior of debris glaciers and infiltration processes in the Altiplano and in the Western Mountain Range of the Andes, which feed the aquifers in the pampas and coastal plains in the current Chilean territory.

12. It is recommended that the Bolivian Foreign Ministry participate in the drafting process of the Water Law, led primarily by the Ministry of Economic Development. In this process, the geopolitical importance of dealing with the transboundary issue must be highlighted.

13. The potential for generating geothermal energy is important in the area, it is recommended not to abandon the 8 million dollars already invested by the National Electricity Company Bolivia (ENDE) in the area, and continue based on guidelines that include the presence component and national possession at the borders.

14. Currently, the institution with the greatest presence in the area is the Eduardo Abaroa Reserve, it is recommended to coordinate with this institution tasks that include the monitoring of basic information, as well as national security tasks

15. It is recommended to encourage national tourism in the southwestern area of Bolivia.

16. It is recommended to propose to the Armed Forces of the Nation the development of a strategic border plan, where not only work from the budgetary and operational limitations of today, but to coordinate a national work based on short, medium and long-term objectives in all border areas.

17. It is recommended to undertake serious studies on the use of the Sica Sica-Arica pipeline, for the purpose of marketing water to the coastal population.

Annex 23

DHI, “Technical Analysis and Independent Validation Opinion of Supplementary Technical studies concerning the Silala Springs”, December 2018

(Original in English)

Technical Analysis and Independent Validation Opinion of Supplementary Technical studies concerning the Silala Springs

International Consultancy Contract by Product

CDP-I No. 41/2018

Single Product /

Pluri-national State of Bolivia,
Ministry of Foreign Affairs,
DIREMAR

The expert in **WATER ENVIRONMENTS**

Dec 2018

This report has been prepared under the DHI Business Management System certified by Bureau Veritas to comply with ISO 9001 (Quality Management)

Approved by

X

Kim Wium Olesen, Head of Department
Water Resources Department
Signed by: Kim Wium Olesen

Pluri-national State of Bolivia,
Ministry of Foreign Affairs,
DIREMAR

Dec 2018

The expert in **WATER ENVIRONMENTS**

Technical Analysis and Independent Validation Opinion of Supplementary Technical studies concerning the Silala Springs

International Consultancy Contract by Product
CDP-I No. 41/2018

Single Product

Prepared for:
Pluri-national State of Bolivia, Ministry of Foreign Affairs, Diremar

Project manager	Roar Askær Jensen
Quality supervisor	Torsten Vammen Jacobsen

Project number	11820137
Approval date	21 December 2018
Revision	2
Classification	**Confidential**

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Annex 4 - Reviewed environmental studies Part 2	Containing: FUNDECO, Part 2 in English and Spanish Versions
Annex 5 - Reviewed hydrologic / hydrogeologic study	Containing: Technical Analyses by F. Urquidi in English and Spanish Versions

Executive Summary

On the request of DIREMAR the following documents have been reviewed by DHI:

1. *Hydraulic study: "Characterization and efficiency of the hydraulic works built and installed in the Silala sector" Authors : Dr. Eng. Jose Luis Montaño Vargas, Dr. Eng. Jose Antonio Luna Vera, MSc. Juan Pablo Fuchs Arce, MSc. Eng. Juana Dolores Mejia Gamarra, MSc. Eng. Javier Carlos Mendoza Rodriguez*

2. *Topography and soil property studies: "Study of geo-referencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs". Prepared by: Consultores Tecnicos Ingenieria y Construccion Campos Barron S.R.L., La Paz Bolivia for DIREMAR*

3. *Environmental Impact Assessment Study in Silala,* Part 1: *Coordinating author Luis F. Pacheco, D. C. Director of the Institute of Ecology (UMSA) et.al.*

4. *Survey of Environmental Impact Assessment Study in Silala,Part 2 PALYNOLOGY. Coordinating author Luis F. Pacheco, D. C. Director of the Institute of Ecology (UMSA) et.al.*

5. *Hydrogeological study: "Technical Analysis of Geological, Hydrological, Hydrogeological and Hydrochemical Surveys Completed for the Silala Water System". Author: Fernando Urquidi Barrau, Bolivian geological consultant*

1st Review, Hydraulic study:

"Characterization and efficiency of the hydraulic works built and installed in the Silala sector"

The scope of the report is to register and characterize the hydraulics work in Silala and asses their effects on the bofedals and springs. Based on a field survey and previous field data collection the hydraulic works are described and classified section by section with total canal lengths calculated. The field work provides a detailed description of extent and properties of the canals. Photos and measurements also demonstrate the extensive drainage and its negative impact on the bofedals.

Field visits and analysis of flow measurements by SENAMHI has led to the conclusions that flow rates are constant and that the Silala spring system is fed by groundwater with no traces of runoff generated by rainfall in the catchment.

Based on field data collected a canal hydraulics model is developed and applied. The results derived from the model include canal Froude numbers and flow velocities. Based on model results and by comparing to flow rates of porous media it is concluded that the canals have altered the flow regime.

Observations from the field suggest that sediment transport is limited, but no final conclusion is made.

The report also concludes that the term 'river' is not a suitable description of the bofedal flow system and that the hydraulic works and canals were constructed for drainage and conveyance purposes.

The review points out unclear sentences or sections, contradictions within the report and minor inconsistencies regarding methodology.

The study provides detailed evidence of the extent and properties of the canals. Photos and measurements also demonstrate the extensive drainage and the negative environmental impact on the natural bofedals.

Overall the review finds that the report provides valuable documentation which supports the conclusion on canal system impacts in agreement with field survey and analysis presented in earlier studies such as (DHI, 2018 b).

Based on field data collected a canal hydraulics model is developed and applied. The model results shows high canal flow velocities. In a natural bofedal the flow regime consist of slow porous media flow in the peat in combination with excess discharge in the form overland flow distributed in a braded two dimensional pattern across the wetland vegetation. As such regime is different from the concentrated high velocity flows in the present canals *the study confirms that the canalization has changed the flow pattern of Silala.*

The methodology applied is, however, not valid for assessment of the *quantitative* impacts of the canalisation on the surface discharge rates from the Silala. This would require quantification of the water exchange between the canals and the wetlands and between the groundwater and the wetlands as in the analyses of (DHI, 2018 b).

2nd Review, Topography and soil properties:

"Study of geo-referencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs"

The Study consist of two independent parts:

Chapter 1 Geo-referencing and topographical Survey

Chapter 2 Assessment of soil properties in the area with focus on hydraulic properties.

A new detailed topographical survey has been executed which has: Established and georeferenced 8 boundary points along the main canals in the Silala Spring area, leveled all springs and piezometer boreholes and established georeferenced cross sections of all canals with a minimum distance of 10 m. The output of the study is a series of maps and tables attached to the report. It is not clear if the digital elevation model of the area has been updated.

The detailed topographical survey is certainly relevant for hydrological and hydrogeological studies in the area. Unfortunately, the new survey does not include specific comparisons to the previous topographical surveys carried out for DIREMAR and applied to geo-reference springs and piezometers by previous studies. Particularly the reference to the previously surveyed detailed digital elevation model (DIREMAR, 2017) or the possible corrections necessary to align it with the new benchmarks is lacking. Such information would add considerable value to the output

To compare the survey with the previous digital elevation model of the area the review has made a few spot checks on the produced elevation maps and compared the average slopes of the northern, the southern and the principal canals. These checks suggest that the new survey may confirm the previous digital elevation model with minor overall corrections. If this is the case the new survey is not likely not to change the conclusions of former assessments such as DHI, 2018 markedly

The soil property study concludes that there is a predominant presence of sandy soils throughout the study area. The soils are highly permeable, with high infiltration capacities. At 15 locations pits were excavated to depths from 0.3 to 1.8 m below the terrain (limited by the topsoil thickness above fractured rock). In the 14 excavations located outside the wetlands moisture contents at the bottom of the pits were found to be rather low and none of these excavations reached the groundwater table.

The field experiments reported suggest ten times higher infiltration capacities than used in the previous studies. Although these values may be uncertain and even too high; the experiments indeed confirm the findings of the previous studies regarding absence of surface runoff outside the wetlands and of the discharge of the Silala Springs and wetlands therefore originating almost entirely from groundwater.

3rd Review:

"Environmental Impact Assessment Study in Silala, Part 1"

The objective of the study was to determine whether the canalisation of the bofedals has had an impact on the ecosystems and if the impacts has caused a risk of survival of the bofedals and their special vegetational patterns and species.

To assess the conditions of the Silala bofedals, located in the Bolivian Andes, seven different surveys were performed to determine the actual influence of the anthropologically caused changes in the form of canalization of the bofedals. The surveys included analysis of vegetation, ichthyofauna, herpetofauna, avifauna and macrofauna.

The findings showed that the vegetation structure in the bofedals has been altered and it has created a more fragmented (dis-integrated) and degraded vegetation cover and diversity. The status of the Silala bofedals showed evidence of areas with the typical bofedal vegetation types but also of areas, with typical dry land vegetation. The study considers the canalization to be the main reason of development of the dry areas and for the deterioration of the environmental conditions for both biotic and abiotic factors. The main evidence came from the study of the vegetation/ species distribution in the bofedals and comparing the findings with studies of other undisturbed bofedals in the region.

The studies confirmed that the bofedals at Silala have more species and areas covered with plants normally dedicated to the dry margin-zones, whereas the vegetation types commonly associated with the bofedals were fewer and did only cover a small portion of the bofedals.

The approach taken by the research team to describe the current conditions in the bofedals in relation to flora and fauna, is considered a standard well proven approach and the results of the individual studies are presented in the report. The conclusions are drawn mainly on basis of the distribution of the vegetation types, related to dry and wet soils, while the studies of fish, birds, herpetofauna and macroinvertebrates did not add much to the overall conclusion.

This study provides the first quantitative analyses documenting the poorer environmental status of the Silala as compared to similar undisturbed bofedals in the Altiplano area. Hereby, it substantiates the *qualitative* assessments and observations made in previous studies. The findings are in accordance with the hydrological analyses and field studies documenting the drainage effects of the canals (e.g. (DHI, 2018 b) and the hydraulic study reviewed above).

4th Review:

"Survey of Environmental Impact Assessment Study in Silala, Part 2 PALYNOLOGY"

The objective of this study has been to reconstruct the history of the development of the vegetation during the last 100-120 years to detect whether the canalisation of the bofedals had caused any changes and effects on the vegetation.

The bofedals in the two valleys in Silala have gone through a change, which has been observed during the last century, allegedly because the water from the area was diverted and utilised for steam trains in Chile. The results of the undertaken survey are based on applying four globally recognised methods for assessing changes over time in habitats/soils.

It is verified that the observed changes in the two bofedals from the original peat-bog habitats to more dry habitats have taken place during the last century. The survey has found indications that the flow paths of the bofedals has changes from small braided streams and seepage through the vegetation to a situation, where the canals route the water faster through the bofedals. This change may be one of the main reasons for the alterations in the habitats, which have taken place during the last century.

The review can conclude that the methods used to assess the past century conditions were successful and in line with similar studies in the region. However, it should also be mentioned that the assessment of the previous vegetation in the Northern and Southern bofedal were only based on full analyses on one core in the Northern bofedal and two in the Sothern bofedal. In addition, the two cores from the Southern bofedal showed large variation in the stratigraphy, indicating long-term dynamic changes to the bofedal, most properly caused by long-term natural changes in how water has flown through the bofedals.

In summary the first of the two environmental impact assessment documents quantitatively that the Silala Bofedal is inhabited by species that are mostly linked to dry land and to a lesser extent species associated with healthy bofedals, as found in other bofedals. The analysis of the second impact assessment study has shown that the changes have taken place during the last century, during which the canalisation was implemented.

5th Review:

"Technical Analysis of Geological, Hydrological, Hydrogeological and Hydrochemical Surveys Completed for the Silala Water System"

Fernando Urquidi, a geological consultant, compiled a technical analysis (the report) based on reviewing the following third-party documents:

- The National Geology and Mining Service of Bolivia report, Study on the Geology, Hydrology, Hydrogeology, and Environment of the Silala Springs Area (SERGEOMIN, 2003).
- The National Geology and Mining Service of Bolivia report, Structural Geological Mapping of the Area Surrounding the Silala Springs (SERGEOMIN, 2017).
- Tomas Frias Autonomous University report, Hydrogeological Characterization of the Silala Springs (UATF, 2017).
- DHI report, Groundwater Flows (DHI, 2018a).
- DHI report, Study of the Flows in Silala Wetland and Spring System (DHI, 2018b).
- Isotope analyses results from Hydroisotop Laboratory (Urquidi, 2018).

The author has provided the following brief summary of the principal assertions and conclusions of his study:

- The Silala area was geologically formed during volcanic episodes in the Upper Miocene, 7.5 to 8-myr that created the Silala Ignimbrite (dominant aquifer).
- The valleys in the Silala were later modified with glacial geomorphological processes such as glacier movement and melt water events.

- The surface waters observed in the bofedals and springs in the Silala are groundwater dependent.
- The average flow from the main channel in the Silala is estimated at 160 to 210-l/s; 60-percent of this flow is believed to originate from the North and South bofedals.
- Fault zones in the ignimbrite are believed to be the dominant contributor to groundwater flow in the Silala groundwater system.
- The hydraulic properties of the Silala aquifer imply semi-confined conditions at depth and unconfined conditions in shallow piezometers.
- The chemistry of water found in the North and South bofedals is significantly different; water discharged into the North Bofedal is younger in age and contains lower concentrations of dissolved solids and bicarbonate. The groundwater discharged in the North Bofedal may be recharged locally. Based on groundwater age and constituents, the South Bofedal is believed to be recharged from the Silala Fault.
- Based on geology, hydrology, hydrogeology, and hydrochemistry, the Silala groundwater system is transboundary in nature.

Overall Urquidi presents a large amount of data from secondary sources in his report; the majority of the material appears to be a reproduction of the documents that were reviewed for the technical analysis. However, due to the lack of referencing, it is difficult to differentiate from secondary source material and the author's technical analysis (i.e. subjective conclusions).

Overall the author's conclusions are largely drawn from either the DHI 2018a report or variants of reports that were used in the DHI study. The findings are largely consistent with those of DHI.

There are some inconsistencies in data used and conclusions drawn, which contradict the findings of DHI 2018b. Key contradictions have been highlighted in preceding sections and largely focus around the role of glaciation in development of the Silala ravine and recharge – discharge relationships in the Silala area. However, numerous other contradictions exist and resolution of these would provide a more coherent and consistent technical assessment.

In DHI's opinion:

- Our conclusions on the recharge –discharge relationship, although related with uncertainty, still seems more trustworthy than those of the author, as DHI's conclusions are based on a broader selection of data sources (satellites, ground stations, reported spatial trends and other studies) and more comprehensive analyses of these data,
- The near continuous discussion of the glaciation of the Silala Ravine itself is irrelevant to the present day hydrogeologic system. It is thought that inclusion of these assertions may provoke unnecessary debate that does not affect transboundary groundwater or surface flows or the management of said flows.

In general, the information provided does not materially change any previous DHI conclusions or study outcomes, including estimates for transborder flow.

0 Introduction

The Bolivian Strategic Office for the Maritime Claim, Silala and International Water Resources – DIREMAR has Under the International Contract by Product CDP-I No. 41/2018 contracted DHI (Reviewer) for the execution of:"Technical Analysis and Independent Validation Opinion of Supplementary Technical studies concerning the Silala Springs" during December 2018.

This report constitutes the second and last deliverable of the contract:
Technical Analysis and Independent Validation Opinion of Supplementary Technical studies concerning the Silala Springs, Final review.

0.1 Objective

The objective of the review is to carry out a technical analysis and issue an independent opinion of validation of five technical-scientific reports provided by DIREMAR in relation to the Silala springs.

0.2 Scope

The scope of the project is to review the following five studies which has been made available to DHI by DIREMAR:

1. Hydraulic study: "Characterization and efficiency of the hydraulic works built and installed in the Silala sector" Authors : Dr. Eng. Jose Luis Montaño Vargas, Dr. Eng. Jose Antonio Luna Vera, MSc. Juan Pablo Fuchs Arce, MSc. Eng. Juana Dolores Mejia Gamarra, MSc. Eng. Javier Carlos Mendoza Rodriguez
2. Topography and soil property studies: "Study of geo-referencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs". Prepared by: Consultores Tecnicos Ingenieria y Construccion Campos Barron S.R.L., La Paz Bolivia for DIREMAR
3. Environmental Impact Assessment Study in Silala, Part 1: Coordinating author Luis F. Pacheco, D. C. Director of the Institute of Ecology (UMSA) et.al.
4. Survey of Environmental Impact Assessment Study in Silala,Part 2 PALYNOLOGY. Coordinating author Luis F. Pacheco, D. C. Director of the Institute of Ecology (UMSA) et.al.
5. Hydrogeological study: "Technical Analysis of Geological, Hydrological, Hydrogeological and Hydrochemical Surveys Completed for the Silala Water System". Author: Fernando Urquidi Barrau, Bolivian geological consultant

This review has only considered the translated English version of the report (attached as Annex 2 to this report). The output data of the topographic study include a large number of cross sections and topographic maps which have not been checked in details as part of this review.

1 Review of Hydraulic Study: "Characterization and efficiency of the hydraulic works built and installed in the Silala sector"

DIREMAR has contracted DHI to make the following independent technical review of the study *"Characterization and efficiency of the hydraulic works built and installed in the Silala sector"*. The study is prepared Dr. Eng. Jose Luis Montaño Vargas, Dr. Eng. Jose Antonio Luna Vera, MSc. Juan Pablo Fuchs Arce, MSc. Eng. Juana Dolores Mejia Gamarra, MSc. Eng. Javier Carlos Mendoza Rodriguez.

This review has considered only the translated English version of the report (attached as Annex 1 to this report).

1.1 Objectives of the Study

The objective of the report is clearly stated: To characterise and asses the effect of the hydraulic works built and installed in the Silala Springs area.

1.2 Methodology and content of the study

The report includes a 'Methodology' section which says that first a field study is carried out to gather information and provide a technical description and an inventory of hydraulic features built in Silala and their effects. It is followed by a literature study of historical documents describing the early intervention by canals and hydraulic works. Finally, the data collected in IHH-UMSA and SENAMHI field surveys along with topographical data are processed and used in a hydraulic model of the canals.

Chapter 2 discusses an international paper (Fox 1922) written by R.H. Fox, Chief Engineer of hydraulics works at the Antofagasta and Bolivia Railway Company Limited. The chapter evolves in some linguistic discussion of the words "river" and "stream" that does not serve the purpose of the study's objective. It is noteworthy, though, that Fox, the engineer in charge of the first intake in Silala, wrote the quoted paper in 1922 - 12 years later than the construction of the first intake, but 6 years *before* the canalization of the wetlands in 1928 (Arcadis 2017). Hence, when Fox describes the intake as "a small dam across the stream which has a daily flow (with very slight variation) of 11,300 cubic meters" he refers to the pre-canalized conditions.

One can therefore not conclude (as done in Chapter 2 page 7) that "the water intake work that currently exist in Bolivian territory corresponds to the works described by Fox". However, it *is* probably correct to assess that the constant surface flow, as described by Fox, means that the flow, also at that time, originated from upstream groundwater springs.

Chapter 3, 'Natural conditions' presents a geological map and briefly describes the main hydro-morphological processes shaping the surface. The upward directed groundwater flow from the fractured ignimbrite deposits are mentioned. The hydrogeological properties, aquifer units and an expanded description of groundwater flow at the larger scale feeding the bofedals is missing (see reference, DHI report).

The report states that 'The analysis of the water movement through the bofedals in its natural state is done considering the body of water as a unit: water–soil–biotope.' It is correct that a hydro-ecological approach is essential in order to understand how the bofedals rely on the hydrological conditions but no 'analysis' is presented. The bofedals are sensitive and have formed slowly due to the presence of a steady, diffuse groundwater supply.

Regarding surface runoff the authors write: 'The field studies support the absence of surface runoff caused by precipitation. A complete tour of the basin allows distinguishing that there are no traces of surface water movement; there is no evidence of surface laminar flow, as can be seen in the photographs presented in Figure 5.' The reviewer finds it unclear which field studies are referred to. It is correct according to the field survey (DHI 2018) that no signs of surface runoff are visible throughout the area. A photo with absence of surface runoff is hardly 'evidence'.

The authors write ''The reach of confluence of the North and South Bofedal, although it is of greater slope than in the high part, it is distinguished by the presence of peat that has developed under natural conditions (see Figure 7a), but that has, due to the effect of the developed actions, abstraction intake and water conveyance canals, originated the predominance of "intrusive" species as is the case of the grasslands.' The sentence is difficult to understand but the reviewer assumes that peat formations associated with the pre-canal situation are found at the canal confluence, but they are being replaced by invasive grasses due to the canalisation'

When the authors refer to the Northern and Southern bofedals as having 'fully saturated soils' it is not meaningful. It does not make sense to talk about saturation across the entire Northern or Southern wetlands. The saturation is highly variable from the perimeter of the wetlands to the areas adjacent to canals and to inundated areas. The effect of drainage is visible in terms of lower water tables, drier soils and consequently changes in vegetation and habitat. Later the authors state: 'The saturation of the North Bofedal reaches 100% while in the South Bofedal it reaches 76%.' This contradicts the previous statement. It does not make sense to talk about % saturation for an entire wetland based on a few samples. It cannot be used for any general characterization. One apparent effect of the canals is areas of lower groundwater tables and soil water contents below saturation.

Regarding the figures in chapter 3, Figure 8 does not show the canals and it is unclear it corresponds to a 'natural or 'canalized' situation. According to the text referring to Figure 9 it should show 'unhealthy wetlands' but the figure does not show anything relating to unhealthy wetlands. Finally Figure 10 and 11 cannot be read as legends are missing.

Also, in chapter 3 the authors write ''As a result of the geophysical studies carried out in the zone corresponding to the North Bofedal, plenty of underground water has been identified.' It is assumed that it refers to a COFADEN report. The word 'plenty' is not a technical term and it is very ambiguous in this context. Despite the presence of water being visible in the geophysical profiles the groundwater can equally well be described as 'scarce' in Silala.

The authors introduce the Darcy flow equation for estimating flow rates in a porous medium. In the Darcy flow approximation is should be noted that groundwater flow occurs both in the fractured ignimbrite rock and the sediment layer in which case a soil permeability is not necessarily representative. In addition, the upward head gradient driving upward groundwater flow is not necessarily equal to the slope of the terrain as the aquifer is confined or semi-confined. In any case the flow rates are low as demonstrated by the calculations. Flow restricted to the near surface soil does not reflect the actual situation in the Northern or Southern bofedals. Due to low soil permeability and/or shallow soils the groundwater tables are forced to the surface creating ponded water and diffuse flows across the surface.

The reviewer finds the paragraph in page 3-16 confusing: 'In general, the bofedals with intermittent regime, that is to say temporary, the flow of water is defined by two scenarios. During rainy season, the precipitation generates a surplus that floods the wetlands and that allows the water levels to be high enough to overcome the terrain's rugosity and cause the water to find "small channels", where it can move due to gravity towards lower areas, generating a network of several stream branches on the surface of the bofedal. Under these conditions and depending on the magnitude of the excess precipitation, runoff can even cause localized erosion processes, allowing the transport of sediments.' This is unclear, and it does not make sense to talk about bofedals 'in general'. The reviewer understands that this section about bofedals in general is supposed not to be applicable to Silala.

It is stated that ''The inventory of springs made by SENAMHI and DIREMAR (2018) and the geophysical study using resistive electrical tomography – ERT, carried out by COFADENA (2017), show that the source of the water fed by the Silala bofedals are the springs that emerge along the entire length of the waterbody' This is correct , but according to 'Study of the Flows in the Silala Wetlands and Springs System, DHI for DIREMAR, Final Report, 2018' diffuse inflows which are not registered at any specific spring locations contribute significantly to canal flows, e.g. in the ravine section outside the bofedals.

In Chapter 4, 'Flow regime', the authors write that '… therefore, a hydrological regime of the fluvial type cannot be defined for this basin'. The term 'fluvial type' is not clear. It is not a common term or definition. The reviewer understands this as 'a basin without surface runoff'.

Further, it is stated that 'The spatial variation of the flow of the South Bofedal in the Silala generally has a growing pattern according to the length and the development of the topographic differences, which goes from the gauging station in the triangular weir C1 until C5, see Figure 12' The sentence is not understood, the reviewer understands it as: 'The flow increases along the canal from C1 to C5', which would be correct.

On the subject of increasing canal flows the report says: 'From this control point the flow increases significantly until reaching control point S-10, because there is a greater concentration of springs'. This is not entirely correct as there are relatively few (visible) springs in this reach. The diffuse inflow may be considerable. The report also says that 'Although there is a discharge of flows through a canal, it must be taken into account that there are no significant flows in the confluence reach, since the variation of flows in the last control points (gauging stations) remain almost constant (see Figure 15). The reviewer is not sure what this sentence says. If it says that there is little or no inflow to the canal along this reach it would make sense.

In chapter 5, 'Physical Characterization of Hydraulic Works', categories and classes used in the systematic registration and characterization of the canal and hydraulic works of Silala is presented.

The methodology of the field work is described as (page 34):

- Topographic survey in detail of the location of the canals.
- Survey of the geometry of the canals.
- The detailed description of the materials used in the canals.
- Geometric and hydraulic layout of the canals.'

It is written that 'The detailed measurements of the geometric configuration of the canals have been taken and there is a quantification of the longitudes of each type.' This is an unclear sentence and the reviewer assumes that canal geometry, lengths and total distances have been measured.

The location of sites inspected is not clear. In some cases, coordinates are specified but no overview map is provided.

Chapter 5 presents a detailed account and description documenting the extent and physical properties of the hydraulic works in Silala. The description corresponds well to field visit observations reported in 'Study of the Flows in the Silala Wetlands and Springs System, DHI for DIREMAR, Final Report, 2018'

Chapter 6 describes and classifies the canal system.

A terminology of 'specific catchment' and 'longitudinal catchment' is presented. This is an unusual description. Commonly the canals collecting spring flows would be called 'secondary or tertiary canals' while the main canals would be referred to as 'primary canals'. When using the term catchment (or sub-catchment) in an area with no runoff, it is unclear if it refers to groundwater sub-catchments.

The report says: ‘According to what has been indicated, it has been demonstrated that the longitudinal collection works capture the water longitudinally along its entire length, as can be seen in Figure 67, the same one that develops through the permeable walls. This is a way of lowering the originally upwelling water table (see Figure 68), this descent channels a flow of the bofedals towards the canals; in this way it is possible to drain the bodies of water located in the bofedals (see similar canals from Figure 70 to Figure 72)’. The formulation is unclear and Figures 67 and 68 do not show what the text says. Figure 67 does not show the effect of canal drainage on wetlands and Figure 68 b) shows a horizontal water table (blue line) which does not make sense.

Chapter 7 describes transport of sediments in the canals. It is not possible to draw any final conclusions if sediment transport occurs in the Canals.

It is concluded that: ‘there is no surface runoff that can cause laminar erosion’. This is probably true under current conditions. Material may be deposited by slides, rock face collapses or by wind.

The authors state that ‘The limnogram of the aforementioned Figure 77 shows that there are no spikes that indicate a hydrological response to precipitation’. This is probably correct, but the period observed is too short to reach a general conclusion on runoff.

Chapter 8 describes the development and application of a hydraulic model.

It is stated that ‘The objective of the present hydraulic analysis is to evaluate the hydrodynamic conditions of the flow or surface runoff of water...’. This is surprising considering previous statements that no surface runoff is generated in Silala. The work does not seem to address surface runoff but only canal flow.

Regarding specific variables included in the model the report says: ‘….or variables of the system in order to characterize the flow regime, velocity, water depths, Froude number, Energy Line, etc.’. It is unclear how these variables can be used to ‘evaluate the influence of the ‘artificial interventions’? There is a discrepancy between scope and methodology.

The authors write: ‘For the present case, where the temporal evolution is not a factor to be taken into account and the flow is eminently one-dimensional, this model is sufficient, although it has been modeled two-dimensionally.’ Confusing sentence – unclear if it is a one-dimensional or two-dimensional model.

The methodology for development of the hydraulic model is presented by a bullet list. Model calibration is not included the list. Model calibration is a required and necessary step before applying a numerical model in analysis. The Manning coefficient is a calibration parameter and it should be verified that the model produces realistic water levels with the Manning values applied. Canal slope is described as a model parameter. This is not correct. It should be a model input derived from measured canal bed elevations.

The report says that ‘The gradient can be extracted from the geometric model, from the topography or from the digital elevation model.’ The report fails to specify which one was actually used in the model.

It is not possible to determine what Figures 82 and 84 in chapter 5 are supposed to show due to missing legend or explanations. Figure 84 does not appear to reflect the actual conditions in Silala.

The sentence, ‘‘The flowrate in the system determines the flow depth necessary for a determined flow, in addition to other hydrodynamic parameters of the environment in which the water flows.’ is not understood by the reviewer.

With respect to the model the authors add that 'In the present study, the surface flow of the system under the baseline average-flow hydrological scenario was simulated for the period with available data' which the reviewer interprets as a steady-state flow simulation.

The model results are presented accompanied by the sentence: 'The hydraulic profile shows that there are slight depressions where a certain amount of water accumulates (in these sections the depth is greater than the average and the water flows out of the main canal). Reference is made to figure 84. The reaches with inundation according to the model are not compared to field measurements and they do not seem to match observations in neither bofedal nor canal reaches. Comments are needed to explain the results.

In the conclusion on model results ranges of canal flow velocities and Froude numbers are mentioned but it is unclear how they relate to the scope of work and the effect of canals. Hydraulic conditions in the canals do not describe the effect of canalization on bofedals or flow rates.

1.3 Discussion of results and conclusions

In Chapter 9 conclusions are presented. It says that 'Within this framework, the waters of the Silala are fully integrated to the high mountain wetlands, independent of the extension, gradient, and vegetation and flow characteristics. Therefore, the water moves within this category [of wetlands].' and 'Although there is a short section in the southern branch where, due to the geological conditions, the movement is superficial over a channel in the rock, the body of water assumes again its status as a bofedal category at the confluence.' This is an unclear formulation, although it is true that the flow pattern vary from the uppermost springs to the international border under influence of groundwater conditions, wetland soils and canal works.

Further it is concluded that 'From a technical point of view, the natural movement of the Silala through the Silala bofedals does not respond to the technical definition of a river, i.e. "a large-scale water stream that drains a basin in a natural way'. This is out of context and the scope of work would not support technical definitions of a river. As opposed to the drained and canalized bofedals the flow through the natural state bofedal is not concentrated in confined surface flow stream/river branch features but diffuse across wide surface and subsurface sections.

Regarding 'Purpose of these interventions' the field work has documented impacts, causes and effects with respect to drainage by the canals but the original purpose or intention of the canal construction is beyond the scope of work of this report.

When stating that 'The introduction of the works in the Silala waterbodies have had characteristics of significant "aggressiveness" to the environment '. The reviewer understands that the canals have significant negative environmental impact.

With respect to the model it is concluded that 'The results of the hydraulic modeling performed for this survey show that the water movement conditions in the Silala waterbodies have been modified significantly. The incorporation of hydraulic works has changed the natural conditions of water movement in porous medium and has turned an unconcentrated surface flow into a free surface flow in the drainage canals implemented.' The reviewer does not find this conclusion substantiated. The field work shows that the water flow in Silala are changed due to the impacts of canals, but the model results do not. Firstly, the hydraulic model simulates canal flow only, which does not account for impacts on e.g bofedals. Secondly, in order to describe changes, it is necessary to compare model scenarios with and without canals. The model cannot and has not been used to simulate a scenario without canals. Consequently, the model results do not describe changes due to canalisation e.g. that water bodies have been modified.

Differences in flow velocities between a porous media and a canal is not an appropriate measure of change or modification. Surface flow may be generated without canals. If the porous media cannot fully drain the groundwater it will rise to the top of the bofedal and runoff on the surface (given the topographical gradient is present). This is seen in similar undisturbed bofedals and supported by the original wetland vegetation in Silala. Typical undisturbed wetlands of this type will have diffuse surface water flows. Water table changes across the area would be a better indicator of impacts.

1.4 Validation of the Results and Conclusions

In the context of the technical work carried out at the Silala springs, 2016-2018, this report provides valuable contributions in terms of the detailed description of the canal and hydraulic construction work based on field inspections. It also documents the impacts on the bofedals in terms of drainage effects and it provides a sediment transport assessment. The hydraulic works built in the Silala constitute an extensive and efficient water collection and conveyance system. The field survey reported clearly shows the degradation of wetlands and the contrasts between canalized and drained wetland sections versus undisturbed patches. The canal and bofedals description is consistent with report 'Study of the Flows in the Silala Wetlands and Springs System, DHI for DIREMAR, Final Report, 2018'.

The field work carried out clearly shows the extent and properties of the hydraulic works, including canals and their impact on wetlands, but does not address effects on canal or cross border flow rates.

The report concludes that the spring and wetland system is fed by groundwater with no sign of basin surface runoff. Constant measured canal flows are associated with groundwater discharge and not intermittent rainfall-runoff events. This is consistent with 'Study of the Flows in the Silala Wetlands and Springs System, DHI for DIREMAR, Final Report, 2018

The output of the hydraulic modeling study is simulated canal flow velocities and Froude numbers. The report argues that canal flow velocities are much higher than estimated saturated flow velocities of wetland soils. The impact of current canalized conditions compared to an undisturbed bofedal system are well described by the field study documentation, but simulated flow velocity differences is not a suitable measure of wetland impact. The integrated hydrological and hydraulic modeling study reported in 'Study of the Flows in the Silala Wetlands and Springs System, DHI for DIREMAR, Final Report, 2018' provides estimates of discharge and water balance impact considering both canalized and non-canalized conditions.

Conclusions regarding intentions and purpose of the original hydraulic works are out of scope of a field survey and the numerical model study. 'Effects', e.g. drainage effects can be documented as part of the field study but the original 'purpose' cannot.

The discussion of terminology and definitions in relation to the flow features, e.g. the term 'river' appears out of context considering the scope of the work. It is, however, correct that the flow in undisturbed bofedals is likely diffuse across a wider section and not concentrated in one-dimensional flow features.

The work reported supplements other studies in Silala, but it also overlaps significantly with the work of. 'Study of the Flows in the Silala Wetlands and Springs System, DHI for DIREMAR, Final Report, 2018' presenting the same or similar analysis of e.g. flow data but without referencing the report. The methodologies, analysis, conceptual understanding and results are not identical. Since the report does not reference the previous work it appears to have been carried out in a standalone parallel effort. It will be possible to extract estimates, assessments and analytical results from the two reports which are not fully aligned but possibly based on the same datasets.

2 Review of “Study of geo-referencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs.”

DIREMAR has contracted DHI to make the following independent technical review of “Study of geo-referencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs”. The study is prepared by Consultores Tecnicos Ingenieria y Construccion Campos Barron S.R.L., La Paz Bolivia for DIREMAR and is dated May 2018.

This review has considered only the translated English version of the report (attached as Annex 2 to this report). The output data of the topographic study include a large number of cross sections and topographic maps which has not been checked in details as part of this review

2.1 Objectives of the Study

The objectives for the topographical study (Chapter 1) is: To carry out the geo-referencing in the area of the Silala Springs. The geo-referencing shall include the hydraulic infrastructure, springs piezometers and reference points in the area.

For the soil characterization study (Chapter 2) the objective is: “To determine the maximum infiltration capacity and physical properties of the soil at fifteen assigned points on the basis of field tests in the area of the Silala Springs and the vicinities so as to assess the occurrence of surface runoff”.

The specific objective of the soil study is:

- To excavate 15 open trial pits
- To identify the soil types of the area by means of the USCS (Universal Soil Classification System) and
- To take samples and perform tests in the field to identify the physical and hydraulic properties of the different hydrological units of the soil and the surface level.

2.2 Methodology used

2.2.1 Topographical study

Advanced GPS technology was used to geo-reference eight boundary points (bench marks) located strategically along the southern and northern wetlands and the principal ravine between the confluence of the canals and the border to Chile. The Boundary points were subsequently leveled from the bench mark at the military post, which has previously been established and leveled from Laguna Colorada by the Military.

The boundary markers were subsequently used to geo-reference the piezometers, springs weirs and canals by tachymetering.

The review considers the implemented survey methodology viable for the objective of the study.

2.2.2 Soil property study

The applied methodology of assessing the important saturated infiltration capacity by double ring infiltrometer assumes vertical drainage by gravity (low lying groundwater table), conditions that seem to be fulfilled outside the wetlands. Only one of the test locations (SSL-1) is located Inside the wetlands where groundwater is found close to the surface, and here infiltration test was (correctly) omitted.

At all test points exploration pits were excavated to depths below ground surface between 0.3 m and 1.8 m (depending on the soil depth). Disturbed soil samples were taken out at the bottom of each of the 15 excavation pits and send to the laboratory to classify them according to texture, identify their Atterberg limits and to determine the natural soil moisture.

Although tests on intact soil samples would have been preferable, as they allow for relevant analyses for porosity and natural and saturated water contents, the disturbed samples also provide important information on the types of soils and drainage conditions in the area.

Atterberg limits of the soils plastic and liquid states are, however, more relevant for geotechnical foundation and stability issues than for hydrological aspects such as infiltration capacity, soil evaporation and surface runoff generation. Retention conditions, field capacity and wilting point would have been much more relevant hydrological properties to assess, since these parameters are essential for drainage and evapotranspiration analyses.

70% of the soil samples are taken 0.5 m below ground surface or deeper. Although soil properties at depth hold less information on the infiltration capacities than intact samples at the surface they do indeed provide valid information about the typical soil types of the area and their drainage properties.

2.3 Discussion of results and conclusions

2.3.1 Topographical study

Eight boundary markers (Bench marks) have been established and georeferenced (Projection: UTM WGS84, Zone 19S). The marks are distributed along the main canals of the northern and southern wetlands and along the principal canal from the confluence point to the international border.

The results include maps with 2 m terrain contours and with locations and elevations of boundary markers and canal structures. However, it is not stated from where these 2 m contours originate. Although they seem to resemble the contours of the previous detailed digital elevation model (DIREMAR, 2017) the study does not mention this source and more importantly it does not mention if this DEM has been adjusted to the new boundary points (bench marks) and the adjustment applied.

Canal cross sections are surveyed and mapped at a maximum distance of 10 m along the canals. Also, all marked springs, piezometer boreholes, and hydraulic weirs have been surveyed, georeferenced and mapped. Longitudinal sections along the main canal have been elaborated and plotted. Field measurements of the canals are also available from previous studies.

The survey of the springs and weirs is very detailed; but future use of the results may be hampered by lack of unclarity on the actual georeferenced points (the spring water level or a spring benchmark, the V-notch or a local weir benchmark).

2.3.2 Soil property study

The study makes conclusions on the geology of the area, the origin and deposition of the soils and the system of joints in the igneous rocks. This is unfortunate, since these aspects are not parts of the objectives of this study, not covered by its analyses, and these statements, true or not true, are not supported by references or analyses. Although such unsupported statements tend to weaken the credibility of a technical study, these statements do not have any bearing on the conclusions of this particular study.

Furthermore, it is stated that: *"It (red.: the area) does not present areas of erosion that could be a problem for sandy materials. It presents slopes with apparent stability due to the quality of the rock presented by families of discontinuity"*. This statement is not clear, but more importantly the objective of the study is not to discover if erosion takes place, but to establish the infiltration capacity of the soils in the area and the possible existence of surface runoff. Absence of signs of recent water erosion in sloping sandy soils with very sparse vegetation is indeed an indicator of surface runoff not taking place, and therefore of local rainfall intensities being lower than the infiltration and drainage capacities of the soils. The fact that no such signs of erosion are observed is therefore very relevant, but its importance is not clearly formulated in these statements. It is however touched upon briefly in another paragraph (point 5) of the conclusions.

According to the Uniform Soil Classification System the soil samples from 14 of the 15 locations have been classified as sand (9 of the samples (60%) as Silty sand, 4 (26%) as silty to clayey sand and 1 sample (7%) as Clayey sand). Only Sample no 15, located in the principal ravine close to the border, was classified as silt.

The study concludes that there is a predominant presence of highly permeable sandy soils throughout the study area. Only at location no. 1 (close to the canal confluence in the center of the wetland) were silt and clay layers visually observed in the excavation pit.

The study also concludes that spatial variability exists in the natural water content. This is not surprising considering that the sampling points were selected to represent, as well as possible, the range of soil types in the area, and because the samples are taken at different depths below ground surface, which could easily influence their moisture contents.

The analyses of the soil samples confirm that soils outside the wetlands are dominantly coarse textured, sandy and well drained soils with the low natural water contents most of which are below 11% (by weight) and probably close to or lower than field capacity. Only sample no 1 close to the canal confluence shows a natural water content over 20% (by weight). This is probably close to saturation, which is in accordance with the soil sample being taken close to the water table.

The infiltration rates determined are actually not the *maximum* rates (as stated in the study), but the important saturated rates under free drainage which are consistent with the saturated hydraulic conductivity. The less characteristic maximum infiltration rates normally occur when the soil is dry and conductivities low, but the tension gradients driving the infiltration very high.

The study presents Infiltration capacities as obtained from in-situ infiltrations test from 9 of the 15 locations. At these locations the soil is classified as Silty sand (6 locations), silty to clayey sand (2 locations) and Silt (1 location). At all locations the infiltration capacity is found to be very high (20-60 cm/hour). The observed capacities are based on observations with a rather large scatter (figures 12 -20) which indicates quite some uncertainty in the results.

Furthermore, the obtained infiltration capacities are around ten times higher than the literature values for normal sandy soils also quoted in the report (2.5-5.0 cm/hour).

However, the study does not make any direct conclusion as to the possibility of surface water runoff with the determined infiltration capacities and it does not discuss the results of the field tests in relation with the literature values.

2.4 Validation of the Results and Conclusions

2.4.1 Topographical study

A detailed topographical survey such as this one is certainly relevant for the studies of the Silala wetlands and was also requested for the completed hydrological and hydrogeological studies (e.g. DHI 2018). Unfortunately, the new survey has not been related to the previous topographical surveys carried out for DIREMAR and used to level springs and piezometers by previous studies such as (DHI 2018) – if such important relations have been established they are not reported.

To compare the survey with the previous digital elevation model of the area the review has made a few spot checks on the produced elevation maps and compared the average slopes of the northern, the southern and the principal canals (See Table 2-1). These checks suggest that the new survey may confirm the previous digital elevation model with minor overall corrections. If this is the case the new survey is not likely not to change the conclusions of former assessments such as DHI, 2018 markedly

Table 2-1 Comparison of canal slopes from the present study (Campos Barron) and the former topography used by (DHI,2018)

Study		Campos Barron Survey					Former Survey					
Canal reach	Point ID	Chainage	Level	Delta Chainage	Delta H	Slope	Chainage	Level	Delta Chainage	Delta H	Slope	Slope diff
		(m)	(m)	(m)	(m)	%	(m)	(m)	(m)	(m)	%	%
Northern	upstream point	0	4362				0	4365				
Canal	Confluence	688	4318	688	44	**6.4**	688	4320	688	45	**6.5**	**-0.15**
Southern	upstream point	0	4407				0	4410				
Canal	Confluence	2881	4318	2881	89	**3.1**	2940	4320	2940	90	**3.1**	**0.03**
Principal	Confluence	2881	4318				2940	4320				
Canal	border	3579	4277	698	41	**5.9**	3560	4282	620	38	**6.1**	**-0.26**

2.4.2 Soil property study

Both the infiltration capacities measured by two different methods on the Chilean side of the border (Arcadis, 2017) (1-8 cm/hour) and the VanGenuchten assessments used in (DHI,2018) (2-5 cm/hour) are fully in line with the literature values quoted in the report (2.5-5 cm/hour). The detailed infiltration modelling carried out in (DHI 2018) with saturated infiltration capacities 2-5 cm/hour did not generate any superficial runoff in the areas outside the wetlands with a 40-year precipitation series representative for the area.

The field experiments reported here suggest ten times higher infiltration capacities than the above mentioned and although these values are uncertain and maybe even too high, the experiments do indeed confirm the findings of the previous studies regarding absence of surface runoff outside the wetlands and of the discharge of the Silala Springs and wetlands therefore originating from groundwater inflow to the wetlands.

2.5 References

DIREMAR, 2017 Digital Surface Model (DSM) based on measurements taken during the drone flight in last half of 2016.

DHI, 2018: Contract CDP-I No 01/2018, Study of the Flows in the Silala Wetlands and Springs System. Product No.2 -2018 Final report.

Arcadis, 2017. Detailed Hydrogeological Study of the Silala River. International Court of Justice Dispute over the status and use of the waters of Silala (Chile vs.Bolivia), s.l.: Memorial of the Republic of Chile, Volume IV, Appendix E.

3 Review of "Environmental Impact Assessment Study in Silala" Part 1

The review carried out in this section is fully based on the English version of the report ***"****Environmental Impact Assessment Study in Silala"* and it has not been cross-checked with the original Spanish version. If there are contradicting interpretations, it may be due to an incorrect translation between the two documents.

3.1 Objectives of the Study

The objective of the environmental study has been to determine whether the present bofedals are in a steady state or in a state of being reduced in size and whether the observed changes were caused by the influence of anthropological induced changes in the form of canalization of the two bofedals.

The environmental study of the Silala bofedals, Part 1 focuses on providing a wide assessment of the many biological elements, living in the two valleys. The study also looks at the unique characteristics, ecology and occurrence of bofedals in the Altiplano of Bolivia. Accordingly, there are several references to other studies carried out in the region concerning the presence of bofedals in the highlands of Bolivia and other countries of South America. Two images from Bolivian Andes have been presented in the study report as an example of well-preserved bofedals.

3.2 Methodology used

The Silala bofedals are described as very important habitats in the Altiplano and the area has been designated as a Ramsar Convention site, which is an international treaty for the conservation and sustainable use of wetlands. It is also a part of the Eduardo Abaroa Andean Fauna National Reserve established in 1973. The protection status of the area indicates the significant importance for the preservation of its environmental values.

The Silala area is naturally divided into three distinct sub-areas: Southern Bofedal, Northern Bofedal and Confluence Area. The division is substantial and highlights the specificity of each zone, from which the Southern Bofedal is described as the most fragmented and at the same time the biggest of the two bofedals. Transparent maps of each area are presented in the report.

The study has been performed based on a range of field surveys carried out during March and April 2018, literature sources of abiotic and biotic factors, as well as interviews with citizens of surrounding areas, who helped to understand the historical background of the region.

3.2.1 Determination of the area of the bofedals

Delimitation of the bofedals was made according to the presence of typical vegetation in the mentioned area. The *Oxychloe andina* were pointed out as the main indicator species in the region in association with *Phylloscripus deserticola* or *Zameioscripus atacamensi,* which was supported by several references. As indicators of the margin formations of the bofedals, the species *Carex cf. maritime* and *Deyeuxia spicigiera* were used. The species mentioned above have been used to identify the area of bofedals based on the method Normalized Difference Vegetation Index (NDVI), which is a method based on analyzing satellite images.

NDVI is the most common index being used in remote sensing technology. In general, vegetation indices are quantitative indicators of biomass of plant origin. To define them, the red (RED) and near infrared (NIR) spectral channels are used and the vegetation index is an artificial image created by dividing selected spectral channels. The higher the NIR reflection and the smaller the RED, the more plants are green and the NDVI value is higher.

NDVI always ranges from -1 to +1. However, there isn't a distinct boundary for each type of land cover. The image of the vegetation index is interpreted as an indicator of biomass. The higher the value of this index, the higher the value of biomass. The negative values of NDVI correspond to the sites devoid of vegetation, e.g. uncovered soil, water and concreted areas.

There are several sectors where NDVI has being applied to, like for example in the agricultural sector to measure biomass, in the forestry sector to quantify forest supply and in assessments of land degradation.

For the analysis the satellite image representing the end of wet season from March 2016 was used. The NDVI analysis showed the threshold of bofedal vegetation occurrence was given an index value of 0.6, whereas the other formations classified as drier were expressed with the index values 0.3, 0.4 and 0.5.

To assess recent changes and to utilize the NDVI method, two example images were chosen for the comparison of changes of bofedals range (Figure 3-1). The image from 2004 was used as the first of the high-resolution image available, which gave the best possible difference in time for this method to be used. The image from 2004 was used as an image from the dry season, whereas the image from 2016 was taken during the wet season. This difference between both age of the images and the fact that one image represents the dry season and the other image represents the wet season might cause the wrong interpretation of the data, and this difference of dry season/wet season vegetation is not clearly presented in the document. Nevertheless, the images clearly show the range of the main bofedal area, where the bofedal indicator species *Oxychloe andina* occurs which is wet during the whole year.

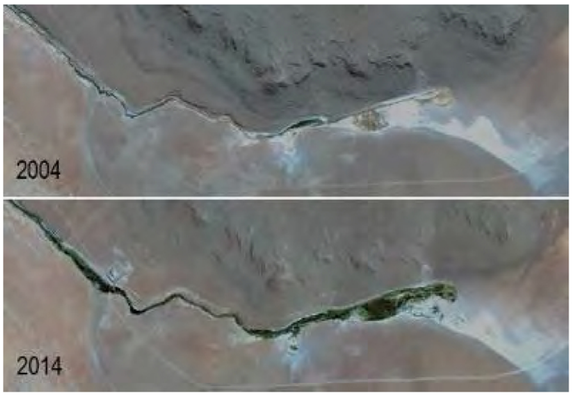

Figure 3-1 Vegetation coverage of the soil in the Southern Bofedal.

The identification of vegetation types was performed during the field works and the border of the bofedals were indicated based on indicator species and marked using the GPS system. The particular steps of determining the borders were described in detail by using analytical features in the ArcMap 10.3 program.

To identify the recent historical range of the bofedal, interviews with local community were carried out and based on their knowledge, and with the use of GPS, the recent historical borders of the bofedals were recorded and added to the GIS maps.

3.2.2 Field works

The investigations of the Northern and Southern bofedals and the Confluence area were done with the involvement of a wide range of biological assessment methods, each dedicated to specific sections of the biology. In total, seven major groups of flora and fauna were investigated, and the results are shown in the table below. Each of the groups are further described below the table.

Table 3-1 Overview of the seven areas of investigation and the outcome, based on total number of species/families identified (Cf. p49 of report)

Taxonomic Group	N° of total species	N° of endemic species for Bolivia	N° of endangered species	New records for Potosi	New records for Bolivia	N° of typical bofedal species
Flora	86	1	9	17	2	13
Macro-invertebrates[¥]	26	0	1	15	1	6
Fish	1	-	-	-	-	-
Amphibians	2	1	1	-	-	-
Reptiles	4	-	2	-	-	-
Birds	35	-	2	-	-	19
Mammals	13*	1	1	#	#	0

Vegetation

For vegetation identification the transects and quadrants methods were used. They are two ecological tools that allow the user to quantify the relative abundance of environmental units in an area. The quadrat is a square sample plot or unit for a detailed analysis of vegetation.

Transects were appointed along the bofedals and the transverse lines were installed. The longest transect line was 50 m and one record was taken out for every 50 cm. Each transect consists of approximately 100 records. Several quadrants of 1 x 1 meter were made on each transect and all vegetation inside the quadrant was recorded. Information about total number of transects in each sector was not given. Besides vegetation cover and species assessment in each quadrant, the following physical measures of the bofedals were made: compaction and the depth of the organic matter.

The weighted weight statistics were performed to evaluate occurrence of each species in the area. Based on data analysis the mapping of categorized plants was performed. The report does not have a direct reference to the produced map.

The analysis included abundance range curves or Whittaker curves, which are used by ecologists to display relative species abundance. The interpretation of graphs was given with references to *Feinsinger 2004*.

In addition, the Principal Component Analysis (PCA) was performed to visualize patterns of the organization of the species. The method is widely used in various fields of investigation and for different tasks including environmental surveys. The objective of principal component analysis is to identify hidden pattern in a data set, and to identify correlated variables. Additionally, the Coronary Canonical Analysis (CCA) was used to determine which environmental variables significantly affect plants communities.

The environmental impacts to the bofedals caused by the artificial canal system were defined based on quadrant data and multivariant analysis. The vegetation units were established and the frequency of them was quantified. The ecological quality evaluation of bofedals was used based on the reference *Meneses et al, 2012 and 2014,* who did several studies of bofedals in Bolivia. Unfortunately, the cited literature is either not published or in Spanish. The study from

2014 (Métodos para cuantificar diversidad y productividad vegetal de los bofedales frente al cambio climático) looked at other bofedals in the Altiplano and the thesis was that the bofedals would most properly be reduced due to the recession of glaciers as the water-feeding system for many of the bofedals.

Aquatic macroinvertebrates

During additional surveys performed in three types of canals (with stone, without stone and naturalized) the aquatic macro-invertebrates were identified. The surveys were performed on 20 sampling stations with 3 subsamples per station. The samples were further analyzed in an external Institute to assess diversity.

Furthermore, on each station the physical-chemical basic parameters and morphological-structural parameters were studied.

The method for collecting the samples are not described in detail, but it is assumed that the sampling method is the standard kick-net method used globally, where kicking the streambed along three transects moves the bed-dwelling macroinvertebrates up into the water column and then they are moved by the flow into the net.

Ichthyofauna / Fish

To determine occurrence of the species of fish, hand nets were used**.** The highest attention was put on the populations of trout (*Oncorhynchus mykiss*) as the rainbow trout was widely introduced to the aquatic system of the Bolivian Altiplano since the 1940s. This exotic species was characterized in detail, and a description of its life cycle was given. It was defined that the trout of the Silala area comes from the fish farming program that was launched in 2013. The authors underlined that the number of this species identified in the waters of Silala could not be estimated. The present study did not catch any fingerlings, which could be caused by the use of nets for catching the fish instead of using electro-fishing. The current density of trout in the area is estimated as 20 to 54 trout per linear kilometer.

It was explained that presence of trout might influence on erosion processes in the margin canals and as a consequence accelerate the flow of the water from the canals. Given the fact that the fish fauna plays an insignificant role, using more than two pages for the description of the inversive trout may be bit out of proportion.

The method using hand nets is usually only used to catch larger fish, whereas fingerlings may easily escape. If the focus had been on the fish, it would have been expected that electric fishing would have been used. However, the review found that the fish fauna is considered having only a minor, if any, effect on the development of the bofedals, although much effort has gone into the investigations. It is also the assessment with most references.

Herpetofauna / Amphibians / Reptiles

The amphibians and reptiles were captures, using the Free capture method. The assessments were carried out both during the day and the night through walks in the terrain. Criteria of estimations were explained, however, there are no references to any of them.

The method used is a standard way of recording amphibians and reptiles, although methods using various types of traps are also common.

Avifauna / Birds

To observe the presence of the bird fauna, the transect method was used. Here an observer goes through the terrain once a day for three days. The method is considered standard, while use of nets are mostly used for recording migratory birds.

Macrofauna

The bofedals are used as grazing areas for the Viscacha's and the Vicuñas, and these species were observed during the surveys. Other larger animals representing medium or large mammals were identified by their feces, tracks and dens.

The assessment of the macrofauna was carried out using traps. In each of the three study areas, a number of rodent-traps were set out during the day and checked the following morning. This was done for 3 days. When the animals were captured, the standard characteristics were taken (length, weight, sex and reproductive status).

The approach and methods used in the study are thus considered applicable

3.3 Discussion of results and conclusions

Historical background of anthropogenic use of the Silala area were given, paying particular attention to canalization of Silala waters. Based on interviews performed among local people, the observation of the drying out the area of bofedals was confirmed, which was substantiated by the decreasing number of typical vegetation of bofedals and other specific flora species for this region (yareta).

Local climatic conditions were described and compared with a study performed in 2004 by Urquidi. Results were collated in a table, where the specific differences were identified. However, the study does not look further into other climatic aspects such as potential climatic changes during the last 100-120 years to assess whether such changes could have been the cause for some of the observed changes to the bofedals.

The lack of some physical-chemical parameters was noticed e.g. morphological-structural parameters. However, the factors mentioned in the table were clearly described.

Quadrant data results were presented in the table, categorized and confirmed by studies of *Palabral- Aguilera* performed in 2016. In these studies, the increasing number of dry zones related vegetations were noted. Information stored by the National Herbarium of Bolivia concerning the diversity of plants from the South Lipez Province were compared to the results of the study. The results showed that registered number of family, genera and species were lower in Silala region comparing to whole mentioned province. The number of endangered and vulnerable species was given for both regions and the report has listed that three of four species of vegetation occurring in Silala region are endangered or vulnerable species.

The results of macro-invertebrates were presented superficially. The taxonomic list of the macro-invertebrates is the result of the first macro-invertebrate survey ever done in the bofedals of Silala. The study of the macro-invertebrates did not add additional information to the overall interpretation of the changes in the bofedals and the results have not been used substantially to underline the overall findings.

Data analysis results concerning ichthyofauna were presented exhaustively. Description of the results is complex with references and supported by distribution map of typical species of ichthyofauna most common in the surrounding region that corresponds well with the descriptions presented in the methodical chapters. However, native fish species found elsewhere in the altiplano were not found in the Silala streams. The report does not look further into reasons for the missing fish fauna.

Data obtained from survey of herpetofauna and avifauna were described well. All information was presented in clear and accessible way. Both photographs, tables and reviews are included.

Statistics

Two statistical tools were used to better interpret the data.

The main method used was Principal Component Analysis (PCA). It is very widely used in multidimensional comparative analysis, which allows the user to compare objects or sets consisting of several variables and find relatively quickly, the most important features and properties of these sets. Multidimensional comparative analysis leads to reduction of a large number of variables, characterizing objects to a few basic ones, which can be subjected to detailed analysis. It is also used for grouping of objects characterized by very similar properties and isolation of the most typical phenomena or processes which results in a reduction in the time and cost of research and explanation of the structure of links between the characteristics of objects. The PCA results were presented in the form of biplots showing among others the plant species examined as a function of the dominant species of the Northern and Southern bofedals and the Silala Confluence (Figure 3-2).

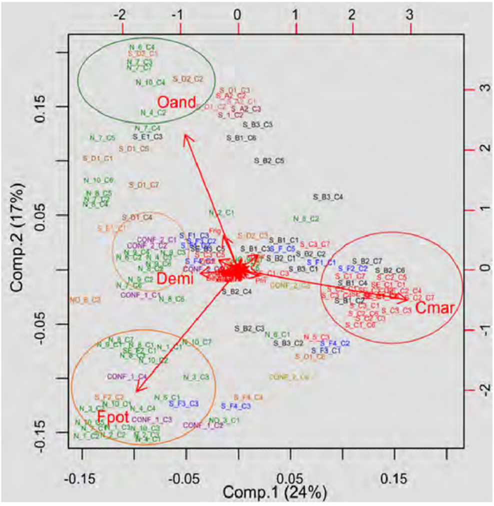

Figure 3-2 Example of biplot used in the report to present articulation of the plant species examined as a function of the dominant species of the Northern (N) and Southern (S) bofedals and the Silala Confluence. The circles depict the different plant groups. This analysis allows depicting the differential impacts of the canalization works on the plant species of the South and North bofedals. The direction and length of the arrows show the correlation between the variables and the principal components. The codes are presented in Annex 2 of the report. Color Green depicts the quadrants of the North (N) fragment; Pink represents the S_A quadrants; Black the S_B quadrants; Red the S_C quadrants; Brown the S_D quadrants; cherry the S_E quadrants; Blue the S_F quadrants; and purple the confluence sites (CONF).

The Canonical Correlation Analysis (CCA) method was used for abundance and composition variations on basis of the main substrate types found in the Silala bofedals. CCA is a method for exploring the relationships between two multivariate sets of variables and has been developed to allow ecologists to relate the abundance of species to environmental variables. In the report CAA method were used to perform the abundance and composition variations (Figure 3-3).

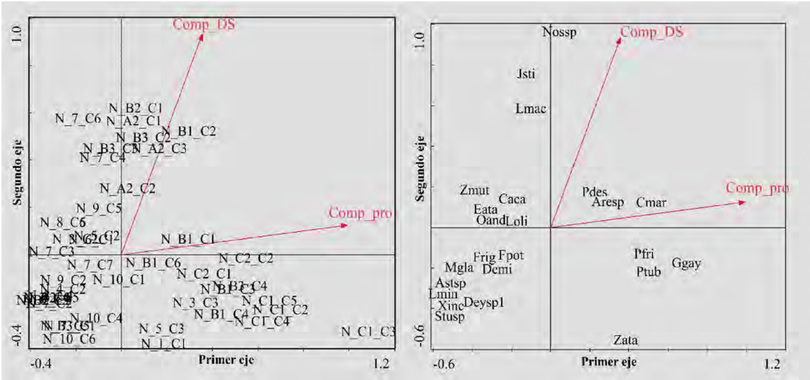

Figure 3-3 Analysis performed to explain the abundance and composition variations on basis of the main substrate types found in the Silala bofedals. Biplot of the canonical correspondence analysis, presenting the environmental variables (based on the Spanish acronyms). To the left, species and environmental variables biplot (morg and hcam). To the right, quadrants present in the bofedals and environmental variables.

The data collected during the survey were appropriate to be used by these types of analytical methods.

3.4 Validation of the Results

The environmental study of the Silala bofedals has shown that the bofedals have apparently shrunk in size, and it is suggested that the introduction of canals in the early 1910-1920s could be the main cause for the changes. Overall, it seems that the reduced area of the bofedals could be linked to a change in the run-off pattern due to the canals, which could have changed the drainage patterns in the bofedals and thereby reducing the areas with permanent wetland status.

The canalization has been a significant factor for the degradation of the bofedals. Their current area is estimated at 0,76 hectares, whereby researches carried out in the Silala region gave raise to assume that the maximum possible extension of bofedals in the past could have covered up to 11 hectares.

This study, in combination with the palynological study, does not indicate a significant change in the amount of water flowing from the two valleys, but the vegetation patterns and the assessment of the stratification in the soils indicate that vegetation close to the canals are represented by typical bofedal species and vegetation further away from the canals are represented by typical dry-land species.

Currently, the Silala bofedals shelter a variety of species and among those also endangered species. However, as a result of the canalisation, the bofedals are now in a fragmented, degraded state of high vulnerability and bringing the bofedals back to previous size and species diversity will require immediate restoration actions.

3.5 References

Several references are cited in the report, although not every method described in the report was supported by references. To ease access to the literature cited, it is proposed to keep the original titles of Spanish literature, which will enable an internet search of the references.

Most of the literature cited is up to date and in many cases not older than 2010, which makes the information included contemporary. That confirms the interest of the region of bofedals and their value. Several publications were checked and assessed and can be considered as credible and reliable, and several of the references are from similar work done in Bolivia or neighboring countries. Below are a few assessments of cited literature.

The reference to *Rambaud et al. (2009)* (p74) related to changes in species diversity in streams with or without canalization. The cited article, although it is related to French streams, showed that changing the physical structure of a stream through canalization will alter the species composition.

The works carried out by *Meneses et al.* and used in the report with three references only leads to one published article from 2014, whereas the other two works cited have not been published and are thus not available for scrutiny.

The reference of *Legendre and Cáceres, (2013)* (p16) was used in relation to the PCA method and the formula used in the statistics to correct for the presence of double zeros between pairs of sites.

Willerslev et al., 2014 is cited, referring to potential usage of antient environmental DNA in sedimentary environments to confirm the presence of fishes in the past. Willerslev focuses in his work on studies of flora in Arctic regions.

The bibliographic references included *Dangles et. all (2017),* however this article has not been cited in the report.

Overall, the cited literature was considered relevant for the study.

In summary, the Silala bofedals have been subject to changes influencing their ecological status comprehensively presented in the report. The anthropological influence in terms of canalization system introduced to the natural environment of bofedals may be an important factor responsible for the changes, as it changed the flows from small braided streams and seepage through the vegetation towards canalized flow.

4 Review of “Environmental Impact Assessment in the Silala, Part 2 – Palynology”

This review has been carried out based on the English version of the report “Survey of Environmental Impact Assessment in the Silala – Palynology” and it has not been cross-checked with the original Spanish version. If there are contradicting interpretations, it may be due to an incorrect translation between the two documents.

4.1 Objectives of the Study

The objective of the *“Survey of Environmental Impact Assessment in the Silala – Palynology”* report under review has been to determine, though various techniques, what has taken place in terms of changes in the vegetation and habitats in the Northern, Southern and Confluence Bofedals of Silala since 1908, when the water in the natural stream was first utilised for feeding steam trains in Chile and later, when a network of smaller and larger canals were dug to improve the flow of water towards Chile. To a large extent this report builds on the findings of the other *“Environmental Impact Assessment Study in Silala”,* which used a wide range of species-investigations of the three sites in Silala. The assessment is mainly focusing on developing a time-line for the last 100-120 years of the development of the bofedals, since 1908 when the utilisation of water from the area started.

The development of the bofedals over time, and especially after the construction of the canals after 1908, has been discussed several times, and the approach in this study has taking several methods into use to assess the different developments in time and space in the bofedals. It is obvious that the canals have changed the drainage conditions in the bofedals and the actual change to specific habitats depends on distance to the canals, where water conditions will determine the development possibilities for the vegetation. Water from precipitation is very limited in the Silala area and the major part of the water comes from groundwater fed springs.

The overall conclusion in the report indicate that substantial changes to the vegetation cover and composition have taken place over the last 100-120 years and that the changes most properly can be related to the initiation of the development of the network of canals in both bofedals. The Southern bofedal has almost completely lost the water- and vegetational features found in an undisturbed bofedal, and the sampling of cores in the outskirts of the valley have also shown that the extent of the bofedal was larger before the canals were introduced in 1928.

The change towards more dry conditions can also be observed when looking at the geochemical results. The geochemical results have also shown that the desiccation was much more advanced between the 1950s and 1960s, which can be taken as an indicator that natural variation may also be a substantial part of the reason for the observed changes. The Northern bofedal seems to have suffered less that the Southern and the report concludes that the geomorphology may play a substantial part in this.

The change towards more dry conditions is also supported by the pollen analyses, which showed a decrease in bofedal and wetland species, incl. algae, from the time of the introduction of the canals. Since 1908 there was an increase in the pollen from vegetation types more associated with dryer conditions.

4.2 Methodology used

The techniques used in the study were carried out on a limited number of soil cores and encompassed the C_{14}- carbon dating method, the pollen dating method, a stratigraphic description and finally the geochemical dating method. The report shows how the combination of the different types of dating methods have added knowledge to better understand the development of the bofedals both before and after the canalisation. Each of the dating methods was used individually and then the results combined to substantiate the findings from each of the methods.

The dating process was carried out only on two cores from the Southern bofedal (stations BSP2 and BSP14) and one core from the Northern bofedal (BNP7), although seven cores were taken in Southern and four cores taken in the Northern bofedal.

The C_{14} dating of the Southern two cores showed large differences between the cores. The C_{14} method mainly works on organic matter and cannot be used for mineral sediment deposits, unless the deposits are interspaced with organic matter or organic matter is embedded in the mineral sediments.

To exemplify the methods used for this report, the core taken out at BSP2 (total depth of the core approximately 40 cm) had a distinguished organic layer on the top, although only 8 cm thick and with the two underlying sediment layers (Cf. Figure 4-1). The upper organic 8 cm was estimated to represent the last 68 years, from 1950 to 2018. The underlying 17 cm was considered to represent to time back to approximately 1880, nearly 30 years before the unset of the utilisation of the water and the consecutive canalisation. The age-profile was also used to add timelines for various metals and their variations during the same years. The sediment layers showed the effects of free-flowing water to carry the sediments, whereas the deposits of organic matter indicate that there were periods with stable and stagnant waters, improving the possibility for the plants to grow and slowly build up an organic layer. However, the vegetation that made the organic layer has been done by species, which are more associated with wetlands and grassland and to a much lesser extent to the expected development of a bofedal.

The development of the flora in the bofedals during time was also assessed by analysing the appearance of pollen in the cores. It is important to realise that pollen is transported with wind and accordingly some types of pollen may come from the outskirts of the bofedals and even from areas beyond the valley. However, the closer to the place of growth, the larger the pollen deposits would usually be.

For BSP2 it was clear that there has been a change from vegetation traditionally associated with the bofedals to vegetation, which to a higher extent represent species, living in more dry land. Remnants of some of the dry-land species were also found in the deeper layers from before the canalisation, but they were most probably growing in the vicinity of the bofedals.

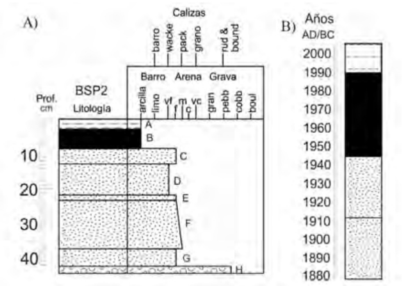

Figure 4-1 Core BSP2 from Southern Bofedal: Example of an age-model, based on a stratigraphic description and the C14 dating method.

The study has used 4 different methodologies to interpret the development of the soil- and sediment conditions in the three bofedals; The Southern, the Northern and the Confluence area. Each of the four methods have added results to a full description of the development of the three sites. This chapter looks into whether the methods used are relevant and have been applied in other places. It also considers known precaution and errors when using the methods.

The cores, which have been used for the assessments have all been taken out with a “Russian Perforator” or “Russian Drill”, which is a manual drill, capable of taking undisturbed soil cores. The use of this type of drill is widely used to extract undisturbed soil cores and the method is used widely for assessments similar to the present project.

4.3 Stratigraphic description

The stratigraphic description of the cores is basically a description of the different layers in the core with indications of colour, texture, soil type, grain size (organoleptic or mechanically from subsamples). Depending on the soil conditions and the stratigraphy of the core, it may sometimes be possible to find objects directly identifiable, e.g. bones, roots and other artefacts. The present study made observations of the layers with high organic contents, indicating vegetational growth as opposed to the sediment layers, indicating conditions with sediment transport in water.

The description is combined with measuring the thickness of specific layers in the core. In principle the stratigraphic description does not say anything about the age of the different layers, but the method can be used to pick out specific layers, which can then be used for additional analyses like C_{14} or other methods. Depending on the conditions in the locality being investigated, the soil descriptions may change substantially on samples take a few meters apart and such diversity was also found in the assessment of the soil cores taken in the three bofedals (Cf. Figure 6 and Figure 14 in the report).

The stratigraphic method is widely used and recognized as an efficient, cheap and reliable method, and in this project, it must be considered basic and necessary for the description of the development of the bofedals over time. As also concluded during the dating processes, it was possible to take out cores, representing nearly 1000 – 1500 years of development in the bofedals.

4.4 C_{14} dating method

The C_{14} method is based on determining the amount of radioactive C_{14} in a sample of organic origin (plant, tree, bone etc). Due to the natural decay rate of C_{14}, it is possible to calculate the age of a specimen with some uncertainty, depending on the age and the condition of the analysed specimen.

The C_{14} method was used to determine the age of the layers recognised in the cores taken out in the two bofedals. As stated above the C_{14} method can only be used on elements of organic origin, which made it a valid method to determine the different layers in the cores and also because the key interest was narrowed down to the last 100-200 years, where the method is relatively precise in determining the age of the elements in the core.

However, it is important to understand that the method for C_{14} dating of soil cores can be hampered through bioturbation, where organic matter from the surface or from the deeper layers may be transported through biological activities (e.g. rodents, or other cave-dwelling animals) up and down in the soil. This may create false dating profiles for a soil as reported by in a paper by Yang Wang et al 1996. Whether this factor has been investigated in the present survey is not stated in the report.

4.5 Geochemical analysis

The geochemical analysis, which makes use of X-ray to analyse the composition of specific metals, has been used in this study. The method was developed in the early 1900'ies and has been refined over the years. The principle is to look for certain metals and look at the interaction between the metals. The metallic composition shows variations under wet and dry conditions and the results can be used as indicators of the soil conditions.

Certain metals like lead (Pb) has a natural occurrence but increases in the contents in most soils in the 20th century co-insides with the use of lead in gasoline and peaks in the lead-profile can be used to a certain extent as rough dating of the soil layers. The soil samples from Silala also show the same trend for lead.

Most of the literature, explaining about the use of the method, are from 1950'ies to 1980'ies and the method is still very common for assessments like the one presented in the report.

4.6 Palynologic analysis (pollen analyses)

The three methods described above can all in combination provide an estimate of the age of a core, whereas the palynology method can add additional information about the vegetation distribution at specific time-frames down through the soil core. The pollen analysis is widely used to investigate the flora at specific periods. The method has many advantages, but it requires skills in identifying the pollen in the sediments. There are some important draw-backs to consider when working with the method and these are not explicitly described in the study. These are among others:

- It is not always possible to identify specific species through the pollen analysis, often only down to family level. In addition, pollen from some species are easily degraded and may not survive in the soil for long
- There is a wide difference in how much pollen the different species produce, and this may lead to an assumption, where a few species seem to be dominant, but in principle it is more about the quantity of pollen produced from the specific species. Flora, where germination is based on interaction with insects, may produce much less pollen than species, who mostly rely on wind-driven germination. Having specific knowledge about such differences can be used to make corrections to the pollen-count.
- The physical size of the plant may also provide large differences in how high above ground pollen is released and thus how far it will fly. Some species are known to have "wind-bags" on the side of the pollen kernel, which makes the pollen fly very far.
- Transport in streams of pollen from terrestrial plants may transport pollen to areas far from where the plant grew and may therefore skew the observation, when the pollen is deposited together with sediments, maybe several kilometres away from the place of growth.
- Bioturbation may move pollen both up and down in the soil and may this create uncertainties in the interpretation of the composition for a given stratigraphic layer (Tayler et al, 2000)

The assessments of vegetation habitats and species diversity made for the two bofedals were based on pollen analyses, but the description of the use of the method does not mention the potential uncertainties, which are exemplified above.

The results from the pollen analyses made on the two samples from the Southern bofedal and one from the Northern bofedal seem to indicate changes in the composition of the vegetation, which could be interpreted as a change from a situation of with another horizontal distribution of water to a situation, where the water is drained into canals and thus a shift from bofedal- and wetlands species to dryland species (especially a substantial growth in species of grass).

The combination of several methods for assessing age and habitat development over longer time spans has also be carried out by other authors in the Argentinian altiplano. *Schittek et al* (2015) have used the same methods and built their age-developments on the same principles, which proves that the methods used in the report is comparable with similar studies, although the other studies did not include the element of assessing water distribution. The study made by *Schittek et al*, both in 2015 and 2016 showed that grazing of the peatlands/bofedals may change the soil structure and eventually increase the compaction of the soil, which may change the porosity and change the water flow in the soil. This aspect has not been assessed in the report, although seasonal grazing and utilisation by humans may indicate potentials for the same situation. Whether the changes in the compaction could also be a reason for the bofedal changes is not assessed any further.

4.7 Discussion of results and conclusions

The assessments carried out in the Silala bofedals in March and April 2018 were made with the aim to prove whether the conditions in the bofedals had gone through a change from wet to dry within the last 100-120 years.

Four methods were used in the assessment: C_{14} carbon dating, stratigraphy, pollen analysis and geochemical analysis. The research team has combined the results from each of the analyses and have tried to provide an age model for the two bofedals. In addition, the age model for each of the three analysed cores has been further developed by adding the results from the pollen analysis and the geochemical analysis.

The combined models for each of the three cores analysed indicate changes in the vegetation patterns with an increase in species adapted to dryer land and a reduction of species adapted to wet land over time. Due to the variations in the findings, the results can be used to indicate that changes in the surface hydrological regime during the last 120 years could have changed the bofedals from a domination of the "original" peat-bogs towards the present situation, where the peat bogs are diminished and only represent a few percentages of the vegetation/habitat cover in the Southern and Northern bofedals.

Due to the very limited number of cores analysed in the two bofedals, the results can only be used as indicators of general changes. However, they show that the bofedals have gone through several structural changes, caused by changes in the hydrology. The cores taken in the Northern bofedal, shown in Figure 4-3, have very different stratigraphic conditions and depths, which indicate that the conditions over time and space have not been constant. This is indicated by the interspersed layers down through the cores. It is therefore important to use the results from the core analyses with caution, when using the results to be representative for the whole area.

The cores used for the analyses in the Southern and Northern bofedals (Cf. Figure 4-2 and Figure 4-3) showed that even within the relatively short distance between the cores BSP2 and BSP14, there are very large differences in the soil stratigraphy and also in the age-depth models, which again indicates that the conditions in the bofedals are and have been very dynamic. The same is the case in the Northern bofedal (Cf Figure 4-3)

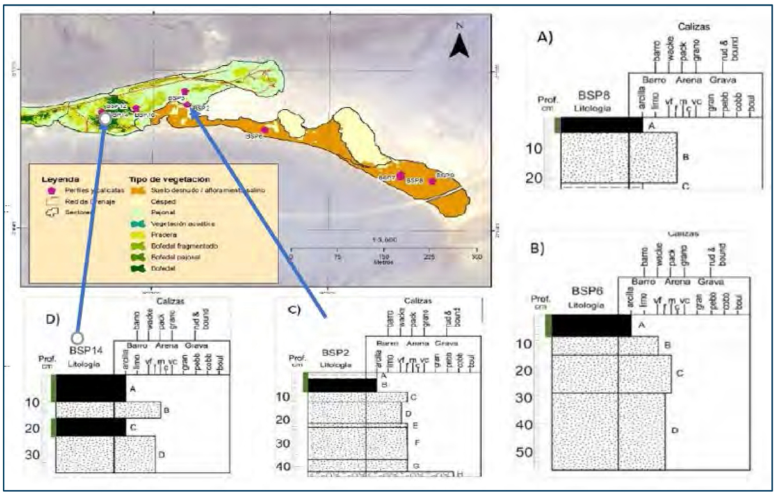

Figure 4-2 Overview of the four cores taken in the Southern Bofedal. The blue arrows indicate the position of the two samples used in the analyses, BSP2 and BSP14.

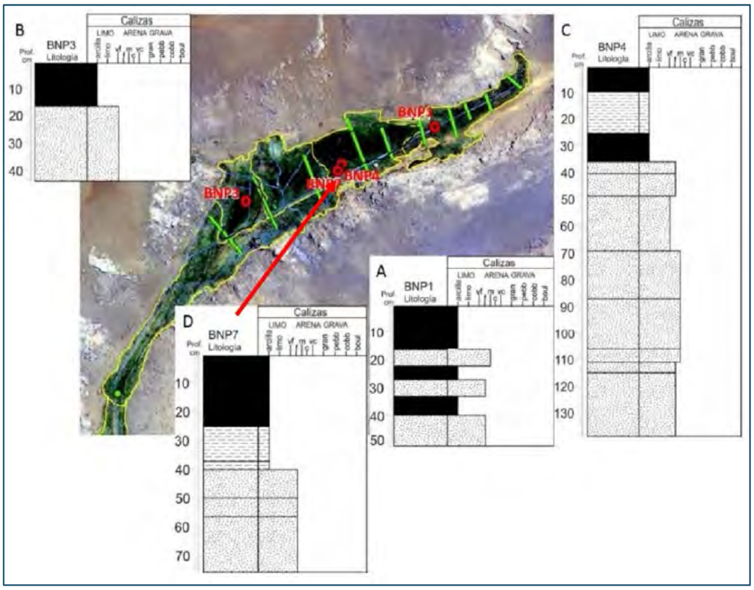

Figure 4-3 Overview of the four cores taken in the Northern Bofedal. The red arrow indicates the position of the sample used in the analysis, BNP7.

All analysed cores are taken from the central part of the valleys and cannot be used to estimate the extension of the vegetation cover for the bofedals. The report does not discuss the known limitations in e.g. the pollen analyses, where biological perturbation or grazing activities may change the pollen contents in the soil profiles.

The introduction of canals in the last century have changed the natural flow-patterns in the bofedals reducing the area with overland flow from large parts of the bofedal surface to the natural topographical "brook" in the lowest part of the valleys. Such change in the flow pattern would likely cause changes in the vegetation cover corresponding to the ones observed.

4.8 Validation of the Results

The overall review of the *"Survey of Environmental Impact Assessment in the Silala – Palynology*" is that the results provided are gained from using recognised methods, which have also been used in other places, both in the region and globally, with the same aim to investigate changes in habitats and soils over time, especially over the last 1000-2000 years.

The results from the core analyses indicate that the central part of the bofedals have gone through a change over the last century from vegetation types associated with wet conditions to vegetation types associated with drier *conditions.* Assuming a constant groundwater inflow to the bofedals the changes in how the water is drained from the area could be the cause of the observed vegetation changes. Figure 4-4 below show the main stone-lined canal in the Southern Bofedal and Figure 4-5 shows the confluence with the two sloping streams coming from the two valleys and flowing towards Southwest.

Figure 4-4 View towards the Northeast in the Southern Bofedal. Observe the stone-lined canal (From DHI 2018)

Figure 4-5 The confluence area. Please observe both the slope of both streams.

Globally, drainage of wetlands has always led to changes in the vegetation cover and have changed the habitats, because the direct access to water for the individual plants have changed. The canals in the bofedals must have led to the same changes, even though the lowering of the groundwater table may only have been a few centimetres. As the main source of water in the Silala area comes from groundwater, the precipitation does only add a limited amount to the water balance in the area and the precipitation by itself is not enough to support the peat-bogs in the valleys.

The impacts from the canalisation is in particular prominent in the Southern Bofedal, where most of the land has vegetation types, mostly linked to dryer land and not to the bofedals. The discontinuation of the maintenance of the canals in the 90's seems to have altered the conditions slightly towards bofedal-type of land at least in the area, where the pollen analyses for the soil core BSP2 has an increase in typical bofedal species from the Juncaceae family.

In conclusion, the results in the report clearly point towards observed changes in the two bofedals, and there are also indications that the changed water flow caused by canalisation, may be one of the main reasons for the changes, which have taken place during the last century.

The limited time has not provided possibilities to look at changes by altering the canal conditions.

4.9 References

Several references are cited in the report and the review has taken out a limited number of these for assessment, whether they can be considered trustworthy and whether the references are made to proper scientific journals.

The relevance of radiocarbon dating is discussed on page 16 and *Hattle and Jull* are cited in relation to how far back the C_{14} method can be used. Searching for the original article did unfortunately not give any results, but the article by *Hattle & Jull* has been cited at least 29 times, which indicate that the reference must be considered acceptable. Other research work from Bolivia has been using the same method for assessing changes in the climate in the Cordillera Real, e.g. *Abbott MB, Wolfe BB, Aravena R, Wolfe AP and Seltzer, G. O.*, in their article from 2000.

5 Review of study: *"Technical Analysis of Geological, Hydrological, Hydrogeological and Hydrochemical Surveys Completed for the Silala Water System"*

5.1 Summary

DHI Water & Environment (DHI) has been commissioned by Strategic Office for the Maritime Claim, Silala and International Water Resources (DIREMAR) to conduct a review of Bolivian geologist, Fernando Urquidi Barrau's *Technical Analysis of Geological, Hydrological, Hydrogeological and Hydrochemical Surveys Completed for the Silala Water System* (Urquidi, 2018). Urquidi (the author[1]), a geological consultant, compiled a technical analysis (the report) based on reviewing the following third-party documents:

- The National Geology and Mining Service of Bolivia report, Study on the Geology, Hydrology, Hydrogeology, and Environment of the Silala Springs Area (SERGEOMIN, 2003).
- The National Geology and Mining Service of Bolivia report, Structural Geological Mapping of the Area Surrounding the Silala Springs (SERGEOMIN, 2017).
- Tomas Frias Autonomous University report, Hydrogeological Characterization of the Silala Springs (UATF, 2017).
- DHI report, Groundwater Flows (DHI, 2018a).
- DHI report, Study of the Flows in Silala Wetland and Spring System (DHI, 2018b).
- Isotope analyses results from Hydroisotop Laboratory (Urquidi, 2018).

The original report generated by the author was translated from Spanish to English and is 263-pages in length, including annexes. The annexes, which contribute to 60-percent of the report, or 159-pages, consist of the referenced SERGEOMIN and UATF reports, and the isotope chemistry results provided by the Hydroisotop Laboratory.

DHI's review has been focused on the author's content, the first 104-pages of the document, covering: the summary of the geology, hydrology, hydrogeology, hydrochemistry of the Silala water system; the author's statements within the body of the document; and the author's general conclusions (i.e. bulleted points limited to the final four pages of the report). The annexes of the report were reviewed in a cursory, high-level manner and where the annexes are referenced in the main body of the report, as the focus of the review was the main document. The annexes have not been reviewed in total but only to the extent they are referenced in the main body of the report.

This memorandum documents DHI's review of the author's report, specifically providing the following:

- a high-level summary of the secondary material presented; and a subjective review of the content and general conclusions.

[1] Ph.D (Applied Geochemistry) and member of the Bolivian National Academy of Sciences.

5.2 Objectives of the Study

No objectives are articulated in the report. However, it is understood that the intent is to provide a comprehensive recapitulation of the hydrogeological work completed to-date by various agencies, universities and consultants on the Silala area.

5.3 Methodology used

As noted above, the study does not include original field investigations or analysis but rather is a recapitulation of a number of studies, including DHI 2018b. The majority of the material in the General Conclusions section is a reproduction of material from the DHI report, Study of the Flows in Silala Wetland and Spring System (DHI, 2018b), and therefore does not constitute a primary technical analysis.

The author's principal findings are summarized in the proceeding subsections.

5.3.1 Overview

The Silala is a transboundary groundwater system located on the Western Cordillera of the Andes, straddling both Chile and Bolivia. The system contains multiple aquifers, over 70 springs, and streams that feed local wetlands (i.e. bofedals). The springs originate from fractured/jointed ignimbrite aquifers that are dacitic, andesitic and rhyolitic in composition. Flow through the aquifers is dominated by secondary porosity, in fractures and joints. The two, local bofedals of concern are the North Bofedal (Cajones) and the South Bofedal (Oriental). Groundwater from areas of the Silala are believed to daylight as springs in areas of the Negra Ravine located within Chile, and in the Main Ravine in Bolivia. The survey of 37 springs in the Main Ravine show that 27 of the springs originate from joints in the ignimbrite on the walls of the ravine, and 10 springs originate from the floor of the ravine. Surface water flows through the Silala have been modified by engineering (i.e. artificial channelization via stone channels) to deliver water from the watershed in Bolivia across the border into Chile. These stone channels drain the two bofedals of concern.

5.3.2 Igneous Geology

The igneous geological framework of the Silala area is made up of three layers of semi-welded volcanic ash (i.e. Silala Ignimbrite 1, 2 and 3), two episodic volcanic detritus flows, and a thin tuff layer below the second volcanic detritus flow. The Silala Ignimbrite 1 (Nis1) is believed to be the unit that contributes groundwater flow to the springs within the Silala.

5.3.3 Quaternary Geomorphology

The valleys in the Silala are filled and covered with Quaternary deposits consisting of the following:

- glacial moraines (i.e. evidence of three groups of moraines at 4,500, 4,600, and 4,800-masl);
- fluvial-glacial deposits (volcanic and pyroclastic rocks deposited on the outlet of glacial valleys);
- colluvial-fluvial deposits (deposited on embankments and product of gravity and intermittent runoff);
- colluvial deposits (blocks, boulders and gravels forming cones at the bases of inactive volcanoes);
- alluvial fans; and

- alluvial deposits (very fine sediments, consisting of mostly organic matter found in the bofedals).

5.3.4 Structural Geology

The general fracture system of the Silala area displays four structural trends. The four domains observed are:

- The main system has a general NE-SW trend with open fractures causing the SEE sector springs.
- The second system has a longitudinal NW-SE trend with closed fractures and lacks springs.
- The third system has a general N-S trend, with volcanoes aligned in the same direction; this system contains closed fractures and lacks springs.
- The fourth, and final domain, presents lineaments in an E-W and E-NE direction with open fractures that lead to springs in the NWW sector.

5.3.5 Hydrology

The North Bofedal and South Bofedal contain a total of 23 and 21 streams, respectively. Each of the streams has an engineered 0.3-m collector channel that flows into a stone-lined main channel, with a width varying between 0.8 to 1-m. The flow in the main channel on the Bolivian side of the Silala has been estimated at 160 to 210-l/s. Approximately 60-percent of the flow in the main channel is from springs in the North and South bofedals[2].

5.3.6 Hydrogeology

A spring survey in the Silala identified 70 springs in four different zones. Physical and chemical parameters (i.e. temperature, pH, dissolved oxygen, salinity, total dissolved oxygen, electrical conductivity, and flow) were collected from each surveyed location. Based on deductions and observations from the spring survey, the bofedals located in the Silala are interconnected to, and are dependent on, groundwater discharge. Geophysical studies conducted in the area confirm that groundwater moves through fractures in the ignimbrite aquifers and from consolidated/unconsolidated rock that feed the bofedals.

Four 2.5-inch diameter, 10-m deep, piezometers exist in the North Bofedal. Water levels collected from the piezometers were observed between 0.4 and 0.67-m above ground level.

A hydrogeological study was completed by DHI with wells drilled and hydraulic testing conducted by SERGEOMIN and Maldonado Explorations SRL. DHI's study was based on the following work:

- drilling of 35 standpipe piezometers at 29 locations to collect water levels and groundwater quality samples;
- single-well slug testing (i.e. slug testing on wells less than 15-m);
- single-well packer testing (a total of 10 Lugeon and 12 Lefranc tests); and
- constant-rate pumping test on DS-4P in the South Bofedal with multiple observation piezometers at various depths.

Data and information gained from DHI's hydrogeological study was used to develop conceptual and numerical groundwater models, delineating seven Hydrogeological Units (HGUs). DHI identified HGU-7 (Silala Fault) being the most important as it hosts the largest number of springs and exhibited the largest hydraulic conductivity (i.e. geometric mean above 7.0-m/d). Hydraulic

[2] Reviewer's note: The remaining 40% originate from diffuse groundwater inflow along the canals (DHI (2018b)

testing showed HGU-6 (ignimbrite with high degree of welding) with the lowest hydraulic conductivity (i.e. geometric mean below 1.0-m/d).

5.3.7 Hydrochemistry

The Bolivian Ministry of Environment and Water carried out four, water quality sampling events in 2017. The sampling campaigns collected water from springs, wells, and channelized surface flows. Results from water quality sampling show a contrast in chemistry between the North and South Bofedals. The samples collected from the South Bofedal contained higher levels of bicarbonate, calcium, magnesium and chloride. Additionally, the South Bofedal contained lower bicarbonate-magnesium ratios. Both bofedals contained water with uniform high silica concentrations (i.e. 22.5-mg/l). Sampling results classify the water type in the Silala springs as sodium bicarbonate.

For radiocarbon dating, 12 samples were collected from the Silala for ^{14}C analyses. Radiocarbon dating results indicate that the water in South Bofedal is approximately 10,000-years older than that in the North Bofedal.

Additional water samples were collected (i.e. 25 surface samples, and nine groundwater samples) for isotope analyses, specifically stable oxygen and hydrogen (i.e. ^{18}O and ^{2}H ratios) and tritium. Results from stable isotope analyses suggest two main groundwater sources: 1) shallow and local recharge; and 2) deeper and older flows from the Silala Fault system. The concentration of tritium was zero, indicating that the water sampled was older than the past 90-years. Furthermore, the isotope analyses suggest that precipitation in the area (at the time where the groundwater infiltrated) did not originate from the Pacific Ocean but was derived from the Atlantic Ocean or from the macro-Amazon basin to the east.

5.4 Discussion of Results and Conclusions

The discussion below is not exhaustive and does not include every occurrence of unsubstantiated conclusions by the author. Furthermore, it also does not address potential translation errors, reference discrepancies or subtle misuse of technical terms or concepts such as the difference between groundwater age and apparent age and oxygen-18 versus delta oxygen-18, which are pervasive throughout the text.

The following is a discussion of the key results or conclusions provided by the author that:

1. provide new information or data that may materially affect DHI's 2018 study;
2. are discordant with DHI's own findings as part of the 2018 study; or
3. are considered relevant to the estimates of the Silala trans-border flows.

The effect of having inconsistent conceptual models and interpretations, as well as, conclusions not well supported by technical data as part the study is not considered as part of this review.

5.4.1 Formation of the Silala Spring System and Proxy Sites

The author states that the Main and North Ravines were formed by glacial processes, and that the valleys exhibit typical glacial geomorphology features such as: "U-Shaped" forms; glacial soil profiles; and striation marks on valley walls. However, the profile could also be interpreted as box-cut, formed by large event, fluvial or glaciofluvial processes (e.g. large melt-water event). It would seem that the description in Annex 2, which emphasizes the glaciofluvial processes along previous zones of weakness (i.e. Silala Fault Zone), appears more reasonable. Regardless, it is immaterial whether the Silala ravine was formed by glacial or glaciofluvial processes and introduction of this material into the technical discussions is unnecessary.

Similarly, there is not a well-developed scientific case presented for Negra ravine being a reasonable proxy for the natural conditions of the Silala ravine system. The spring discharge rates, streambed slopes and geologic controls on flow have not been shown to be comparable. While the ultimate source of the discharging water at Negra ravine is likely the same as the southern wetland based on the water quality comparisons, there are many other considerations that would need to be evaluated to argue it can be used for a proxy of pre-channelized conditions in the Silala ravine.

5.4.2 Recharge - Discharge Relationships

There are a number of discrepancies between the precipitation reported by the study, its appendices and DHI (2018b). Precipitation is an important parameter as it provides insights into the degree to which modern precipitation shapes the geomorphology of the area and the potential for modern groundwater recharge. Furthermore, some of the data relied upon by these studies was shown to be of dubious quality (DHI, 2018b).

The author states that water produced by the mass melting of glaciers was an important source of the current groundwater stored in the Silala Aquifer and that glacial thawing and copious rain of the Tauca Facie is the biggest source of the current groundwater stored in the Silala Aquifer. No data is used to support these statements and thus the case for this hypothesis cannot be reasonably evaluated. Based on the data available to DHI, all that can be stated presently is that the apparent age of groundwater in association with the South Bofedals is older than 10,000 years. Therefore, while perhaps it is not unreasonable from a timing perspective, the origins of the deeper water discharging to the South Bofedals remains poorly defined.

The conclusion that recharge in the Silala area is not possible (Annex 3) due to the water deficit is inconsistent with DHI 2018b, as well as other studies in the Andes that demonstrate that while modern recharge may not happen every year it does occur in response to large events (Houston, 2002; Houston, 2007 etc.).

Not all water discharging to the springs is interpreted as artesian, as stated in the report. Some of the springs along the margins appear to be seepage faces associated with the phreatic surface. Furthermore, available time series data series from the Bolivian and Chilean permanent flumes show mean flow rates around 160 l/s – 210 l/s with the series from Chile generally being 15-25 l/s lower than the Bolivian ones. However, the assertion that flows are constant relies on the limited time periods measured which are not sufficient for a final conclusion, see (DHI 2018b).

The statement “the quantity of surface water was highly modified by artificial channelization”, while likely true, it is stated without evidence to support this assertion. For the a technical study of this type to appear confident and unbiased, such types of strong statements, emblematic of much of the text, should be moderated to reflect the certainty by which the statement can be supported, and be backed by technical analyses and data. It would be of significantly more value to reference the findings of the DHI study and any other information/studies used to develop various concepts and conclusions. Furthermore, the reviewer recommends limiting the findings to technical determinations rather than non-technical conclusions such as whether Silala is an international river course.

5.5 Validation of the Results

Overall the author’s conclusions are largely drawn from either the DHI 2018a report or variants of reports that were used in the DHI study. The findings are largely consistent with those of DHI.

However, the author's narrative seems not solely based on technical objective interpretation of data and analyses presented. This impression stems from the numerous unsupported statements and lack of presentation of or referencing materials on which the author's conclusions are drawn.

There are also inconsistencies in data used and conclusions drawn, which contradict the findings of DHI 2018b. Key contradictions have been highlighted in preceding sections and largely focus around the role of glaciation in development of the Silala ravine and recharge – discharge relationships in the Silala area. However, numerous others contradictions exist and resolution of these would provide a more coherent and consistent technical assessment.

In DHI's opinion:

- Our conclusions on the recharge –discharge relationship, although still rather uncertain, still seems more trustworthy than those of the author, as DHI's conclusions are based on a broader selection of data sources (satellites, ground stations, reported spatial trends and other studies) and more comprehensive analyses of these data,
- the discussion of the glaciation of the Silala Ravine itself is irrelevant to the present day hydrogeologic system. It does not affect present transboundary groundwater or surface flows or their management.

In general, the information provided does not materially change any previous DHI conclusions or study outcomes, including estimates for transborder flow.

5.6 References

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6 Final validation of the results of all studies

This section describes the overall results of the five studies and evaluate if they affect the findings of previous studies and how they contribute to a better technical understanding of the environmental, and water aspects of the Silala Springs System.

1st Review, Hydraulic study:

"Characterization and efficiency of the hydraulic works built and installed in the Silala sector"

The study provides detailed evidence of the extent and properties of the canals. Photos and measurements also demonstrate the extensive drainage and the negative environmental impact on the natural bofedals.

Overall the review finds that the report provides valuable documentation which supports the conclusion on canal system impacts in agreement with field survey and analysis presented in earlier studies such as (DHI, 2018 b).

Based on field data collected a canal hydraulics model is developed and applied. The model results show high canal flow velocities. In a natural bofedal the flow regime consist of slow porous media flow in the peat in combination with excess discharge in the form overland flow distributed in a braded two dimensional pattern across the wetland vegetation. As such regime is different from the concentrated high velocity flows in the present canals *the study confirms that the canalization has changed the flow pattern of Silala.*

The methodology applied is, however, not valid for assessment of the *quantitative* impacts of the canalization on the surface discharge rates from the Silala. This would require quantification of the water exchange between the canals and the wetlands and between the groundwater and the wetlands as in the analyses of (DHI, 2018 b).

2nd Review, Topography and soil properties:

"Study of geo-referencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs"

The methodology used to produce the detailed *topographical survey* is deemed to be valid for the purpose and the output of the study is certainly relevant and valuable for further hydrological and hydrogeological studies in the area.

Unfortunately, the new survey does not include specific comparisons to the previous topographical surveys carried out for DIREMAR and applied to geo-reference springs and piezometers by previous studies. Particularly the reference to the previously surveyed detailed digital elevation model DIREMAR (2017) or the possible corrections necessary to align it with the new benchmarks is lacking. Such information would add considerable value to the output.

The soil property study documents a predominant presence of sandy soils throughout the study area. The soils all have high infiltration capacities and are considered well drained since none of the test locations outside the wetlands encountered free groundwater tables.

The field experiments reported suggest ten times higher infiltration capacities than used in the previous studies. Although these observations may be uncertain and even too high; the experiments indeed confirm the findings of the previous studies regarding absence of surface runoff outside the wetlands and of the discharge of the Silala Springs and wetlands therefore originating almost entirely from groundwater.

3rd Review:

“Environmental Impact Assessment Study in Silala, Part 1”

The findings showed that the vegetation structure in the bofedals has been altered and it has created a more fragmented (dis-integrated) and degraded vegetation cover and diversity. The status of the Silala bofedals showed evidence of areas with the typical bofedal vegetation types but also of areas, with typical dry land vegetation. The study considers the canalization to be the main reason of development of the dry areas and for the deterioration of the environmental conditions for both biotic and abiotic factors. The main evidence came from the study of the vegetation/ species distribution in the bofedals and comparing the findings with studies of other undisturbed bofedals in the region.

The studies confirmed that the bofedals at Silala have more species and areas covered with plants normally dedicated to the dry margin-zones, whereas the vegetation types commonly associated with the bofedals were fewer and did only cover a small portion of the bofedals.

The approach taken by the research team to describe the current conditions in the bofedals in relation to flora and fauna, is considered a standard well proven approach and the results of the individual studies are presented in the report. The conclusions are drawn mainly on basis of the distribution of the vegetation types, related to dry and wet soils, while the studies of fish, birds, herpetofauna and macroinvertebrates did not add much to the overall conclusion.

This study provides the first quantitative analyses documenting the poorer environmental status of the Silala as compared to similar undisturbed bofedals in the Altiplano area. Hereby, it substantiates the *qualitative* assessments and observations made in previous studies. The findings are in accordance with the hydrological analyses and field studies documenting the drainage effects of the canals (e.g. DHI 2018b and the hydraulic study reviewed above).

4th Review:

“Survey of Environmental Impact Assessment Study in Silala,Part 2 PALYNOLOGY”

The results of the undertaken survey are based on applying four globally recognised methods for assessing changes over time in habitats/soils.

It is verified that the observed changes in the two bofedals from the original peat-bog habitats to more dry habitats have taken place during the last century. The survey has found indications that the flow paths of the bofedals has changes from small braided streams and seepage through the vegetation to a situation, where the canals route the water faster through the bofedals. This change may be one of the main reasons for the alterations in the habitats, which have taken place during the last century.

The review can conclude that the methods used to assess the past century conditions were successful and in line with similar studies in the region. However, it should also be mentioned that the assessment of the previous vegetation in the Northern and Southern bofedal were only based on full analyses on one core in the Northern bofedal and two in the Sothern bofedal. In addition, the two cores from the Southern bofedal showed large variation in the stratigraphy, indicating long-term dynamic changes to the bofedal, most properly caused by long-term natural changes in how water has flown through the bofedals.

In summary the first of the two environmental impact assessment documents quantitatively that the Silala Bofedal is inhabited by species that are mostly linked to dry land and to a lesser extent species associated with healthy bofedals, as found in other bofedals. The analysis of the second impact assessment study has shown that the changes have taken place during the last century, during which the canalisation was implemented.

5th Review:

“Technical Analysis of Geological, Hydrological, Hydrogeological and Hydrochemical Surveys Completed for the Silala Water System”

Overall the author's conclusions are largely drawn from either the DHI 2018a report or variants of reports that were used in the DHI study. The findings are largely consistent with those of DHI.

However, the author's narrative seems not solely based on technical objective interpretation of data and analyses presented. This impression stems from the numerous unsupported statements and lack of presentation of or referencing materials on which the author's conclusions are drawn.

There are some inconsistencies in data used and conclusions drawn, which contradict the findings of DHI 2018b. Key contradictions have been highlighted in preceding sections and largely focus around the role of glaciation in development of the Silala ravine and recharge – discharge relationships in the Silala area. However, numerous other contradictions exist and resolution of these would provide a more coherent and consistent technical assessment.

In DHI's opinion:

- Our conclusions on the recharge –discharge relationship, although related with uncertainty (mainly from the climate), still seems more trustworthy than those of the author, as DHI's conclusions are based on a broader selection of climate data sources (satellites, several ground stations, reported spatial trends from other studies) and more comprehensive analyses of these data.
- The discussion of the glaciation of the Silala Ravine itself is irrelevant to the present day hydrogeologic system and does not affect transboundary groundwater or surface flows or the management of said flows.

In general, the information provided does not materially change any previous DHI conclusions or study outcomes, including estimates for transborder flow.

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UATF, 2018, “Hydrogeological Characterization of the Silala Springs,” 2017, Tomas Frias Autonomous University, Potosi, Bolivia.

Annex 23.1

IHH, "Characterization and Efficiency of the Hydraulic Works built and installed in the Silala Sector", April 2018

(English Translation)

DIREMAR

CHARACTERIZATION AND EFFICIENCY OF THE HYDRAULIC WORKS BUILT AND INSTALLED IN THE SILALA SECTOR

Instituto de Hidráulica e Hidrología
Universidad Mayor de San Andrés

FINAL REPORT, APRIL 2018

HIGHER UNIVERSITY OF SAN ANDRES

FACULTY OF ENGINEERING

CIVIL ENGINEERING MAJOR

INSTITUTE OF HYDRAULICS AND HYDROLOGY

"CHARACTERIZATION AND EFFICIENCY OF THE HYDRAULIC WORKS BUILT AND INSTALLED IN THE SILALA SECTOR"

This study has been carried out by the research professionals of the Institute of Hydraulics and Hydrology – UMSA (Higher University of San Andres):

Dr. Eng. Jose Luis Montaño Vargas

Dr. Eng. Jose Antonio Luna Vera

MSc. Juan Pablo Fuchs Arce

MSc. Eng. Juana Dolores Mejia Gamarra

MSc. Eng. Javier Carlos Mendoza Rodriguez

Director of the Institute of Hydraulics and Hydrology – UMSA (Higher University of San Andres): Institute of Hydraulics and Hydrology, University Campus, Cota Cota Zone, CP 699, La Paz, Bolivia

April, 2018

[Footer on all pages Diremar and IHH's logos]

CHARACTERIZATION AND EFFICIENCY OF THE HYDRAULIC WORKS BUILT AND INSTALLED IN THE SILALA SECTOR

MAIN DOCUMENT

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List of Acronyms

ALC	Latin America and the Caribbean
DIREMAR	Strategic Office for the Maritime Claim HAA High Andean Wetlands
IHH	Institute of Hydraulics and Hydrology, UMSA
UMSA	Higher University of San Andres
IGM	Military Geographic Institute of Bolivia
MMAyA	Ministry of Environment and Water MPD Ministry of Development Planning
SENAMHI	National Service of Meteorology and Hydrology of Bolivia
SERGEOMIN	Bolivian Geological and Mining Service
SNHN	National Service of Naval Hydrography of Bolivia
VIPFE	Vice-Ministry of Public Investment and External Financing

STUDY SUMMARY

The study shows that the level of intervention in the Silala bofedals has been remarkably high, a situation that is reflected by the magnitude of the works built and by the high level of efficiency of water abstraction and channeling. The length of the canals built exceeds 6 kilometers and the catchments in the major contribution springs reach almost a hundred works. The flow with very low velocities –in its natural state– has reached comparatively much higher values, due to the water channeling through the built canals.

The interventions have not only affected the natural water supply of the springs to the bofedals, but they have also affected the body of the bofedales themselves, causing the drainage of these by means of the implementation of permeable canals.

The hydraulic works have caused a strong impact on the natural environment, since the initial condition of these bodies of water has not been respected as natural reservoirs and regulators of the soil–water–biotope system.

The conservation of water bodies has been subordinated to a vision of intervention with the basic principle of improving the amount of water abstraction for use purposes.

In short, the main objective has been to **drain the bodies of water from the springs and bofedals.**

1 INTRODUCTION

1.1 BACKGROUND

With the purpose of studying the legal alternatives to assume the defense of the Silala Springs and other water resources before competent international instances, by means of Supreme Decree N° 2760 of 11 May 2016, the Strategic Office for the Defense of the Silala Springs and all the Water Resources on the Border with the Republic of Chile (DIRESILALA) was created.

On 6 June 2016, the Republic of Chile filed a claim with the International Court of Justice against the Plurinational State of Bolivia, regarding the dispute over the Status and Use of the Waters of Silala (Chile vs. Bolivia), with a deadline for the presentation of the Counter-Memorial of the Plurinational State of Bolivia.

In this framework, the Government of the Plurinational State of Bolivia, by means of Supreme Decree N° 3131 of 29 March 2017, determined the merger of the Strategic Office for the Maritime Claim (DIREMAR) with the Strategic Office for the Defense of the Springs of Silala and all the Water Resources on the Border with the Republic of Chile (DIRESILALA), establishing the Strategic Office for the Maritime Claim, Silala and International Water Resources, maintaining the institutional acronym DIREMAR.

With the purpose of structuring the technical procedural defense of the waters of the Silala Springs, and in order to know the characteristics of the constructed infrastructure that caused an impact on the water flows that emerged naturally from the springs, as well as the hydraulic efficiency intentionally increased to abstract more water volume, it has been deemed necessary to carry out hydraulic technical studies already mentioned above, therefore, the Strategic Office for the Maritime Claim, Silala and International Water Resources, within the framework of its competences, has entrusted the Institute of Hydraulics and Hydrology (IHH), dependent on the Higher University of San Andres (UMSA), the elaboration of the "STUDY OF THE CHARACTERIZATION AND EFFICIENCY OF THE HYDRAULIC WORKS BUILT AND INSTALLED IN THE SILALA SECTOR."

1.2 OBJECTIVE

The general objective of the consultancy work is:

> Carry out a technical study of the characterization and ef ficiency of the hydraulic works built and installed in the Silala Springs area.

1.3 STRUCTURE OF THE REPORT

The report is composed of the following chapters:

1. Documentation review and technical analysis report. The chapter makes a description of the previous documents that are related to the hydraulic works built in the Silala springs area.
2. Natural conditions. It shows the characteristics of possible water movement within the existing bodies of water, in their natural conditions, before being intervened.
3. Registration and description of the materials used. It includes the description of the field works carried out for the survey of the hydraulic works and other infrastructure built.
4. Quantification of the hydraulic works that are in the Silala. It refers to the quantification of the interventions carried out.
5. Detailed physical characterization of all hydraulic works (length, surface area, sections, diameters, gradients, and others).
6. Description and classification of the water intakes built in the springs.
7. Detailed physical characterization of the sections without canalization (lengths, surfaces, sections, diameters, slopes and others).
8. Evaluation of sediment transport that occurs in the sector.
9. Simulation of the hydrodynamic behavior of the flows in the main canal network through the mathematical model HEC- GeoRAS (Hydrologic Engineering Center, 2011) in the current conditions.
10. Conclusions.

1.4 LOCATION

The Silala waters are located in the Quetena Chico Canton, of the Municipality of San Pablo de Lipez (Figure 1); it is part of the South Lipez Province of the Department of Potosi. The bodies of water are classified according to their location as follows:

- Northern reach where the North Bofedal is located.
- Southern reach that is composed of the South Bofedal.
- Reach of confluence and exit to the Bolivia–Chile border.

The use of the previous name corresponds to the conditions of water movement depending on the existing hydraulic works and their operating characteristics.

1.5 METHODOLOGY

The investigation consists in a detailed examination of the field and analysis of the available bibliographic information, both the one that was already published in past years and the one documented in other international publications that date back to when the Silala Springs were intervened. All the related documents are referred to in the bibliography presented herewith.

Through field inspections and information gathering in situ, the IHH-UMSA has carried out an inventory of the hydraulic works [of Silala] at a geographical, topographic, documental, and hydraulic scientific-technical level in order to detail and describe the functioning of the hydraulic works installed in the Silala Springs and their effects.

The analysis of data, research and conclusions to which this document has arrived are supported by a technical inspection works completed in the field. It should be noted that earlier works have also been completed, i.e. hydrometric measurements performed by the National Service of Meteorology and Hydrology of Bolivia (SENAMHI), as well as by the Military Geographic Institute of Bolivia (IGM, 2016) and the topographic studies and canal surveys carried out by the CB Engineering and Construction Technical Consultancy Company in 2018.

The data obtained in the field has been processed and incorporated in a hydraulic simulation to determine the hydrodynamic conditions of the canal flows.

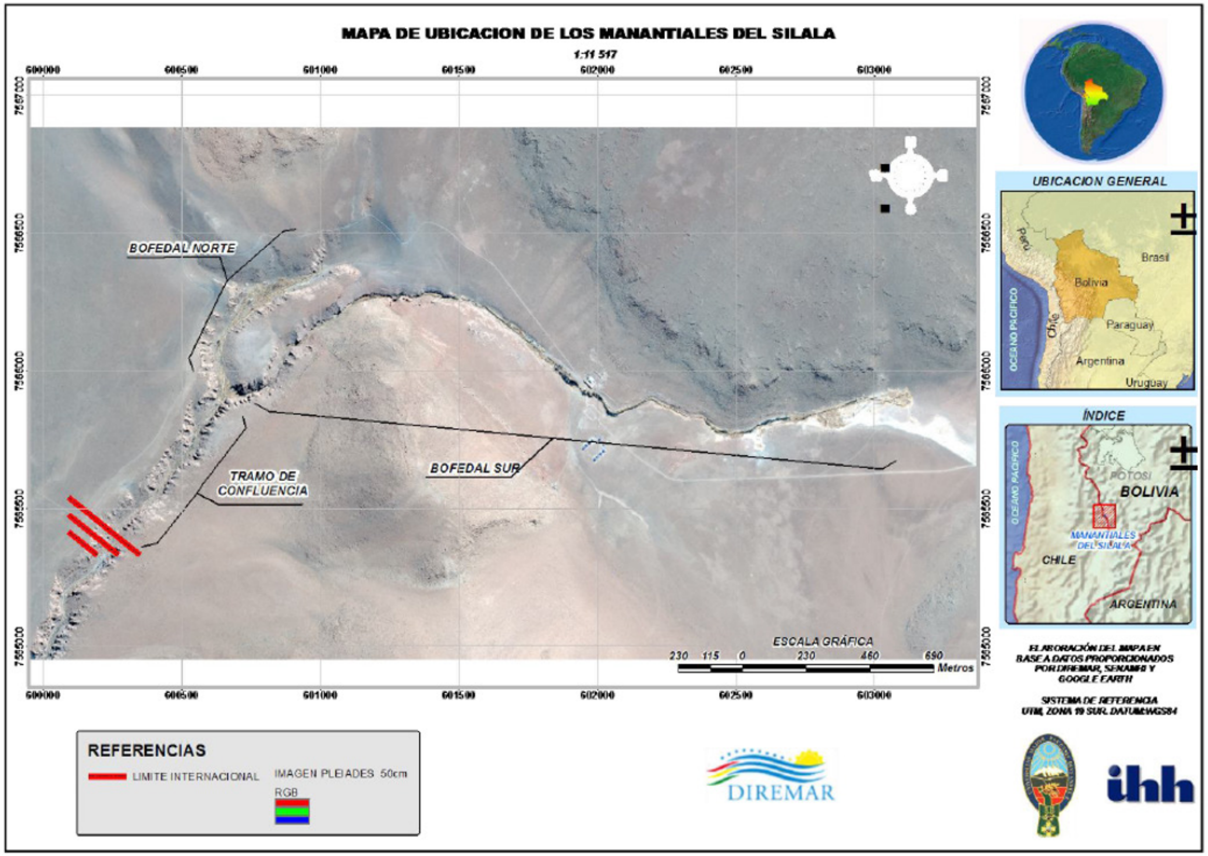

Figure 1. Location of the study area.

2 DOCUMENT REVIEW AND ANALYSIS REPORT
2.1 CONCESSION FOR THE EXECUTION OF HYDRAULIC WORKS

2.1.1 Fox Report (1922)

One of the documents where a description of the first actions carried out on the bodies of water of the Silala is made corresponds to Fox (1922). In this document, reference is made to the fact that "there are four sources of supply from which the company has the right to take water", below, reference is made to a "Siloli Stream" located at 14,154 feet above sea level, which corresponds to a height of 4,314 meters above sea level, that is, above the binational limit that is 4,306 meters above sea level. The company to which the document refers is The Antofagasta (Chili) and Bolivia Railway Company Limited.

In relation to the description made by Fox (1922) the following observations can be made:

- The document refers to a "Siloli Stream". In this regard it should be noted that according to the International Hydrological Glossary (WMO, 2012), "Stream" means a water current and has four meanings:

  1) Mass of water flowing in a natural canal (channel).
  2) Water flowing through an open or closed pipeline.
  3) Water jet that flows from a hole.
  4) Groundwater mass flowing in a karstic formation.

  Thus, the description that is given to the Silala water body in the Fox document is "stream", a word that does not correspond to the physical process of water movement developed in the water bodies of Silala, because in its natural state there was no natural canal (natural channel), **but the movement of water developed in its natural state, as indicated later, in an interaction between water, soil and biotope.**

- In the Fox document reference is made to the other possible sources for the company: "San Pedro River", "Palpana Springs" and "Polapi Springs". In first instance, the San Pedro River description is clearly differentiated from the Silala stream concept, because the Silala is not qualified as a river, but as a current, although in fact the Silala water body does not fit within the definition of current (stream).

It should be clarified that the WMO document (No. 385) defines the term "river" as a "large water stream that drains a basin in a natural way", throughout Fox's document no reference is made or, the category of "river" is not given to the bodies of water of the Silala [sic]. Additionally, the term "spring", according to the WMO, is a "Place where water emerges naturally from a rock or the ground and flows towards the surface or towards a mass of surface water," which reflects that the characteristics of the Silala waterbodies, owing to their condition as springs, in terms of its origin.

•Fox indicates that in the Siloli a small dam was built crossing the current and that it generates a daily flow (with very small variations) of 11,300 cubic meters. In this regard it is necessary to make the following assessments:

- There is no evidence in Bolivian territory about the existence of a small dam, although later the author indicates that this work would be the "abstraction work" (intake), which would have the highest altitude in the world, therefore the water intake work that currently exists in Bolivian territory corresponds to the work described by Fox. Similarly, Fox (1922) indicates that in order to provide good quality water, a water conveyance pipeline was implemented in the year 1900 in several distant springs located in the Andes Mountain Range.

- It is indicated that the flow has "very small variations." In this regard it is pertinent to note that "conventional" river basins that react to a certain precipitation have significant flow variations, in the dry season the water flow rates are low while in the rainy season flows are high, typical regime of a river (which responds to the rainfall- runoff relation in a basin). By indicating that there are "very small variations" in flow, the recognition of the characteristics of the water is demonstrated, in the sense that the contribution of the Silala body of water comes from the upwelling of groundwater manifested through the contribution of the springs, a flow that shows "very small variations," namely, said flow is practically constant throughout the year. This assertion corroborates the fact that the waters of Silala do not respond to a rainfall – runoff relation in its basin (precipitation that does not give rise to runoff).

2.2 SPRINGS ABSTRACTION AND CHANNELING WORKS

Around 1928, specifically through Note N° 143 of 27 January 1928, the construction of the abstraction and channeling works from the springs has been proposed, this is the result of a request sent by the company The Antofagasta (Chili) & Bolivia Railway Company Ltd. (1928), where the order N° 1441 is made known, where it is indicated the need to execute the construction of open canals from the springs of Siloli (The Antofagasta (Chili) & Bolivia Railway Company Ltd.,1928.

In this document, the first possibility of implementing ground canals from the upper springs to the already existing water intake works is proposed. The second possibility is also proposed for the construction of concrete canals instead of earth canals, although it is indicated that, as necessary, the earth canals will be preliminary tasks to the construction of concrete canals. In the facts concrete canals were not built; the earth canals were either left in place of at most protected with joined stonework to drain the bofedals.

The main argument to intervene with canals in the bofedales is based on the water quality, although in the document it is considered as a "small difficulty" (little difficulty) of the source in relation to the need to have a high level of water purity, this situation is justified in the fact of "having found fly eggs" under microscopic examination.

Regarding the document presented by The Antofagasta (Chili) & Bolivia Railway Company Ltd., the following considerations are made:

- It's surprising that the arguments raised for the execution of the works in the bofedales have relation with aspects related to the quality of water, that is, with sanitary aspects, a situation that calls into question the fulfillment of the concession granted by the Department of Potosi, whose objective was to provide water for the "provision or supply for railroad machines". If it is indicated that the quality standards of the source are not desirable, it follows that the water resources of the Silala have been expressly used in the provision of water for human consumption.

- The document indicates "that for some time a small difficulty has been found to keep the water from this source within a high level of purity," in the document it is recognized that the problem posed constitutes a "small difficulty" since a situation described in this way is easily solved by subjecting the water to a disinfection process, this way the pathogens are eliminated, in this case the fly eggs; however, the substantive issue is that the central argument that is posed to intervene in the bofedales does not explicitly manifest it, which is to improve the efficiency of abstraction by increasing the flow, and not so the arguments that are related to the improvement of the water quality.

3 NATURAL CONDITIONS

3.1 WATER BODIES OF SILALA

3.1.1 Bofedals

The Quaternary deposits on the Silala constitute the physical scenario for the formation of bofedales. The mapping performed by SERGEOMIN (2017) – see Figure 2– distinguishes exogenous geological agents, mainly glacial, wind, gravitational processes to a lesser degree fluvial processes in addition to weathering; especially physical and erosion, distinguishing geo-forms of accumulation and erosion. The glacial activity, together with the volcanic activity and weathering, are those that modeled the current geo-morphological structures of the region.

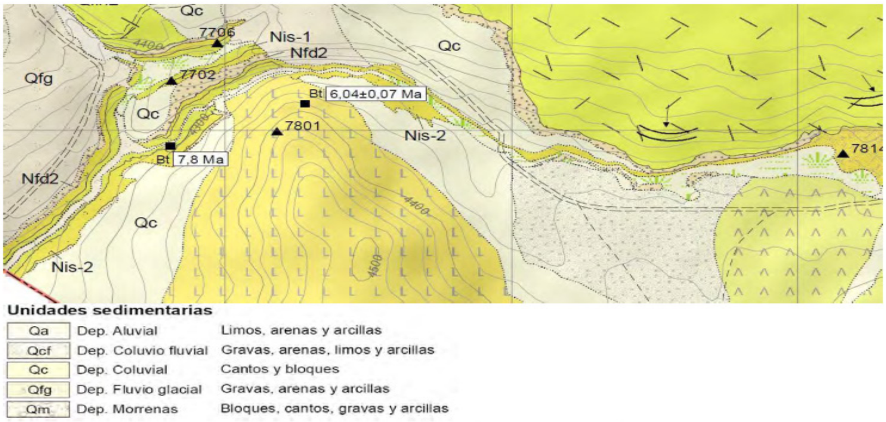

Figure 2. Quaternary deposits (SERGEOMIN, 2017).

The water supply to the Silala bofedales originates in the upwelling of water from fractured rocks. This is the case of the geological formations in the zone, such as the Silala Ignimbrite 1 (Nls1), Silala Ignimbrite 2 (Nls2) and Silala Ignimbrite 3 (Nl3), the variation of the flow with respect to distance is shown in a later chapter, a situation that shows that the underground contribution develops along the bofedals.

The analysis of the water movement through the bofedales in its natural state is done considering the body of water as a unit: water–soil–biotope (see Figure 3). There is a "physical–biological synapse" between these elements; there is a "link between them." It is evident that the biotope includes the other two categories that are water and soil; however, it is intended to link water and soil as elements that act on the eco-zone or eco-region.

The bofedales are High Andean Wetlands (HAA), they belong to a type of ecosystem that is characterized by its perennial vegetation within the semi-arid landscape of the Western Andes; they play an important role in the provision and regulation of water in the basin (Eco-hydrological characterization of high Andean wetlands using multi-temporal satellite images at the head of the Santa river basin, Ancash, Peru, 2015). The Silala bofedales are bodies of perennial water, they are fed by groundwater.

According to the Ramsar Convention (2016), wetlands, in general, are "extensions of marshes, swamps and peatlands, or surfaces covered with water, whether natural or artificial, permanent or temporary, stagnant or running, sweet, brackish or salty." Wetlands are "areas where water is the main factor controlling the environment and the plant and animal life associated with it. Wetlands occur where the water table is on or near the earth's surface or where the land is covered by shallow water."

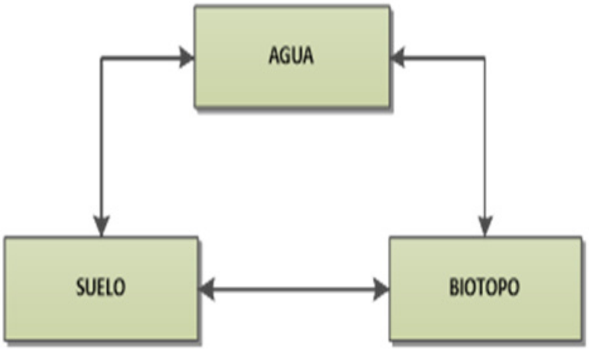

Figure 3. Body of water as a unit.

The term bofedal is very typical of Bolivia, Chile and Peru; it is used to characterize a wetland zone under natural grassland conditions, where there is a type of natural vegetation always green and succulent with high forage potential. The soil is permanently wet (saturated). Its name comes from the word "bofe" or soft organic material that makes it up. They are fragile water systems.

3.1.2 Characteristics of the Silala bofedales

The main characteristics of the Silala bofedales are described below:

- The bofedales are fully related to the springs. The bofedales and springs are related by groundwater mechanisms (see Figure 4). The source of water is entirely underground, along the supply basin there is no trace of possible surface runoff, caused by precipitation.

  The field studies support the absence of surface runoff caused by precipitation. A complete tour of the basin allows distinguishing that there are no traces of surface water movement; there is no evidence of surface laminar flow, as can be seen in the photographs presented in Figure 5.


a) b)
Figure 4. Underground origin of the Silala waters, a) North Bofedal, b) South Bofedal.

Figure 4. Underground origin of the Silala waters, a) North Bofedal, b) South Bofedal.

a) Slope in the upper zone of North Bofedal. b) Slope in the middle zone of the North Bofedal.

Figure 5. Evidence on the absence of traces of surface runoff.

- **The vegetation cover is permanent.** Because bofedales have water in both the dry season and the wet season, the vegetation of these natural reservoirs is always green. The existence of high mountain peat is generally distinguished.

According to DIREMAR (2017), the bofedales of Silala (North and South) have been formed in flat lands, in the bottoms of valleys, where its vegetation contrasts markedly with that of its surroundings due to the lack of humidity or because it is deeper. Coverage that is mainly controlled by the amount and availability of water during the year, since they are considered high altitude wetlands, giving rise to the so-called high Andean peatlands or peatlands with evergreen vegetation, associated with a permanent water supply, predominantly groundwater (see Figure 6).

The vegetation cover observed in the South Bofedal is characterized by vegetation characteristic of bofedales such as Distichia sp, Andean Oxychloe and/or Plantago tubulosa in some places, since there are areas with a lower degree of humidity, there are also low-lying species with predominance of Plantago sp, Gentiana sp, and others that inhabit bofedales without submersion and superficial water table (DIREMAR, 2017).

a) b)

Figure 6. Vegetation cover, a) North Bofedal, b) South Bofedal

The reach of confluence of the North and South Bofedal, although it is of greater slope than in the high part, it is distinguished by the presence of peat that has developed under natural conditions (see Figure 7a), but that due to the effect of the developed actions, abstraction intake and water conveyance canals, has originated the predominance of "intrusive" species as is the case of the grasslands. The construction of the access roads has also markedly modified the bofedals' original nature (see Figure 7b).

a) b)

Figure 7. Confluence reach, a) presence of peat, b) access road.

■ **Saturated floors.** It is observed that both in the North and in the South Bofedal, the soils are fully saturated.

North Bofedal. From the profiles studied by DIREMAR (2017) at the North Bofedal, the depth of the soils varies between 0.55 and 1.4 of depth; below this depth there is parental material, where the water table reaches depths between 0.4 and 0.1 meter. In terms of texture, the soils are sandy-loamy and loamy-sandy. In general, the texture shows a predominance of sand with an average of 90%, 6% silt and 4% clay. The organic matter has a depth that varies between 30 and 48 cm, in some cases up to 80 cm. The sand develops from 0.4 to approximately 1.0 meter.

South Bofedal. In the Bofedal Sur, the depth of the bofedal varies between 0.40 to 1.20 meters deep; underneath there is parental material. The organic layer varies between 0.13 to 0.24 meters, where the water table is between 0.45 to 0.15 meters. In terms of texture there is a greater presence of sand and less amount of sandy-loamy soil. In percentage terms, there is an average of 91% sand, 5% silt and 3% clay.

It is distinguished that the North Bofedal has more organic matter than the South Bofedal; the latter has a mostly sandy texture. The saturation of the North Bofedal reaches 100% while in the South Bofedal it reaches 76%.

■ **They regulate the water system.** From the hydrological point of view and the water regime, bofedales are classified as hydromorphic or udic, because they contain water permanently.

Under natural conditions, the regulation of the water regime is developed in the following areas:

- It receives water contributions from springs.
- It keeps the soil saturated.
- It generates a storage process.
- Water evaporates and evapotranspires according to weather patterns, especially temperature.
- Delivers water to an organic medium.
- Delivers water slowly.

The North and South Bofedales of Silala receive water contributions from springs, as shown schematically in Figure 8. There is no contribution of surface water derived from rainfall; the latter is demonstrated by the measured flows, which demonstrate the variability of its annual regime, a situation that is shown in the next chapter.

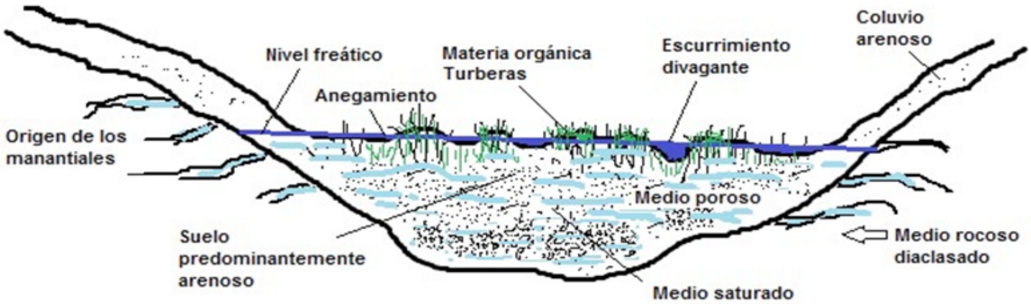

Figure 8. Cross-sectional schematic of the Silala bofedal

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The soils that make up the bofedales are saturated; the water tables are practically located at the surface level (see Figure 8). As a result of the drainage interventions carried out on the water bodies, part of the coverage area of the bofedales gradually lost its natural condition, giving place to unhealthy bofedales (see Figure 9) and allowing the invasion of species that do not require saturated soils, as in the case of grasslands.

Associated to the water storage process of the bofedals are other processes that occur between the soil – atmosphere interface, such as evaporation and evapotranspiration of these waterbodies, whose mechanisms are linked to meteorological conditions and present organic matter. In any case, it is possible to note that due to the effect of low temperatures, surface water freezes.

The water coming from aquifers wells up at the points identified as springs and is integrated into the porous and organic bofedal medium, generating a close interaction between water, soil and biotope.

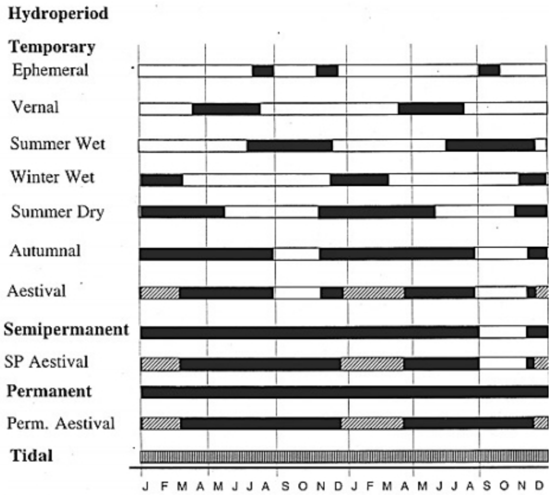

Figure 9. Silala bofedal category according to the water period (Jackson, et. al. 2014)

As a result of the geophysical studies carried out in the zone corresponding to the North Bofedal, plenty of underground water has been identified, arranged in the fractures of the ignimbrites. In the lower part of the valley we can see strongly fractured and jointed rocks, in whose secondary porosity we find water (Sangueza, 2016), which emerges to the surface by pressure difference.
In the South Bofedal it is shown that the waters that emerge come from low depths. According to Sangueza (2016), the bofedal lost its natural storage capacity as a result of the works implemented.

3.1.3 Movement of water in the bofedales

3.1.3.1 Darcy flow

The water movement conditions in the bofedales are governed by gravity, both in the porous medium and on the surface. The movement in the porous medium develops between the inter-granular spaces, while surface movement is generally subdivided into small courses in a disperse and non-concentrated movement.

The conditions of water movement in a porous medium –generally for unsaturated and unconfined flow– are considered from the forces of gravity, friction and suction, the latter corresponds to the force that joins water with soil particles through surface tension. When the inter-granular spaces are filled with water the suction force is reduced. In a saturated medium, however, it practically disappears.

The movement of water in the porous medium can be represented by Darcy's Law:

$$v = k(\psi)\frac{dH}{dL}$$

Where:

v is the velocity of water in the medium

$k(\psi)$ is a permeability tensor that generally depends on the suction load ψ.

dH/dL is the hydraulic gradient.

In natural conditions, the flow of the Silala waterbodies develops in a saturated medium; the suction load ψ is thus nil and the runoff velocity depends on the permeability tensor and the hydraulic gradient.

The permeability tensor k=k(x,y,z) can vary in different directions. However, in the case of the Silala bofedales, they are limited by the parental material. In consequence, there is a predominance of permeability in terms of development of the bofedal along the valley.

If a global analysis of the movement of water in the North and South Bofedales is made, it is noticed that the hydraulic gradient is practically the slope of the terrain, because the medium is saturated.

According to the results of the soil study (DIREMAR, 2017), the permeability and porosity in the North Bofedal have values of 2.6×10^{-7} cm/s and a porosity of 0.47, while in the South Bofedal there is an average permeability of 1.15 $\times 10^{-7}$ cm/s and an average porosity of 0.46. The flow velocity or referential Darcy's flow for the North Bofedal will be of 2.32×10^{-9} cm/s and the linear velocity will be of 4.95×10^{-9} cm/s. The referential flow velocity for the South Bofedal will be 6.54×10^{-9} cm/s, while the linear velocity will be of 1.42×10^{-8} cm/s.

At the referential velocities shown above, the effect of the organic material acting on the inter-granular spaces is added, causing even greater interferences to the movement.

3.1.3.2 Non-concentrated surface flow

In general, the bofedales with intermittent regime, that is to say temporary, the flow of water is defined by two scenarios. During rainy season, the precipitation generates a surplus that floods the wetlands and that allows the water levels to be high enough to overcome the terrain's rugosity and cause the water to find "small channels" where it can move due to gravity towards lower areas, generating a network of several stream branches on the surface of the bofedal. Under these conditions and depending on the magnitude of the excess precipitation, runoff can even cause localized erosion processes, allowing the transport of sediments.

The process of surface runoff described above is opposed to the movement of water in the Silala bofedales, for two specific reasons:

- The precipitation that falls in the Silala contribution basin does not generate an effective precipitation that could cause runoff.
- The precipitation is solid, so that when covering the surface, it has two possibilities: on the one hand, it sublimates, thaws and infiltrates; the precipitation in a liquid state does not manage to generate runoff.

By virtue of what has been described, the Silala bofedales do not receive any surface runoff from rainfall. Therefore, there is no physical process that might form or reach water levels that have the capacity to create a defined channel or drainage network. In contrast, the flow develops as a scattered sheet (Jackson, et. al. 2014) in an environment where micro-topography plays a very important role, as defined by the irregular growth of peat and vegetation.

Under natural conditions, where the area of the bofedales was larger than the current surface area, the flow on the surface was developed in a "**disperse, non-concentrated**" manner in directions defined by the growth of the surface vegetal mass, particularly peat; thus, in the facts there was n**o predominant channel**[1], defined as such, but diffuse movements with components of velocity in different directions.

3.2 GROUNDWATER SOURCES – SPRINGS

The inventory of springs made by SENAMHI and DIREMAR (2018) and the geophysical study using resistive electrical tomography – ERT, carried out by COFADENA (2017), show that the source of the water fed by the Silala bofedales are the springs that emerge along the entire length of the waterbody.

The SENAMHI has identified 138 springs—differentiated in three categories based on their inflows (See table 1) (between major and minor)—that emerge mainly in the South Bofedal and North Bofedal; the springs listed correspond to the most important in terms of contribution and in relation to the abstraction and canalization works developed.The survey of the springs

1 According to the International Glossary of Hydrology (WMO, 2012) a channel is defined as:
1) Clearly defined water course through which water flows periodically or continuously.
2) Water course that connects two bodies of water.
3) Deepest part of a watercourse through which the main current flows.

carried out by the SENAMHI ends at the confluence between the south and north branches with the most important springs.

In the South Bofedal (Figure 10), in the upper part, 49 springs of higher contribution have been recorded (see Table 2); the average slope of the terrain is 0.9%. It can be indicated that the bofedal is the flattest in terms of slope; it is the farthest body of water in relation to the border.

From the upper part of the South Bofedal and the confluence with the South Bofedal (Figure 10), 10 important springs have been recorded. see Table 2.

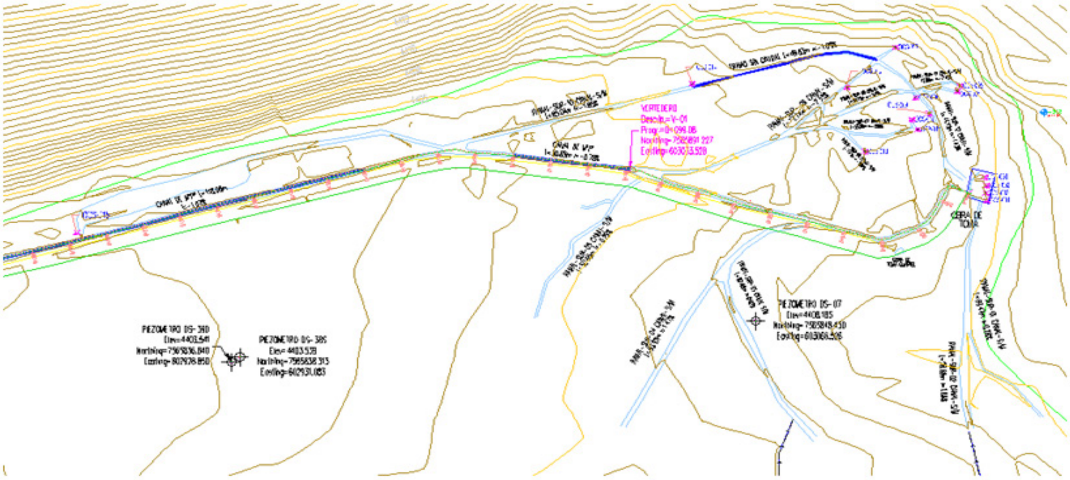

Figure 10. Springs recorded in the South Bofedal (Campos Barron- DIREMAR, 2018)

In accordance with hydrometeorological measurements completed SENAMHI-DIREMAR (2018), 45 springs of higher contribution have been recorded in the upper part, in the North Bofedal (see Table 2), with a slope of 5.7%.

The bofedales located in the Silala Springs area are hydro-geologically interconnected to adjacent masses of groundwater, although this degree of interaction varies from one bofedal to another. In other words, both Bofedales (North and South) are completely dependent on the water transfer mechanism and the type of upwelling of groundwater in any climatic condition.

Table 1. General detail of the Silala Springs
(SENAMHI – DIREMAR, 2018)

SILALA SPRINGS		
CATEGORY	NO.	DESCRIPTION
1	21	With greater surface inflows (measurable with micro-propeller).
2	80	With minor surface inflows (not measurable with micro-propeller).
3	37	With sub-superficial and perceptible flows due to the soil wetting.
Total	138	

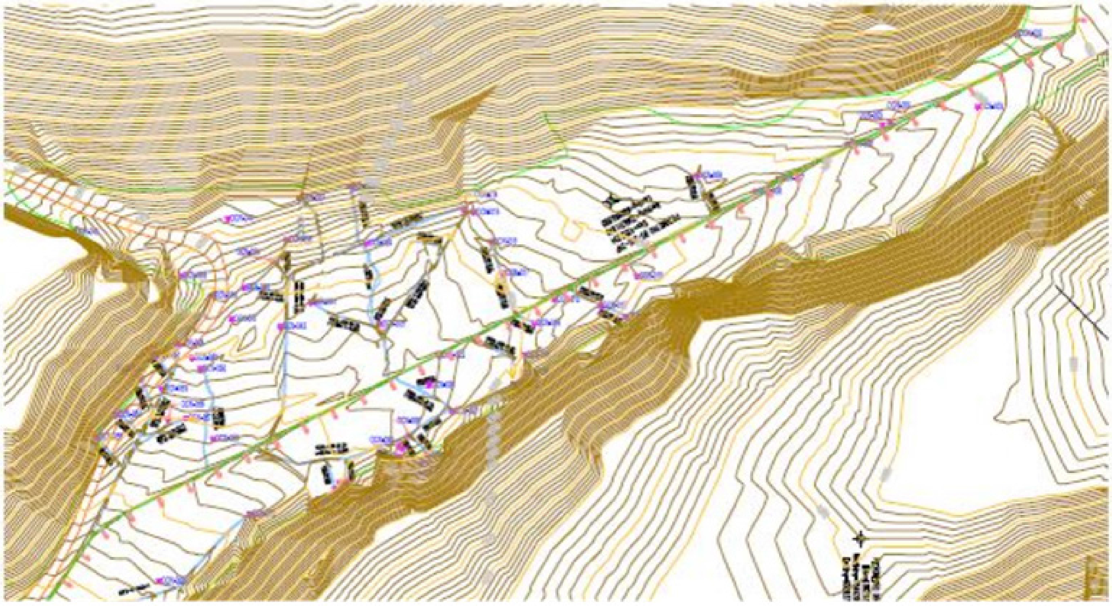

Figure 11. Springs recorded in the North Bofedal (Campos Barron – DIREMAR, 2018)

Table 2. Category of the springs in the South and North Springs (SENAMHI-DIREMAR, 2018)

RAVINE	1ST CATEGORY	2ND CATEGORY	3RD CATEGORY	No.
South	10	39	12	61
North	11	34	32	77

4 FLOW REGIME

The estimated monthly flow values for all the water control points (Figure 12) indicate that the hydrological regime of the basin does not have marked variations in the months and seasons of the year. The first results of the flow analysis in the gauging stations, indicate that there is no clearly differentiated seasonal behavior during the year, therefore, a hydrological regime of the fluvial type cannot be defined for this basin; although there is a discharge towards the Chilean border and even when the flow is through an artificial canal. The hydrological regime shown has similar characteristics to the production of an aquifer.

The flow monitoring in the sector of the Silala Springs area was carried out by the SENAMHI, for which continuous gauging measurements were performed, denominated with the acronym C, and simultaneous gauges, symbolized with the letter S. In both cases the numbering is progressive towards the border.

4.1 Flows in the South Bofedal

The spatial variation of the flow of the South Bofedal in the Silala generally has a growing pattern according to the length and the development of the topographic differences, which goes from the gauging station in the triangular weir C1 until C5, see Figure 12.

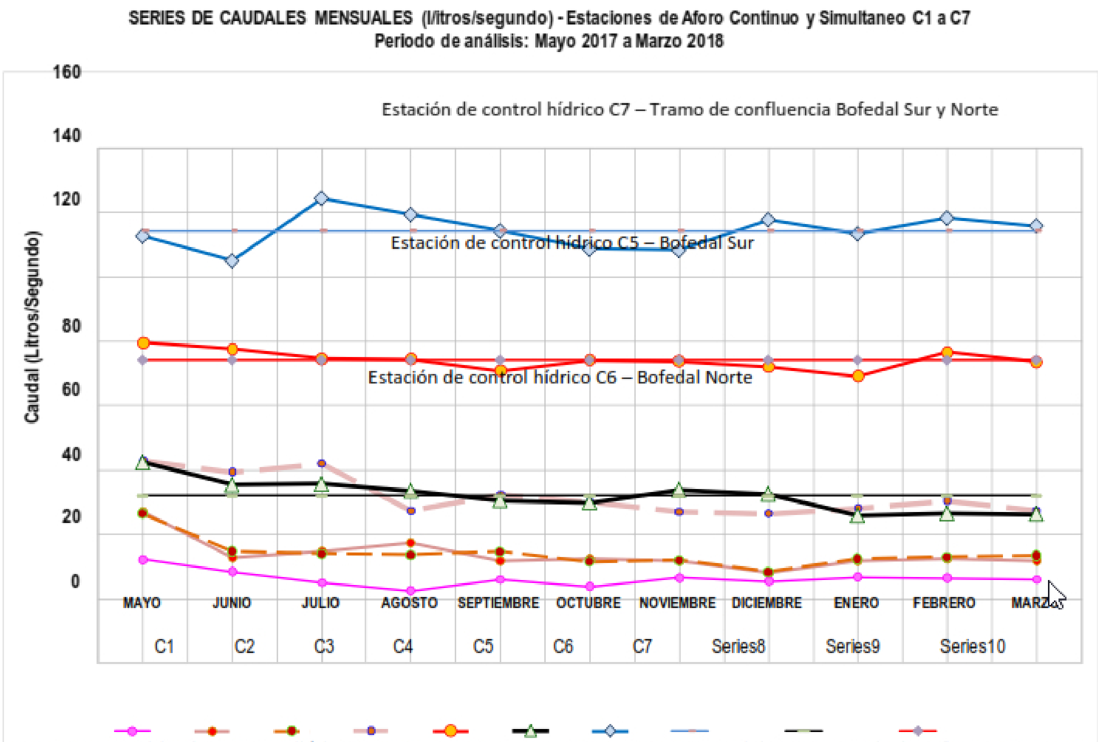

Figure 12. Monthly Flow Series (l/s) – C1 to C7 Gauging Stations. Source: Own elaboration with data from SENAMHI-DIREMAR (2018).

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In station C1 (Figure 13), flows are recorded from springs of the upper part of the South Bofedal. From this control point, little increase of the flow is observed up to the control point S-7, because in the reach there are few contributing springs. From this control point the flow increases significantly until reaching control point S-10, because there is a greater concentration of springs.

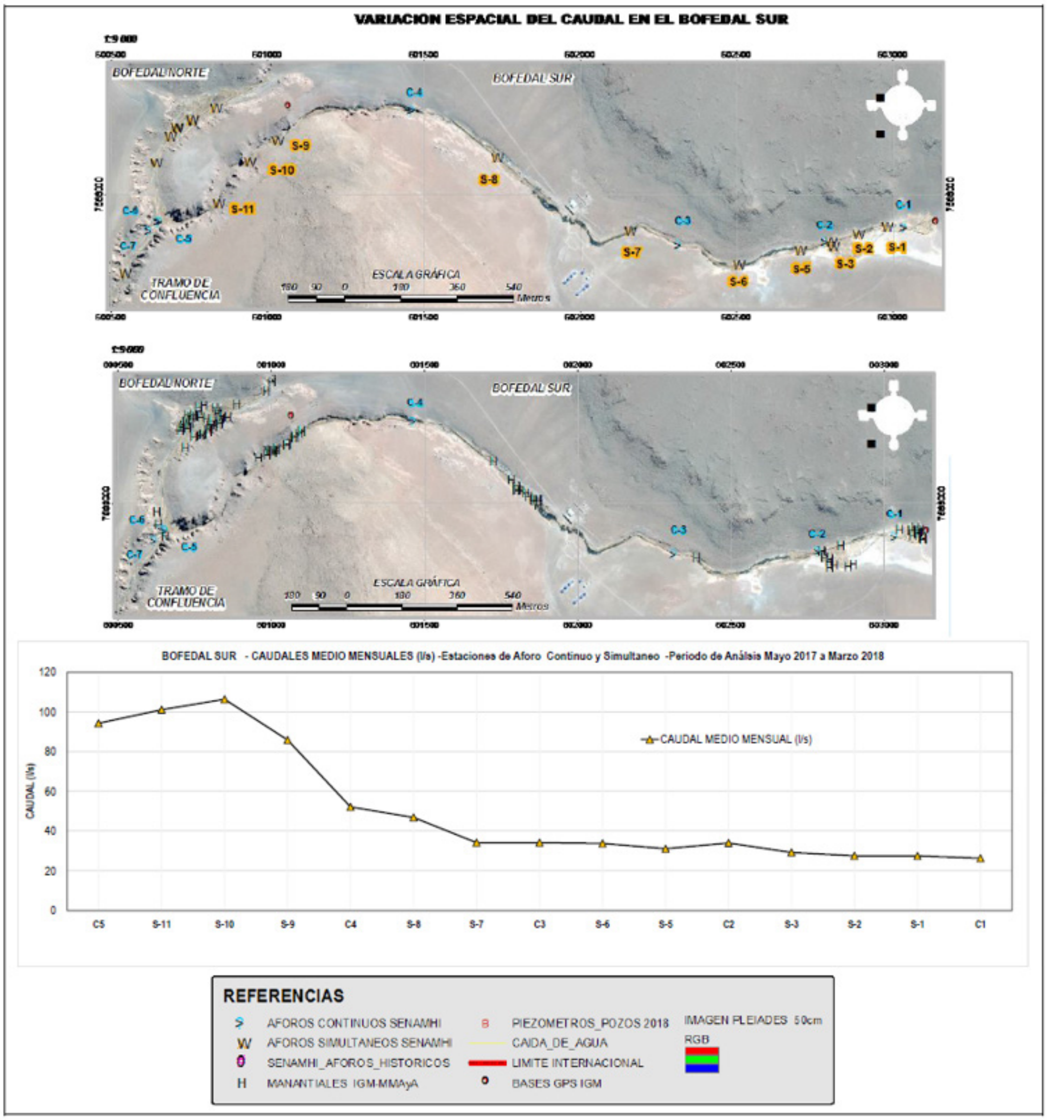


Figure 13. Spatial variation of the flow in the South Bofedal (for the May 2017 to March 2018 period). Source: Own elaboration based on data from SENAMHI, DIREMAR, (SENAMHI-DIREMAR, 2018).

4.2 Flows in the North Bofedal

The spatial variation of the flow of the North Bofedal in the Silala generally has an increasing pattern according to the length and the development of the topographic differences, which goes from the control point S-18 to C6, see Figure 14.

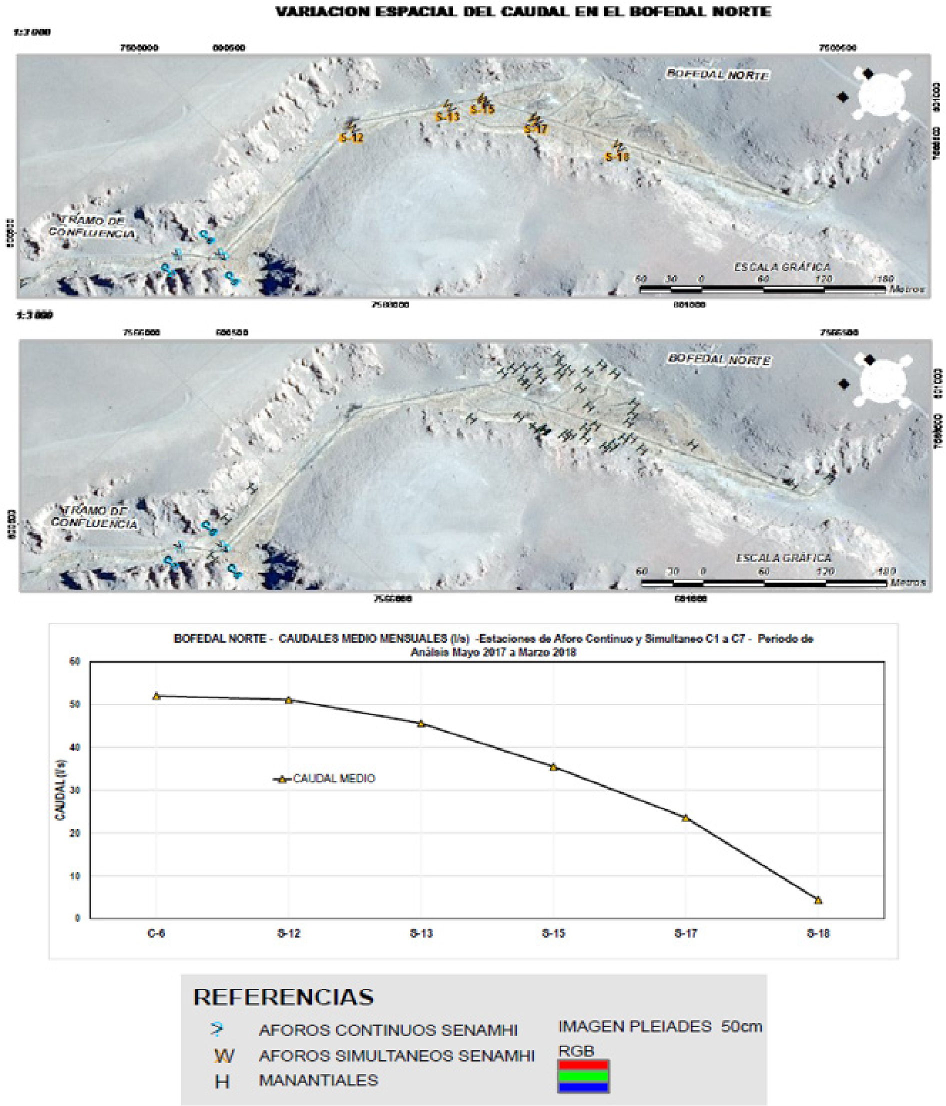


Figure 14. Spatial variation of the flow in the North Bofedal. Source: Own elaboration based on data from SENAMHI-DIREMAR (2018).

At the control point S-18 flows are recorded from the springs in the sector. From this control point, a gradual increase in flow is observed until reaching station C6, because in the section there is a greater concentration of springs which are drained to the North Bofedal canal.

4.3 Confluence Reach of the South and North Bofedal

In the confluence section there is a low increase in flow from control station C7 to S-19. From this point the flow remains almost constant up to point S-21, because in this reach there are no springs that increase the flow.

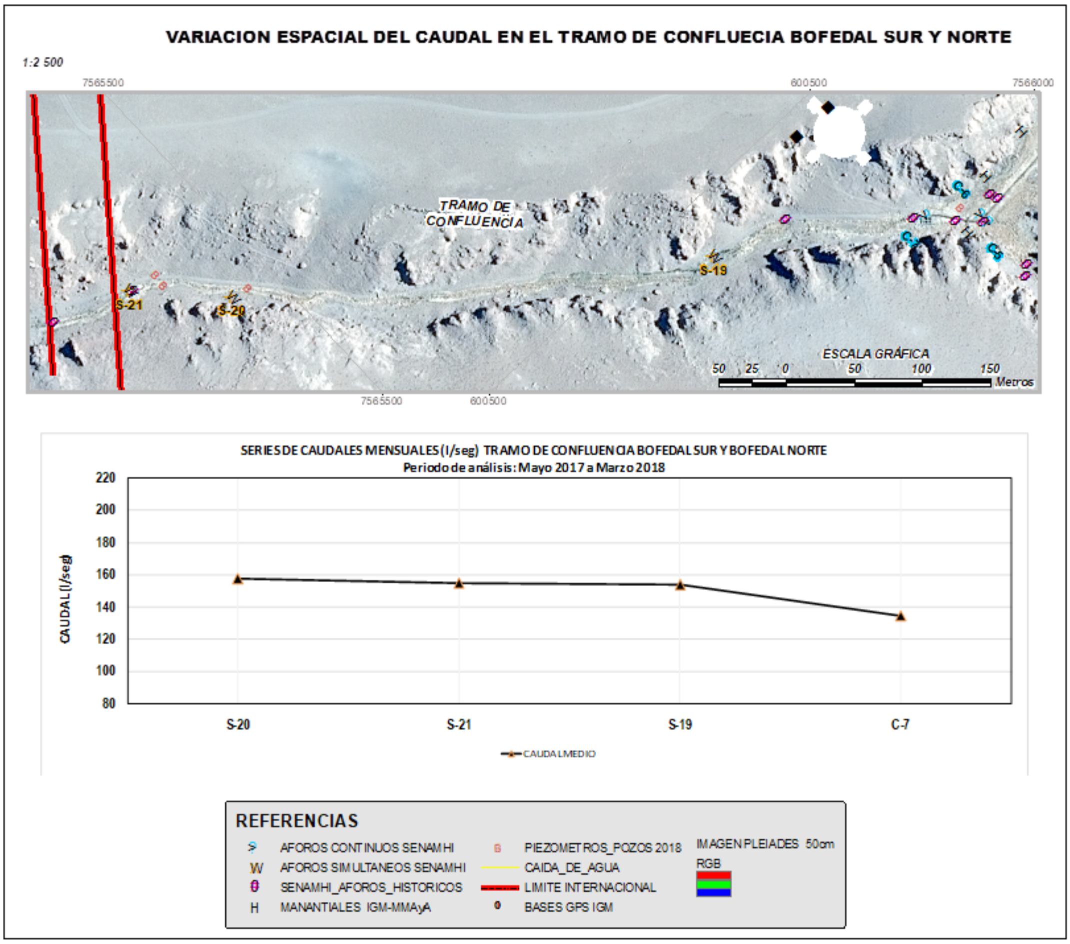
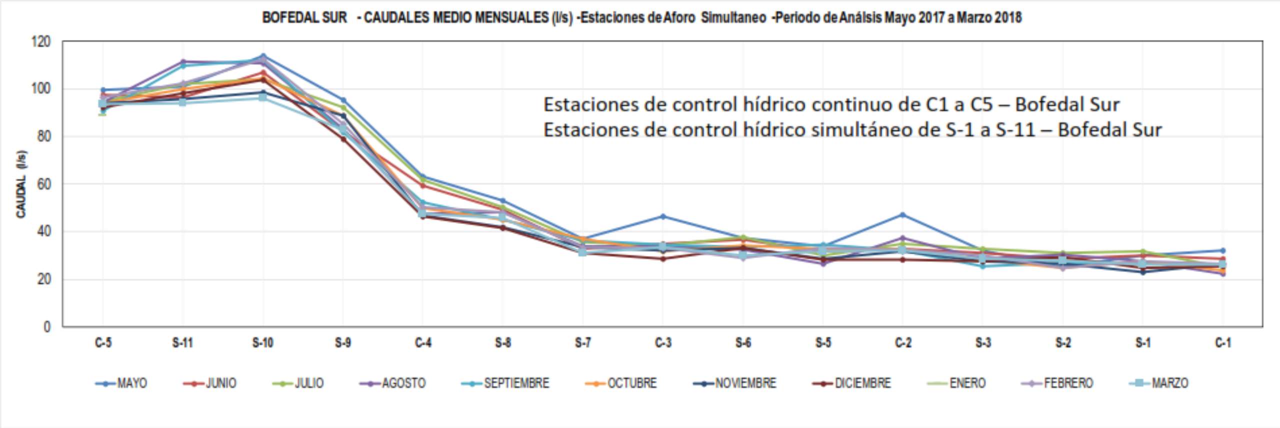


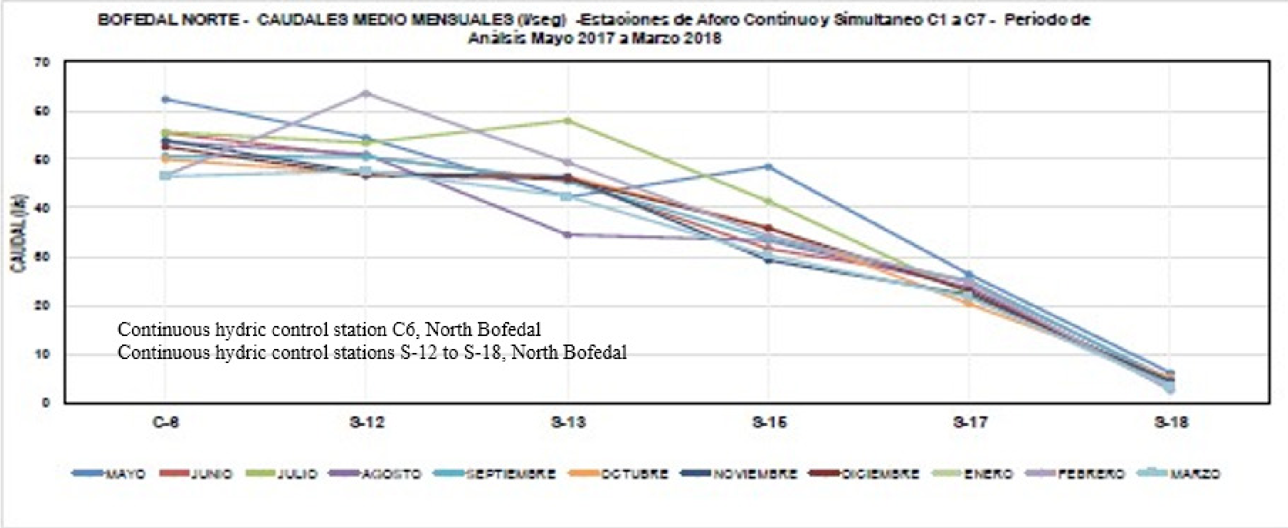
Figure 15. Spatial variation of the flow in the North Bofedal. Source: Own elaboration based on data from SENAMHI-DIREMAR (2018)

Although there is a discharge of flows through a canal, it must be taken into account that there are no significant flows in the confluence reach, since the variation of flows in the last control points (gauging stations) remain almost constant (see Figure 15).



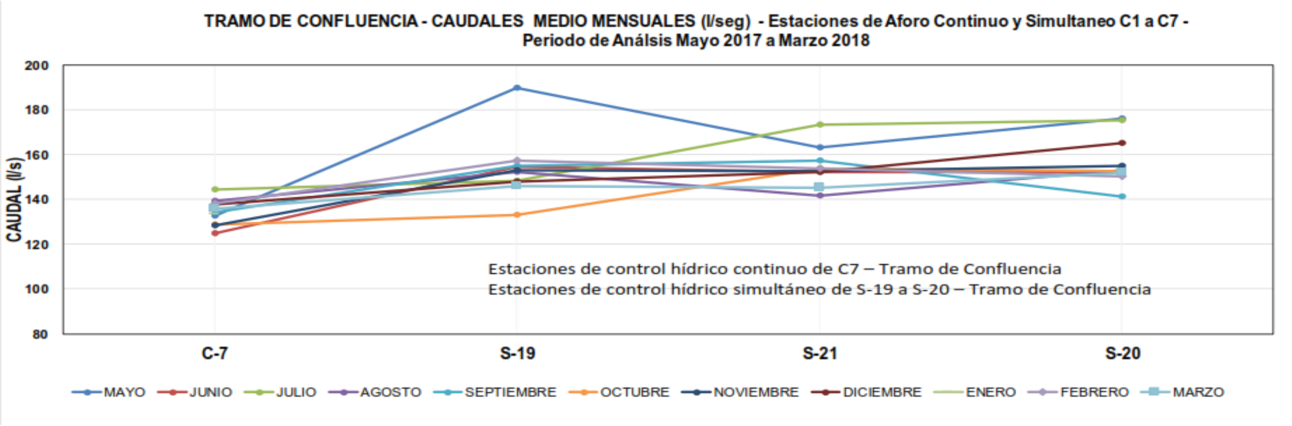
		C-5	S-11	S-10	S-9	C-4	S-8	S-7	C-3	S6	S-5	C-2	S-3	S-2	S-1	C-1
2017	MAYO	99.57	100.91	113.95	95.24	63.03	53.15	36.81	46.52	37.49	33.79	46.97	32.10	25.20	30.09	32.22
	JUNIO	97.47	96.25	106.85	82.02	59.44	49.30	32.62	34.94	36.63	31.60	32.76	31.15	28.58	29.93	28.45
	JULIO	94.55	102.10	104.00	92.30	61.95	50.15	35.50	34.05	37.75	29.90	34.80	32.85	30.90	31.75	24.95
	AGOSTO	94.43	111.25	110.60	83.00	47.30	48.27	33.90	33.78	32.55	26.40	37.48	28.50	30.45	27.45	22.43
	SEPTIEMBRE	90.93	109.80	112.15	81.70	52.28	45.00	36.15	34.70	33.45	34.45	31.95	25.35	26.95	26.45	26.00
	OCTUBRE	94.10	100.00	104.50	88.70	50.05	44.90	36.85	31.68	34.05	32.90	32.63	28.35	24.85	27.70	23.70
	NOVIEMBRE	93.85	95.60	98.65	88.75	46.93	41.80	33.45	32.10	33.10	28.60	31.85	27.45	26.60	23.05	26.55
	DICIEMBRE	92.05	98.25	103.60	78.75	46.40	41.65	31.15	28.53	33.20	28.25	28.28	27.50	29.35	24.85	25.35
2018	ENERO	89.15				48.00			32.55			32.00				26.65
	FEBRERO	96.50	102.35	112.40	85.20	50.33	48.20	33.65	33.15	29.05	33.05	32.60	30.00	24.75	27.65	26.63
	MARZO	93.58	93.88	96.18	82.75	47.30	45.55	30.95	33.55	30.03	31.75	32.03	28.55	27.88	26.08	25.98
CAUDAL MEDIO MENSUAL (l/s)		**94.20**	**101.04**	**106.29**	**85.84**	**52.09**	**46.80**	**34.10**	**34.14**	**33.73**	**31.07**	**33.94**	**29.18**	**27.55**	**27.50**	**26.26**

Figura 16. Series de Caudales Medio Mensuales (l/s) - Estaciones Simultaneas – Bofedal Sur. Fuente: Propia con datos de SENAMHI-DIREMAR (2018).



		C-6	S-12	S-13	S-15	S-17	S-18
2017	MAYO	62.26	54.39	42.31	48.44	26.50	6.26
	JUNIO	55.37	50.45	45.57	31.70	25.17	4.80
	JULIO	55.58	53.35	57.85	41.50	22.40	4.55
	AGOSTO	53.50	51.05	34.55	33.30	23.80	3.80
	SEPTIEMBRE	50.60	50.45	45.40	33.65	25.20	4.90
	OCTUBRE	49.98	46.90	46.50	36.05	20.45	5.20
	NOVIEMBRE	53.90	47.20	46.50	29.35	22.30	4.60
	DICIEMBRE	52.55	46.65	46.00	35.95	23.15	3.40
2018	ENERO	45.95					
	FEBRERO	46.58	63.40	49.30	34.35	24.80	2.70
	MARZO	46.42	47.73	42.38	30.33	21.80	3.68
CAUDAL MEDIO MENSUAL (l/s)		52.06	51.16	45.64	35.46	23.56	4.39

Figure 17. Average Monthly Flow Series (l/s) – Simultaneous Stations – North Bofedal. (Source: Own elaboration based on data from SENAMHI-DIREMAR (2018)



		C-7	S-19	S-21	S-20
2017	MAYO	132.66	189.60	163.13	176.19
	JUNIO	125.00	154.45	152.00	152.07
	JULIO	144.34	148.35	173.25	175.40
	AGOSTO	139.30	152.05	141.55	152.95
	SEPTIEMBRE	134.25	155.05	157.10	141.30
	OCTUBRE	128.55	133.00	153.70	152.55
	NOVIEMBRE	128.23	152.85	152.50	155.10
	DICIEMBRE	137.70	147.90	152.20	164.90
2018	ENERO	133.35			
	FEBRERO	138.20	157.15	153.90	150.35
	MARZO	135.82	145.80	145.30	151.68
CAUDAL MEDIO MENSUAL (l/s)		**134.31**	**153.62**	**154.46**	**157.25**

Figura 18. Caudales Medio Mensuales (l/s) - Estaciones Simultaneas – Tramo de Confluencia. Fuente: Propia con datos de SENAMHI-DIREMAR (2018)

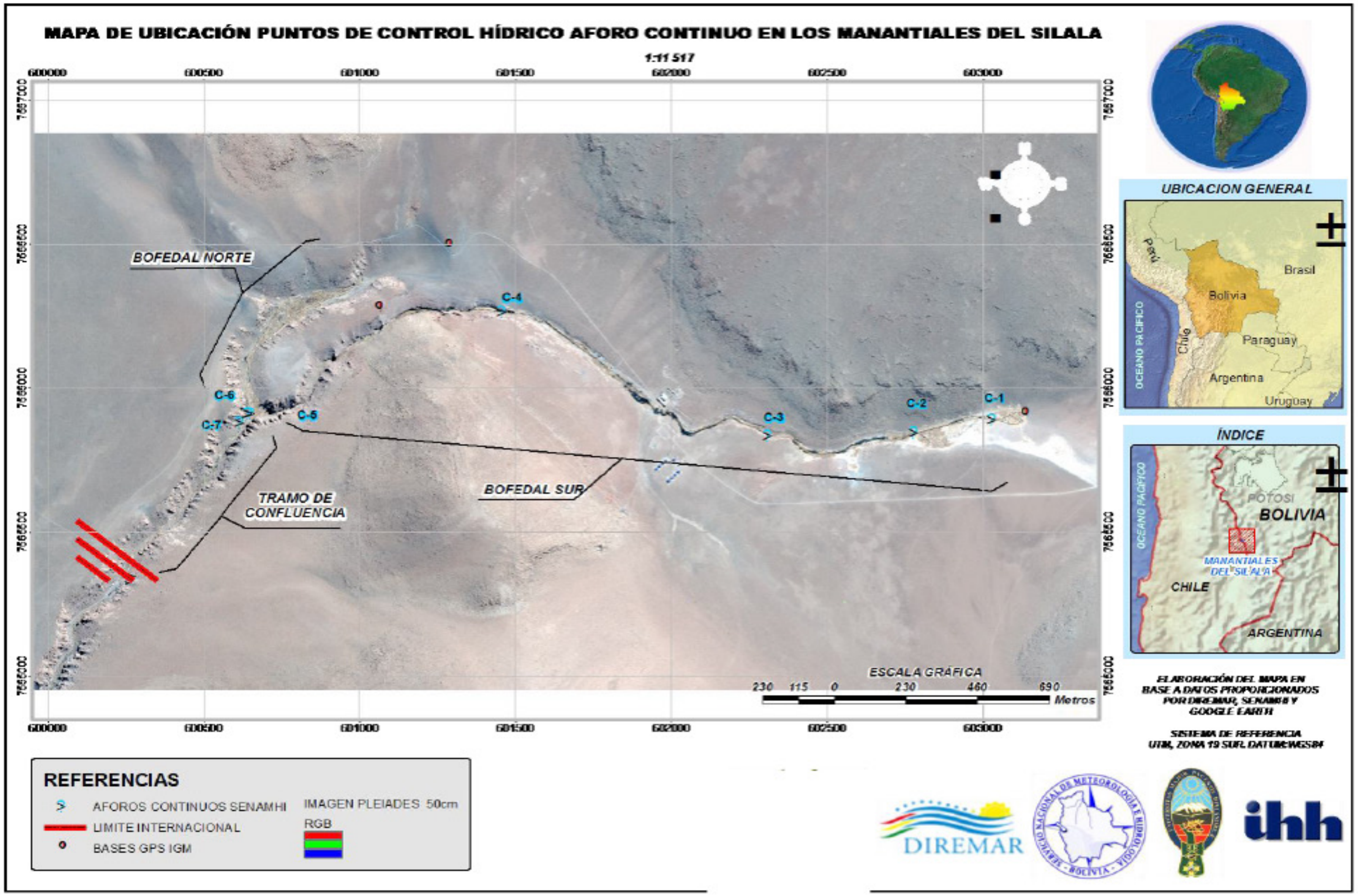


Figure 19. Map of the Location of Hydraulics Control Points of Continuous Gauging in the Springs of Silala. (Source: Own elaboration based on data from SENAMHI-DIREMAR (2018)

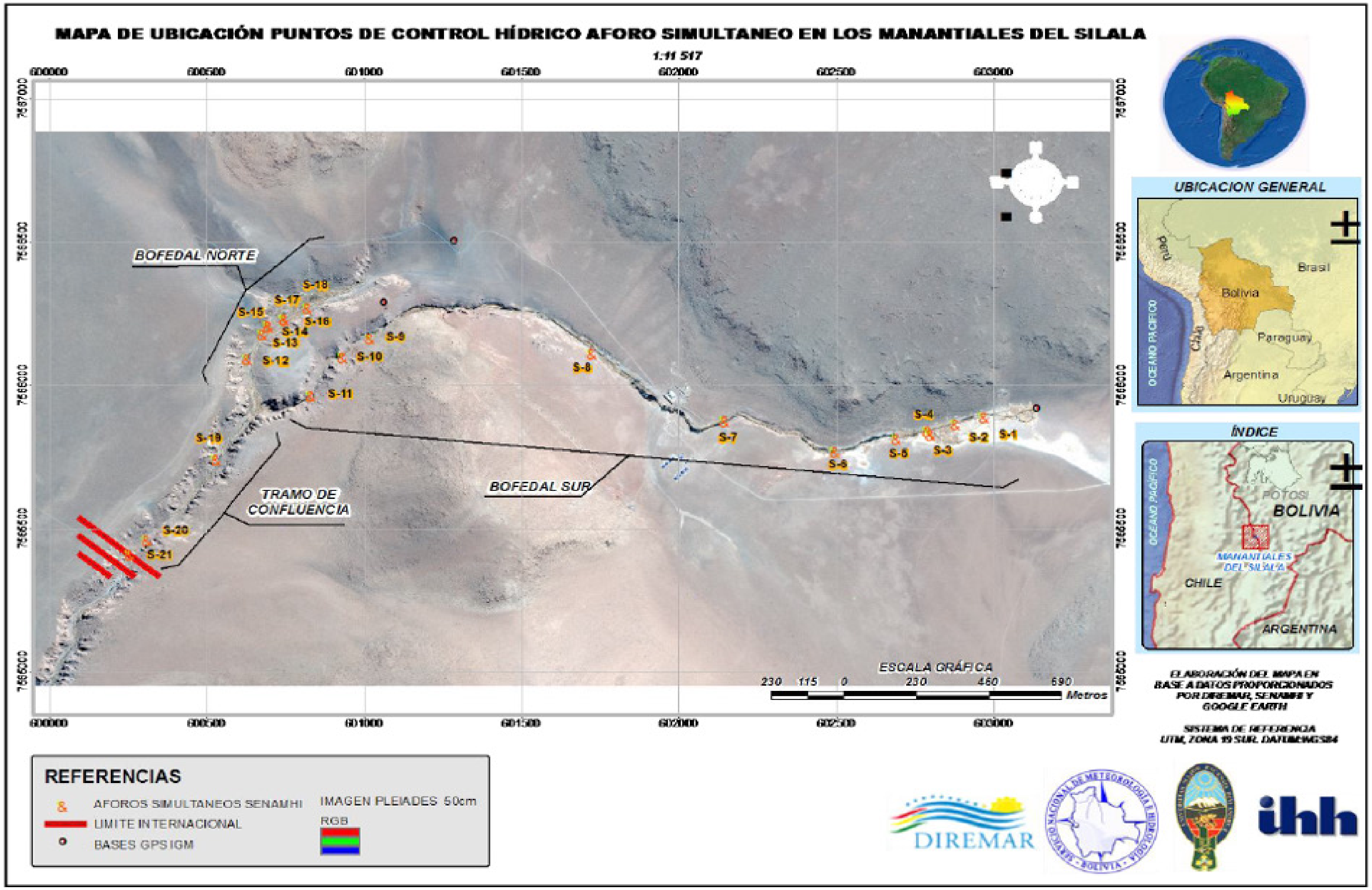


Figure 20. Map of the Location of Hydraulics Control Points of Simultaneous Gauging in the Springs of Silala. (Source: Own elaboration based on data from SENAMHI-DIREMAR (2018))

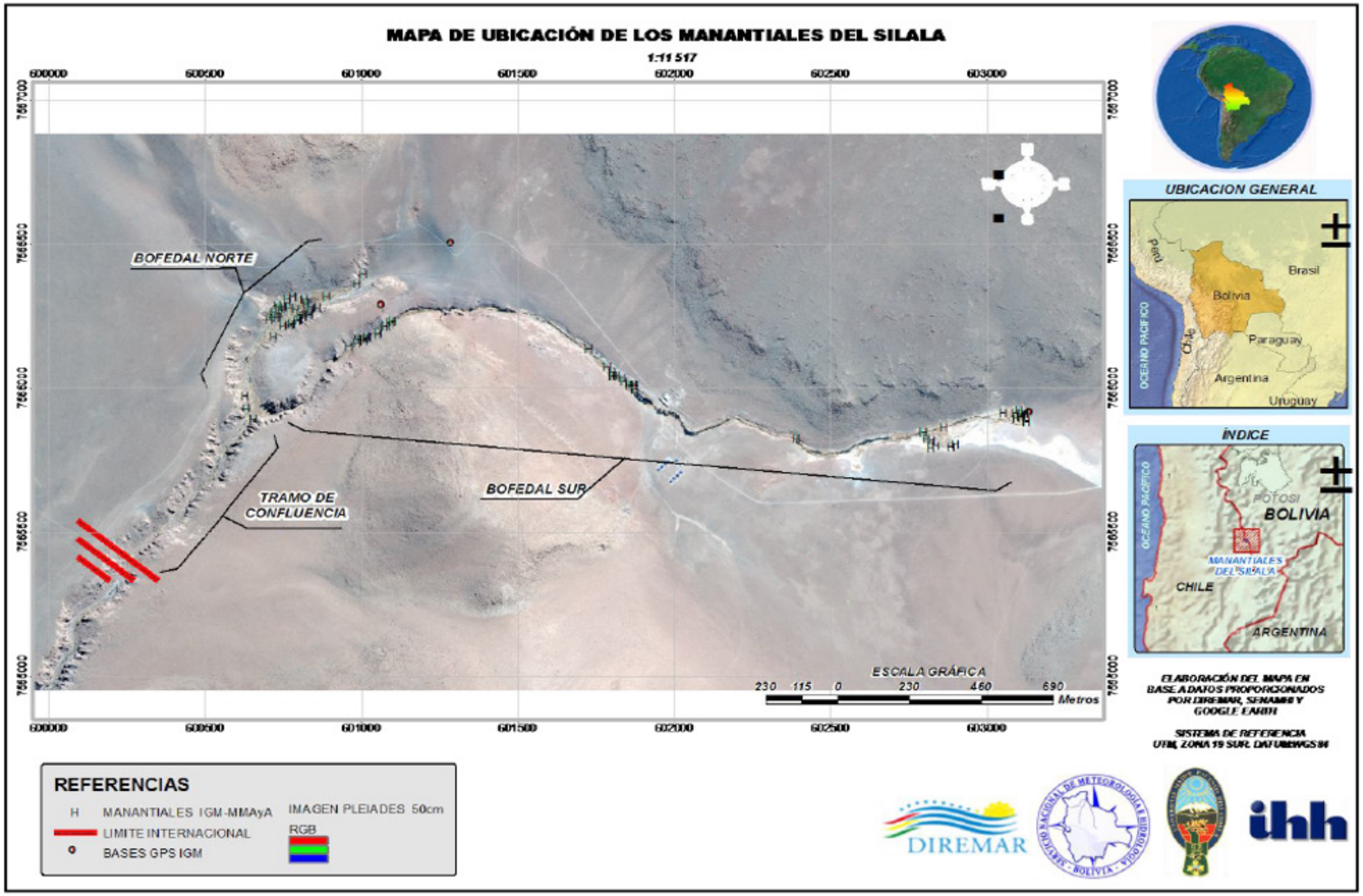


Figure 21. Location Map of the Silala Springs. (Source: Own elaboration based on data from SENAMHI-DIREMAR (2018)).

5 PHYSICAL CHARACTERIZATION OF HYDRAULIC WORKS.

5.1 GENERAL ASPECTS

In order to characterize the hydraulic works, the main aspects of the existing canals in the region of the Silala springs are detailed, such as their size, shape and the function that they fulfill in the hydraulic system. As a first approximation they are classified as:

- Main canals and
- Secondary canals.

The description of the works presented below is based on the geographical location in the area, for which they are classified in:

- Works of the South Bofedal.
- Works of the North Bofedal.
- Works of the Confluence Reach.

In turn, in accordance with the previous classification, the description of the works includes:

- Materials employed.
- Geometric characteristics of the canal network.

Regarding the type of material used in the interventions, four categories can be defined:

- Canals without coating excavated in natural soil.
- Canals with dry masonry coating[2] (rock coating without binder).
- Canals with stone masonry coating (rock coating with mortar).
- Canals in rock.

The base map showing the sites where the detailed description was made are shown in Figure 22. From site 1 to site 26 they correspond to the South Bofedal, from site 27 to site 43 to the North Bofedal and in the confluence reach there are sites 44 to 45.

2.It is understood by dry masonry to the ordered arrangement of stones arranged without binding elements, such as mortar, lime or cement.

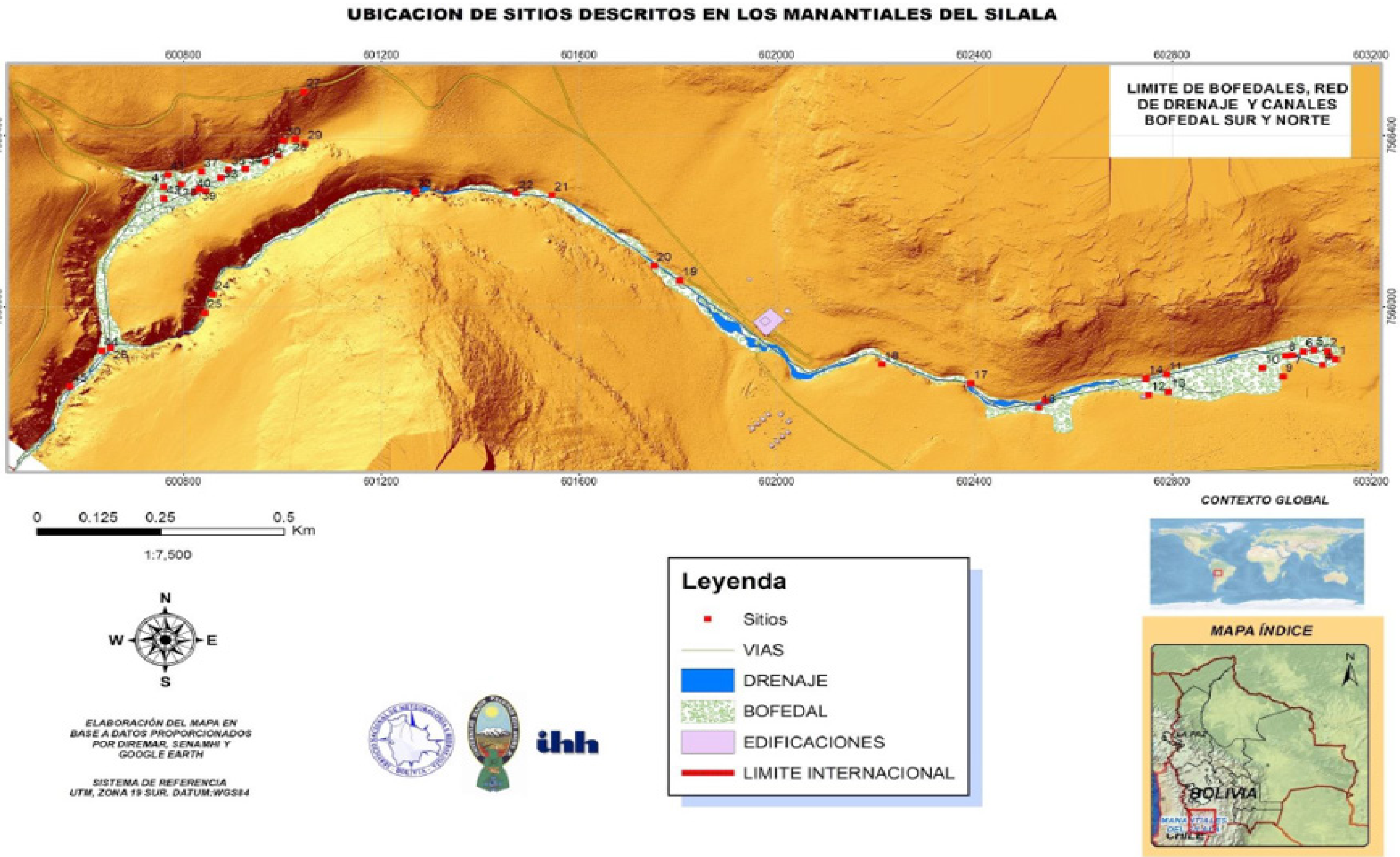


Figure 22. Arrangement of the canal network of the Silala Springs.

The methodological process used in the evaluation of the works, includes:

- Topographic survey in detail of the location of the canals.
- Survey of the geometry of the canals.
- The detailed description of the materials used in the canals.
- Geometric and hydraulic layout of the canals.

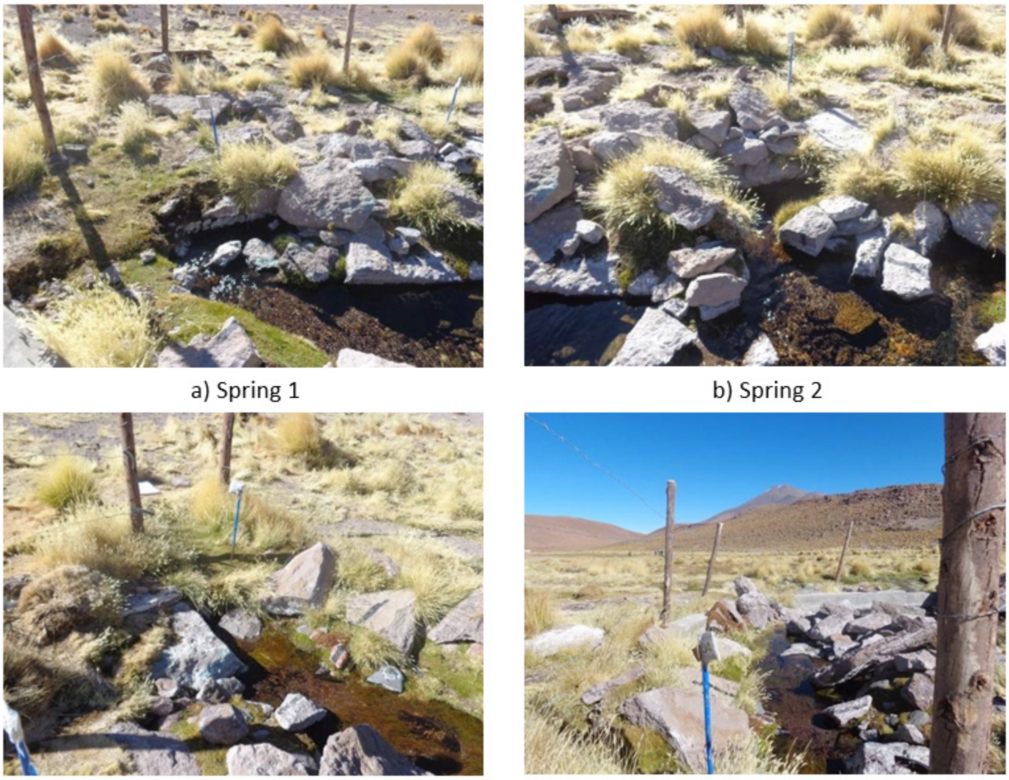
The description that follows sets out in detail the hydraulic works along the canals of the South and North Bofedals and the confluence reach. The detailed measurements of the geometric configuration of the canals have been taken and there is a quantification of the longitudes of each type.

5.2 WORKS IN THE SOUTH BOFEDAL

5.2.1 DETAILED DESCRIPTION

Site 1: The water springs of this area are located in the upper area of the South Bofedal (see Figure 22), located geographically at 4,414 meters above sea level, E 603130 m and N 7565881 m (UTM System WGS1984). In this site the protection of these water springs is perceived, the work consists of an old small dam approximately 10 meters long, 0.5-meter-high and 0.24-meter-wide, in order to generate a small storage. The water abstraction work has a perimeter fence formed by callapos and barbed wire, with the purpose of preventing the entry of animals or people (see Figure 23).

The photographs in Figure 23 show the location of four springs with small flows and constant flow (with an approximate total of 2 l/s). Freezing water was not detected during the field visit (April, 2018). The dam comprises earlier constructions (Figure 24a).



a) Spring 1 b) Spring 2

c) Spring 3 d) Dam and spring 4

Figure 23. Springs 01 to 04.

Site 2: Exit of the water intake work. Two artificially constructed canal branches are observed (canals excavated in natural soil, bofedal peat), as seen in Figure 24a. In addition, it is appreciated that the zone of the springs and canals at the exit were part of the bofedal (see Figure 24b), with irregular terrain and presence of small gravels that are a product of a fluvial-glacial disintegration.

The orderly arrangement of the rocks shows that they were artificially placed as dry masonry works, built after the excavation (Figure 24b), and for the purpose of retaining water, with a maximum depth of 25 cm.

a) Dam and spring protected with rock

b) Springs protected by a dam of old rocks and recen masonry.

Figure 24. Water retaining dam and springs at the headwaters of the South Bofedal.

Site 3: There is a PVC tube with a diameter of 4 inches, perforations of 1 cm and spaced every 5 cm (Figure 25a). The water abstracted at this site is taken to a small cement pond protected by two movable lids (Figure 25b). From this point the water is channeled to the Silala Military Outpost of the Armed Forces of Bolivia, destined for the human consumption of the military that live in said place (with an approximate flow of 0.5 l/s).

a) Pipe to divert water to the pond.

b) Recent small pond.

Figure 25. Water intake work and desiltation chamber.

Site 4: The chamber is built in stone lined masonry, with refined walls in good condition. Its dimensions are: 1.35 x 1.35 meters in the ground and 0.24 meters thick.In the upper part there is a ventilation pipe (see Figure 25b). The area described is geographically located at the coordinates E 603104 m, N 7565867 m, 4,411 meters above sea level (UTM System WGS1984).

Downstream there are water streams that form natural grooves formed by typical high Andean wetland (bofedales)[3] contours, as shown in Figure 26b. However, the bases of some natural canal reaches have been lined with stones (canal soles).

Sediment transport: At a distance of 1 meter from the dam of streams 01 to 04, the bed is formed by rocks and heavy gravel. Generally, the bases of the canals have sediments deposited where [sediment] transport at the bottom is not visible; only particles characteristic of gravels and angular sand lay at the bottom of the canal in a static way. For the initial reach, no particle movement can be appreciated. The main characteristics of the canal contours are composed of granular sediments and peat, see Figure 26.

Figure 26 a shows the right side of the canal shown in Figure 26b; in the upper part of this canal, there are sandy sediments and a small canal that comes from above (as shown in Figure 26c). In the high areas, it is possible to observe traces of former springs that lack any vegetation; only loose sands are found with scattered rocks and vegetation formed by straw and dry Yareta are visible.

a) Sediments of sand and gravel. b) Peat sediments and rocks lining canals. c) Groove and old bofedal without water.

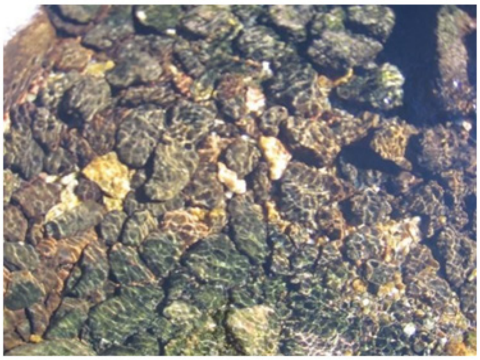
Figure 26. Sediments in the upper zone of southern springs and bofedales.

Site 5: The photographs in Figure 27 show the sediments that lie in the bed of the canal excavated at the exit of springs 01 to 04. There is also a poorly dispersed granulometry well accommodated in the bed, however, under this bed there is peat. The sediments found in the bed of the canals generally come from the surrounding contour of the canal. In the field inspection of the place, it has been evidenced that the flow of the water does not produce movement of

3 In the classification of the RAMSAR agreement, wetlands are of different types, being that a bofedal is a high Andean wetland with special characteristics; they form peat soils with varying thicknesses and slopes. In addition, the soil is mixed with gravel and sand resulting from the fluvial-glacial abrasion.

particles, not even the smaller diameter particles, which further corroborates the fact that the flows are practically constant.

a) Artificial canal bed formed by sands and small gravels.



b) Artificial canal bed formed by angular gravels.

Figure 27. Bed covered with sediments formed by angular gravels.

The water conveyance for the supply of water at the military outpost consists of a 3-inch PVC pipe (Figure 28a); next, the pipe connects with a poly-tube of the same diameter, and then it extends along one side of the artificial canals (Figure 28b) until the water is discharged into a pool in the back part of the military outpost.

a) Interior of the masonry chamber with pipes and gate valves.

b) Pipe that extends towards the military outpost and passes by a side of the canal excavated by the bofedal.

Figure 28. Water conveyance chamber and pipe.

Site 6: Downstream of the first four springs are others; the spring 06 (Figure 29a) joins the right branch that emanates from the small dam. On the other hand, the spring 07 (Figure 29b) supplies less water and both are channeled by small canals, covered by rocks, with traces and little defined sections, in the form of ditches. The lining of the canals is deteriorated, both in the bottom and in the walls, because they were manually removed at the sides or because they have been turned obstructing the flow. Instead, other rocks have been fractured by the repetitive changes in temperature. There is no sediment transport or displacement, since the flows and slopes are very low. Consequently, the efforts that the current generates on the bottom do not exceed the capacity of resistance to the displacement of sediments.

a) Collector canal of springs 01 to 06. b) Collector canal of spring 07.

Figure 29. Spring water conveyance canals.

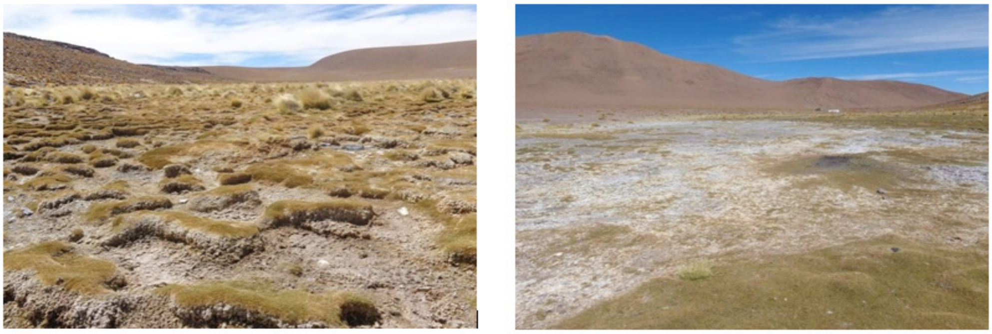
Site 7: The junction of the main collector canals 01 to 07 occurs at the confluence shown in the photograph of Figure 30a. In this photograph we can see a construction of canals covered with rock and protected to avoid the collapse of its walls.

a) Union of collector canals of springs 01 to 07. b) Weir 1 in the South Bofedal.

Figure 30. Ancient artificial union of canals and current outlet to measure the flow.

Site 8: On this site there is a triangular weir (Figure 30b), which is entered by two main canals excavated artificially, since in these canals almost vertical cuts are observed in the walls; both its alignment and slope have a constant line, without bifurcations, floods or overflows. This weir is geographically located at the coordinates E 0603030 m, N 7565889 m, with an altitude of 4,412 meters above sea level (UTM System WGS1984).

From the Weir 1 downwards a concentrated runoff can be distinguished in a main canal, which has a wide section excavated in the soil type of the bofedal, as shown in Figure 29 and in the following up to Figure 30b. The margins and floors near the canal remain moist, with green areas and water streams with vegetation. In contrast, those high areas of the margins of the bofedal, which probably have reached humidity, were drained by artificial pipes. These drained areas were dry and now sandy soils with brave straw predominate that occur sporadically (see Figure 31). The sands are the product of disintegration due to sudden changes in temperature, since there are no sediment displacement processes.



a) Natural sector of the South Bofedal, seen upwards. b) Natural sector of the South Bofedal, seen downwards.

Figure 31. South Bofedal after the extraction of water through drainage actions.

The description made in the previous paragraph indicates that these sectors accumulated water at some time, similar to a flooding or water-logging. However, at present only small areas of bofedal are observed, as shown in Figure 32.

Site 9: In the upper part of the South Bofedal, several reaches of canals excavated in natural soil without water flow were found (Figure 32a); their lines are rectilinear and they are directed towards a larger main canal. These canals could initially be useful to collect only the waters of the wetlands, since on the south side of the same bofedal there are no springs on the surface.

Site 10: On the right flank of the middle part of the South Bofedal there are large wetlands, and on the left flank no water is visible (Figure 32b), although in some sections there are very dry soils, containing paja brava (Stipa ichu – tall Altiplano grass) (see Figure 32).

Site 11: Weir 2 is located in this place, whose coordinates are E 602792 m, N 7565804 m, altitude 4,440 (UTM System WGS1984). These hydraulic structures were installed since August of 2017; they have the purpose of measuring the flows in the installed points. Therefore, at this point the waters of a large part of the upper South Bofedal converge and before following the flow to the intermediate bofedal area, it narrows and in this sector the flows of the springs 01 to 20 are measured; and what is collected from the bofedales along the collecting canals (Figure 34b), although in some reaches they are dry and in their place there is paja brava (Stipa ichu) (see Figure 32).

a) Margin of the South Bofedal without vegetation.

b) Natural sector of the South Bofedal without water with a view towards the southwest.

Figure 32. Dry sectors in the South Bofedal.

Site 12: Here we have a water storage tank (see Figure 33), it is located at coordinates E 602752 m and N 7565797 m (UTM System WGS1984). The photograph shows a provision of the water conveyance pipe that feeds this deposit that was recently built in order to provide water to ten houses (at present, said storage tank is not in operation because there are no inhabitants occupying the aforementioned houses). The configuration of the terrain shows that it was flooded with water and/or snow, and currently a completely dry bofedal is observed. See the left flank of Figure 33.

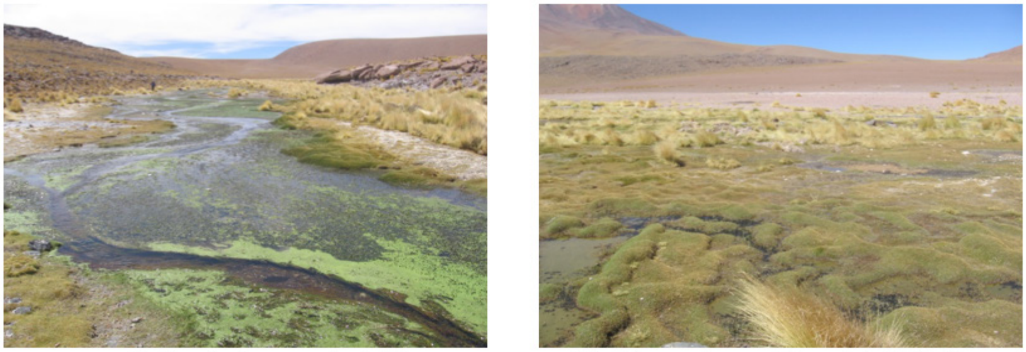
Figure 33. Storage tank.

Site 13: downstream from the triangular weir No. 2, a native bofedal species was found. See Figure 34.

Figure 34. Native species (toad).

Site 14: In this sector there is an appreciable decrease of the South Bofedal, since the ground narrows in a rocky formation and there is an increase in the slope, as seen in the chapter on hydraulic modeling. Between the slopes there is an approximate space of 20 meters; the left slope has rock formation and the other has sand that covers the total surface. Subsequently, the water follows its movement through a reach of artificial canal until the narrowing, whereby it flows naturally through another short reach without canalization, see Figure 35a.

The bed is made up of sands with gravels and in certain reaches there is aquatic vegetation typical of the Andean high wetland (Figure 35b). The margins are composed of bofedal peat (see Figure 35a). However, in some reaches there are walls protected by well-arranged and jointed rocks in the form of a lining.



a) Reach of a narrow bofedal. b) Flow reach comprising a bofedal that has not been intervened.

Figure 35. Characteristics of the canal and bofedal around Weir 3.

Site 15: In the site presented in Figure 38, we can see traces of a road; there is an access in the form of a ditch that is located at the end of the bofedal. The flow that passes through this point is with a very small tie-rod and downwards we can see more vegetation with an approximate width of 8 meters and a short length; then it narrows and goes through the artificial canal. This site is located at the geographic coordinates of E 602543 m, N 7565784 m and altitude 4,408 meters above sea level (UTM System WGS1984).

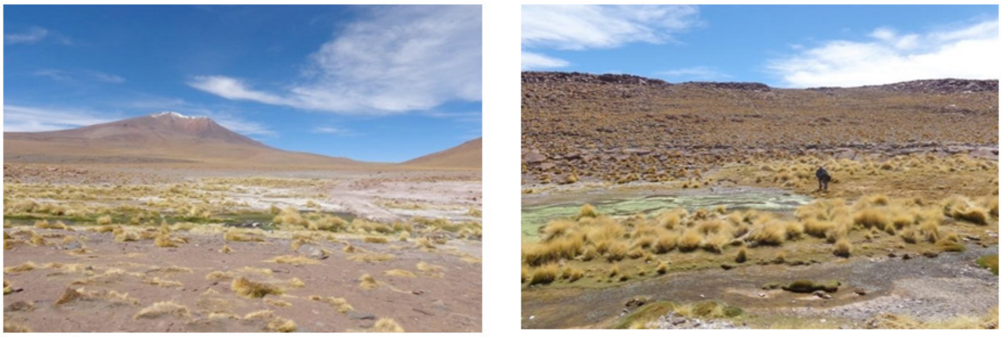


Figure 36. Ditch for vehicular crossing through a piped reach of the bofedal.

Site 16: The canal returns to be restored by the right flank after the passage of the ditch (see Figure 37a) and on its left margin there are surfaces of smaller bofedales (see Figure 37b). In addition, the canalized reach appears with little rock protection (see Figure 37a).

a) Canal with view upstream.

b) Left flank with reduced bofedal.

Figure 37. Bofedal that narrows and canal excavated by the bofedal.

Site 17: In this place we can see a spring (see Figure 38a) on the right margin of the canal, in a reach found within ravine and with very little water contribution. This reach seems to flow in natural conditions, although it is not possible to observe it easily due to the large size of the grasslands (see Figure 38b). This sector is geographically located at the coordinates E 602392 m, 7565824 m and altitude 4,399 meters above sea level (UTM System WGS1984).

a) Spring 21.

b) Scrubland on the left flank.

Figure 38. Canal covered by very developed scrubland.

Site 18: In this sector there is a reach of unlined canal (little protection is seen, as shown in Figure 39a); although the canal is part of an artificial drainage, this watercourse is channeled and the flow presents upwelling waters on the right flank. We can also see rocks with slightly worn edges, which show that at some time there was movement of sediments and that caused the wear of the rocks at the margin of the canal (Figure 39b). There is also movement of water in the area that narrows, it changes in slope increasing the velocity and generating a slight turbulence. However, the wetlands that cover it extend from one end of the slope to the other. These slopes are made of rock and have almost vertical cuts (Figure 39c and d). This sector is geographically located at the coordinates E 602212 m, N 7565869 m and altitude 4,398 meters above sea level (UTM System WGS1984).

Site 19: The sector is located in front of the Silala Military Outpost in Bolivia. The other spring is located in this reach. In the sector of the canal it is seen that there was an intervention with protection of embankments and rock walls. It is located at the coordinates E 601804 m, N 7566061 m and altitude 4,390 meters above sea level (UTM System WGS1984). The reach is flooded, which shows evidence that the bofedal is saturated, mainly on the left margin (Figure 39a).

In the same reach there is a fish project consisting of two types of ponds, one made by rocks and the other by a group of reinforced concrete. Both fish ponds are abandoned.

Site 20: Regarding the water channeling, from the fish sector downwards there is a rectilinear channeling, which shows that this reach was intervened artificially, since they have also sporadically protected the walls of the canals with some rocks. (Figure 39a and b).

a) Intervened canal with a view upstream. b) Canal with flow, seen from upstream.

Figure 39. Canal in the reach of the Silala Military Outpost.

Site 21: A reach with short natural channeling is presented, whose flow passes through a rocky opening (Figure 40a). However, another reach drains through a saturated wetland (Figure 40b).

a) Canal reach with a flow seen from downstream. b) Canal narrowing down, seen from downstream

Figure 40. Narrowing of the canal's reach with natural flow.

Site 22: Weir 3 (see Figure 41a) is located in this place, with the coordinates E 601473 m, N 7566264 m, 4378 m (UTM System WGS1984). The reach downstream of the weir is intervened by means of canalization in natural soil (bofedal peat), see Figure 41b. There also are protections on the sides of the canal.

a) Location of Weir 3. b) Reach canalized after Weir 3.

Figure 41. Reach of the natural canal and the intervened canal in proximity of Weir 3.

Site 23: In this sector there is an opening in the reach found within the ravine and in the same way there is a difference in the terrain's profile, producing a fall of water with an approximate height of 5 meters. The site is geographically located at the coordinates E 601267 m, N 7566267 m and 4,383 meters above sea level (UTM System WGS1984), see Figure 42a. In the greater narrowing there is a very strong slope change.

Downwards there is a flow through the bofedal, where its wet condition is maintained. However, it is possible to appreciate a channeling, where the flow develops on both sides and then expands throughout the water course, occupying the entire width of the reach found within the ravine (see Figure 42b). The reach does not have a defined course, but has a dispersed flow through the bofedales.

a) Water fall at the end of the narrow reach. b) Reach of the bofedal after the waterfall

Figure 42. Waterfall and reach of the bofedal in the canal's zone – South Bofedal.

In the presence of the drainage works seen in the upper part of the South Bofedal, it is noted that the flow has been channeled; being that in its natural condition, the flow through the bofedales is very much reduced. This assertion is based on the observation of artificially constructed drainage sections, since the altered reaches are those in which canals have been excavated and in which rocks have been placed for protection. On the other hand, in other reaches, the porous medium of the bofedales that maintain their natural characteristics presents slow flows or that are flooded. The reach does not show a typical section with natural terraces, but in the middle there is an excavated canal with overflow or deviated flow, which covers the entire width.

Site 24: The reach of this site (Figure 43a) is found within a ravine with semi-vertical walls. The flow in this reach is natural.

Figure 43b and c show an intervened reach of the flow, which is excavated on the bofedal and is protected with stone masonry. The geographical location of this sector is E 600859 m, N 7566029 m, 4,350 meters above sea level (UTM System WGS1984).

Site 25: In the reach, there is a rock canal (Figure 43c) that has been intervened with the construction of a stone masonry. The reach is rectangular, although in the reach a narrow rocky geomorphology is observed, as seen in Figure 43d. The site is located at the coordinates E 600843 m, 7565986 m and 4,347 meters above sea level (UTM System WGS1984).

a) Reach found within a ravine of the South Bofedal.

b) Reach canalized in the South Bofedal.

c) Canal protection at the beginning of the reach found within the ravine.

d) The bofedal and canal ends and starts a fall through rock with natural flow.

Figure 43. Reach found within the ravine and canalization near the end point of the South Bofedal.

Site 26: A reach completely found within the ravine is presented and below is the confluence of the canals of the North and South Bofedales (Figure 44). The confluence is geographically located at the coordinates E 600652 m, N 7565908 m and 4,323 meters above sea level (UTM System WGS1984).

The sector found within the ravine has the following characteristics:

- The slope is greater in the rocky reach, reason why the runoff develops naturally between rocky walls that contain the flows.
- Upwelling waters have been observed in the rocky outcrops. This situation is not visible in the upper reaches. The slopes have vertical cuts and in their base it is possible to observe formations caused by abrupt waterfalls.
- At the exit of the reach found within the ravine there is a change of the slope to a low slope, restoring the flow back through an excavated and lined canal.

a) The South Bofedal ends and a fall begins along an uneven reach found within the ravine.

b) Fall through rock with flow and a canalized reach after it.

Figure 44. Reach found within the ravine and canalization at the end point of the South Bofedal.

5.2.2 REACHES OF CANALIZATION IN ROCK

As a result of the topographic survey, between the progressive 2+060 to 2+462 and 2+618 to 2+800 that constitutes a predominantly rocky reach, there is evidence of sections that have a fairly regular geometric shape, showing sections of the rectangular and trapezoidal type. Although there are no documents that claim that the rock has been carved in this reach, however, the regular geometric layout shown gives strong indications that there have been rock carving works, to form the canals in this reach. Table 3 presents a detail of the rock canal longitudes.

The detailed physical characterization of the reaches of rock canals is presented in Annex 1; Figure 45 shows the indicated reach. It is necessary to clarify that the classification adopted as "canalization in rock" refers to two cases; rock canals with presence of peat and canals only in rock.

Table 3. Classification by reaches according to a slope range. Detailed physical characterization of the reach with rocky outcrop, South Bofedal.

REACH	PROGRESSIVE		LONGITUDE (m)	SLOPE (%)
	START	END		
REACH 1	2+060	2+092	32	5.5-6.6
REACH 2	2+092	2+310	218	2.5-4.5
REACH 3	2+310	2+377	67	9.09
REACH 4	2+377	2+462	85	4.95
REACH 5	2+618	2+710	92	1-33
REACH 6	2+710	2+800	90	1-30
TOTAL =			584	

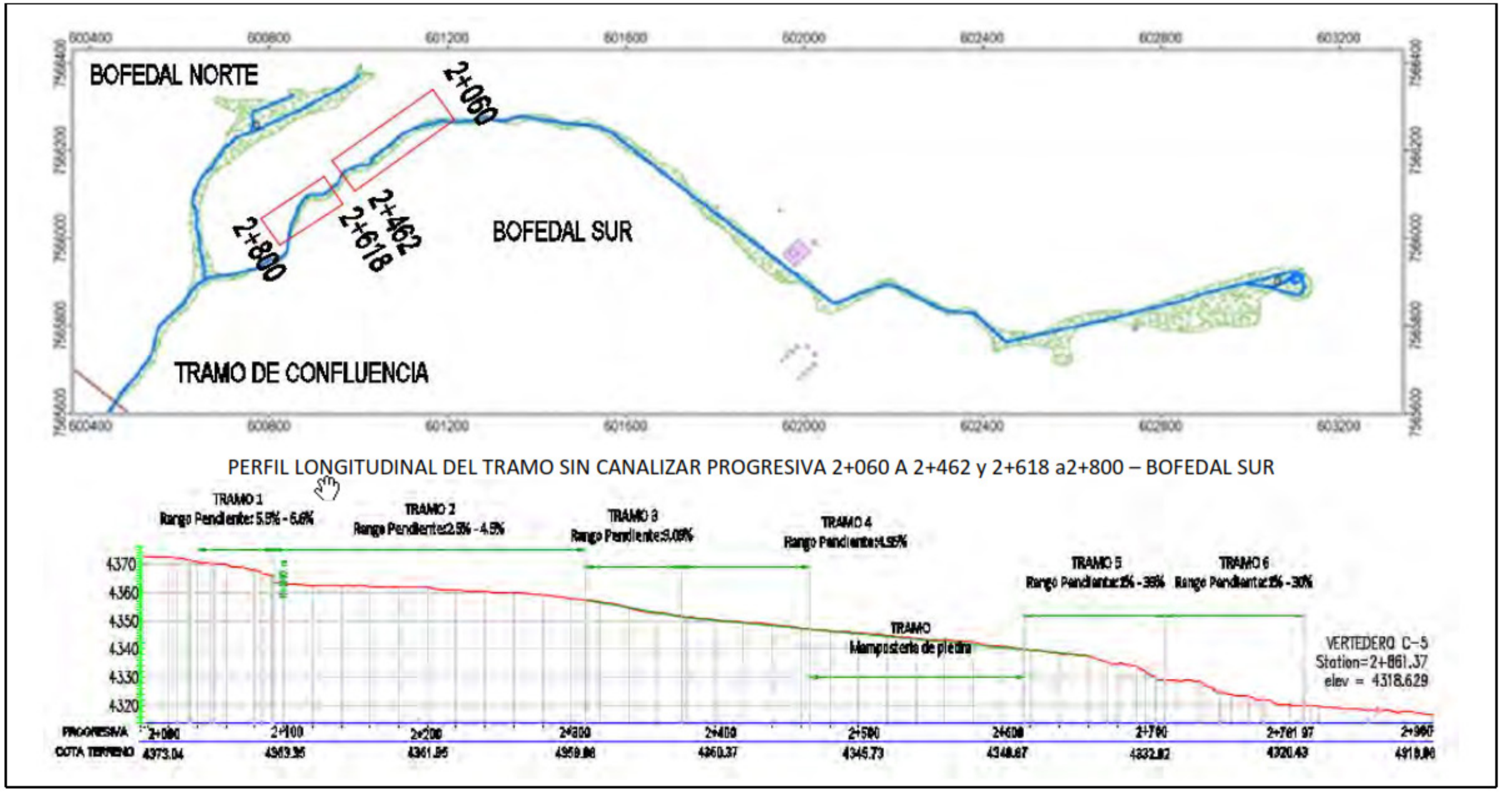


Figure 45. Location of stone-lined reaches in the South Bofedal. Source: Own elaboration based on data from DIREMAR, GOOGLE EARTH

5.2.3 SUMMARY OF THE WORKS OF THE SOUTH BOFEDAL

In the South Bofedal the following aspects are distinguished:

- The drainage canals start from the water collection works built on the upwelling springs.
- There is a predominance of canals built without coating, with excavations in natural soil, in this case being understood as "natural soil", that which corresponds to the body of the bofedal, i.e. a combination of soil, water and organic material.
- In the upper part of the bofedal there is a main canal with secondary canals, these are composed of two secondary canals of considerable longitude and small branch canals of the reach.
- The geometrical arrangement of the uncoated canals maintains a trapezoidal rectangular shape. There is no fall of lateral material, so that the conformation is practically regular.
- As the progressive increases, the main canal adopts a masonry coating, until the place where the runoff develops on rocks.
- In the upper reach, the slopes are low and as it approaches the channelized reach it increases until it leaves the rocky sector.
- The horizontal alignment of the canals has predominantly a rectilinear conformation. The changes of direction are not gradual, so there is no transitional curvature.
- The main canal of the South [Bofedal] has an average slope of 3.1% from the top of the ravine up to the confluence with the North Bofedal canal.
- As for the canal dimensions in the South Bofedal reach, the widths vary from 0.71 to 3.2 m; and the depths from 0.19 to 0.50 m.

A summary of the canal types, their longitudes, material type and total length is presented in Table 4 below. It can be seen that the largest number of canals built are main and uncoated.

Table 4. Summary of longitude of canals in the South Bofedal (measured in meters).

TYPE OF CANAL	WITHOUT COATING EXCAVATED IN NATURAL SOIL	WITH MASONRY COATING	CANALS IN ROCK	TOTALS
MAIN	1826.0	461.0	584.0	2871.0
SECONDARY	764.67	49.8	–	814.5

5.3 WORKS IN THE NORTH BOFEDAL

Site 27: In Figure 46 there is a panoramic view of the upper area of the North Bofedal. The soil is constituted by loose fine sands, with remains of rocks deposited and disintegrated due to weathering and wind erosion.

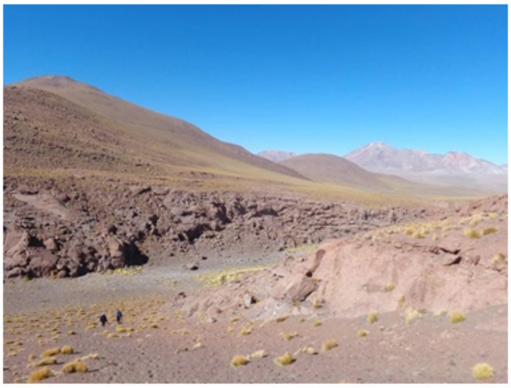
There is no presence of water or any indication of slope erosion or soil washing by surface runoff (laminar erosion), much less in gullies, which shows that there are no floods in the region, as occurs in river basins.

In addition, Figure 46 shows an overview of the type of soil of hillsides and slopes near the bofedales and the flow of water through them. In general, the slope cover is typical of arid basins with many areas covered with bare soil. On the other hand, the sediments of the surface are granular materials that are produced by abrupt changes of temperature and wind erosion, but not by water erosion.

Figure 46. Upper part of the North Bofedal.

In addition, at lower elevations it can be seen that the topography of the terrain is depressed and the outcrop of fissured rock on both flanks is observed. Further down, accumulations of fine granular sediment are observed, which come from the bofedal and also the emerging of springs that are channeled by small canals to another main collector canal.

Site 28: Figure 47 shows jointed rock, with rock blocks and pieces of broken rock. Among other configurations, disaggregated rock fragments can be seen on the rock massif. In general, it is observed that the soil is bear with tenuous paja brava (Stipa ichu) on the surface of slopes and in scattered clusters (thin coverage).



a) Upper reach of the North Bofedal

b) Right slope in the South Bofedal

Figure 47. Jointed rocks on the slopes of the North Bofedal.

Site 29: In the site with the coordinates E 601045 m, N 7566380 m, 4,390 meters above sea level (UTM System WGS1984) there is an observation well or piezometer (Figure 49a). Figure 49b shows that there is no erosion on this site.

a) Observation well in the North Bofedal.

b) Surface without erosion.

c) First spring in the North Bofedal.

d) First water upwelling in the North Bofedal.

Figure 48. Upper Sector of the North Bofedal.

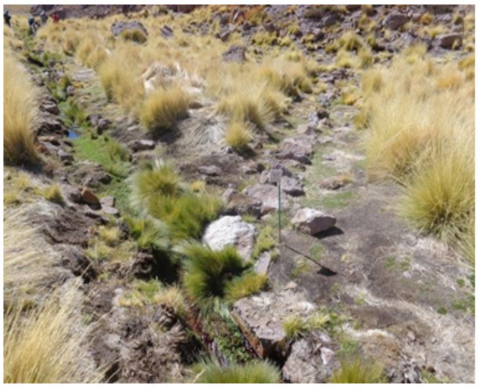
Site 30: The first spring in the North Bofedal is located at the foot of a rocky massif. Humid soil with little flow can be seen on the site, see Figure 48c. Figure 49d shows minimal flow upwelling water emanating from the subsoil.

Site 31: The first canal is observed in the upper part of the bofedal (Figure 50a). The characteristics of the canal are the following:

- Its alignment is straight, which implies intervention.
- The canal material is excavated in natural soil (bofedal) and the sediment from the excavation has been deposited on the right margin.
- The canal has no lining.

Site 32: Figure 49b shows how the flow originates from a spring, then it is channeled by canalization in natural soil, protected by rocks like a vault, and the flow is delivered to another main dirt canal of a larger

a) Channeling of water from the first spring through the artificial canalization at the North Bofedal.



b) Union of canals (confluence) for the channeling of water from springs.

Figure 49. Upper reach of the drainage canal in the North Bofedal.

a) Flow in the canal without sediment transport.

b) Joints in the North Bofedal.

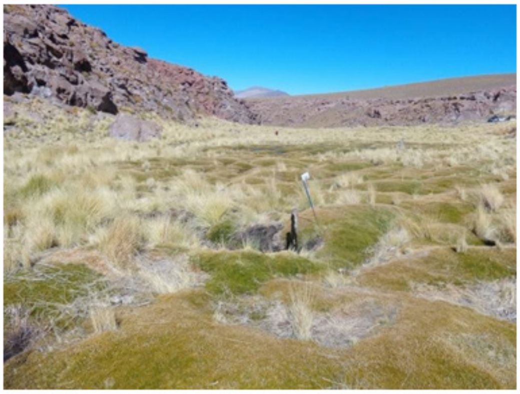
Figure 50. Canal bottom and slope in the North Bofedal.

Site 33: Figure 50a shows a canal with the characteristics described as most artificially constructed conduits, in which there is no evidence of sediment transport, such as boulder and pebbles. On the other hand, Figure 50b shows a jointed rock formation in the north slope.

Site 34: In the photograph of Figure 51 a ditch built for vehicular traffic is shown, which shows that there was already an access route to the springs, surely with the purpose of maintenance and inspection of the water abstraction hydraulic works. This work is located at the coordinates E 600925 m, N 7566322 m, 4,367 meters above sea level (UTM System WGS1984).

In addition, there is a pipe below the speed bump, which extends perpendicular to the road. This work has the function of driving the spring water from its upper part and extracting the water from the bofedal, since the pipe has perforations on its upper side. The length of the pipe cannot be estimated because it is covered with vegetated peat.

a) Speed bump for vehicle crossing.



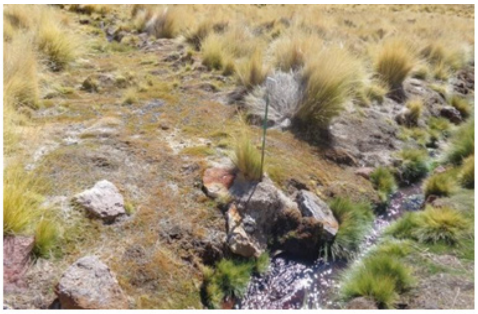
b) Flow throughout the bofedals.

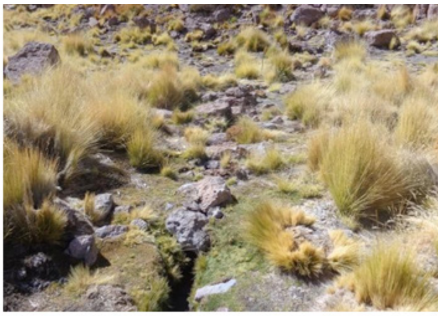
Figure 51. Ditch for vehicular passage and pipe for water flow.

Site 35: The bofedal of the photographs shown in Figure 51a is close to the springs, and is located at the coordinates E 600890 m, N 7566319 m, 4,361 meters above sea level (UTM System WGS1984). The sector is a typical area of bofedales where the surface of the soil is not uniform, but protuberances and depressions appear on the sides of the canal (see Figure 51b). The protuberances are formed by material from the bofedal (slime-sandy peat) of green color and with vegetation. In contrast, the depressions have sands and contain wetland and retained water. The difference in elevations between the flooded area.

Site 36: The photographs in Figure 52 show sediment promontories with characteristics similar to peat from bofedales; we can even see vegetation formed in clusters that protrude from the natural surface of the surroundings. It is probable that this material has been extracted from the excavation carried out in order to form artificial canals. The appreciation of soil promontories is from both sides of the canals, similarly, they run parallel to these.

A particular feature of this site is the reticulated trace of canals with lateral drains, those that collect water from the springs in secondary canals that are almost parallel. The water contribution from springs is carried out in series, that is to say, as progress is made in the route towards the border, a greater flow is collected through the main canal. Finally, the water collections of each spring are added longitudinally and converge until reaching a confluence canal in the South Bofedal canal.





a) Collector canal with accumulated sediments on the sides.

b) Secondary canal with sediment clusters on tl sides.

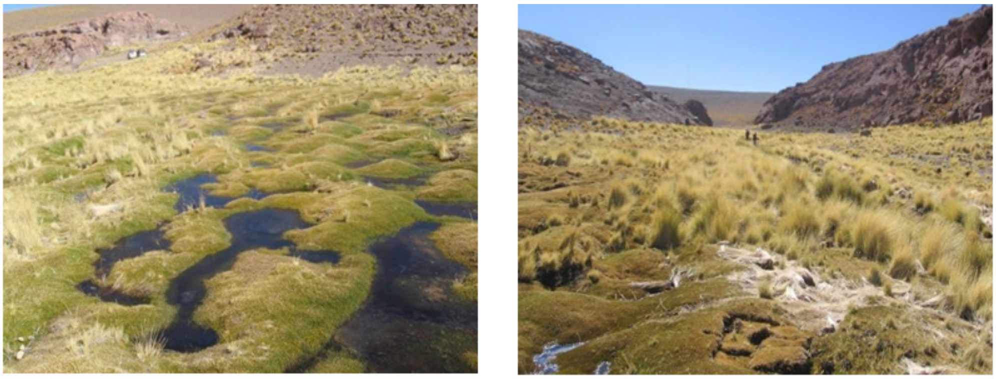
a) Canal lined with rocks.

b) Spring with rock protection.

Figure 52. Reach of minor canalizations (secondary canals).

Site 37: The photograph in Figure 53a shows the bofedales with high humidity retention and the direction of flow is not observed, so it is considered that this is a flooded zone. This bofedal configuration is seen in the mid-west sector of the North Bofedal, it is also seen that in the sector there are no canalization works, reason why there is accumulation of water among the vegetation clusters. It is believed that this bofedal configuration is the natural condition of a bofedal in the region, as can be seen in other photographs that are described in the chapter that describes wetlands in natural conditions.

Figure 53b shows a view of the main canal to the north, in which the alignment line of the canal and its relationship with the natural slope of the bofedal can be seen, this means that the main canal has been traced in such a way that it runs through the lowest topographic levels, in such a way that the water from the springs can be easily abstracted and drain the water from the bofedales to channel it through the secondary canals.



a) North Bofedal with a downward view. b) North Bofedal and drainage canals with an upward view.

Figure 53. Flooded zone in the North Bofedal.

Site 38: In Figure 54a a perforated transverse pipe is observed, which has the function of channeling the spring water located at the top, to then deliver it to a secondary canal that collects water from other springs. Also, it is shown that the pipe is covered with natural dirt and protected with rocks, which is justified because this space was built for vehicular traffic above such channeling.

Site 39: The photographs presented in Figure 54b show a spring in the North Bofedal. It is located at the coordinates E 600831 m, N 7566275 m, 4,359 meters above sea level (UTM System WGS1984), next to the access road to the area. There is a protection of rock that surrounds the spring and its exit is achieved towards a small canal covered with rocks. In this spring there is a flow somewhat higher than the others located in higher elevations, probably because here there is a greater hydraulic gradient or the fissures in the jointed rocks are in greater number or size.

a) Perforated pipe. b) Spring.

Figure 54. Abstraction of springs through pipes and canals of accommodated rock.

Site 40: In the photograph of Figure 55a, seen upwards, there is a lateral canal that flows along the left flank. This is located at the coordinates E 600821 m, N 7566267 m, 4,361 meters above sea level (UTM System WGS1984).

a) Spring Protection. b) Confluence of secondary canals.

Figure 55. Spring protection and dome channeling

Site 41: In the photograph of Figure 57b, another canal can be seen going down the right flank and dislodging a small flow through a pipeline and merging with a secondary canal, just at the confluence with another canal. Additionally, it can be observed that this canal has been protected with rocks in its upper part, forming a chamber-shaped canal.

Site 42: Figure 56 shows the water that is conveyed through small canals excavated in the soil of the bofedal; these small canals then enter the main collector canal.

a) Input of collector canal. b) Flow in the secondary collector canal.

Figure 56. Collection of water from springs.

Site 43: The photograph of Figure 57 shows a spring that emerges at a relatively high level with respect to the main collector canal. The flow is appreciable since its inception. The intervention is very noticeable since it has rock canals that have been carefully placed, in such a way that the flow has a regular wall. In its lower part, it enters into another canal in line with the slope; in addition, its section is more or less constant and comprises canals that collect water from other springs. This sector is geographically located at the coordinates E 600768 m, N 7566308 m (UTM System WGS1984).

a) Spring of the north bofedal | b) Channeling of water from the spring.

Figure 57. View of spring 50.

In the panoramic view of the North Bofedal (Figure 58 and Figure 59) the following aspects are observed:

a) From the geo-morphological point of view, it can be distinguished that two deep valleys have been formed, originated by fluvial-glacial processes that have given rise to a characteristic geological configuration, with slopes in both Silala bofedals.

b) The north flank has a moderate slope with loose soil that gives it the shape of a hillside valley with very sparse vegetation, mainly straw. The opposite flank is a cliff of high slope formed by rocks. On both flanks there is no evidence of surface runoff by slope or effects of laminar erosion.

c) The bofedal extends to the south in which a series of artificial canals with well-defined tracings and slopes that join a larger main collector canal can be seen from the top.

d) Upwelling waters that occur in the valley are linked to the process of deposition of loose and disintegrated material, which have allowed the bofedal to develop throughout the valley, but with greater incidence on the northern flank.

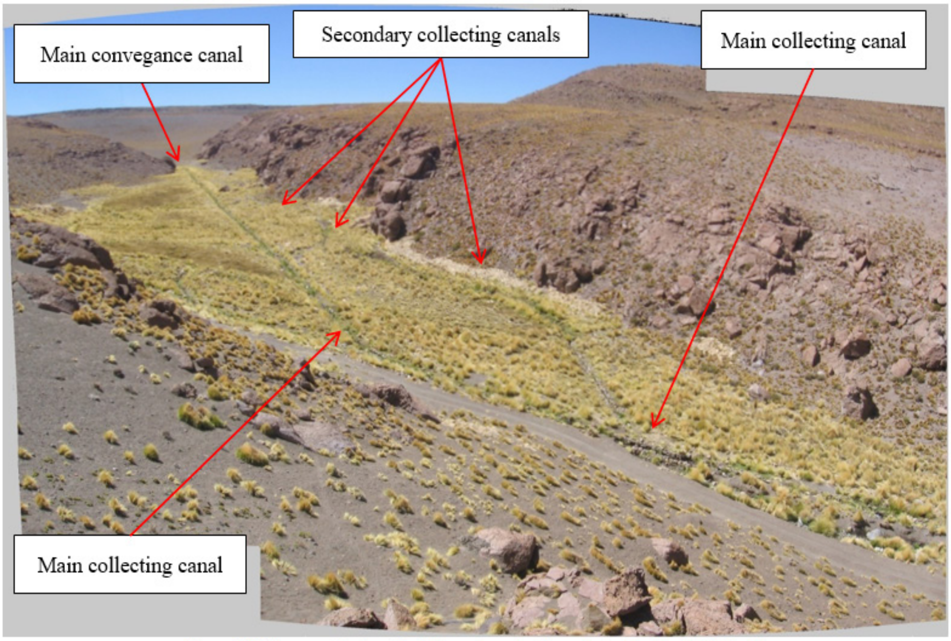


Figure 58. Panoramic view 1 of the network of canals in the North Bofedal.

The configuration of secondary collector canals has a trace in the shape of a fishbone, which consists of the construction of almost parallel canals that enter in series to a main conveyance canal. This form of drainage clearly demonstrates that the springs are being channeled from its upwelling to the confluence with a larger canal. In turn, another quantity of water is collected from the bofedales, since these are drained longitudinally until achieving the delivery of water in the main canal.

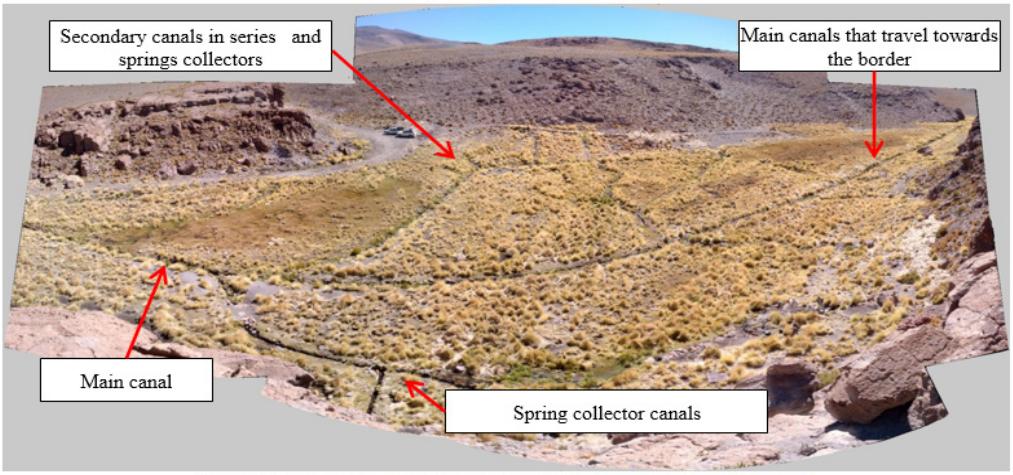


Figure 59. Panoramic view 2 of the network of canals in the North Bofedal.

5.3.1 SUMMARY OF THE WORKS OF THE NORTH BOFEDAL

In the North Bofedal the following aspects are distinguished:

- The conformation of the North Bofedal differs from the South Bofedal, in its geometric arrangement. The North Bofedal along the movement of water through the canals is developed on the bofedals and not on channelized bedrock as evidenced in the South Bofedal.
- The number of springs of the North Bofedal is higher than that of the South Bofedal. This situation means that the number of water catchments per spring is greater and therefore the number of secondary canals is greater. The disposition of the drainage network –that is to say of the network of canals of the North Bofedal– is of the "fishbone" type, that is to say there is a main canal and the secondary canals generate the indicated geometric disposition.
- Only part of the main canal –specifically the upper part– is uncoated on natural soil. Making an abstraction of this reach, practically all the canals (main and secondary) have stone masonry coating without binder material. In some sectors the use of stone is "denser" as is the case of the main canal.
- In the North Bofedal, the presence of pipes as secondary canals has been evidenced. The canals operate at free flow, that is, they do not work under pressure.
- The drainage density of secondary canals is higher than in the South Bofedal, which shows a much higher degree of intervention.
- The use of stone masonry without binder material greatly helps lateral drainage along the canals. So the process of collecting water is not only located at the outlet of the springs but also along the entire canal.
- The secondary canals were protected with dry masonry both in the walls and in their upper part, forming canals in the form of a vault.
- In the reach before the confluence with the canal coming from the South Bofedal it is observed that the use of stone masonry is accompanied by a stone drilling in the sole (the bottom of the canal).
- The plan layout of the primary and secondary canals is rectilinear. The horizontal alignment of the canals is rectilinear, with no gradual curvature in the direction changes.
- The main canal of the North [Bofedal] has an average slope of 6.4%, from the upper part to the confluence with the South Bofedal canal.
- The dimensions of the North bofedal canal vary from 0.40 to 0.48 m, at its base, and from 0.22 to 0.55 m in depth.

Table 5 presents a summary of the longitudes of canals, types and materials that are found in the North Bofedal reach. It is observed that there is a greater predominance of secondary canals, a situation that can be clearly noted by the existence of a greater number of springs.

Table 5. Summary of canal longitude in the North Bofedal (measured in meters).

TYPE OF CANAL	WITHOUT COATING EXCAVATED IN NATURAL SOIL	WITH MASONRY COATING	CANALS IN ROCK	TOTALS
MAIN	170.0	518.0	–	688.0
SECONDARY	–	1112.0	–	1112.0

5.4 CONFLUENCE REACH CANAL

5.4.1. DETAILED DESCRIPTION

Site 44: The confluence of the drainage canals in the South and North Bofedales of Silala occurs at the coordinates E 600650 m, 7565900 m. The entry canals are straight and fully lined with masonry walls, see Figure 60. There is no sediment transport and the flow is turbulent.

Before the confluence there are two metallic triangular weirs that monitor the flow with level sensors.

The main feature at the confluence of the channels of the South and North Bofedales is that on both sides there is stone masonry canalization with some type of binder (at bare sight, it has not been possible to establish with precession the type of binder that might have been employed in said section). The masonry shows conditions of high resistance to the velocities of the flow (the magnitudes of the speeds are presented in the chapter corresponding to the hydraulic modeling).

Figure 60. View of the confluence of canals of the South and North Bofedales.

Site 45: After the confluence of the south and north canals, the collected water is delivered to a main collector canal, constructed of totally artificial stone masonry, which channels the volume of water of all the springs and the drainage of bofedales, as can be seen in Figure 61.

The main characteristic of this canalized reach, from the collection – desiltation work up to the border (see Figure 62) – is its artificial alignment, which has been generated from a typical drainage project.

a) Straight reach.

b) Curved reach.

Figure 61. View of the masonry canal towards the border with Chile.

First, Figure 61a shows a canal reach in straight line. Secondly, in the same alignment of the canal, a rock slope with an almost vertical cut can be seen in the background. Therefore, the drainage has been diverted, as shown in Figure 61b.

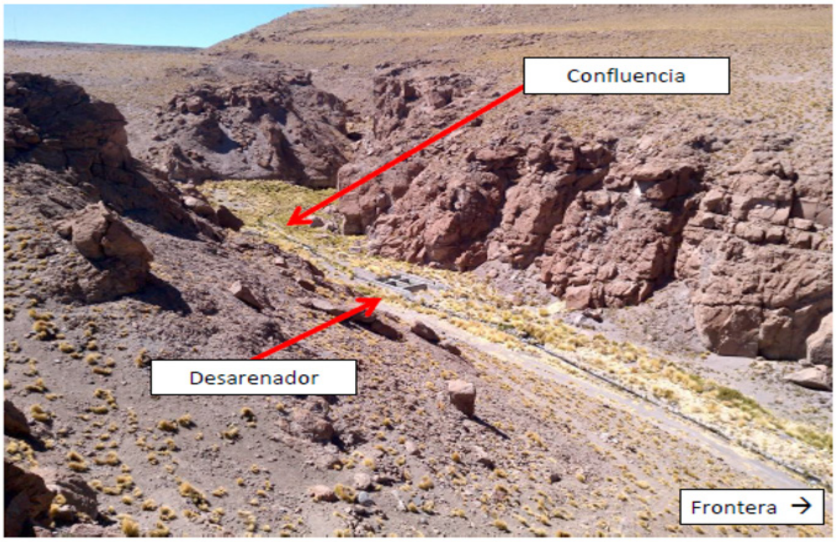


Figure 62. Intake works, desilting chamber and load chamber near the border.

Site 46: Finally, Figure 63 shows a view of the exit canal towards the border with the Chilean territory. In this figure we can see the line of canals that were aligned according to the topography of the terrain.

Figure 63. Panoramic view of the exit canal towards the border

5.4.2. SUMMARY OF THE WORKS OF THE CONFLUENCE REACH

In the confluence reach the following aspects are distinguished:

- Once the North and South Bofedal canals converge, the channeling canal carries water from both bodies of water to the border.
- The canal is of greater capacity and its disposition obeys to the configuration of the ravine. The canal has been built by the central part of the ravine where it has been shown that the intervention has been developed on a natural body.
- The canal has been built in stone masonry on the walls and stone treads on the sole.
- In this reach is located the largest water abstraction work carried out in the area, consisting of a desiltation chamber and a loading chamber. At present, this work is in disuse.
- The horizontal alignment of the main canal of the confluence reach is quite straight and the curves in the direction changes are not gradual.
- The slope is uniform, with an average value of 5.6%.
- The cross section of the almost constant canal. Its mean dimensions are 0.80 meters wide by 0.65 meters deep.

Below, Table 6 provides information about the longitudes of the canals in the confluence reach. In addition, the characteristics of these and their material are indicated.

Table 6. Summary of the longitude of canals in the Confluence Reach (measured in meters).

TYPE OF CANAL	WITHOUT COATING EXCAVATED IN NATURAL SOIL	WITH MASONRY COATING	CANALS IN ROCK	TOTALS
MAIN	0.0	706.0	–	706.0
SECONDARY	–	238.0	–	238.0

6 DESCRIPTION AND CLASSIFICATION OF WATER COLLECTION WORKS

6.1 WATER COLLECTION WORKS

6.1.1. CLASSIFICATION

For purposes of accuracy it is necessary to differentiate between two types of water collection, as they are addressed in this work:

- Specific catchment
- Longitudinal catchment

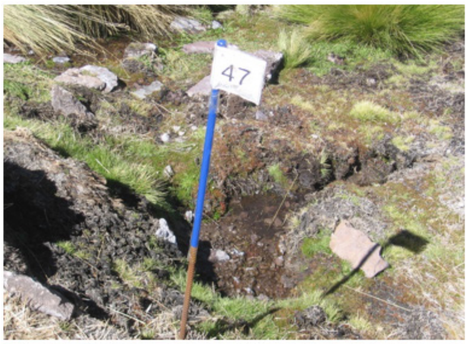
The specific catchment is understood as the works executed to collect the waters at the exit of each spring, while the longitudinal catchment is understood as the capture of waters along the drainage canals.

In turn, the specific catchment differs between smaller and larger catchments, the smaller catchments are those that, due to their volume of work, are located at the exit of each spring, whereas a greater catchment is the one that is in the confluence reach, where the works are bigger and where the objective is to collect the water that flows to that point coming from the north and south canals.

6.1.2 MINOR SPECIFIC CATCHMENTS

Based on the methodological approach of this study, 138 springs are accounted for (SENAMHI-DIREMAR, 2018).

In order to achieve greater efficiency in collecting the entire flow of each spring, especially those with greater water contribution, small hydraulic collection structures have been built consisting of concrete walls or stone masonry. At the exit of these small catchments, there are the secondary canals of the drainage network. These water catchment works in turn fulfill the objective of channeling the emerging water.



a) Catchment work without protection to collect water from the spring.

b) Catchment work with protection to collect water from the spring.

Figure 64. Collection of water from springs.

63

According to the field inspections, the water collection or abstraction works in the springs are practically equivalent to the number of existing water eyes with the greatest contribution, and according to the observations made, it is distinguished that said works are adequately protected. In the photograph of Figure 64a it shows a work of unprotected catchment in the spring 47; however, Figure 64b presents a more elaborated protection. The difference is that the greatest protection is for the highest flow springs.

6.1.3 LONGITUDINAL ABSTRACTION WORKS

The canals have been built with dry stone masonry or have been simply excavated in natural soil in order to form cross sections in an almost rectangular shape. The dimensions of the canals vary, as described above.

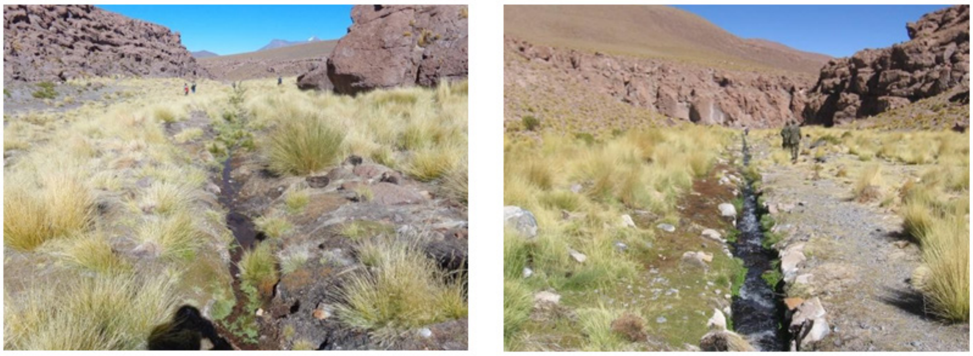
It is possible to characterize the canals in terms of their conformation and their dimensions, the widths of the canals are highly variable, in both the South and North bofedals (see Figure 65a and Figure 66a and b respectively), similarly, their depths are diverse.

a) Average canal without lining in the South Bofedal.

b) Average Canal with lining in the North Bofedal.

Figure 65. Longitudinal abstraction stone-lined canals

The canals in the North and South Bofedales have different characteristics. The main characteristic is that it has reaches with lining and others without lining. Figure 65 and Figure 66 present canals of both bofedales with similar interventions. The first shows the non-lined canal, while the second shows the canal lined with dry stone masonry. The canals do not present any concrete or binder that might make the rock assembly impermeable.



a) Average canal without lining in the North Bofedal. b) Average canal with lining in the North Bofedal.

Figure 66. Average canals in the North Bofedal.

According to what has been indicated, it has been demonstrated that the longitudinal collection works capture the water longitudinally along its entire length, as can be seen in Figure 67, the same one that develops through the permeable walls. This is a way of lowering the originally upwelling water table (see Figure 68), this descent channels a flow of the bofedals towards the canals; in this way it is possible to drain the bodies of water located in the bofedals (see similar canals from Figure 70 to Figure 72).

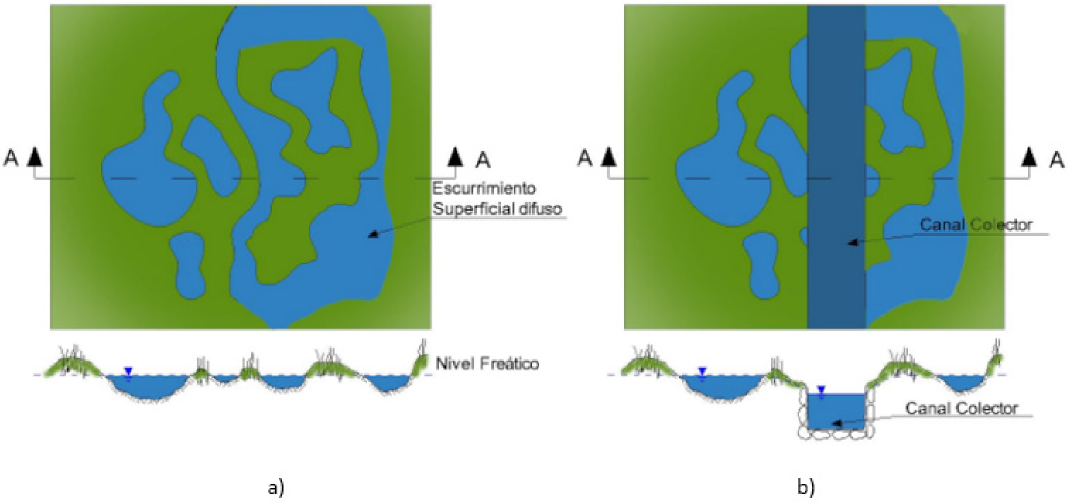


Figure 67. Wetland waterbodies a) natural and b) intervened.

The drainage of the waterbodies is manifested both in the main canals and the secondary canals.

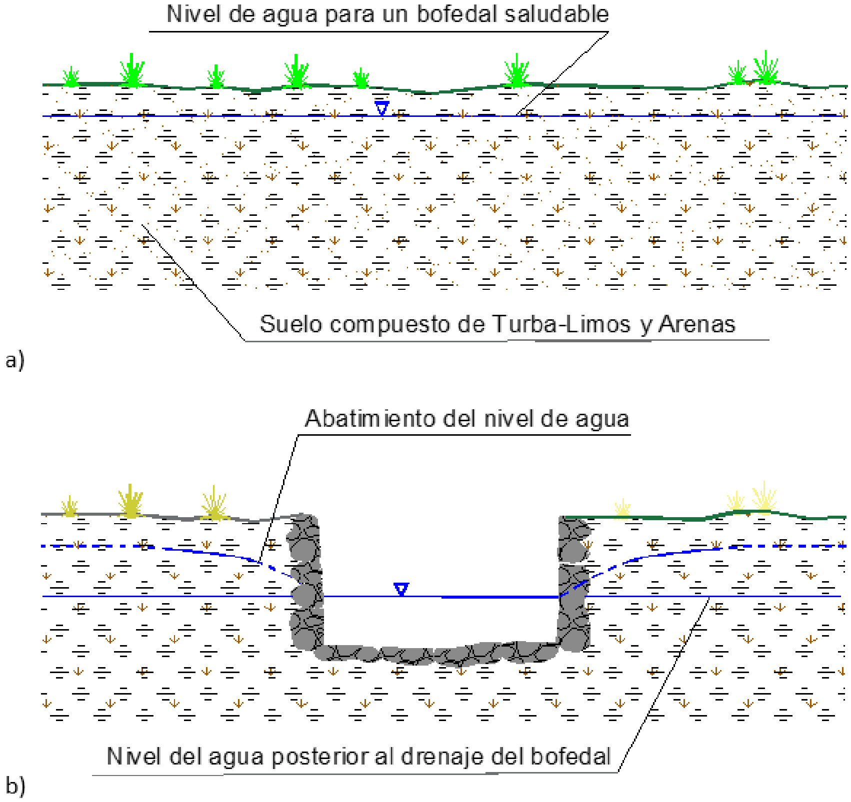


Figure 68. Water abstraction in the bofedales, a) before the canals were built and b) after canal construction

The main channels collect the waters that are delivered from the secondary channels, in addition, these have a trace that runs through the lowest points of the land, since when superimposing them with the topography of the land it is verified that they travel in linear lines and with slopes regulated by the same terrain, as drainage projects are carried out on roads or agricultural lands. These assertions were studied and verified in the topographic plans, therefore, the construction shows that not only the springs have been drained, but also the bofedales have been drained.

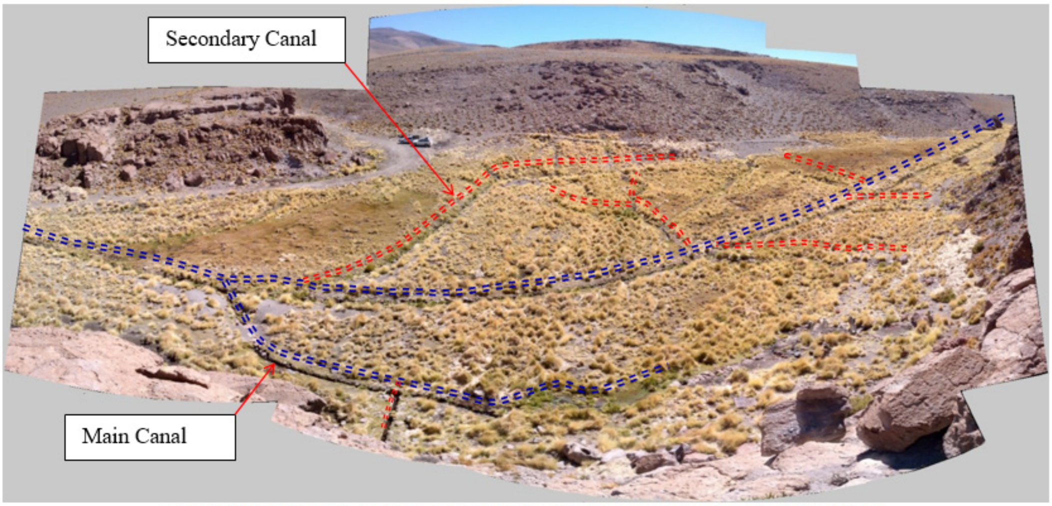


Figure 69. Characteristics of the layout of main and secondary canals in the North Bofedal.

a) Main canal in the South Bofedal.

b) Secondary canal in the South Bofedal.

Figure 70. Main and secondary canals in the South Bofedal.

a) Main canal in the North Bofedal.

b) Secondary canal in the North Bofedal.

Figure 71. Main and secondary canals in the North Bofedal.

Figure 72. Panoramic view in which the main canal of the North Bofedal can be seen.

6.1.4 GREATER SPECIFIC CATCHMENT

The largest specific water catchment work is at the beginning of the confluence reach, which is composed of concrete masonry works. Its objective has been to collect the water flow from the main confluence canal. It consists of collector canals and a chamber that acts as a loading chamber for the abduction of steel pipes.

The water intake work is located a few meters below the confluence point of the South Bofedal and North Bofedal canals; see Figure 73. This work also has the purpose of retaining fine sediments, since its configuration and structure is designed for it, which makes us suppose that at some time, with the canalization works, sediment transport of certain characteristics was presented. However, at present it is not possible to establish accurate criteria for its functionality due to the scarce information and, mainly because in the upper part there is no evidence of sediment transport.

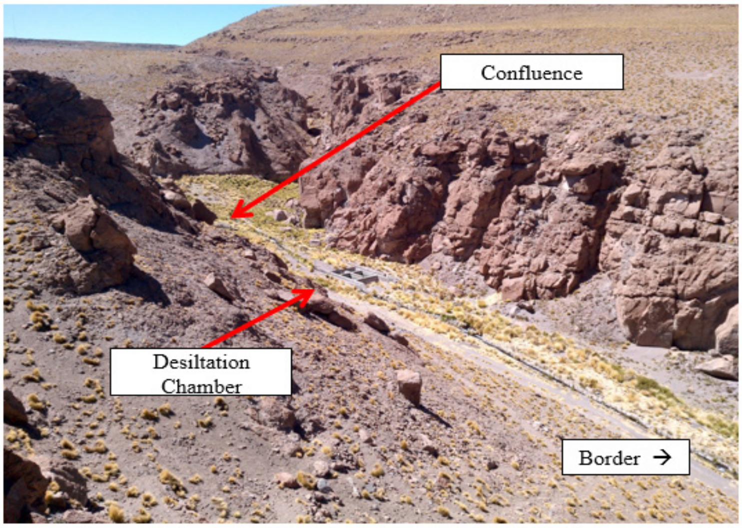
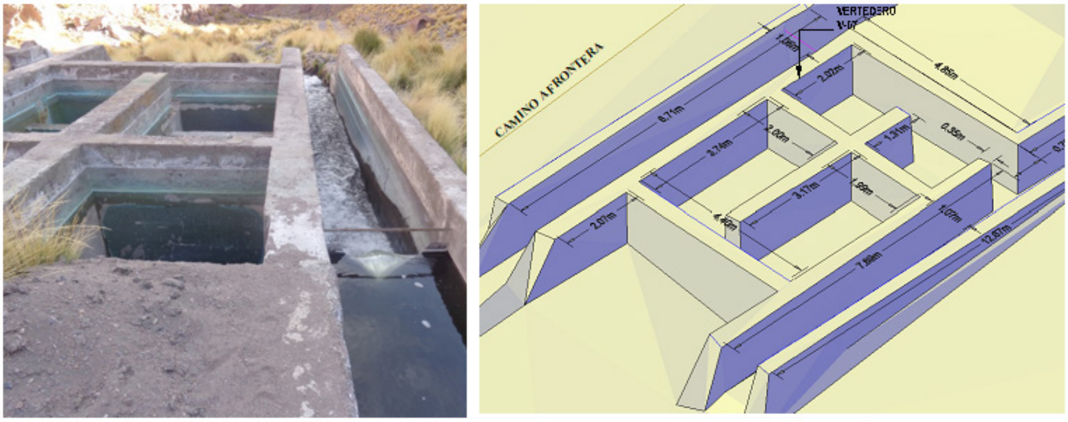


Figure 73. Water intake work, desiltation chamber and loading chamber near the border.

The water intake work and the desiltation chamber (Figure 74a) also fulfill the function of loading chamber (as it is observed in the Figure 74b), because at the exit of the same two steel pipes were connected that started from inside the work.

As mentioned, the intake works at the border, collects water from a canal on the left bank, the water is collected by raising the water level, then passing through several slopes with the function of depositing the solid particles and then divert them to a tank that connects to two pipes with diameters of 10” and 12”.

Currently, the outlet canal of the intake work, located on the left bank, is in disuse and buried.



a) Desiltation chamber and loading chamber near the Border with Chile. b) Dimensions of elements of the water intake work.

Figure 74. Water Intake Work (Source: DIREMAR).

6.1.5 ADDUCTION

Although drainage canals fulfill the function of collecting and channeling water, in the present analysis they are not considered as adduction works. The adduction in the past context refers to the pipes that came out of the larger work. The adduction consists of three types: 1) the one that is drawn from the springs, in order to channel the water towards the main canals in the bofedals; 2) the one that corresponds to the main canals that collect the water drained from the bofedals and 3) the one that carries out the final collector or exit canal towards the border.

7 DESCRIPTION OF THE SEDIMENT TRANSPORT PROCESS

This analysis of sediment transport is not based on field measurements made to evaluate the bottom trawl transport, since this transport does not occur in the Silala canals with the measured flows.

The description of the sediment transport process is based on the field evidences and also on the results of the water quality analysis elaborated by DIREMAR. The field inspections consider two main aspects:

- Processes related to laminar erosion.
- Transport of sediments in the canals.

7.1 PROCESSES RELATED TO LAMINAR EROSION

The entire basin has been covered in order to find some evidence to indicate the existence of signs of laminar erosion caused by an atmospheric agent, precipitation or wind.

The field inspection shows that although there is topographic relief and surface highly vulnerable to water erosion; that the precipitation is snow-like and there is no erosion by water action, despite the fact that the surface of the basin has disintegrated soils with high potential to generate erosion and movement of sediments. Described in other terms it can be explained that there are no traces of runoff caused by precipitation as it occurs in a basin where runoff is caused by an excess of precipitation and saturation of soils, that is, there are no courses that could show the concentration of flow in a drainage network.

In conclusion, there is no surface runoff that can cause laminar erosion (see Figure 75).

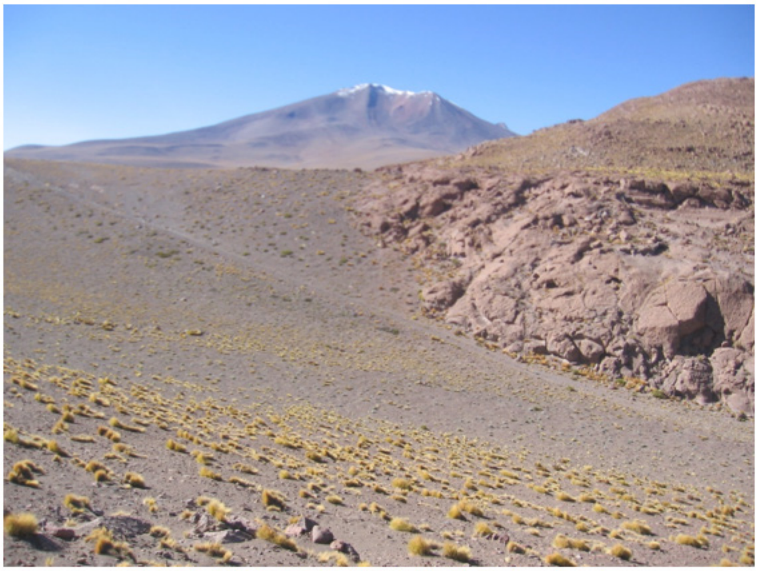
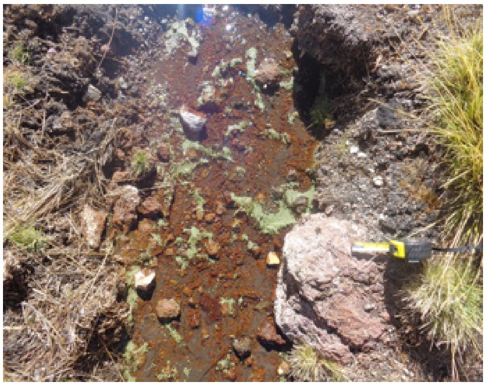


Figure 75. Hillside of the North Bofedal without signs of erosion.

7.2 TRANSPORT OF SEDIMENTS IN THE CANALS

From the field inspection it is observed that there is no bottom transport in the canals as can be seen in the photographs of Figure 76. This situation is corroborated with the daily flow records of the period between December-2017 and March-2018, which shows a limnogram of measurements in which it is clearly distinguished that extreme events do not occur, that is, no events that are related to a storm are observed. The limnogram of the aforementioned Figure 77 shows that there are no spikes that indicate a hydrological response to precipitation. In this way, it has been demonstrated that bottom transport does not exist due to seasonal variations.

According to the inquiries made to the hydrometric technicians of SENAMHI that carry out measurement work and flow gauging on a monthly basis, they indicate that sediment retention exists in the anterior part of some weirs.



a) Canal in the North Bofedal with sediments in the bottom without movement.

b) Canal in the South Bofedal with sediments in total rest.

a) Sediments on slopes of the South Bofedal (Site 2, Dm = 0.2 cm)

b) Sediments in the upper zone of the South Bofedal canal (Site 1, Dm = 0.3 cm)

Figure 76. Sediments in the canals and hillside in the upper area of the bofedals.

Along the canals it is observed that the particles located in the bottom of the canals do not show a configuration that allows assuring the presence of spherical particles, cobbles or boulders as it happens in the fluvial canals.

It is recommended to carry out an evaluation or specific studies based on measurements with sediment traps. Consequently, under the current state of information about sediments, it is not possible to draw definitive conclusions.

However, there is material that is transported in suspension. This is verified with the water quality sheets taken in different campaigns, which are attached in Annex 3.

The results of the water quality analysis show very low concentrations of suspended solids, even null in some measuring points, with an average of 2.9 mg/l..

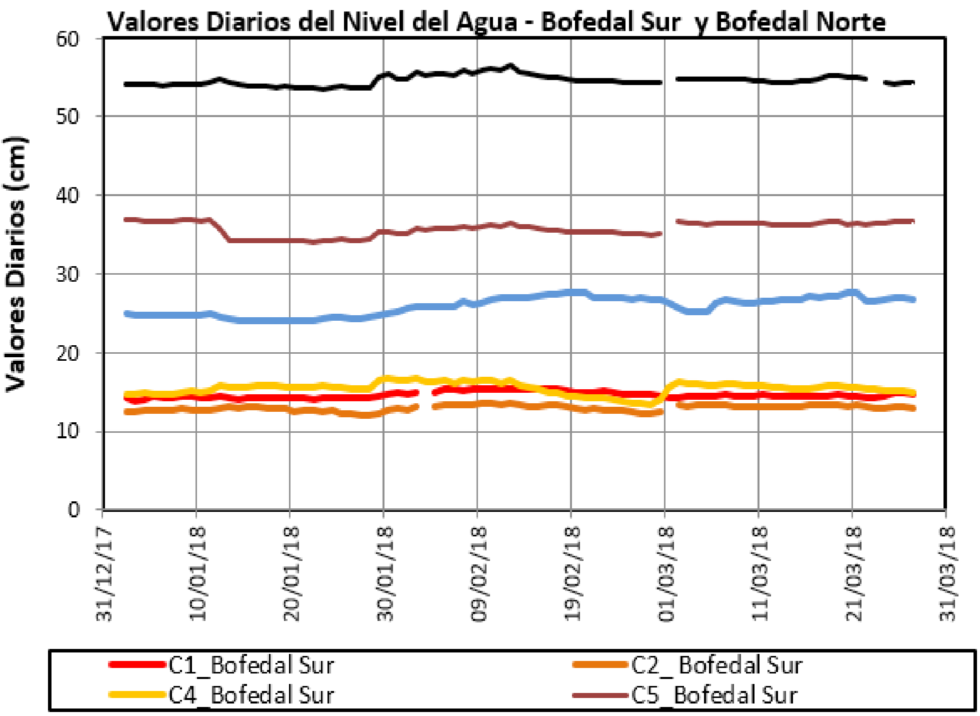


Figure 77. Water levels in the weirs C1 to C6 for the period December-2017 to March-2018.

8 SURFACE FLOW HYDRAULIC MODEL IN HEC-GEORAS

8.1 SPECIFIC OBJECTIVE

The objective of the present hydraulic analysis is to evaluate the hydrodynamic conditions of the flow or surface runoff of water in the Silala canal water system and to evaluate the influence of the artificial interventions (canalization introduced to abstract and convey the water)—which alter the surface and subsurface natural water regime—on the bofedal outflows.

8.2 HYDRAULIC MODEL

In the system surveyed, in which canals predominate a mathematical model has been completed with the HEC – RAS Model (HEC-GeoRAS), in its unidimensional and bi- dimensional hydraulic simulation modules, which provide the hydrodynamic elements, or variables of the system in order to characterize the flow regime, velocity, water depths, Froude number, Energy Line, etc.

The HEC-RAS mathematically determines the hydraulic profiles by means of the relations of classical hydrodynamics. Its application requires the definition of the land surface to be modeled and flow data for hydrological events or regimes. The geometrical and hydrometrical data are used to calculate the hydraulic profile of a gradually varied flow from calculations of energy losses. HEC-RAS is able to model a complete network of canals, dendritic systems, or a simple river course (depending on how detailed the information available is, the decision can be made to idealize the system). The HEC-RAS requires the introduction of geometric data to represent a canal network, data on the cross-sections Since the introduction of its 2.0. version, the HEC-RAS allows the use of three-dimensional geometry to describe flow networks and cross-sections, and its latest versions allow the extraction of the geometry of a digital terrain model by means of an interface, or extension into Geographic Information Systems (ARCGIS).

The model uses cross-section geometric data to characterize the channel's transport capacity (effective hydraulic area) and geomorphological characteristics. The following parameters must be inserted:

• The Canal's Morphometry, which will represent the surface and its location in the section to be modeled (Reach). This geometry is taken by means of cross-sections perpendicular to the flow direction of the main canal (cross-section data). The portions of the main canal (canal) axis are defined with those of the edge of the flood area (banks), helping define the flow's hydraulic loading capacity.

• Distances longitudinal to the channel between cross-sections (Reach lengths), allowing to determine the energy loss that takes place in each reach in-between sections. These distances must be taken from the left and right edges, or margins, and from the main channel axis.

• Roughness coefficients ("n" Manning), which are taken into consideration for the calculation of the energy losses produced by friction between the surface of the bed and margins with water, this is given for each reach in-between sections and by type of material present in the bed and canal walls. This coefficient is usually represented by the "Manning" coefficient.

• Shrinkage and expansion coefficients, which depend on the characteristics and the changes produced in the canals.

The HEC-RAS model (River Analysis System) can calculate the hydraulic parameters of a river by simulating its behavior with the existing structures.

For the present case, where the temporal evolution is not a factor to be taken into account and the flow is eminently one-dimensional, this model is sufficient, although it has been modeled two-dimensionally. These model types are based on relatively simple but effective numerical schemes. The fundamental equation in mathematical modeling is the preservation of energy between two sections, although the preservation of movement amounts for local phenomena, such as regime changes, can also be used, as well as other more or less empirical equations for other local effects.

8.3 METHODOLOGY

The hydrodynamic flow analysis of the canal system by modeling and mathematical simulation requires the following steps to be followed:

• Collection of detailed topographical (Planialtimetric) data, satellite imagery and digital aerophotography provided by DIREMAR, in dwg format for CIVIL 3D as a surface model and for Autocad with detail of contours and planimeters, such as canals, bofedal areas, infrastructures, flumes, roads, etc.
• Collection and revision of previous referential documentation for the area surveyed, or similar water systems.
• Topographical survey with stationary total stations for each relevant point or gauging section.
• Based on the detailed topography, digital elevation or terrain models (DEM) were generated in Geographic Information Systems (ARCGIS) in Grid and TIN format; for the model to best describe the terrain's surface configuration, the model has a resolution of 20x20 cm.
• Setting up of the geometry of the canal system in HEC Geo RAS, which works in an interface in ARCGIS and creates the geometry to be exported from a DEM, to then be exported to HEC- RAS. Cross-sections were defined every 10 meters to achieve a better detail of the hydraulic conditions by sections.
• Parameterization and estimation of hydraulic parameters (slopes, Manning roughness coefficients) on basis of hydrometric information provided by SENAMHI through DIREMAR to for its processing and management (calibration curves).
• Definition of the hydrological scenario (flowrate) on basis of the available hydrometric information of drainage (levels and gauges) provided by SENAMHI through DIREMAR.
• Parameterization of the simulated hydraulic conditions, by sections, nodes or confluences.
• Refining the information to achieve an optimal simulation of the mathematical model for the Silala drainage system in HEC-RAS.
• Hydraulic simulation for the baseline scenario.
• Presentation of results and evaluation.

8.4 GEOMETRY OF THE WATER SYSTEM

The configuration and length of the system is defined by the influence of the inflows and main water sources in the bofedal areas at the headwaters and springs.

A detailed topographic map with level curves was prepared, see Figure 78.

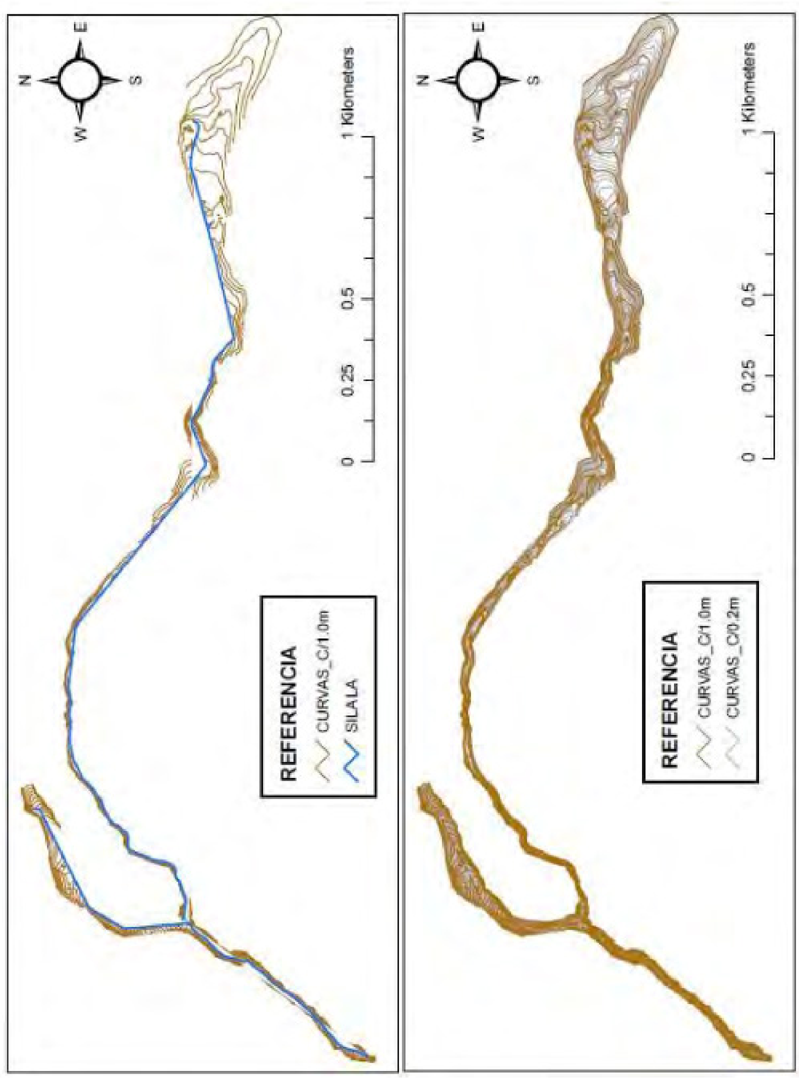
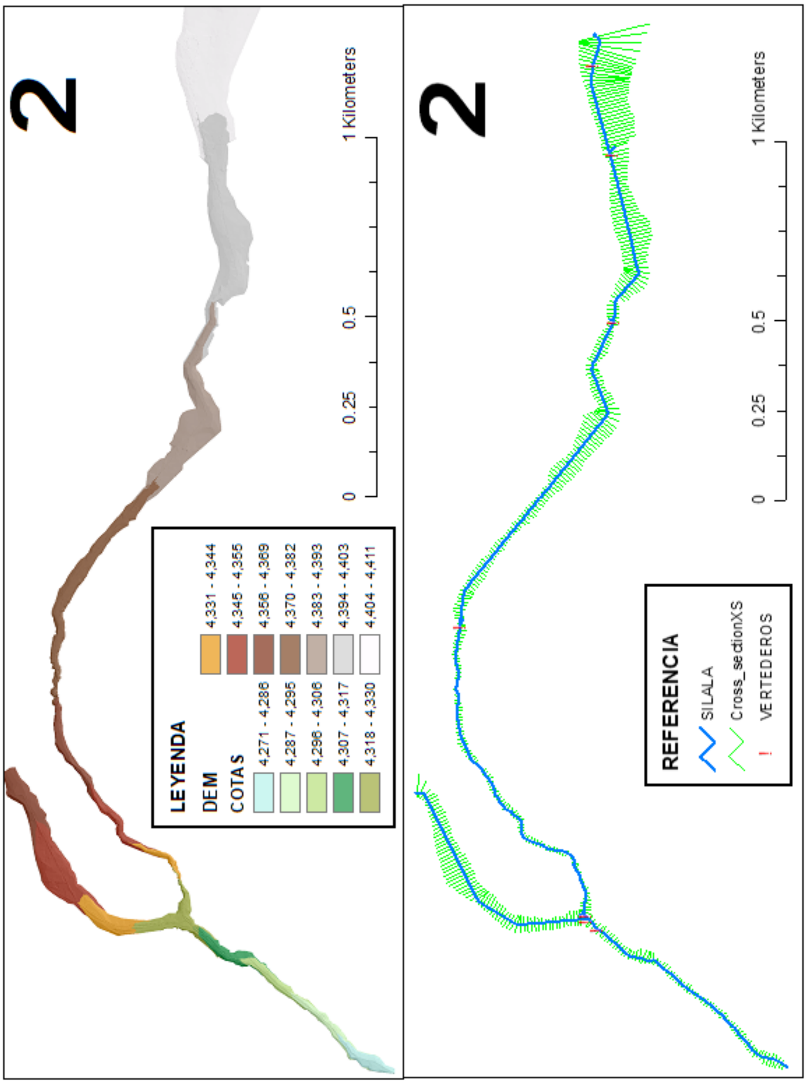


Figure 78. Topographic Survey Map with Level Curves every 1 meter and every 20 cm. (Source: Own elaboration, based on the topography provided by DIREMAR)

Subsequently, a digital terrain model was constructed (Figure 79), a three-dimensional surface of the hydraulic system was generated, for processing in ARCGIS HEC-GEORAS and subsequent importation to HEC-RAS.



a) b)

Figure 79. Map of the Digital Terrain Model and generation of the Geometric Model in ArcGIS. (Source: Own elaboration, based on the topography provided by DIREMAR).

Figure 80 shows the geometry of the HEC RAS Model with its cross sections and results of the run of the hydraulic simulation. Figure 81 then shows the network of channels in perspective and the 3D model in the HEC-RAS program, with the location of the cross sections. The system has been divided into three axes or sections:

- South Silala. Longer branch, which develops predominantly from east to west.
- North Silala. Short branch, it develops predominantly from northeast to southwest.
- Silala Confluence Section. Confluence of the North and South Branches, it develops predominantly from northeast to the south west.

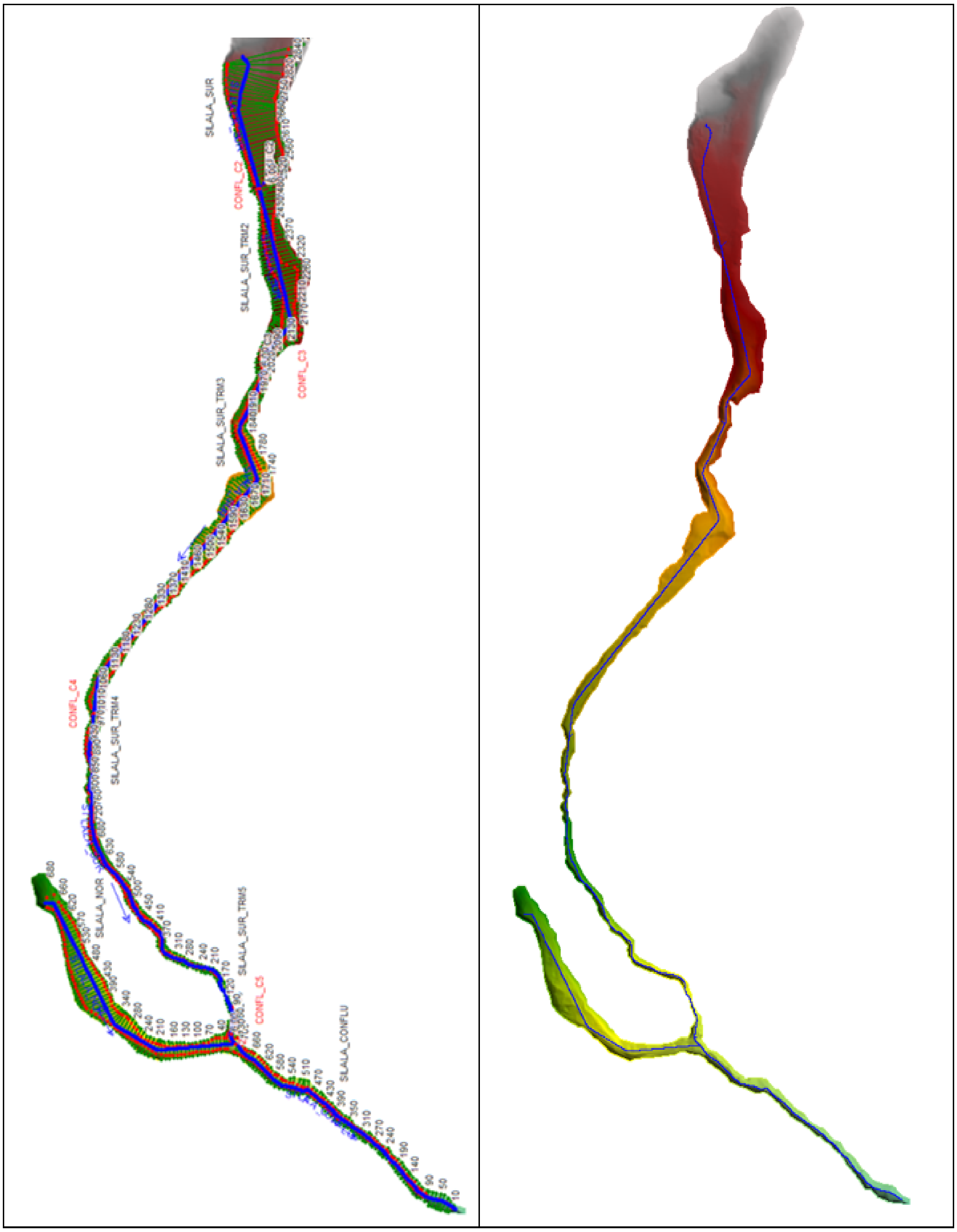


Figure 80. Geometry in the HEC-RAS Model (Digital Elevation Model (DEM), Electrode Emplacement Points, Cross-Sections). (Source: Own elaboration, based on the topography provided by DIREMAR).

Annex 2 presents the detailed geometry of the three reached mentioned (North, South and Confluence).

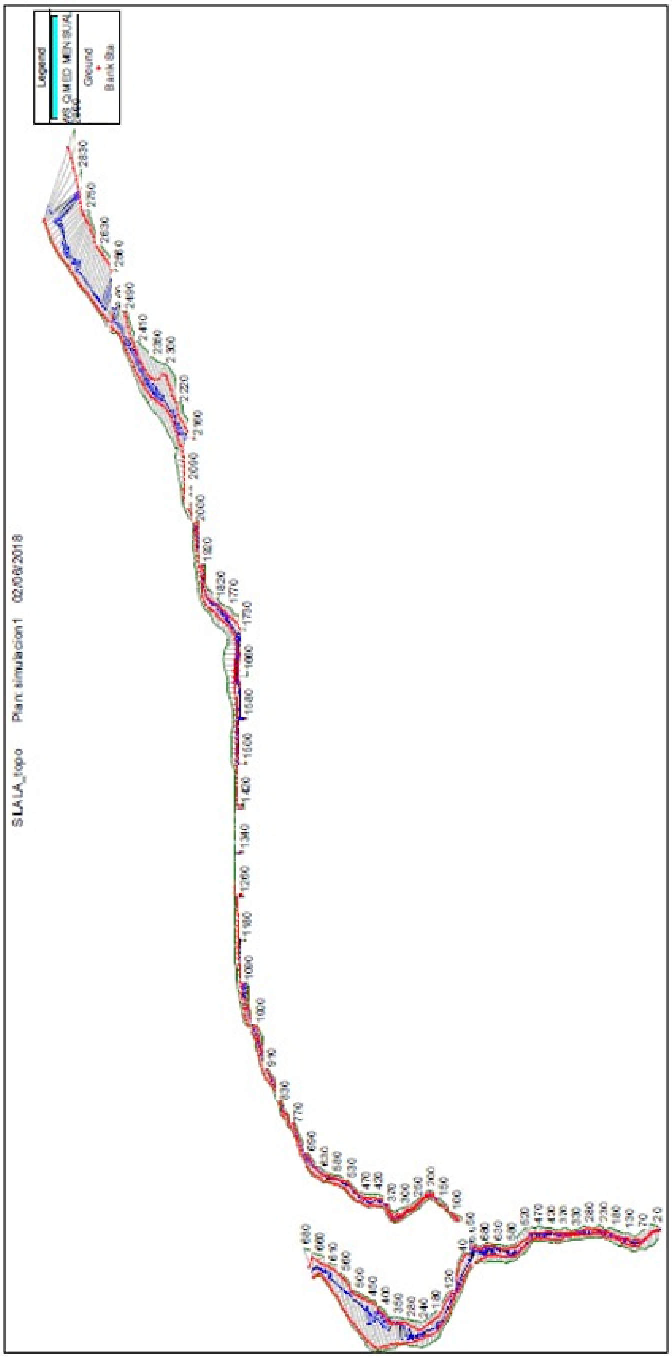


Figure 81. Geometry in the HEC-RAS Model (Perspective, Cross-Sections). (Source: Own elaboration)

8.5 DRAINAGE SYSTEM GRADIENT

The gradient is decisive in the hydraulic conditions inasmuch as it determines the flow regime in the canal, where the critical, subcritical and supercritical flows are defined. The gradient can be extracted from the geometric model, from the topography or from the digital elevation model.

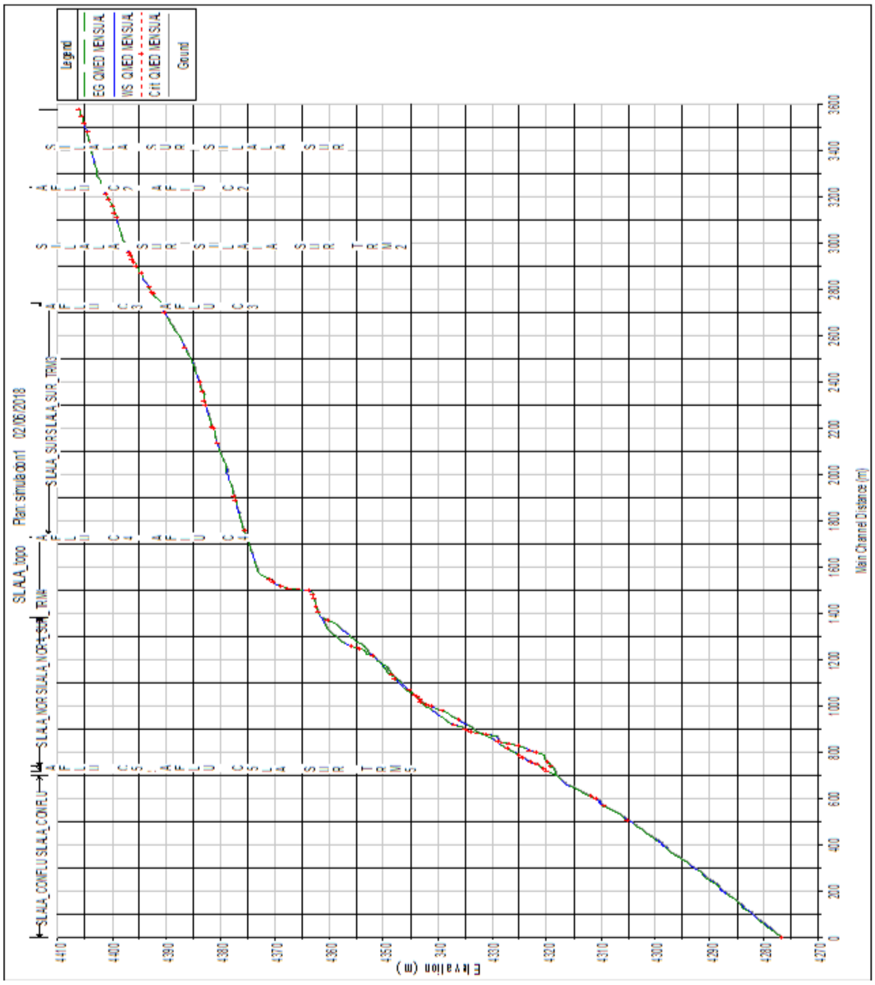


Figure 82. Longitudinal Profile of the Main Course. (Source: Own elaboration).

The system's gentlest gradients are presented in the highest part (electrode emplacement points 3+600 m-a 1+600 m) of the South branch of the Silala system, and increase as the course develops, south branch (electrode emplacement points 1+600 m to 0+00 m), particularly the north branch and the confluence sections [sic]. The slope varies from 0.012 to 0.062 m/m.

A detail of the longitudinal and hydraulic profiles is presented for the three reaches (i.e. the North, South and Confluence reaches) is presented as Annex 2 hereto.

8.6 MANNING COEFFICIENT (n)

This coefficient provides the degree of resistance to the flow generated by the canal contour and is related to its surface and the formation of materials.

The predominant material in the system of canals that are not stone-lined are peats, high-altitude materials, and saturated areas; and in the system of stone-lined canals are rigid, rough, and solid [materials] in which the variation of the water level is small, reason why a slow flow is estimated (subcritical regime). Under these characteristics, the roughness coefficient is high, and varies between 0.06 and 0.25.

Table 7. Referential Manning roughness coefficient values. (Source: Ven Te Chow)

Tipo de canal y descripción	Mínimo	Normal	Máximo
Excavado o dragado			
a. En tierra, recto y uniforme			
1. Limpio, recientemente terminado	0.016	0.018	0.020
2. Limpio, después de exposición a la intemperie	0.018	0.022	0.025
3. Con gravas, sección uniforme, limpio	0.022	0.025	0.030
4. Con pastos cortos, algunas malezas	0.022	0.027	0.033
b. En tierra, serpenteante y lento			
1. Sin vegetación	0.023	0.025	0.030
2. Pastos, algunas malezas	0.025	0.030	0.033
3. Malezas densas o plantas acuáticas en canales profundos	0.030	0.035	0.040
4. Fondo en tierra con lados en piedra	0.028	0.030	0.035
5. Fondo pedregoso y bancas con malezas	0.025	0.035	0.040
6. Fondo en cantos rodados y lados limpios	0.030	0.040	0.050
c. Excavado con pala dragado			
1. Sin vegetación	0.025	0.028	0.033
2. Matorrales ligeros en las bancas	0.035	0.050	0.060
d. Cortes en roca			
1. Lisos y uniformes	0.025	0.035	0.040
2. Afilados e irregulares	0.0356	0.040	0.050
e. Canales sin mantenimiento, malezas y matorrales sin cortar			
1. Malezas densas, tan altas como la profundidad de flujo	0.050	0.080	0.120
2. Fondo limpio, matorrales en los lados	0.040	0.050	0.080
3. Igual nivel máximo de flujo	0.045	0.070	0.110
4. Matorrales densos, nivel alto	0.080	0.100	0.140
Corrientes naturales			
1- Corrientes menores (ancho superficial en nivel creciente 100 < pies)			
a. Corrientes en planicies			
1. Limpias, rectas, máximo nivel, sin montículos ni pozos profundos	0.025	0.030	0.033
2. Igual al anterior, pero con mas piedras y malezas	0.030	0.035	0.040
3. Limpio serpenteante, algunos pozos y bancos de arena	0.033	0.040	0.045
4. igual al anterior, pero con algunos matorrales y piedras	0.035	0.045	0.050
5. Igual al anterior, niveles bajos, pendientes y secciones mas ineficientes	0.040	0.048	0.055
6. Igual al 4, pero con mas piedras	0.045	0.050	0.060
7. Tramos lentos, con malezas pozos profundos	0.050	0.070	0.080
8. Tramos con mucha maleza, pozos profundos o canales de crecientes con muchos arboles con matorrales bajos.	0.075	0.100	0.150

Table 8. Referential Manning roughness coefficient values (Continued). (Source: Ven Te Chow)

Tipo de canal y descripción	Mínimo	Normal	Máximo
b. Corrientes montañosas, sin vegetación en el canal, bancas usualmente empinadas, árboles y matorrales a lo largo de las bancas sumergidas en niveles altos			
1. Fondo: Gravas, cantos rodados y algunas rocas	0.030	0.040	0.050
2. Fondo: Cantos rodados con rocas grandes	0.040	0.050	0.070
2- Planicies de inundación			
a. Pastizales, sin matorrales			
1. Pasto corto	0.025	0.030	0.035
2. Pasto alto	0.030	0.035	0.050
b. Áreas cultivadas			
1. Sin cultivo	0.020	0.030	0.040
2. Cultivos en línea maduros	0.025	0.035	0.045
3. Campos de cultivo maduros	0.030	0.040	0.050
c. Matorrales			
1. Matorrales disperses, mucha maleza	0.035	0.050	0.070
2. Pocos matorrales y árboles, en invierno	0.035	0.050	0.060
3. Pocos matorrales y árboles, en verano	0.040	0.060	0.080
4. Matorrales medios a densos, en invierno	0.045	0.070	0.110
5. Matorrales medios a densos, en verano	0.070	0.100	0.160
d. Árboles			
1. Sauces densos, rectos y en verano	0.110	0.150	0.200
2. Terreno limpio, con troncos sin retoños	0.030	0.040	0.050
3. Igual al anterior, pero con una gran cantidad de retoños	0.050	0.060	0.080
4. gran cantidad de árboles, algunos troncos caídos, con poco crecimiento de matorrales, nivel del agua por debajo de las ramas.	0.080	0.10	0.120
5. Igual al anterior, pero con nivel de creciente por encima de las ramas	0.100	0.120	0.160
3- Corrientes mayores (ancho superficial en nivel creciente > 100 pies). El valor de n es menor que el correspondiente a corrientes menores con descripción similar, debido a que las bancas ofrecen resistencia menos efectiva.			
a. Sección regular, sin cantos rodados ni matorrales	0.025	---	0.060
b. Sección irregular y rugosa	0.035	---	0.100

8.7 HYDROLOGICAL SCENARIO OF THE SYSTEM

The hydrological scenario of the system to be used for the hydraulic analysis and evaluation of surface flow involves the analysis and processing of hydrometric information (limnimetric levels and gauging in canals) to obtain a series of values of simulation flowrates and average monthly values (see Table 9, Table 10 and Figure 83). The hydrological regime establishes that the monthly and seasonal variability is not significant, that is to say, that the oscillations and magnitudes do not respond to the rain and drought seasons, but remain rather stable throughout the year with very small range variations.

The flowrate in the system determines the flow depth necessary for a determined flow, in addition to other hydrodynamic parameters of the environment in which the water flows.

Table 9. Point average flows measured in Continuous Gauging Sites "C". (Source: Own elaboration, based on information from SENAMHI)

Codigo Punto	Punto de Aforo	CAUDAL	
		[l / s]	[m3 / s]
C1	Aforo en el punto C-1 canal sur	26.25	0.0263
C2	Aforo en el punto C-2 canal sur	33.94	0.0339
C3	Aforo en el punto C-3 canal sur	34.14	0.0341
C4	Aforo en el punto C-4 canal sur	52.09	0.0521
C5	Aforo en el punto C-5 canal sur	94.20	0.0942
C6	Aforo en el punto C-6 canal norte	52.06	0.0521
C7	Aforo en el punto C-7 canal principal	134.31	0.1343

In the present study, the surface flow of the system under the baseline average-flow hydrological scenario was simulated for the period with available data, determined on basis of the information provided by SENAMHI through DIREMAR and the processing and analysis of said data.

Table 10. Incremental average flows in Continuous Gauging Points "C". (Source: Own elaboration, based on information from SENAMHI)

POINT CODE	INCREMENTAL FLOW PER REACH	FLOW	
		[l / s]	[m3 / s]
C1	Q c1	26.25	0.0263
C2	Δ Qc2 = Q c2 - Q c1	7.69	0.0077
C3	Δ Qc3 = Q c3 - Q c2	0.20	0.0002
C4	Δ Qc4 = Q c4 - Q c3	17.95	0.0180
C5	Δ Qc5 = Q c5 - Q c4	42.11	0.0421
C6	Qc6	52.06	0.0521
C7	Δ Qc7 = Q c7 - Q c6 - Qc5	-11.95	-0.0120

Figure 83 shows the spatial distribution of continuous gauging points monitored by SENAMH; the scheme shows the gauging points from which the incremental flows where obtained. Table 10 presents the incremental flows and their calculation for the application of modeling scenarios by reaches.

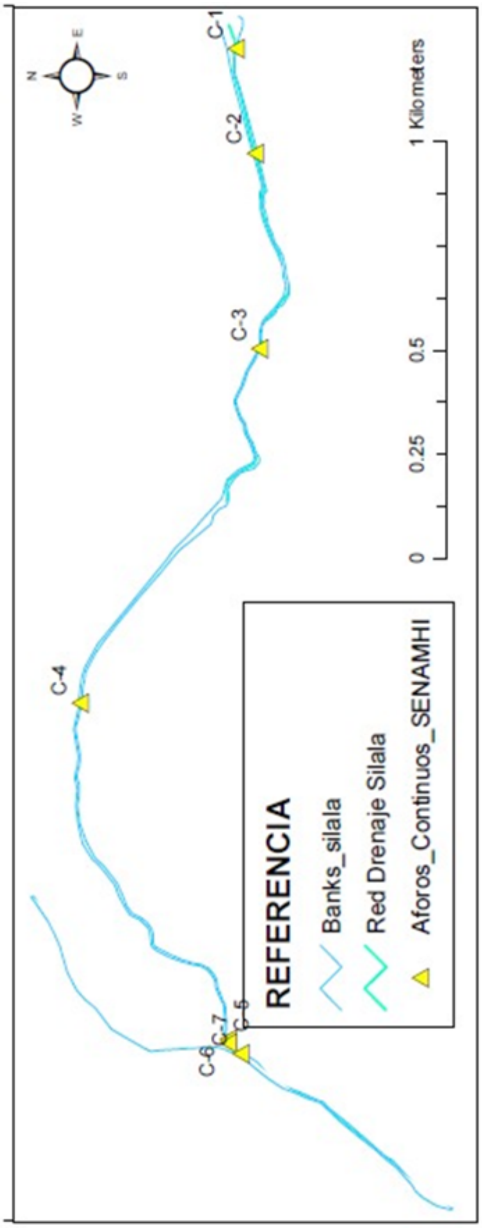


Figure 83. Hydraulic System of Silala and continuous Gauging Points monitored by SENAMHI.

8.8 HYDRAULIC REGIME OF THE FLOW

The hydraulic regime of the flow was calculated with the Froude number, which defines whether the regime is Subcritical, Supercritical or Critical (Fr <1, Fr> 1, Fr = 1), through the HEC-RAS surface flow simulation program. The Froude number was calculated for each point and the results are reflected in Annex 1. This reach has a predominant Subcritical regime.

8.8.1. Gauging campaign of April 2018

The objective of the gauging campaign was to determine the referential roughness coefficients and geometric and hydraulic parameters to calibrate the model.

Gauging has been carried out in 21 cross sections of the network of channels, in correspondence with the gauging points of the SENAMHI.

Table 11 shows the results of the 21 measurements; 18 points correspond to the main canal and 3 points correspond to secondary canals.

Table 11. Hydraulic characteristics at the measurement points of the April 2018 campaign.

Main canal denomination	Main Canal	Secondary Canal	Depth (m)	Water mirror (m)	Area (m2)	Gradient (m/m)	Velocity (m/s)	Manning Roughness	Flow (m3/s)	Froude Number	Flow type	Horizontal alignment of the canal in point
South drainage canal	C1		0.18	0.81	0.140	0.0246	0.264	0.148	0.037	0.20	Subcritical	Straight canal
	S1		0.165	0.60	0.096	0.0123	0.302	0.084	0.029	0.24	Subcritical	Straight canal
	S2		0.15	1.10	0.147	0.0143	0.259	0.105	0.038	0.21	Subcritical	Straight canal
	C2		0.09	0.90	0.088	0.0430	0.443	0.086	0.039	0.47	Subcritical	Straight canal
	S6		0.13	1.20	0.138	0.0098	0.333	0.063	0.046	0.30	Subcritical	Straight canal
	C3		0.17	0.94	0.141	0.0325	0.298	0.144	0.042	0.23	Subcritical	Straight canal
	S7		0.11	1.00	0.101	0.0420	0.366	0.108	0.037	0.35	Subcritical	Straight canal
	S8		0.14	1.62	0.222	0.0224	0.206	0.175	0.046	0.18	Subcritical	Straight canal
	C4		0.12	0.90	0.100	0.0224	0.521	0.058	0.052	0.48	Subcritical	Straight canal
	S10		0.25	1.00	0.222	0.0624	0.509	0.142	0.113	0.33	Subcritical	Flow on rock with soft curve
	S11		0.29	0.96	0.246	0.0624	0.519	0.150	0.128	0.31	Subcritical	Flow on rock with soft curve
	C5		0.19	0.60	0.096	0.0624	1.013	0.057	0.097	0.61	Subcritical	Flow on rock with soft curve
North drainage canal		S18	0.07	0.36	0.024		0.103		0.002	0.12	Subcritical	Straight canal
		S17	0.09	0.45	0.036		0.915		0.033	0.97	Critical	Straight canal
	S16		0.12	0.44	0.046	0.0520	0.255	0.156	0.012	0.24	Subcritical	Straight canal
	S15		0.10	0.60	0.049	0.0520	0.756	0.055	0.037	0.76	Subcritical	Straight canal
		S13	0.12	0.60	0.081		0.786		0.064	0.72	Subcritical	Straight canal
	S12		0.15	0.55	0.074	0.0520	0.854	0.056	0.063	0.70	Subcritical	Straight canal
	C6		0.11	0.85	0.095	0.0624	0.635	0.078	0.061	0.74	Subcritical	Straight canal
Confluence drainage canal	Desilting chamber		0.09	1.00	0.090		1.726		0.155	1.84	Subcritical	Straight canal
	C7		0.30	0.90	0.251	0.0624	0.748	0.104	0.187	0.44	Subcritical	Straight canal
	S19		0.33	0.85	0.266	0.0624	0.815	0.099	0.217	0.45	Subcritical	Straight canal

8.9 HYDRAULIC SIMULATION OF THE SURFACE FLOW IN HEC-RAS

Simulation outputs are presented graphically for:

- Hydraulic profiles by reach
- Velocity profiles throughout the reach
- Longitudinal profile of the Froude number throughout the reach
- Longitudinal profile of the gradient throughout the reach
- Longitudinal profile of the hydraulic depths throughout the reach

The HEC-RAS program uses abbreviated parameters for its edition; those that are of interest for the present project are listed below:

Q Total:	Total Flow
Min Ch El:	Minimum altitude in the main canal
Q Total:	Total Flow
Min Ch El:	Minimum altitude in the main canal
W.S. Elev:	Water film elevation
Crit W.S:	Water film elevation in a critical regime.
E.G. Elev:	Elevation of the Energy line
E.G. Slope:	Gradient of the power line
Vel Chnl:	Velocity in the main canal
Flow Area:	Hydraulic area
Top Width:	Width of the water film
Froude # Chl:	Froude Number
Vel Head:	Energy of velocity
Wetted Per:	Wet perimeter
Hydr. Depth:	Hydraulic depth
Avg. Vel.:	Average velocity

Annex 2 presents in detail the hydraulic profiles and simulated cross sections for the hydrological base scenario, and the geometric and morphological conditions described, for the three sections (North, South and confluence).

Figure 84 shows the results in Ras Mapper of Hec-Ras of the simulation, with the DEM digital elevation model and the surface of the water film in light blue.

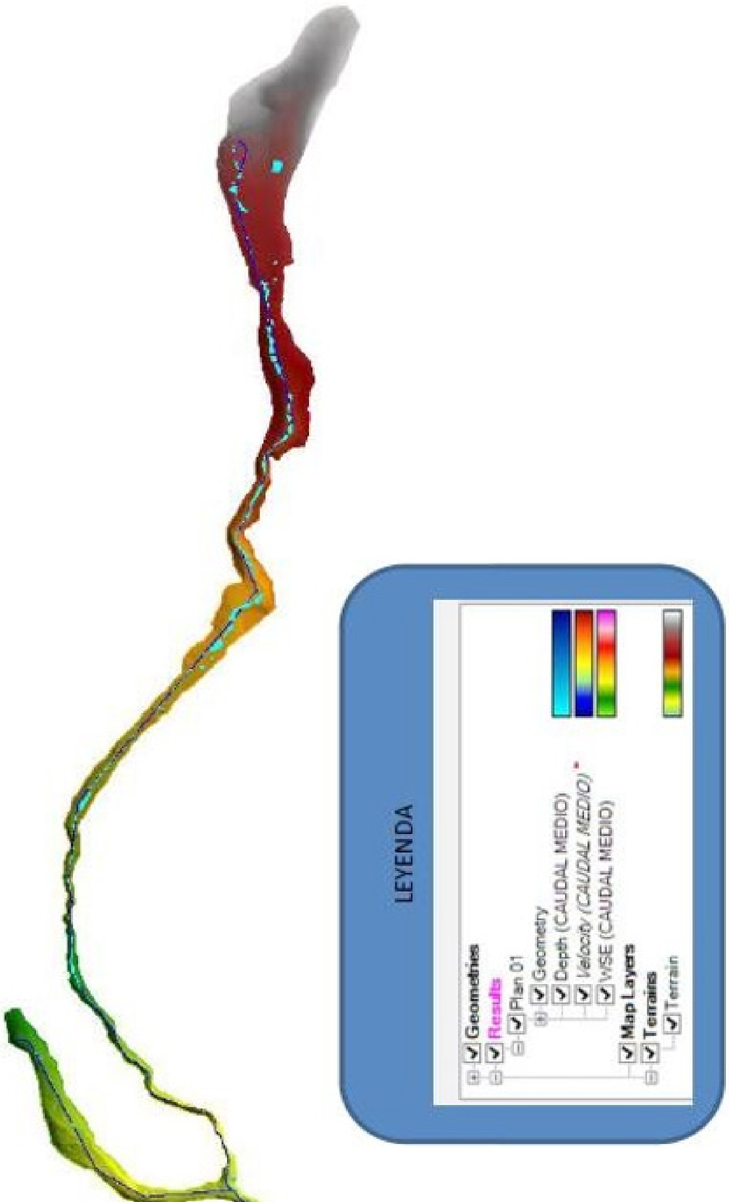


Figure 84. Presentation of the Hydraulic Simulation in RAS Mapper (Silala).

8.10 Hydraulic Model Results

From the presented results, in both graphs and tables (annexes), concerning the hydraulic simulation of the surface flow in the Silala System, it can be concluded:

- Based on the topography provided by DIREMAR, it has been possible to construct a DEM Digital Terrain Model with a 20x20 cm resolution detail, which properly represents the Silala system with the detail required to obtain a geometric model for a hydraulic simulation in HEC- RAS.
- The hydraulic parameters defined for the simulation (Manning roughness coefficient and gradient) represent the conditions of the Silala hydraulic system.
- The hydraulic profile shows that there are slight depressions where a certain amount of water accumulates (in these sections the depth is greater than the average and the water flows out of the main canal).
- The velocity profile shows that speeds between 0.4 m/s predominate and that velocities vary from a minimum of 0.2 m/s to a maximum of 1.0 m/s, approximately. This also happens in the reaches with both gentle and greater slopes, respectively.
- The predominant flow regime is subcritical, of the Froude Number profile, in which values of Fr <1 predominate; however, there are areas of steeper gradients (slope profile), which implies a higher speed and a Fr> 1 over 1.5, approximately. This happens only at certain points.
- Average or predominant depth are less than 0.2 m, some stretches or points of greater tension accumulate water or there are certain conditions that raise the water flow depth.

9 CONCLUSIONS

9.1 NATURAL CONDITIONS

a) Bofedal category

The natural conditions of the waters of the Silala must be understood from a physical- biological category defined by a water–soil–biotope unit. Trying to explain the development of the water in isolation entails destroying the existing link between the elements mentioned and the environment.

Within this framework, the waters of the Silala are fully integrated to the high mountain wetlands, independent of the extension, gradient, and vegetation and flow characteristics. Therefore, the water moves within this category [of wetlands].

Although there is a short section in the southern branch where, due to the geological conditions, the movement is superficial over a channel in the rock, the body of water assumes again its status as a bofedal category at the confluence.

b) Water source

- There is no contribution from surface runoff in the basin.

The absence of surface runoff in the basin, as a result of the hydrological response of precipitation, is demonstrated by two aspects:

- ■ The flow regime in each of the monitoring points does not vary in terms of time; its behavior is practically constant throughout the whole year, i.e. there is no seasonal variation.
- ■ Throughout the contribution basin it is not possible to find signs of laminar runoff. There are no traces, even at the micro basin scale, of a drainage network. In concrete terms, there are no fluvial processes in the basin due to the absence of surplus precipitation. Surface flow is absent in the basin.

- The water source of the bofedals comes from groundwater inflows.

The waters that upwell along the bofedales are manifested as springs, which deliver the water in the form of groundwater inflows to the bofedals; otherwise it would not be possible to explain their existence.

The behavior of the flows in the different water control points, taking into account the study period from May 2017 to March 2018, indicates that the only source of inflows to the water bodies, defined by the bofedals and transition zones, originates from groundwater. This hypothesis is also founded in the fact that the estimated variation of the flows at the monthly level for the same water control point (gauging points) does not show significant variations with respect to the average flows.

c) Water movement

- Combination of movement in porous medium and surface flow that does not concentrate in the bofedal.

The movement of water in the bodies of water of the Silala is governed by gravity, however, it is necessary to differentiate this movement in the following categories:

■ The movement of water through the bodies of bofedales develops slowly and at a very slow pace, depending on the characteristics of the permeability, porosity, content of organic matter, hydraulic gradient and flowrates.

■ The movement of water on the bofedals, under natural conditions, without artificial intervention, has been developed in a micro-surface fashion through unconcentrated branches where it is not possible to define a channel or watercourse, properly speaking.

From a technical point of view, the natural movement of the Silala through the Silala bofedals does not respond to the technical definition of a river, i.e. "a large-scale water stream that drains a basin in a natural way".

Although the term "of large dimensions" can be subjective in relation to the magnitude of flow, however, it is distinguished that the contributions of the body of the Silala are in the approximate order of 160 l/s, a comparatively low value with other courses that originate in the Andean Cordillera.

In the Silala basin, there is no surface drainage because there is no contribution of surface water that has the capacity to generate the mentioned flow.

9.2 STATE OF INTERVENTION ON BODIES OF WATER

The following conclusions have been reached in relation to the interventions introduced in the waterbodies of Silala, through the implementation of hydraulic works:

- **Hydraulic system**

The interventions introduced in the Silala waterbodies account for a hydraulic system, these are not isolated works, but rather respond to a set of works, from the abstraction works to outside the Bolivian territory.

- **Purpose of these interventions**

The main objective of the hydraulic works has been to improve the hydraulic efficiency of abstraction and conveyance, by means of the intake works of the springs and the drainage of water bodies through the channels.

The construction of unlined channels, channels with dry stone lining and perforated pipes in the bofedales has caused a remarkable modification of the original water regime. It has even caused the reduction of the flow that fed the bofedales and in some cases the water supply has been interrupted to a great extent, causing the desiccation of the bofedales.

- **First intervention**

Intake works

The intake works on the section of the confluence, according to the current dimensions, had the capacity to capture and convey all the contribution of the waters. The intake work was built in concrete.

Water conveyance works

The purpose of the conveyance works was to drive all the water collected in the confluence, within Bolivian territory, to Chilean territory connecting a load chamber to the intake.

- **Second intervention**

Specific intake works

The second intervention in the field of hydraulic works does not respond, as in the case of the first intervention, to isolated actions, but to a global intervention, composed of a set of collection or intake works in each of the springs that have a higher flow. Its objective is to operate on the source of water right where it originates, trying to reduce water losses as much as possible.

Longitudinal water conveyance works (conveyance canals)

The conveyance canals do not respond to the category of waterproofed pipes designed "only" to direct the flow to lower areas, but are in themselves "drainage canals", whose objective is also to collect the water "laterally", that is to say through the depletion of the water table to increase the flow rate already abstracted from each spring; hence these conveyance works are considered longitudinal conveyance works.

- **General characteristics of the hydraulic works**

The introduction of the works in the Silala waterbodies have had characteristics of significant "aggressiveness" to the environment, not only for its effects on the water regime, but on the biotic environment. The drainage of the phreatic level in the wetlands has caused the disappearance of healthy wetlands both in the north and south bofedals.

The results of the hydraulic modeling performed for this survey show that the water movement conditions in the Silala waterbodies have been modified significantly. The incorporation of hydraulic works has changed the natural conditions of water movement in porous medium and has turned an unconcentrated surface flow into a free surface flow in the drainage canals implemented.

The modifications to the hydraulic behavior of the natural state of the bofedals are striking in their impact on the velocities of the predominant water movement in the porous medium, which is in the order of 2.3 x 10-9 cm/s in the North bofedal and 6.5 x 10-9 cm/s in the south bofedal in its prior condition, but then intervention reaches speeds of up to 0.4 m / s with extremes that vary between 0.2 m/s and 1.0 m/s, approximately. The predominant flow regime is sub-critical (Froude Number inferior to one), there are drops or inclined slope areas with sub-critical regime (Froude Number inferior than one). In average, the predominant depths are inferior to 0.2 m.

- **Lengths and Types of Material of the Canals in Silala**

The adduction systems in the South and North Bofedals, as well as in the confluence canal are constructed with different materials and different lengths. Among the most repetitive criteria for the construction of canals it has been identified the canals excavated in natural soil, similarly, it has been identified canals lined with dry masonry, masonry canals with binder and stone canals.

The length of the main and secondary canals in the South bofedal is of 3,685.5 m, while that comprising the main and secondary canals of the North bofedal is of 1,800.0 m. The length of the main and secondary canals at the confluence reach, on the other hand, is of 944.0 m.

The total length of main channels in the north, south and confluence bofedales reaches 4,265 m, while the secondary lengths reach a length of 2,114.4 m. The total length of channels built is 6,379 m.

Table 12 presents a summary of the lengths of the main and secondary canals of the South and North Bofedals, and the confluence reach.

Table 12. Hydraulic characteristics at the measurement points during the April 2018 campaign.

Canal lengths (m)			
Sector	**Main Canal**	**Secondary Canal**	**Sub-Total**
South bofedal	2871,0	814,5	3685,5
North bofedal	688,0	1112,0	1800,0
Confluence reach	706,0	238,0	944,0
Total	**4265,0**	**2164,5**	**6429,5**

9.3. SUMMARY

For all that has been verified and explained in the above chapters, it can thus be concluded that the degree of intervention in the Silala bofedals, due to the magnitude of the hydraulic works built, as well as the high level of efficiency of water abstraction and channeling, has been demonstrated. The length of the canals built exceeds 6 kilometers and the catchments in the major contribution springs reach almost a hundred works. The flow with very low velocities –in its natural state– has reached comparatively much higher values, due to the water channeling through the built canals.

The interventions have not only affected the natural water supply of the springs to the bofedals, but they have also affected the body of the bofedales themselves, causing the drainage of these by means of the implementation of permeable canals.

The hydraulic works have caused a strong impact on the natural environment, since the initial condition of these bodies of water has not been respected as natural reservoirs and regulators of the soil–water–biotope system.

The conservation of water bodies has been subordinated to a vision of intervention with the basic principle of increase the amount of water abstraction for use purposes.

In short, the main objective has been to drain the bodies of water from the springs and bofedals.

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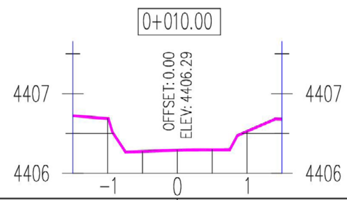
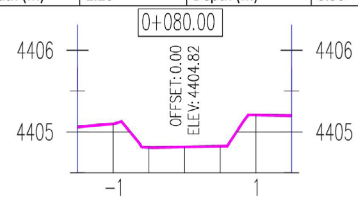
10 ANNEXES

ANNEX 1: DETAILED CHARACTERIZATION OF THE CANALS OF THE SOUTH, NORTH AND CONFLUENCE BOFEDALS

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH BOFEDAL – PROGRESSIVE 0+000 – 0+099.04

UMSA-IHH	WATER SYSTEM: SILALA SPRNGS				DIREMAR
EVALUATION SHEET OF CANALIZED REACH					
1. LOCATION					
DEPARTAMENT	POTOSI			MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE	SOUTH LIPEZ			CANTON	QUETENA CHICO
WATER SYSTEM	SILALA SPRINGS				
COMPONENT	SOUTH CANAL				
	PROGRESSIVE	COORDINATES		ELEVATION (m.a.s.l)	
		ESTE	NORTE		
START	0+000	603122.247	7565884.6	4406.98	
END	0+099.04	603033.528	7565891.227	4404.45	
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH					
LONGITUDINAL PROFILE					
	PROFILE SHAPE	REACH OF UNIFORM SLOPE WITH ALTERNATING REACHES WITH CROSSES WITH DIVERSION CANALS			
SLOPE RANGE %		2.3			
DOMINANT LONGITUDINAL SLOPE %		2.3			
CROSS SECTIONS IN THE REACH					
PROGRESSIVE 0+010			PROGRESSIVE 0+080		
Width (m)	1.40	Depth (m) 0.18	Width (m)	1.20	Depth (m) 0.30
					
	MORPHOLOGY	THE REACH IS MADE UP OF BOFEDAL PEAT MATERIAL. NO EROSION PROCESSES ARE OBSERVED. THE TERRAIN IS UNIFORM WITH SLIGHT SLOPE DOWNWARDS			
PLANT					
	FORM OF ALIGNMENT	CURVILINEAR IN THE FIRST THIRD OF THE REACH AND STRAIGHT IN THE MIDDLE AND FINAL PART OF THE REACH.			
CHANNEL WIDTH VARIABILITY		WITH NARROWING AND WIDENING			

3. DESCRIPTION OF THE REACH
THE MATERIAL OF THE ANALYZED REACH IS OF NATURAL SOIL WITHOUT COATING. THE REACH PRESENTS A UNIFORM SLOPE OF 2.3%. THE HORIZONTAL ALIGNMENT OF THE DRAINAGE CANAL IS CURVED IN THE FIRST THIRD OF THE REACH AND STRAIGHT IN THE MIDDLE AND FINAL PART OF THE REACH. THE REACH IS MADE UP OF BOFEDAL PEAT MATERIAL. NO EROSION PROCESSES ARE OBSERVED. THE TERRAIN IS UNIFORM WITH SLIGHT SLOPE DOWNWARDS. THE CIRCULAR SHAPE OF THE FIRST THIRD OF THE REACH AND THE SOUTHEAST TO NORTHWEST DIRECTION OF THE STRAIGHT REACH HAS A HIGHLY EFFICIENT WATER COLLECTION FUNCTION. - REACH OF THE PROGRESSIVE 0+000. COLLECTION OF WATER WITH SMALL CANALS FROM THE SPRINGS TO THE MAIN CANAL. - REACH OF THE FIRST THIRD. THE CIRCULAR SHAPE OF THE REACH AVOIDS THE MOVEMENT OF THE REMAINING WATER FLOW FROM THE WATER EYES TOWARDS THE SOUTHEAST (CURRENTLY THE SALINE BOFEDAL). - MIDDLE AND FINAL REACH. THE STRAIGHT SECTION OF APPROXIMATELY 70 METERS AVOIDS THE REMAINING FLOW OF THE WATER EYES TOWARDS THE SOUTHEAST (SALINE BOFEDAL) AND TOWARDS THE WEST (SOUTH BOFEDAL AFTER THIS REACH). THE IMPACT OF THE EFFICIENT UPTAKE OF WATER IN THIS REACH IS OBSERVED IN THE SOUTHEASTERN BOFEDAL, WHICH IS TOTALLY DEGRADED (CURRENTLY THE SALINE BOFEDAL) AND THE SOUTH BOFEDAL AFTER THIS REACH (DEGRADED BOFEDAL).
4. PHOTOGRAPHS

BOFEDAL SOUTHEAST OF THE ANALYZED REACH. THE MOVEMENT OF WATER TOWARDS THIS BOFEDAL HAS BEEN TOTALLY ANNULLED, AT THE MOMENT IT IS A DEGRADED SALINE BOFEDAL

SOUTH CANAL - PROGRESSIVE 0+170 - 0+288.08 – SLOPE 1.4 %

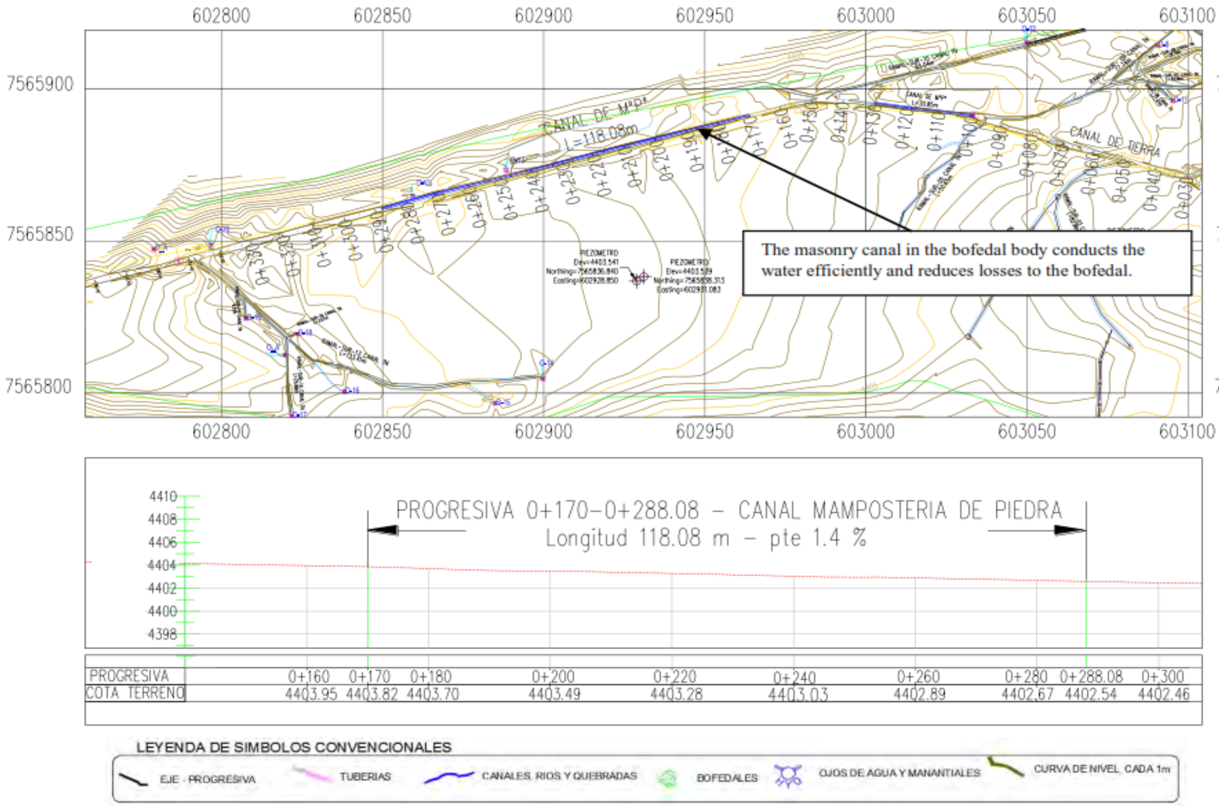
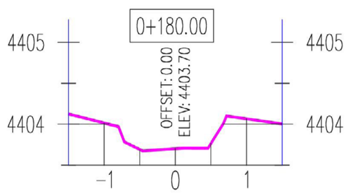
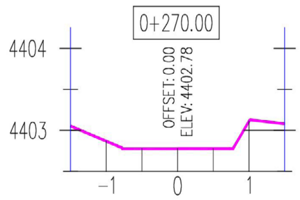


Figure 86. Plant and Longitudinal Profile of the South Canal Reach between the progressives 0+170 and 0+288.08 – South Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR)

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH CANAL – PROGRESSIVE 0+170 – 0+288.08

UMSA-IHH	**WATER SYSTEM: SILALA SPRNGS**				DIREMAR
EVALUATION SHEET OF CANALIZED REACH					
1. LOCATION					
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO
WATER SYSTEM		SILALA SPRINGS			
COMPONENT		SOUTH CANAL			
	PROGRESSIVE	COORDINATES		ELEVATION	
		EAST	NORTH	(m.a.s.l)	
START	0+170	602963	7565891	4403.95	
END	0+288.08	602850	7565860	4402.58	
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH					
LONGITUDINAL PROFILE					
		PROFILE SHAPE	UNIFORM PROFILE WITH FAIRLY ALIGNED CANALIZATION.		
SLOPE RANGE %			1.4		
DOMINANT LONGITUDINAL SLOPE %			1.4		
CROSS SECTIONS IN THE REACH					
PROGRESSIVE 0+180			PROGRESSIVE 0+270		
Width (m)	0.95	Depth (m) 0.28	Width (m)	1.55	Depth (m) 0.24
					
		MORPHOLOGY	IN BOTH MARGINS THERE ARE BOFEDALS AND THE CONFIGURATION OF BOTH FLANKS IS UNIFORM		
PLANT					
		FORM OF ALIGNMENT	STRAIGHT REACH		
		CHANNEL WIDTH VARIABILITY	WITH NARROWING AND WIDENING		

3. DESCRIPTION OF THE REACH
The material of the analyzed reached is of stone masonry. The reach presents a uniform slope. In both margins there are bofedals and the configuration of both flanks is uniform. The reach does not present lateral water income. The rectilinear alignment and the masonry material prevent losses of water from the canal towards the bofedal. The impact of the efficient water channeling of the analyzed reach (and the efficient abstraction and channeling of the reaches upstream) can be seen in the difference in groundwater levels from the progressive 0+000 to 0+280. The water table in the vicinity of the progressive 0+000 is 0.20 meters below the surface of the terrain, while the water table in the progressive 0+250 is 0.45 meters below the surface (Orzag, 2017).

SOUTH CANAL - PROGRESSIVE 0+170 - 0+288.08 – SLOPE 1.4 %

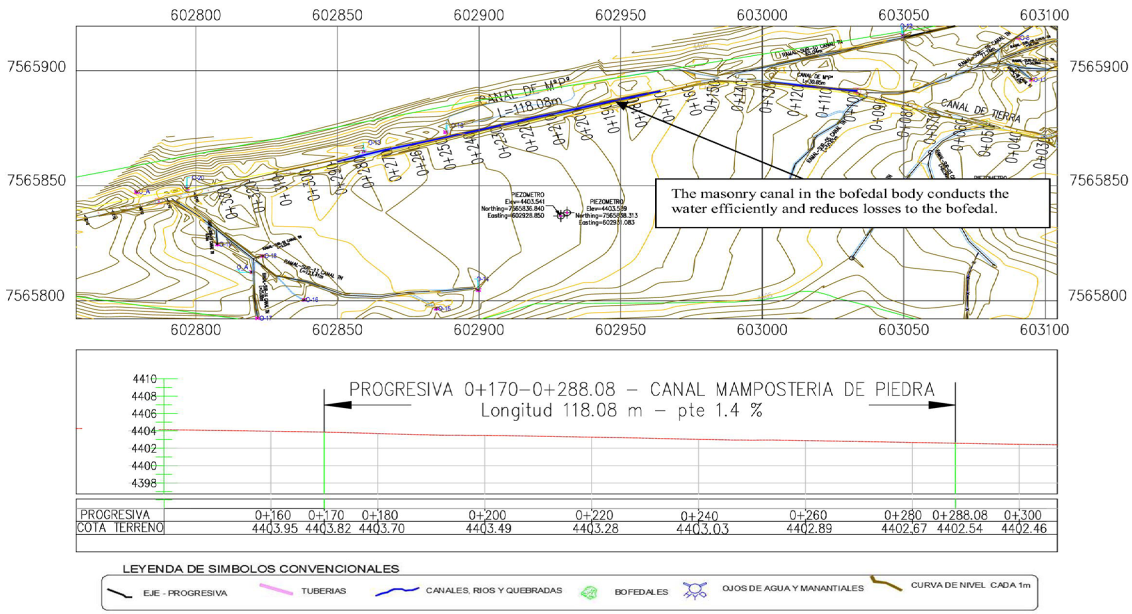
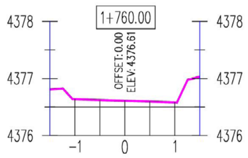
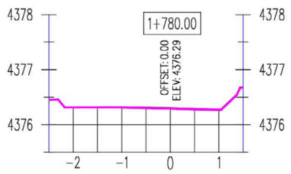


Figure 86. Plant and Longitudinal Profile of the South Canal Reach between the progressives 0+170 and 0+288.08 – South Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR)

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH CANAL – PROGRESSIVE 1+760 TO 1+783.66

UMSA-IHH	WATER SYSTEM: SILALA SPRNGS						DIREMAR
EVALUATION SHEET OF CANALIZED REACH							
1. LOCATION							
DEPARTAMENT		POTOSI			MUNICIPALITY	SAN PABLO DE LIPEZ	
PROVINCE		SOUTH LIPEZ			CANTON	QUETENA CHICO	
WATER SYSTEM		SILALA SPRINGS					
COMPONENT		SOUTH CANAL					
	PROGRESSIVE	COORDINATES			ELEVATION (m.a.s.l)		
		EAST		NORTH			
START	1+760	601576		7565242	4376.61		
END	1+783.66	601555		7565252	4376.23		
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH							
LONGITUDINAL PROFILE							
		PROFILE SHAPE		UNIFORM SLOPE OF 1.6%			
SLOPE RANGE %				1.6			
DOMINANT LONGITUDINAL SLOPE %				1.6			
CROSS SECTIONS IN THE REACH							
PROGRESSIVE 1+760				PROGRESSIVE 1+780			
Width (m)	2.10	Depth (m)	0.24	Width (m)	3.20	Depth (m)	0.19
							
		MORPHOLOGY		THE RIGHT FLANK OF THE REACH IS LOOSE GRANULAR MATERIAL AND THE LEFT FLANK IS ROCKY MATERIAL WITH EXPOSURE TO WIND EROSION PROCESSES			
PLANT							
	FORM OF ALIGNMENT			CURVILINEAR			
CHANNEL WIDTH VARIABILITY				WITH NARROWING AND WIDENING			

3. DESCRIPTION OF THE REACH
THE MATERIAL OF THE ANALYZED REACH IS OF STONE MASONRY. THE REACH PRESENTS A UNIFORM SLOPE. THE RIGHT FLANK OF THE REACH IS LOOSE GRANULAR MATERIAL AND THE LEFT FLANK IS ROCKY MATERIAL WITH EXPOSURE TO WIND EROSION PROCESSES. THE WIDTH FROM THE PROGRESSIVE 1+630 TO THE PROGRESSIVE 1+740 IS WIDE, IT VARIES BETWEEN 3 TO 4.5 METERS AND THE DEPTH VARIES BETWEEN 0.2 TO 0.4 METERS. IN THE ANALYZED REACH THERE IS A SLIGHT NARROWING OF THE WIDTH TO 2.1 METERS. THE STONE MASONRY MATERIAL OF THE ANALYZED REACH PROTECTS THE CURVE OF THE CANAL FROM THE EROSION OF THE FLOW, WITH THE FLOW IN THE REACH OF 0.05 M^3/S.

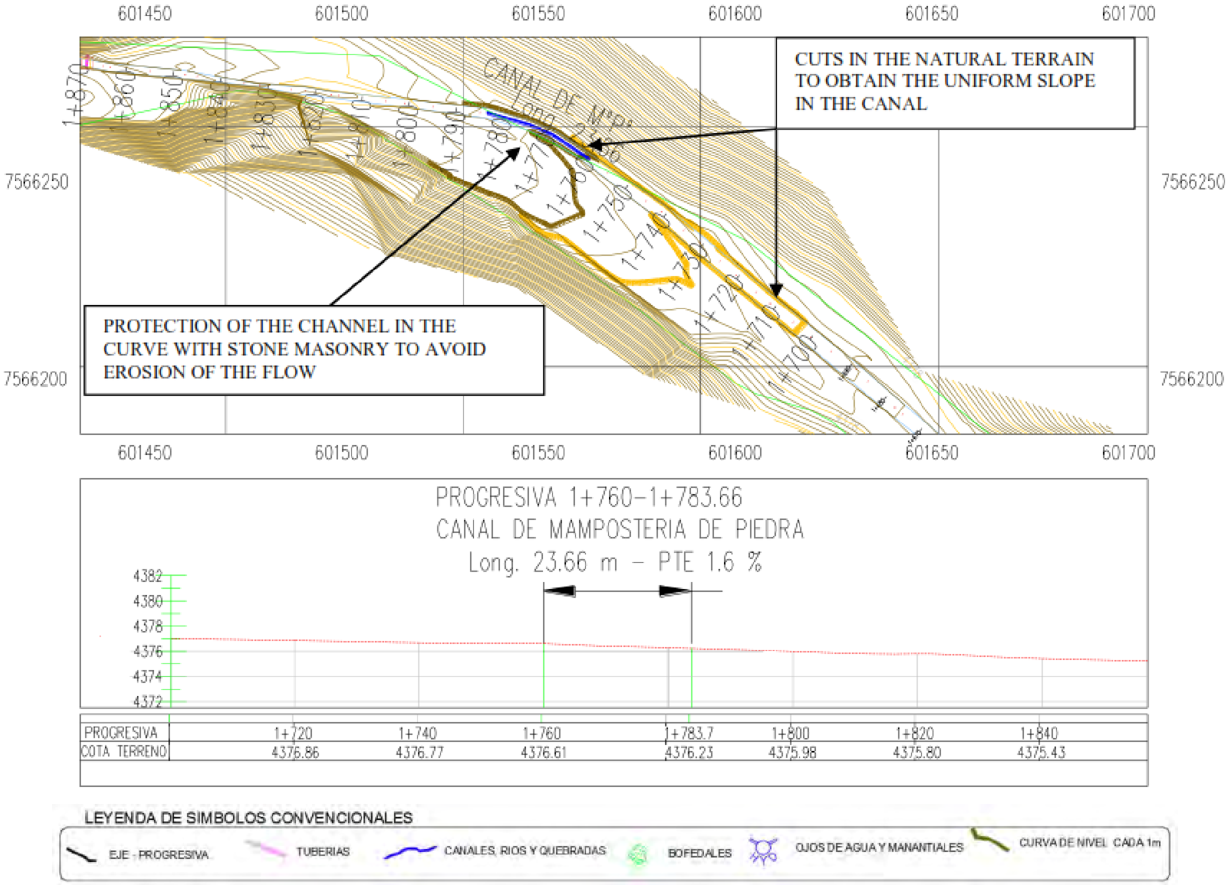


Figure 87. Plant and Longitudinal Profile of Reach between the progressives 1+783 and 1+783.66 – South Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR)

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH BOFEDAL – REACH 1

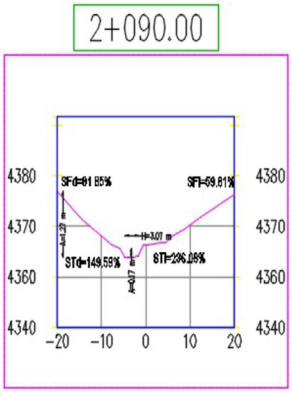
UMSA-IHH		**WATER SYSTEM:**		**SILALA SPRNGS**		DIREMAR
EVALUATION SHEET OF THE NATURAL SECTION CANAL						
1. LOCATION						
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ	
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO	
WATER SYSTEM		SILALA SPRINGS				
COMPONENT		SOUTH SPRING				
	PROGRESSIVE	COORDINATES		ELEVATION (m.a.s.l)		
		EAST	NORTH			
START	2+060	601302.667	7566271.441	4371.21		
END	2+092	601252.916	7566276.059	4366.16		
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH						
LONGITUDINAL PROFILE						
		PROFILE SHAPE	VARIABLE AT SHORT AND MEDIUM DISTANCES. INTERNAL REACHES OF VARIED SLOPES TO SUB-HORIZONTAL			
SLOPE RANGE %			5.5 - 6.6			
DOMINANT LONGITUDINAL SLOPE %			5.75			
CROSS SECTION TYPE - CANAL (ST)						
FORM OF THE SECTION			IRREGULAR TRAPEZOIDAL			
AVERAGE WIDTH IN THE BED (A) [m]			1.15			
DEPTH OF THE SECTION (H) [m]			0.21			
RIGHT BANK SLOPE (STd) %			144.90			
LEFT BANK SLOPE (STi)%			268.75			
MORPHOLOGY			STEEP FLANKS DUE TO EROSION OR ANTHROPOGENIC EFFECT			
CROSS SECTION TYPE – FLANK (SF)						
RIGHT FLANK SLOPE (SFd) %			250.87			
LEFT FLANK SLOPE (SFI) %			52.83			
AVERAGE DEPTH OF THE FLANKS (H) [m]			12.92			
PLANT						
	FORM OF ALIGNMENT		CURVILINEAR WITH THREE MAIN CURVES			
CHANNEL WIDTH VARIABILITY			WITH NARROWING AND WIDENING			

3. DESCRIPTION OF THE REACH

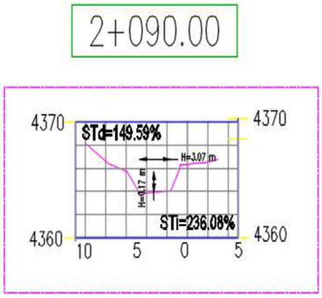
THE DOMINANT LITHOLOGY OF THE BED IN THE ANALYZED REACH HAS SANDS AND ROCK, WITH DISPERSED ORGANIC MATERIAL. IN THE CURVED PARTS OF THE ALIGNMENT OF THE CHANNEL THE PRESENCE OF BOFEDALS STANDS OUT WHERE THE FLOW HAS A DIFFUSE BEHAVIOR. THE CROSS SECTIONS OF THE REACH HAVE HIGH SLOPE FLANKS WITH A MINIMUM HEIGHT OF 16 METERS.

4. REPRESENTATIVE CROSS SECTION

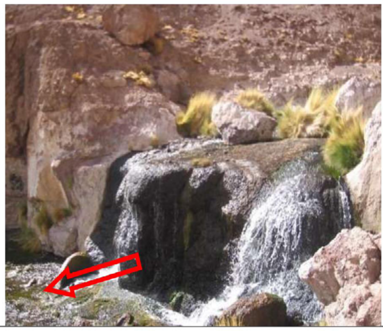
a) FLANK



b) CANAL



5. FOTOGRAFÍA



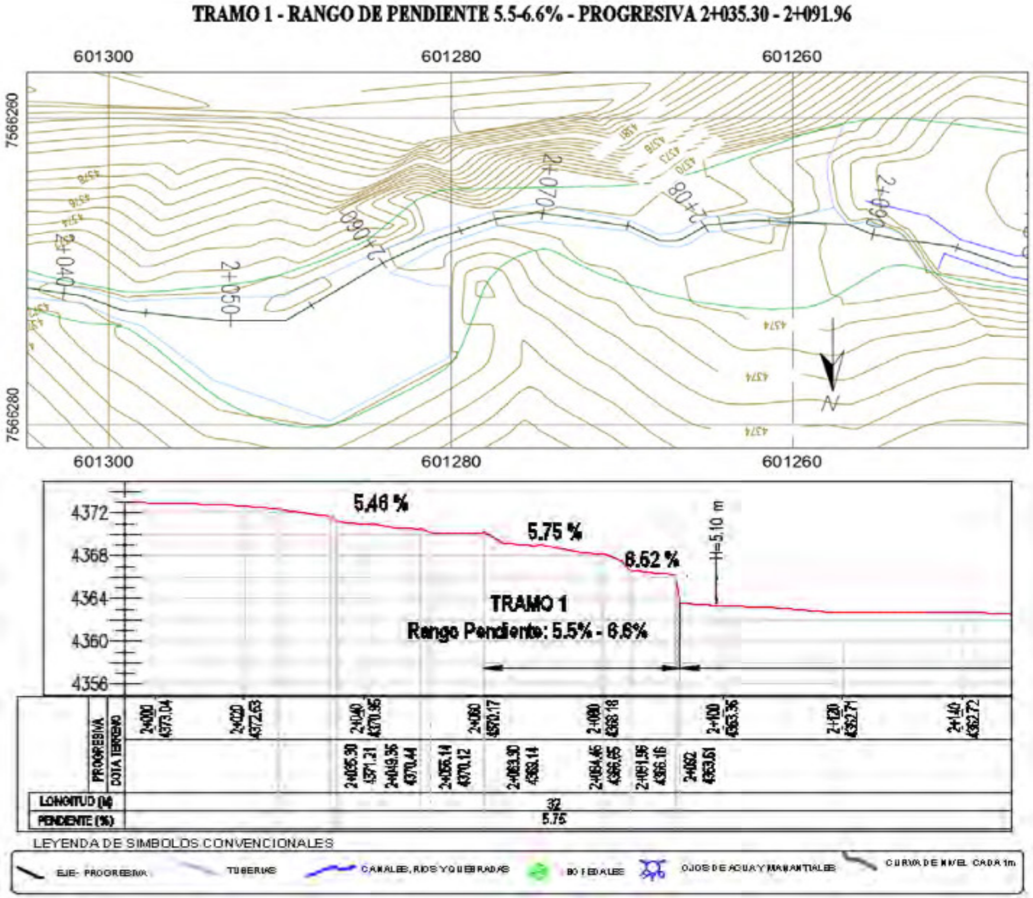


Figure 88. Plant and Longitudinal Profile of Reach 1, between the progressives 2+060 and 2+092 – South Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR)

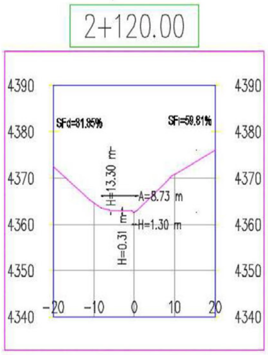
DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH CANAL – REACH 2

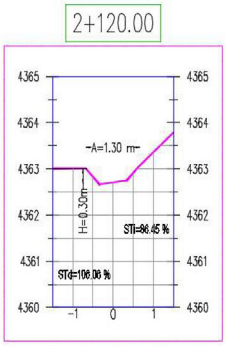
UMSA-IHH		**WATER SYSTEM:**	**SILALA SPRNGS**		DIREMAR
EVALUATION SHEET OF THE NATURAL SECTION CANAL					
1. LOCATION					
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO
WATER SYSTEM		SILALA SPRINGS			
COMPONENT		SOUTH SPRING			
	PROGRESSIVE	COORDINATES		ELEVATION	
		EAST	NORTH	(m.a.s.l)	
START	2+092	601253.175	7566268.023	4363.61	
END	2+310	601067.271	7566199.469	4357.68	
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH					
LONGITUDINAL PROFILE					
		PROFILE SHAPE	VARIABLE AT MEDIUM AND LONG DISTANCES. REACHES WITH LOW SLOPES TO SUB-HORIZONTAL.		
SLOPE RANGE %			2.5 – 4.5		
DOMINANT LONGITUDINAL SLOPE %			3.36		
CROSS SECTION TYPE - CANAL (ST)					
FORM OF THE SECTION			IRREGULAR TRAPEZOIDAL		
AVERAGE WIDTH IN THE BED (A) [m]			0.90		
DEPTH OF THE SECTION (H) [m]			0.40		
RIGHT BANK SLOPE (STd) %			716.67		
LEFT BANK SLOPE (STi)%			400		
		MORPHOLOGY	STEEP FLANKS DUE TO EROSION OR ANTHROPOGENIC EFFECT		
CROSS SECTION TYPE – FLANK (SF)					
RIGHT FLANK SLOPE (SFd) %			50.22		
LEFT FLANK SLOPE (SFI) %			84.80		
AVERAGE DEPTH OF THE FLANKS (H) [m]			9.38		
PLANT					
FORM OF ALIGNMENT			CURVILINEAR WITH ONE MAIN CURVE		
CHANNEL WIDTH VARIABILITY			WITH CONSTANT SECTION, NARROWING AND WIDENING		
3. DESCRIPTION OF THE REACH					
THIS SECTION PRESENTS A TOPOGRAPHIC DIFFERENCE OF 5 METERS. ITS MAIN CHARACTERISTIC IS THE CONCENTRATED FLOW THROUGH A CHANNELIZED REACH WITH ROCK FORMATION. THROUGHOUT THIS REACH THERE IS NO FLOW CANALIZATION, PROBABLY BECAUSE THE FLOW IS FORCED TO PASS THROUGH THE NARROWING AND THE CONTOUR FORMED OF APPARENTLY HEALTHY ROCK.					

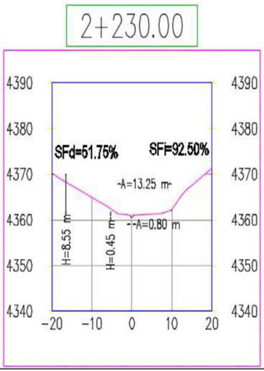
4. REPRESENTATIVE CROSS SECTION

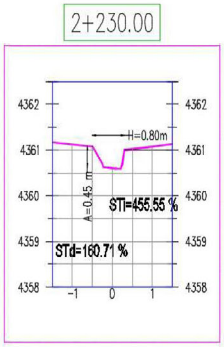
a) FLANK

b) CANAL



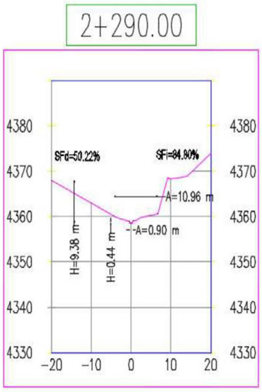




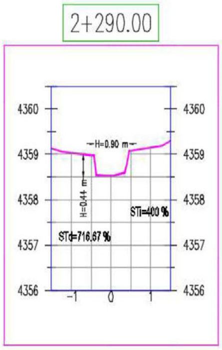


4. REPRESENTATIVE CROSS SECTION

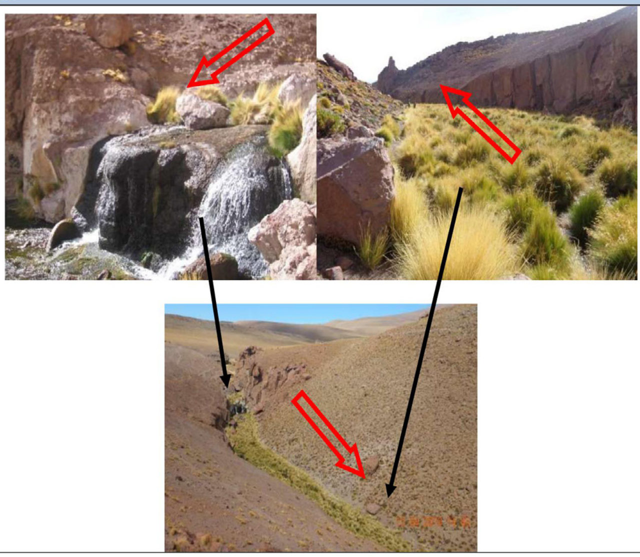
a) FLANK



b) CANAL



5. FOTOGRAFÍA



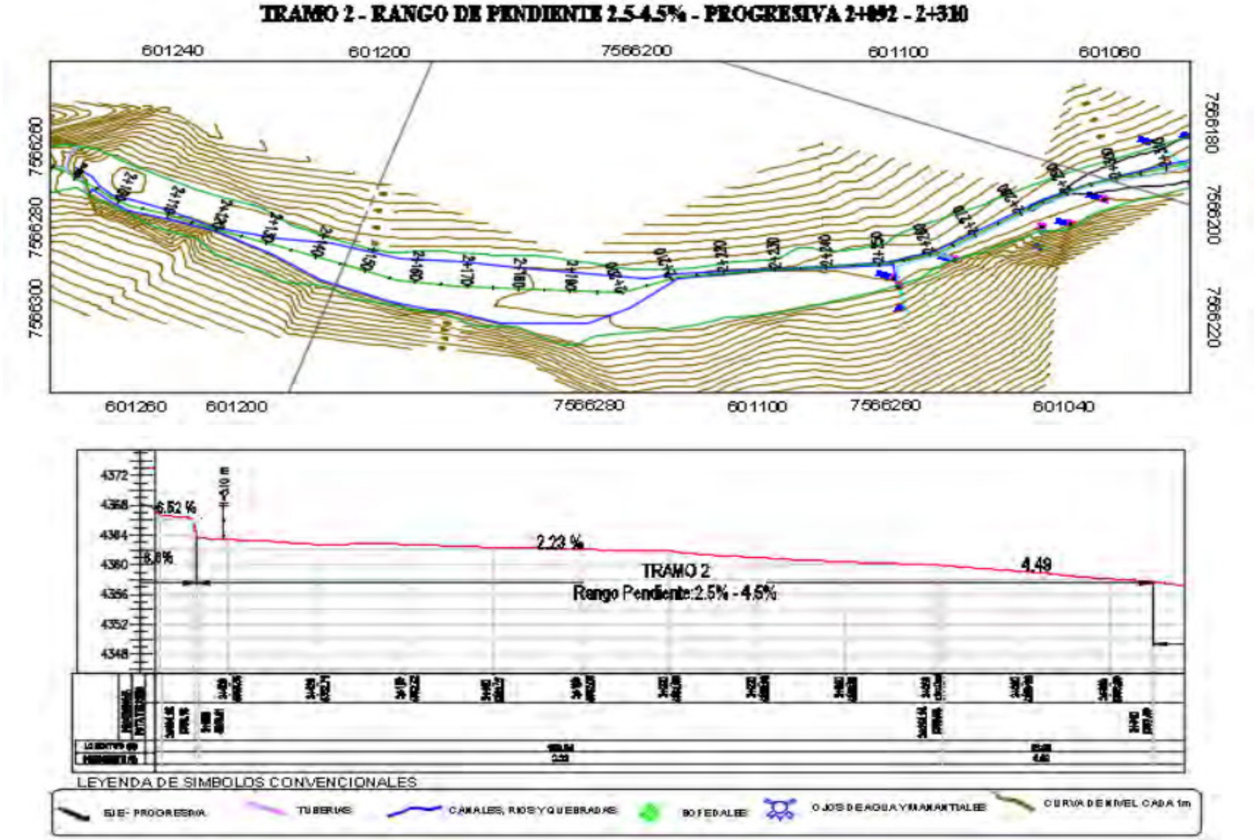
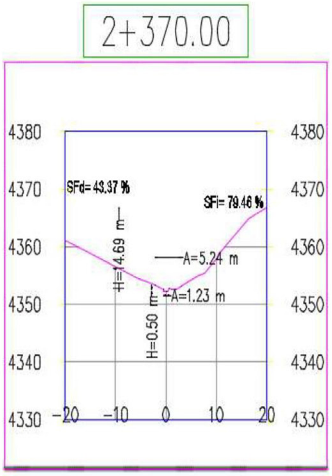


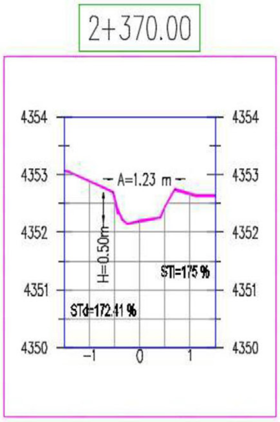
Figure 89. Plant and Longitudinal Profile of Reach 2, between the progressives 2+092 and 2+310 – South Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR, GOOGLE EARTH)

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH CANAL – REACH 3

UMSA-IHH		**WATER SYSTEM:**		**SILALA SPRNGS**		DIREMAR
EVALUATION SHEET OF THE NATURAL SECTION CANAL						
1. LOCATION						
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ	
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO	
WATER SYSTEM		SILALA SPRINGS				
COMPONENT		SOUTH SPRING				
	PROGRESSIVE	COORDINATES		ELEVATION		
		EAST	NORTH	(m.a.s.l)		
START	2+310	601067.271	7566199.469	4357.68		
END	2+377	601000.401	7566163.514	4351.60		
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH						
LONGITUDINAL PROFILE						
		PROFILE SHAPE	CONSTANT WITH LOW SLOPES.			
SLOPE RANGE %			9.09			
DOMINANT LONGITUDINAL SLOPE %			9.09			
CROSS SECTION TYPE - CANAL (ST)						
FORM OF THE SECTION			IRREGULAR TRAPEZOIDAL			
AVERAGE WIDTH IN THE BED (A) [m]			1.23			
DEPTH OF THE SECTION (H) [m]			0.50			
RIGHT BANK SLOPE (STd) %			172.41			
LEFT BANK SLOPE (STi)%			175			
		MORPHOLOGY	STEEP FLANKS DUE TO EROSION OR ANTHROPOGENIC EFFECT			
CROSS SECTION TYPE – FLANK (SF)						
RIGHT FLANK SLOPE (SFd) %			43.37			
LEFT FLANK SLOPE (SFI) %			79.46			
AVERAGE DEPTH OF THE FLANKS (H) [m]			14.69			
PLANT						
FORM OF ALIGNMENT			STRAIGHT AND CURVILINEAR WITH ONE MAIN CURVE			
CHANNEL WIDTH VARIABILITY			WITH CONSTANT SECTION			
3. DESCRIPTION OF THE REACH						
THIS REACH HAS A NATURAL COURSE WITH ROCK PROTECTIONS ON THE WALLS, THE SLOPES ARE SMOOTH AND THE FLOW IS SLIGHTLY TURBULENT. THERE IS NO SEDIMENT TRANSPORT AND NO SEDIMENTATION PROCESSES ARE OBSERVED.						

4. REPRESENTATIVE CROSS SECTION	
b) FLANK	b) CANAL





5. FOTOGRAFÍA

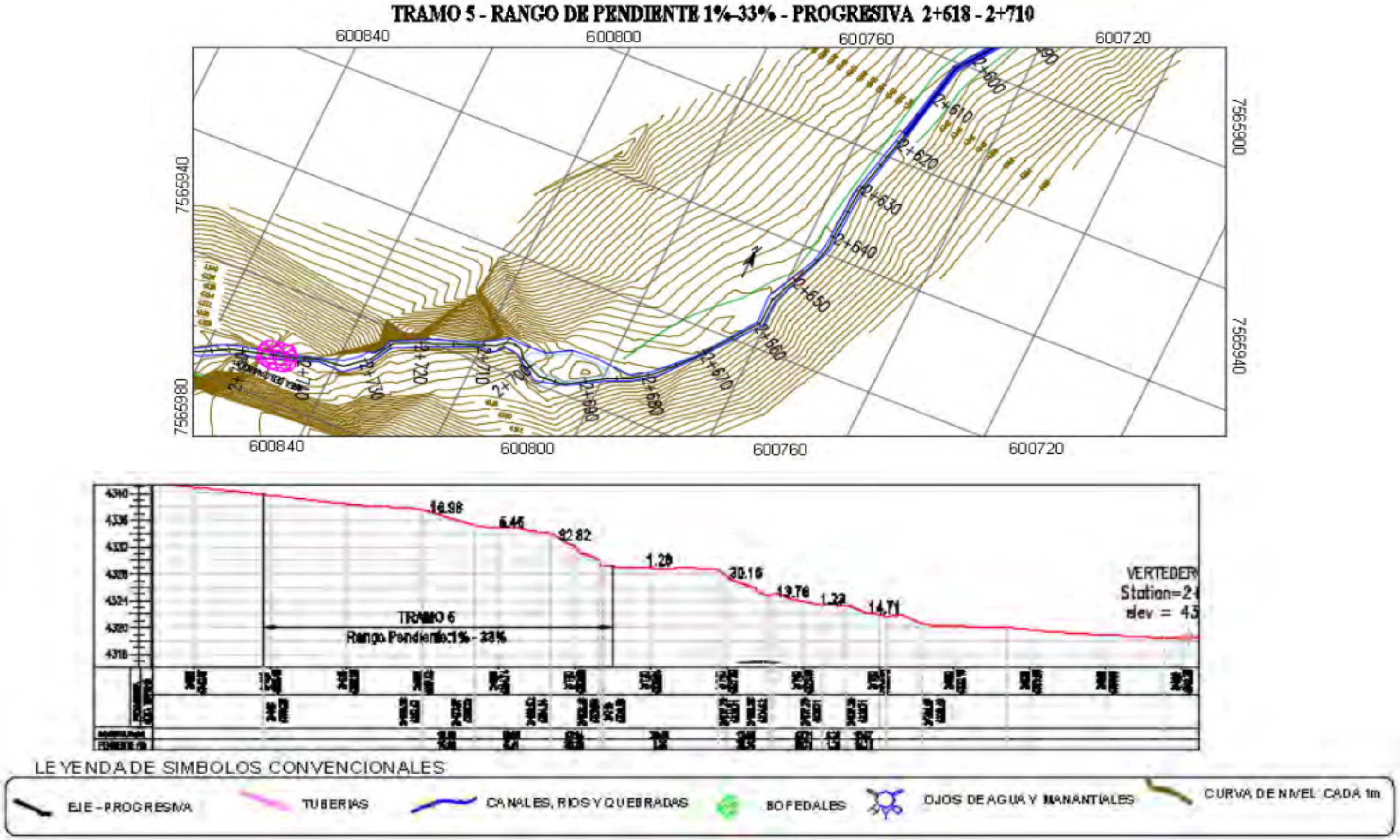


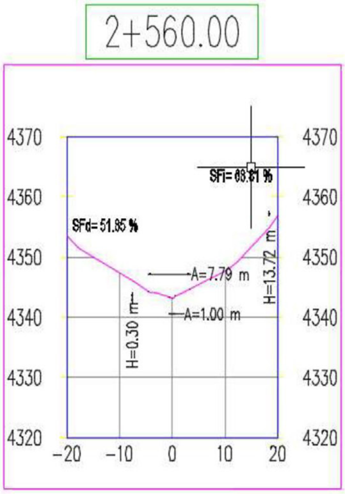
Figure 92. Plant and Longitudinal Profile of Reach 5, progressive 2+618 to 2+710 – South Bofedal of the Silala Springs. Source: Own elaboration based on data provided by DIREMAR, GOOGLE EARTH.

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH CANAL – REACH 4

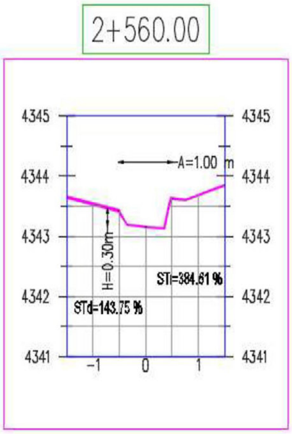
UMSA-IHH		**WATER SYSTEM:**		**SILALA SPRNGS**		DIREMAR
EVALUATION SHEET OF THE NATURAL SECTION CANAL						
1. LOCATION						
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ	
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO	
WATER SYSTEM		SILALA SPRINGS				
COMPONENT		SOUTH SPRING				
	PROGRESSIVE	COORDINATES		ELEVATION		
		EAST	NORTH	(m.a.s.l)		
START	2+377	601001.015	7566163.683	4351.56		
END	2+462	600839.034	7565964.318	4337.57		
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH						
LONGITUDINAL PROFILE						
PROFILE SHAPE			CONSTANTS WITH LOW SLOPES.			
SLOPE RANGE %			4.95			
DOMINANT LONGITUDINAL SLOPE %			4.95			
CROSS SECTION TYPE - CANAL (ST)						
FORM OF THE SECTION			IRREGULAR TRAPEZOIDAL			
AVERAGE WIDTH IN THE BED (A) [m]			1			
DEPTH OF THE SECTION (H) [m]			0.30			
RIGHT BANK SLOPE (STd) %			143.75			
LEFT BANK SLOPE (STi)%			384.64			
MORPHOLOGY			STEEP FLANKS DUE TO EROSION OR ANTHROPOGENIC EFFECT			
CROSS SECTION TYPE – FLANK (SF)						
RIGHT FLANK SLOPE (SFd) %			13.72			
LEFT FLANK SLOPE (SFI) %			51.85			
AVERAGE DEPTH OF THE FLANKS (H) [m]			68.81			
PLANT						
FORM OF ALIGNMENT			STRAIGHT AND CURVILINEAR WITH THREE MAIN CURVES			
CHANNEL WIDTH VARIABILITY			WITH CONSTANT SECTION AND NARROWING OF THE CHANNEL			
3. DESCRIPTION OF THE REACH						
THIS REACH HAS CHARACTERISTICS SIMILAR TO THE IMMEDIATELY SUPERIOR REACH, HOWEVER IT IS SEEN THAT THE TURBULENCE IS SMALLER AND THE SLOPE DECREASES WITH RESPECT TO THE PREVIOUS ONE. THE PRESENCE OF GREATER FLOW IS ALSO APPRECIATED, BUT NO SPRINGS ARE OBSERVED WITH THE NAKED EYE.						

4. REPRESENTATIVE CROSS SECTION

a) FLANK



b) CANAL



5. FOTOGRAFÍA

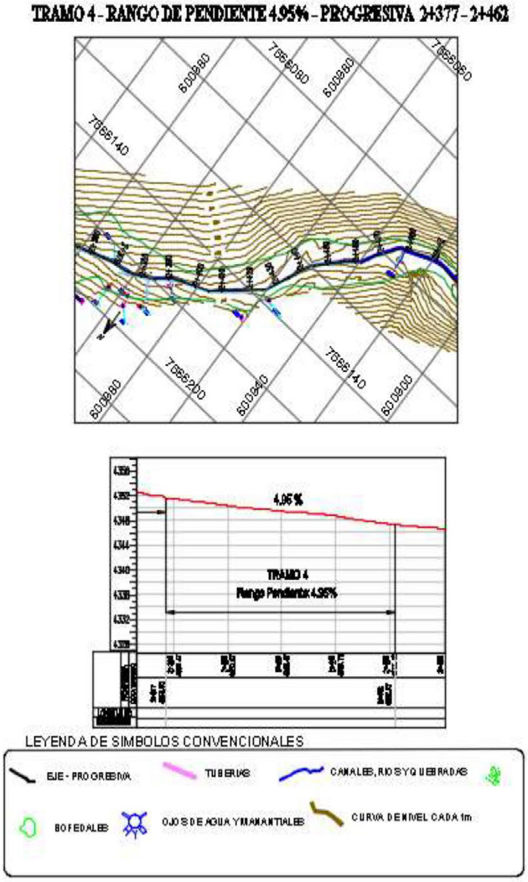
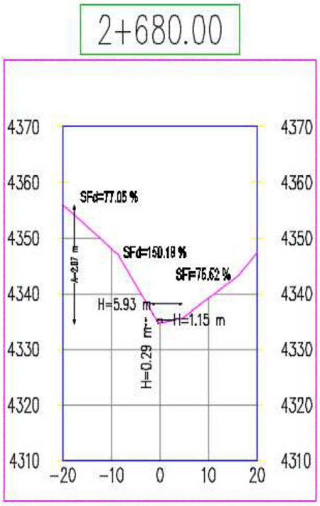


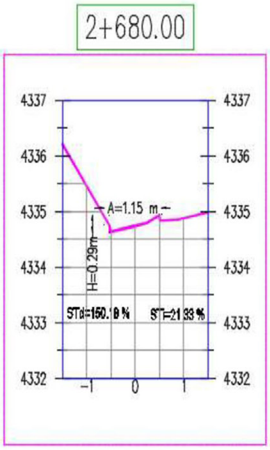
Figure 91. Plant and Longitudinal Profile of Reach 4, between the progressives 2+380 and 2+462 – South Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR, GOOGLE EARTH)

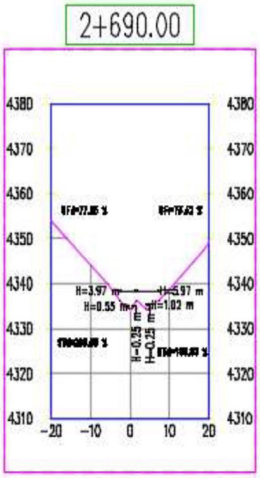
DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH BOFEDAL – REACH 5

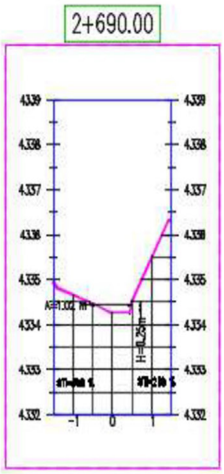
UMSA-IHH		**WATER SYSTEM:**	**SILALA SPRNGS**		**DIREMAR**
EVALUATION SHEET OF THE NATURAL SECTION CANAL					
1. LOCATION					
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO
WATER SYSTEM		SILALA SPRINGS			
COMPONENT		SOUTH SPRING			
	PROGRESSIVE	COORDINATES		ELEVATION (m.a.s.l)	
		EAST	NORTH		
START	2+618	600839.034	7565964.318	4339.20	
END	2+710	600737.348	7565914.940	4329.10	
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH					
LONGITUDINAL PROFILE					
		PROFILE SHAPE	VARIABLE AT SHORT AND MEDIUM DISTANCES. INTERNAL REACHES OF VARIED SLOPES TO SUB-HORIZONTAL.		
SLOPE RANGE %			1-33		
DOMINANT LONGITUDINAL SLOPE %			15.76		
CROSS SECTION TYPE - CANAL (ST)					
FORM OF THE SECTION			IRREGULAR TRAPEZOIDAL		
AVERAGE WIDTH IN THE BED (A) [m]			1.62		
DEPTH OF THE SECTION (H) [m]			1.15		
RIGHT BANK SLOPE (STd) %			VERTICAL		
LEFT BANK SLOPE (STi) %			VERTICAL		
		MORPHOLOGY	STEEP FLANKS DUE TO EROSION OR ANTHROPOGENIC EFFECT		
CROSS SECTION TYPE – FLANK (SF)					
RIGHT FLANK SLOPE (SFd) %			477.87		
LEFT FLANK SLOPE (SFI) %			110.05		
AVERAGE DEPTH OF THE FLANKS (H) [m]			25.16		
PLANT					
FORM OF ALIGNMENT			STRAIGHT AND CURVILINEAR WITH THREE MAIN CURVES		
CHANNEL WIDTH VARIABILITY			WITH CONSTANT SECTION AND NARROWING OF THE CHANNEL		
3. DESCRIPTION OF THE REACH					
THE LAST REACH OF THIS CHANNELIZED AREA HAS A TYPICAL CHARACTERISTIC OF FLOW THROUGH CHANNELS, BECAUSE THERE IS NO CLEAR ALIGNMENT AND TOTALLY IRREGULAR SECTION DUE TO THE ROCK FORMATION. THE FLOW DEVELOPS WITH TOTAL TURBULENCE AND THE VELOCITIES ARE VERY HIGH.					

4. REPRESENTATIVE CROSS SECTION	
a) FLANK	b) CANAL









5. FOTOGRAFÍA

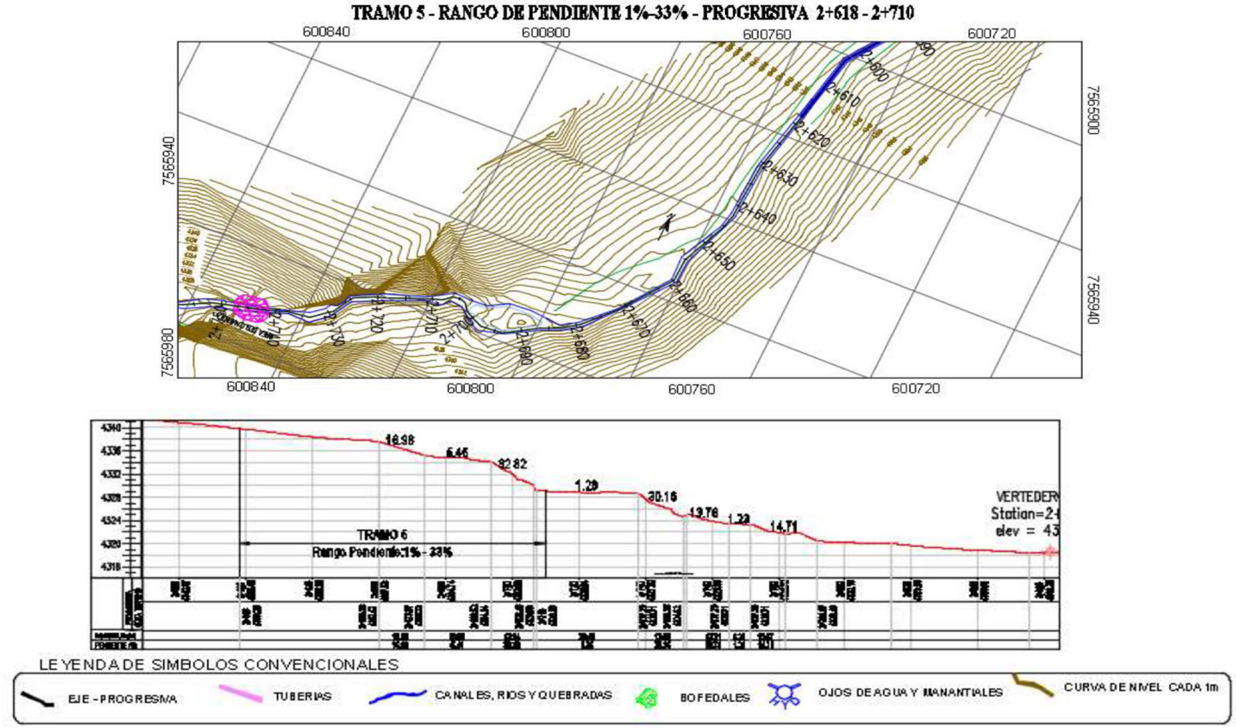


Figure 92. Plant and Longitudinal Profile of Reach 5, progressive 2+618 to 2+710 – South Bofedal of the Silala Springs. Source: Own elaboration based on data provided by DIREMAR, GOOGLE EARTH.

DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE SOUTH CANAL – REACH 6

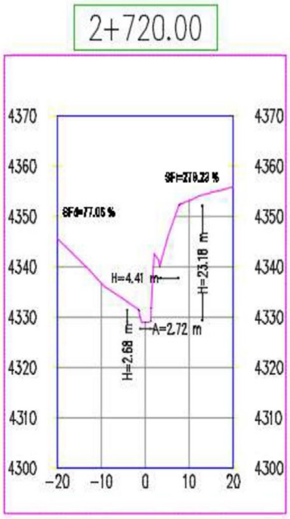
UMSA-IHH		WATER SYSTEM:	SILALA SPRNGS		DIREMAR
EVALUATION SHEET OF THE NATURAL SECTION CANAL					
1. LOCATION					
DEPARTAMENT		POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE		SOUTH LIPEZ		CANTON	QUETENA CHICO
WATER SYSTEM		SILALA SPRINGS			
COMPONENT		SOUTH SPRING			
	PROGRESSIVE	COORDINATES		ELEVATION (m.a.s.l)	
		EAST	NORTH		
START	2+710	600737.348	7565914.940	4329.10	
END	2+800	600737.348	7565914.940	4329.18	
2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH					
LONGITUDINAL PROFILE					
		PROFILE SHAPE	VARIABLE AT SHORT AND MEDIUM DISTANCES. INTERNAL REACHES OF VARIED SLOPES TO SUB-HORIZONTAL.		
SLOPE RANGE %			1-30		
DOMINANT LONGITUDINAL SLOPE %			15.76		
CROSS SECTION TYPE - CANAL (ST)					
FORM OF THE SECTION			IRREGULAR TRAPEZOIDAL		
AVERAGE WIDTH IN THE BED (A) [m]			2.72		
DEPTH OF THE SECTION (H) [m]			2.68		
RIGHT BANK SLOPE (STd) %			294.44		
LEFT BANK SLOPE (STi) %			VERTICAL		
		MORPHOLOGY	STEEP FLANKS DUE TO EROSION OR ANTHROPOGENIC EFFECT		
CROSS SECTION TYPE – FLANK (SF)					
RIGHT FLANK SLOPE (SFd) %			77.06		
LEFT FLANK SLOPE (SFI) %			278.23		
AVERAGE DEPTH OF THE FLANKS (H) [m]			23.18		
PLANT					
FORM OF ALIGNMENT			STRAIGHT AND CURVILINEAR WITH THREE MAIN CURVES		
CHANNEL WIDTH VARIABILITY			WITH CONSTANT SECTION AND NARROWING OF THE CHANNEL		
3. DESCRIPTION OF THE REACH					

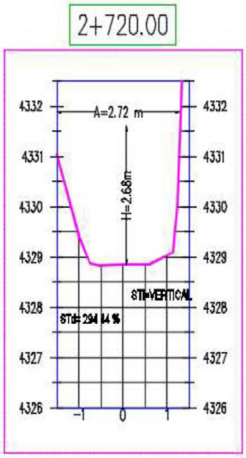
THE LAST REACH OF THIS CHANNELIZED AREA HAS A TYPICAL CHARACTERISTIC OF FLOW THROUGH CHANNELS, BECAUSE THERE IS NO CLEAR ALIGNMENT AND TOTALLY IRREGULAR SECTION DUE TO THE ROCK FORMATION. THE FLOW DEVELOPS WITH TOTAL TURBULENCE AND THE VELOCITIES ARE VERY HIGH.
ALMOST AT THE END OF THE REACH A DECREASE IN THE SLOPE IS OBSERVED AND THERE ARE TWO DISSIPATING MATTRESSES THAT CUSHION THE ABRASIVE EFFECT OF WATER.
AFTER A CHANGE IN THE SLOPE, THE FLOW IS SLOWER AND FINALLY LEAVES THE SOUTH BOFEDAL CANAL TO JOIN THE NORTH BOFEDAL CANAL.

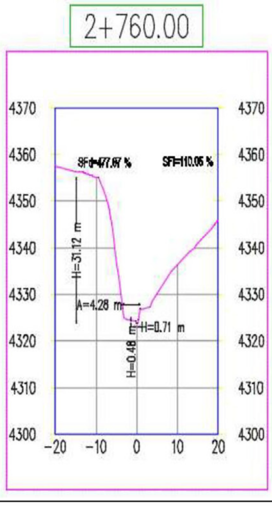
4. REPRESENTATIVE CROSS SECTION

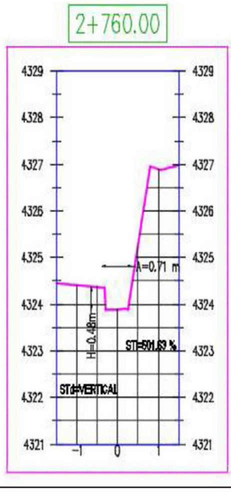
a) FLANK

b) CANAL









5. PHOTOGRAPH

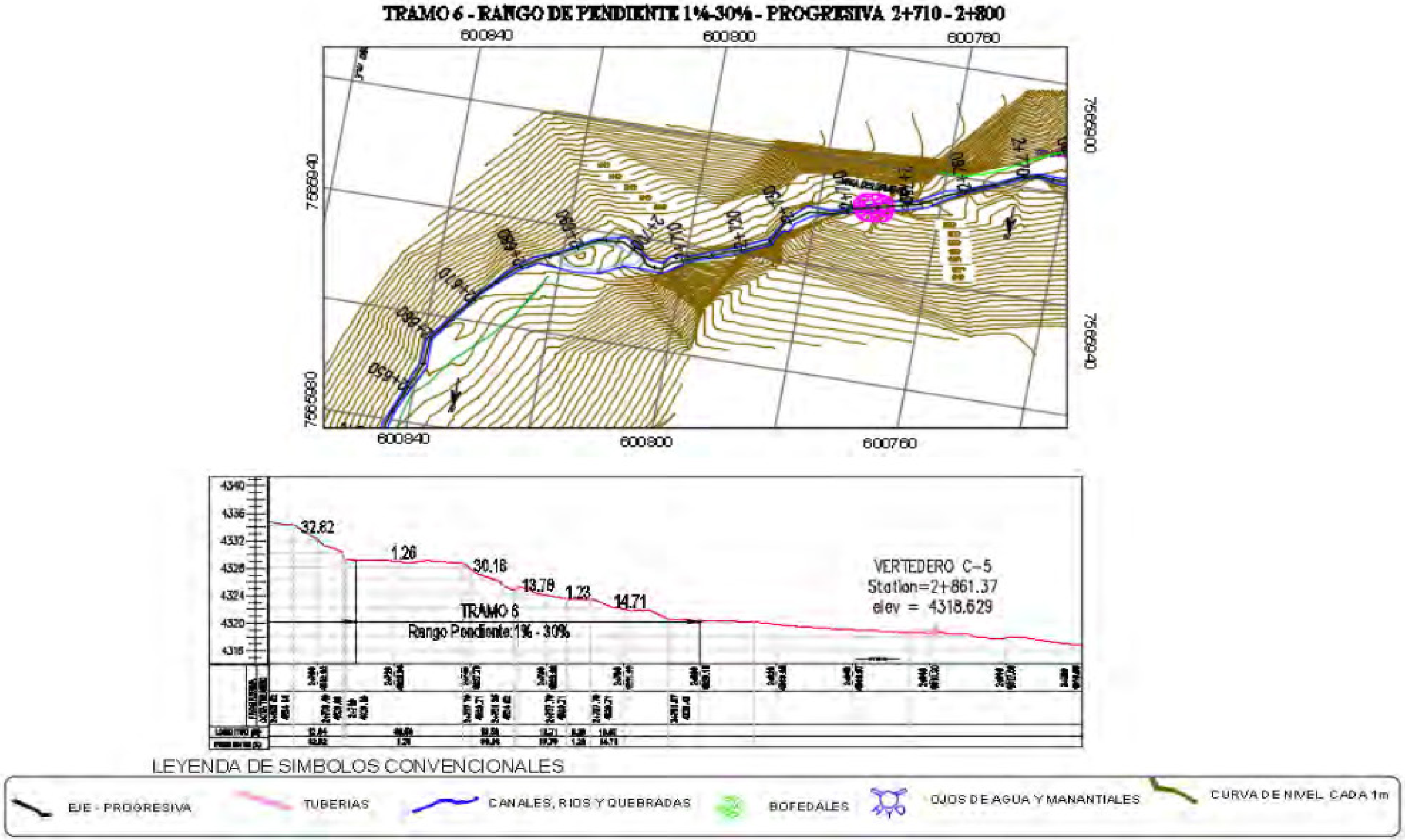


Figure 93. Plant and Longitudinal Profile of Reach 6, progressive 0+710 to 2+800 – South Bofedal of the Silala Springs. Source: Own elaboration based on data provided by DIREMAR.

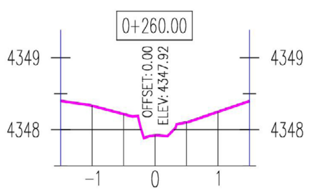
DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE NORTH CANAL – PROGRESSIVE 0+260 – 0+360

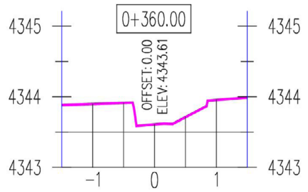
UMSA-IHH				DIREMAR
	WATER SYSTEM: SILALA SPRNGS			
EVALUATION SHEET OF THE CANALIZED REACH				
1. LOCATION				
DEPARTAMENT	POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE	SOUTH LIPEZ		CANTON	QUETENA CHICO
WATER SYSTEM	SILALA SPRINGS			
COMPONENT	NORTH CANAL			

	PROGRESSIVE	COORDINATES		ELEVATION (m.a.s.l)
		EAST	NORTH	
START	0+260 (NORTH CANAL)	600704.1	7566211.1	4347.92
END	0+360 (NORTH CANAL)	600792.7	7566256.7	4343.61

2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH	
LONGITUDINAL PROFILE	
PROFILE SHAPE	REACH WITH VARIABLE SLOPE BETWEEN 3.2 TO 5.9% WITH TENDENCY TO INCREASE THE SLOPE DOWNWARDS
SLOPE RANGE %	3.2 – 5.9
DOMINANT LONGITUDINAL SLOPE %	4.5

CROSS SECTIONS IN THE REACH							
PROGRESSIVE 0+260				PROGRESSIVE 0+360			
Width (m)	0.40	Depth (m)	0.22	Width (m)	0.58	Depth (m)	0.32





MORPHOLOGY	The start of the reach is the exit of the ravine. Rocky material is found on both sides of the canal. The protection material of the walls improves downwards, thus the jointing of the masonry contains binder material. The width of the canal is extended from 0.40 to 0.60 meters.
PLANT	
FORM OF ALIGNMENT	STRAIGHT REACH
CHANNEL WIDTH VARIABILITY	WITH NARROWING AND WIDENING

3. DESCRIPTION OF THE REACH
THE MATERIAL OF THE REACH ANALYZED IS OF STONE MASONRY. THE REACH HAS A VARIABLE SLOPE OF 3.2 TO 5.9%. THE WIDTH OF THE CANAL IS EXTENDED FROM 0.40 TO 0.60 METERS. THE START OF THE REACH IS THE EXIT OF THE RAVINE. ROCKY MATERIAL IS FOUND ON BOTH SIDES OF THE CANAL. THE PROTECTION MATERIAL OF THE WALLS OF THE CANAL IMPROVES DOWNWARDS, THE JOINTING OF THE MASONRY IS OBSERVED WITH BINDER MATERIAL. PHYSICAL CHARACTERISTICS OF THE REACH, ITS HYDRAULIC IMPLICATION AND ENVIRONMENTAL IMPACT THE RECTILINEAR LINE OF THE CANAL IN A STEEP TERRAIN LEADS TO STEEP SLOPES IN THE CANAL. DUE TO STEEP SLOPES, THE VELOCITIES IN THE CANAL ARE GREATER THAN 0.7 M/S (VELOCITIES THAT INCREASE DOWNSTREAM). DUE TO THE NEED TO PROTECT THE WALLS AND THE SCREED OF THE CHANNEL AGAINST THE EROSIVE EFFECT OF HIGH SPEEDS, THESE HAVE BEEN WELDED WITH A VERY SPECIAL BINDER MATERIAL WITH HIGH RESISTANCE TO EROSION. THE WATER ABSTRACTION WITH THE FISHBONE SYSTEM IN THE SECONDARY CANALS FROM THE PROGRESSIVE 0 + 000 TO 0 + 360, EROSION PROTECTION OF THE WALLS AND FLOOR OF THE CANAL TO THE EROSION OF THE STRONG VELOCITIES AND WATERPROOFING OF THE MAIN NORTH CANAL, MAKES THE WATER ABSTRACTION AND CHANNELING SYSTEM HIGHLY EFFICIENT. THE ENVIRONMENTAL IMPACT EXEMPLIFIED IN THE WATER TABLE VARIABLE SHOWS THE DESCENT OF THE WATER TABLE IN A SHORT REACH OF THE ANALYSIS AREA. POINT 600833 EAST, 7566295 NORTH, WATER TABLE 0.10 METERS BELOW THE SURFACE OF THE TERRAIN, POINT 600775 EAST, 7566269 NORTH, 0.4 METERS BELOW THE SURFACE OF THE TERRAIN, DISTANCE BETWEEN THE TWO POINTS 62 METERS (ORZAG, 2017).

NORTH CANAL – PROGRESSIVE 0 + 260 - 0 + 360 – SLOPE 4.5%

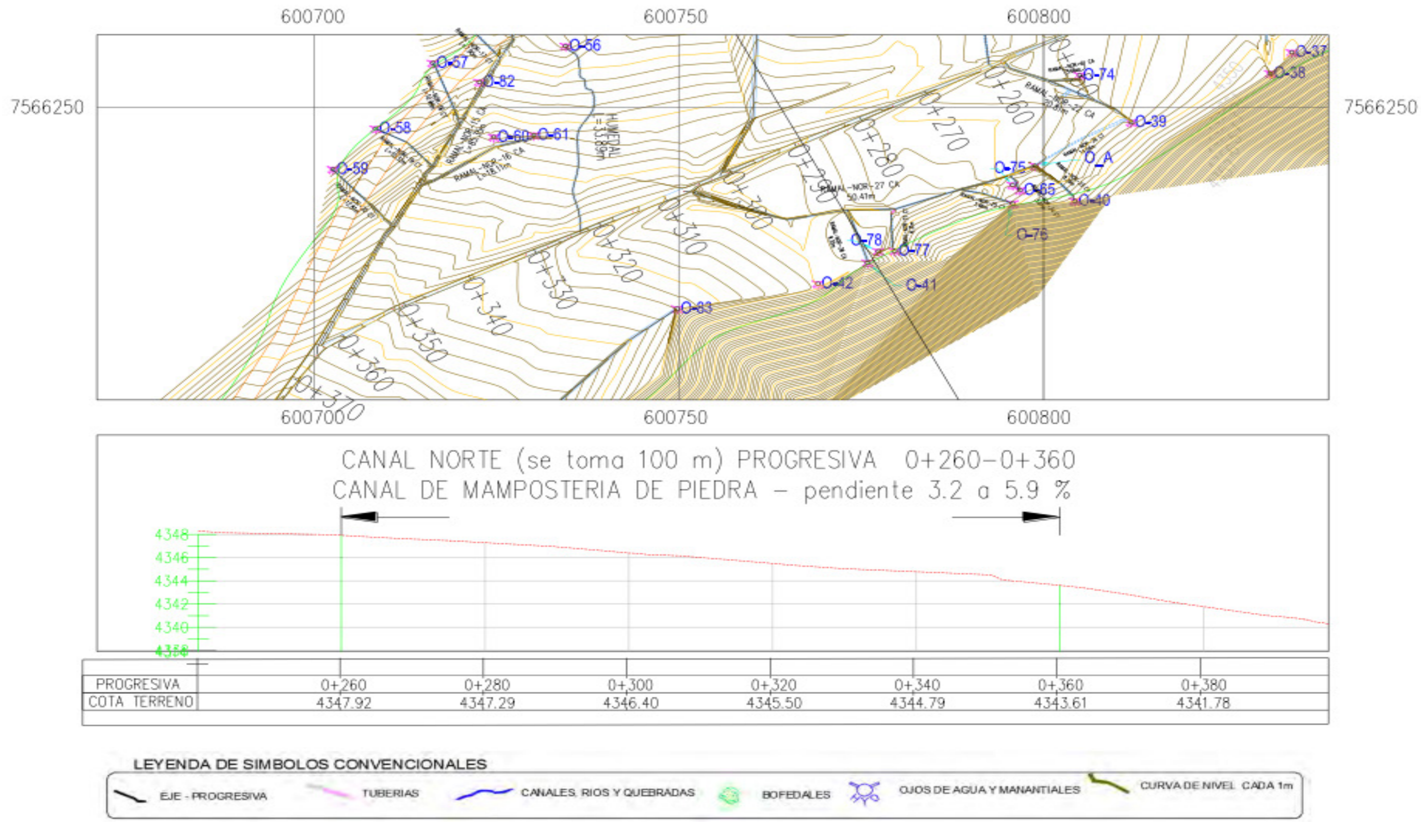


Figure 94. Plant and Longitudinal Profile of the North Canal of the reach between the progressive 0 + 260 to 0 + 360 – North Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR, GOOGLE EARTH)

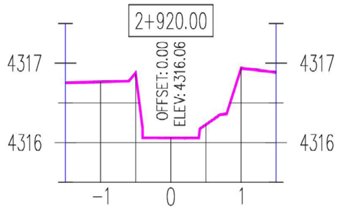
DESCRIPTION OF THE PHYSICAL CHARACTERISTICS OF THE CONFLUENCE CANAL – PROGRESSIVE 2 + 920 TO 2 + 970

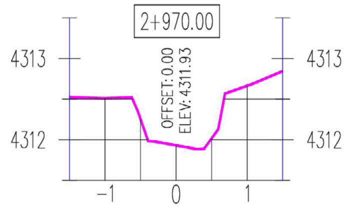
UMSA-IHH	WATER SYSTEM: SILALA SPRNGS			DIREMAR
EVALUATION SHEET OF THE CANALIZED REACH				
1. LOCATION				
DEPARTAMENT	POTOSI		MUNICIPALITY	SAN PABLO DE LIPEZ
PROVINCE	SOUTH LIPEZ		CANTON	QUETENA CHICO
WATER SYSTEM	SILALA SPRINGS			
COMPONENT	CONFLUENCE CANAL			

	PROGRESSIVE	COORDINATES EAST	COORDINATES NORTH	ELEVATION (m.a.s.l)
START	2+920 (CONFLUENCE CANAL)	6000618.4	7565870.5	4316.08
END	2+970 (CONFLUENCE CANAL)	600586.87	7565832.3	4311.96

2. MORPHOLOGICAL CHARACTERISTICS OF THE REACH	
LONGITUDINAL PROFILE	
PROFILE SHAPE	VARIABLE AT SHORT AND MEDIUM DISTANCES. THE PREDOMINANT SLOPE IS 5.9%
SLOPE RANGE %	3.2 – 5.9
DOMINANT LONGITUDINAL SLOPE %	5.9
CROSS SECTIONS IN THE REACH	

PROGRESSIVE 2+920				PROGRESSIVE 2+970			
Width (m)	0.80	Depth (m)	0.82	Width (m)	0.68	Depth (m)	0.65





MORPHOLOGY	THE CONFLUENCE REACH IS LINED AT THE BEGINNING. THE CONFLUENCE REACH CANALS IN THE CONFLUENCE REACH ARE THE DEEPEST OF THE ENTIRE DRAINAGE SYSTEM. THE CONDITIONS OF THE PIPELINE FROM THE INTAKE WORK UP TO THE PROGRESSIVE 3 + 000 IS DIVERSE, THERE ARE REACHES IN GOOD CONDITION AND IN POOR CONDITION, WITH MOST OF THE REACHES IN GOOD CONDITION.
PLANT	
FORM OF ALIGNMENT	STRAIGHT REACH
CHANNEL WIDTH VARIABILITY	WITH NARROWING AND WIDENING

3. DESCRIPTION OF THE REACH
THE CANAL REACH ANALYZED AND THE ENTIRE REACH OF THE CONFLUENCE CANAL ARE BUILT WITH STONE MASONRY; THE BINDER OF THIS COATING MATERIAL IS A MIXTURE OF LIME AND SOME TYPE OF POZZOLAN THAT PRODUCES A RESISTANT AND APPARENTLY DURABLE MIXTURE. THE SLOPE IN THE ANALYZED REACH IS VARIABLE WITH AN AVERAGE OF 5.9%. THE CANALS IN THE CONFLUENCE REACH ARE THE DEEPEST OF THE ENTIRE DRAINAGE SYSTEM. THE CONDITIONS OF THE PIPELINE FROM THE INTAKE WORK UP TO THE PROGRESSIVE 3 + 000 IS DIVERSE, THERE ARE REACHES IN GOOD CONDITION AND IN POOR CONDITION, WITH MOST OF THE REACHES IN GOOD CONDITION. THE CHARACTERISTICS OF A STEEP SLOPE IN THE CONFLUENCE REACH (WHOSE SLOPE IS SLIGHTLY GREATER THAN THE NORTH CANAL) INDICATE THE SAME CONDITIONS OF SLOPE FLOW AND CANAL PROTECTION OF THE NORTH CANAL. THE RECTILINEAR LINE OF THE CANAL IN A STEEP TERRAIN LEADS TO STRONG SLOPES OF AROUND 6% AND HIGH VELOCITIES GREATER THAN 0.75 M/S (VELOCITIES THAT INCREASE DOWNSTREAM). THE PROTECTION OF THE WALLS AND THE FLOOR OF THE CANAL AGAINST THE EROSIVE EFFECT OF THE HIGH VELOCITIES HAS BEEN MADE WITH A VERY SPECIAL BINDER MATERIAL WITH HIGH RESISTANCE TO EROSION. DESPITE THE EXISTENCE OF SOME REACHES IN POOR CONDITION OF THE CONFLUENCE CANAL, THE HYDRAULIC CHANNELLING IS EFFICIENT REFLECTED IN THE DEGRADATION OF THE SLOPING BOFEDAL OF THE CONFLUENCE REACH.
4. PHOTOGRAPHS

Confluence Canal.

CONFLUENCE CANAL - PROGRESSIVE 2+920 – 2+970 - SLOPE 4.5 %

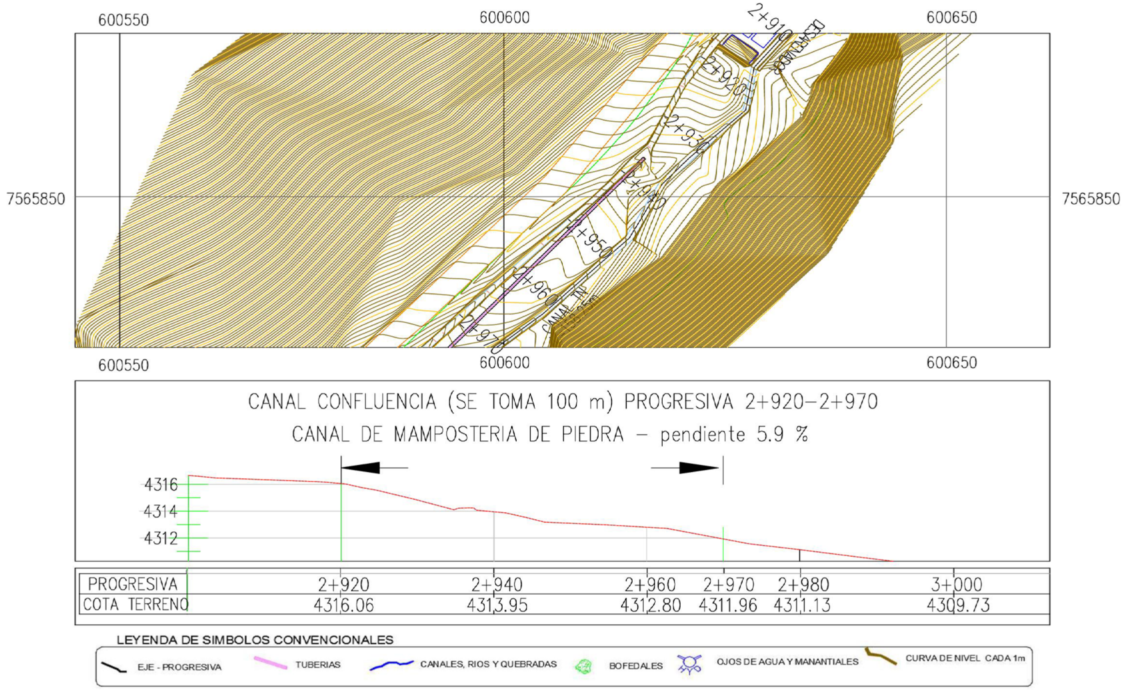


Figure 95. Plant and Longitudinal Profile of the Confluence Canal Reach between the progressive 2 + 920 to 2 + 2970 - Confluence Bofedal of the Silala Springs. (Source: Own elaboration based on data provided by DIREMAR)

ANNEX 2: CHARACTERIZATION OF THE CANALS OF THE SOUTH BOFEDAL

HYDRAULIC MODELING WITH HEC GEO RAS HYDRAULIC SYSTEM INCLUDING THE BOFEDALS AND CANALS

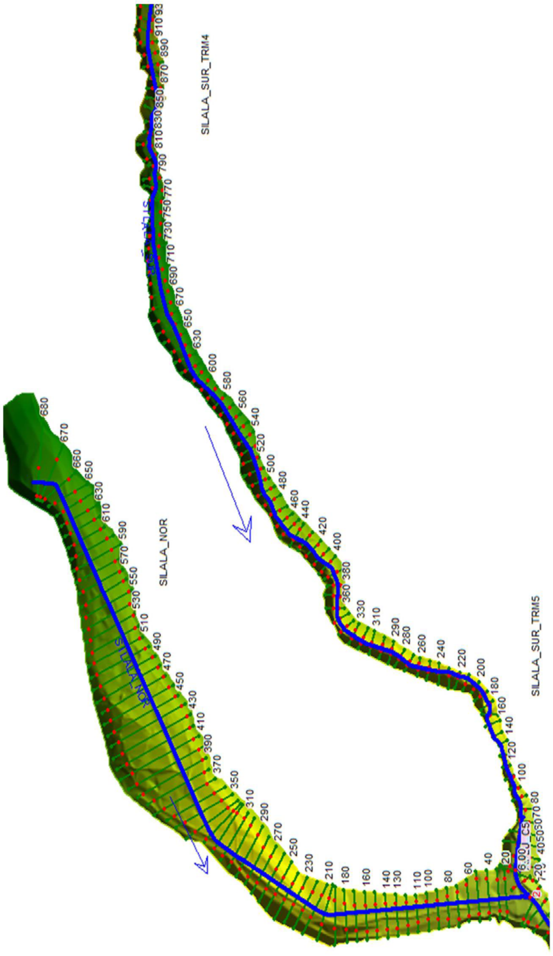


Figure 96. Detail of the hydraulic model for the North Branch of Silala in HEC-RAS. (Source: prepared by the authors)

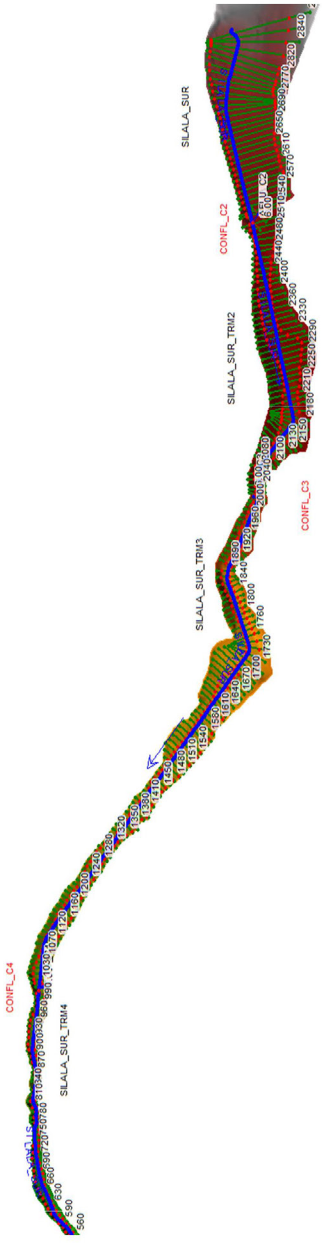


Figure 97. Detail of the hydraulic model for the South Branch of the Silala in HEC-RAS

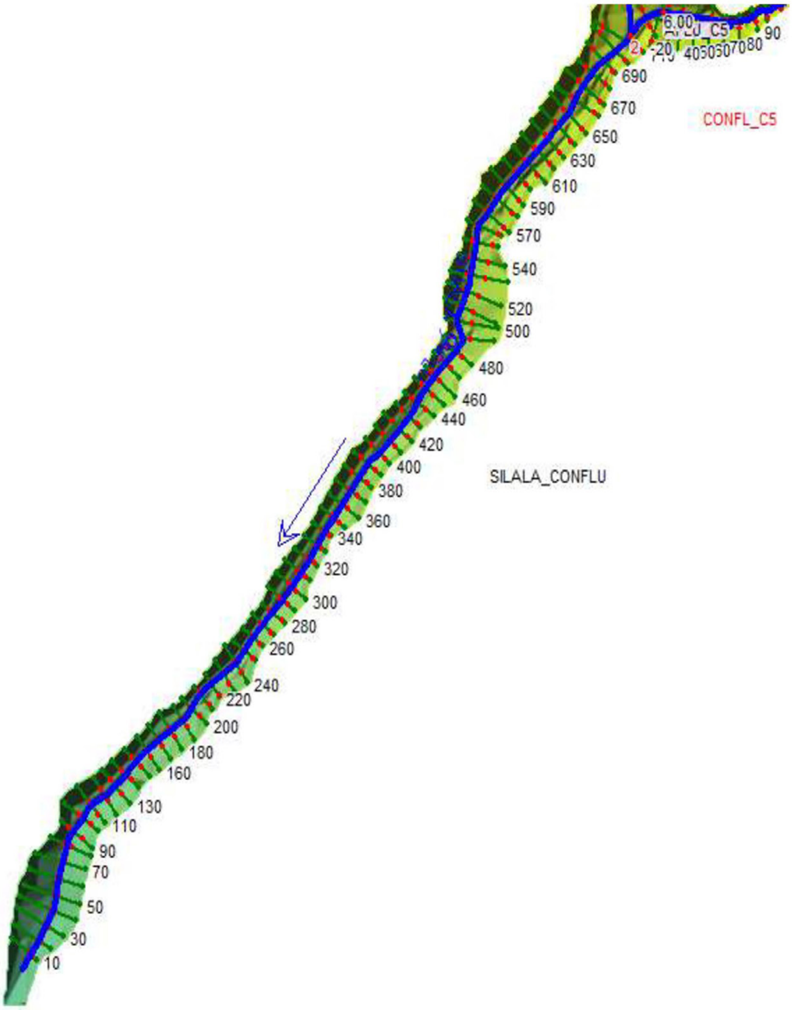


Figure 98. Detail of the hydraulic model for the Confluence Branch of the Silala in HEC-RAS

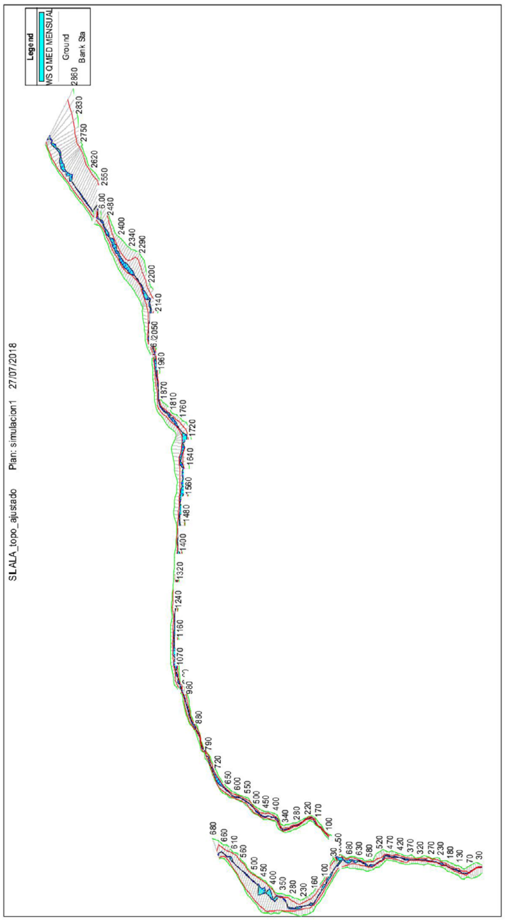


Figure 99. Detail of the Hydraulic Model of the Confluence Reach of the Silala in HEC-RAS

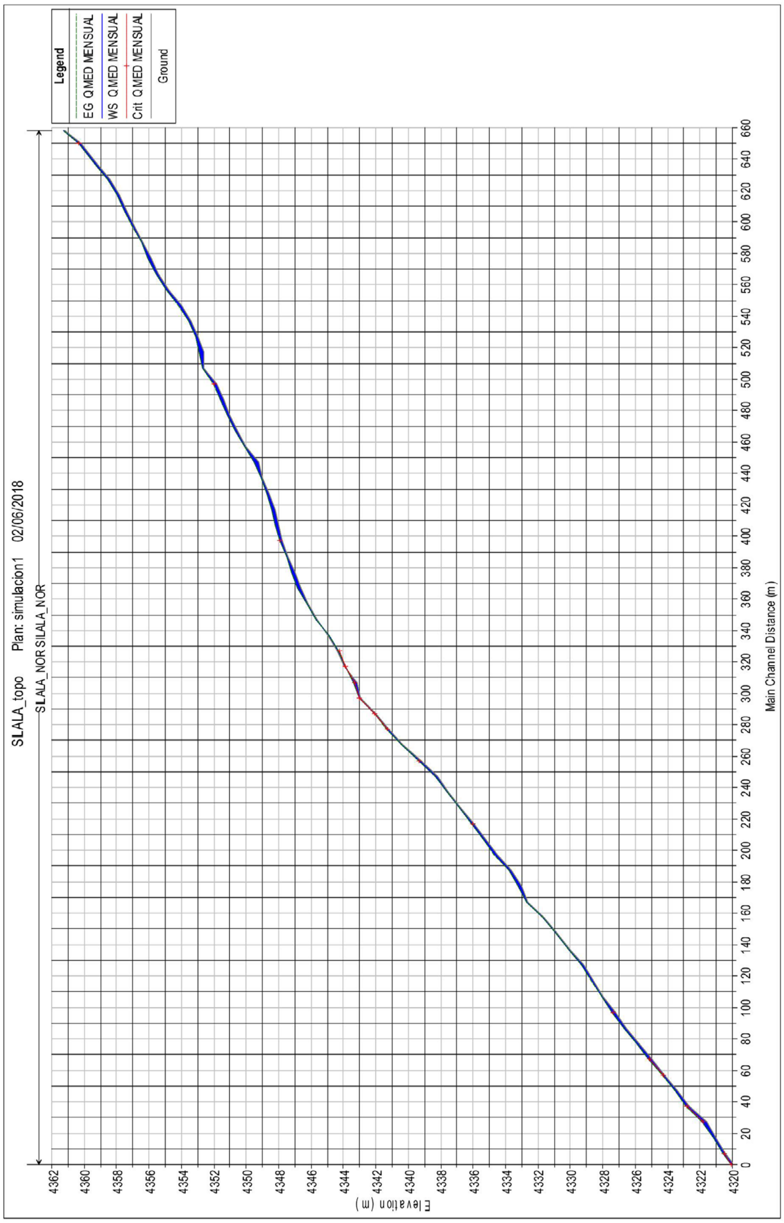


Figure 100. Hydraulic profile in the North Branch Silala in HEC-RAS

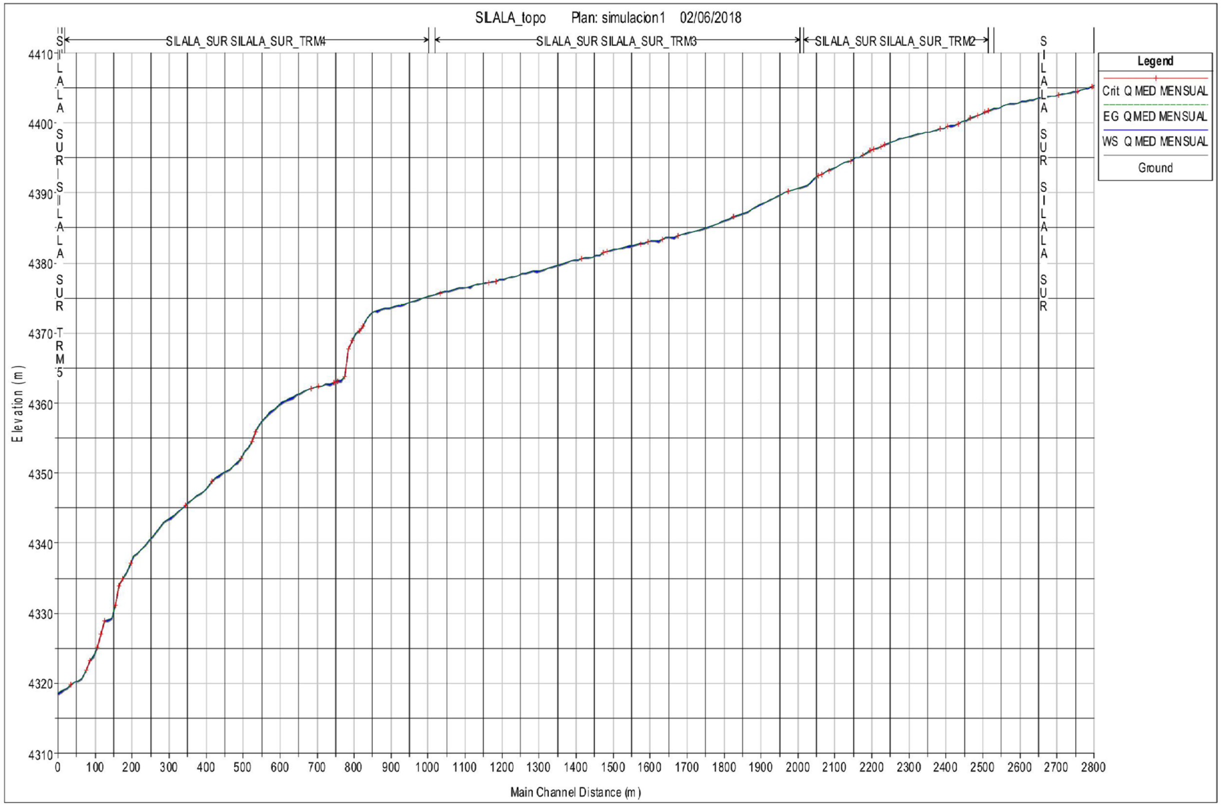


Figure 101. Hydraulic profile of the South Branch of the Silala in HEC-RAS

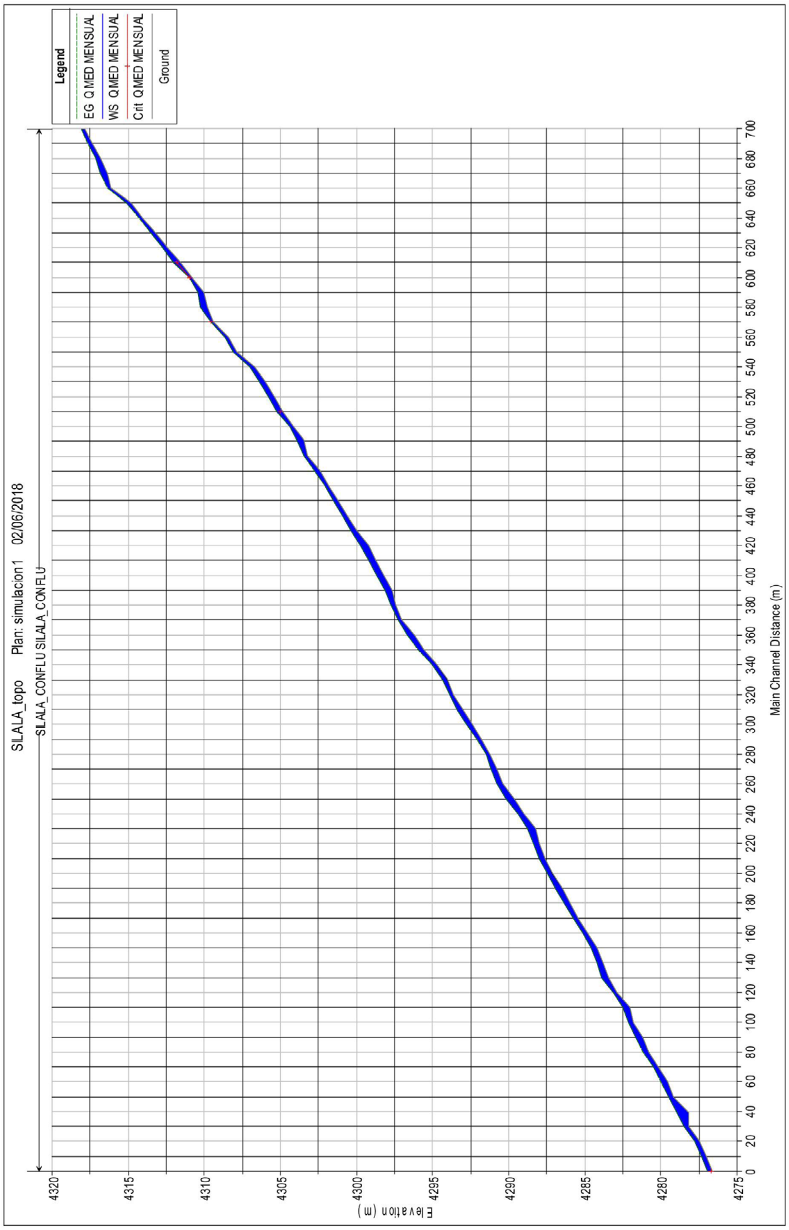


Figure 102. Hydraulic profile of the Confluence Branch of the Silala in HEC-RAS

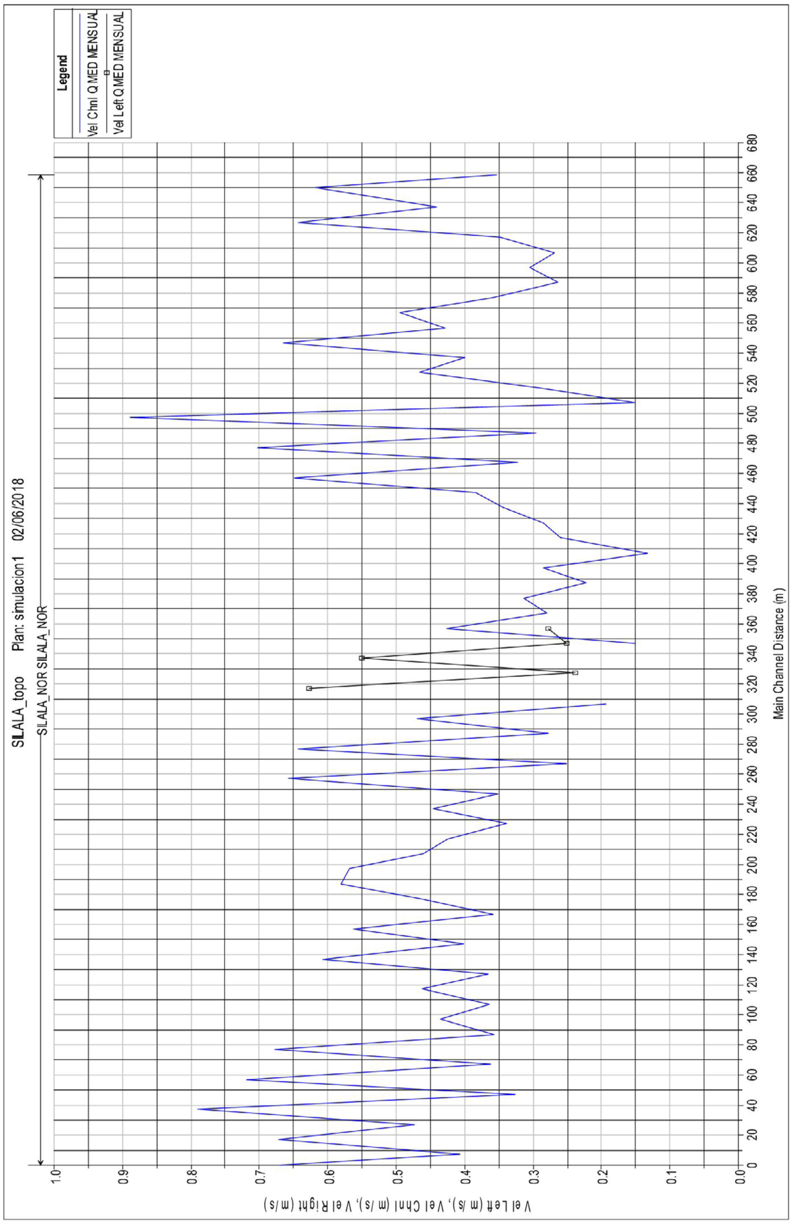


Figure 103. Hydraulic Profile of the velocities in the North Branch of the Silala in HEC-RAS

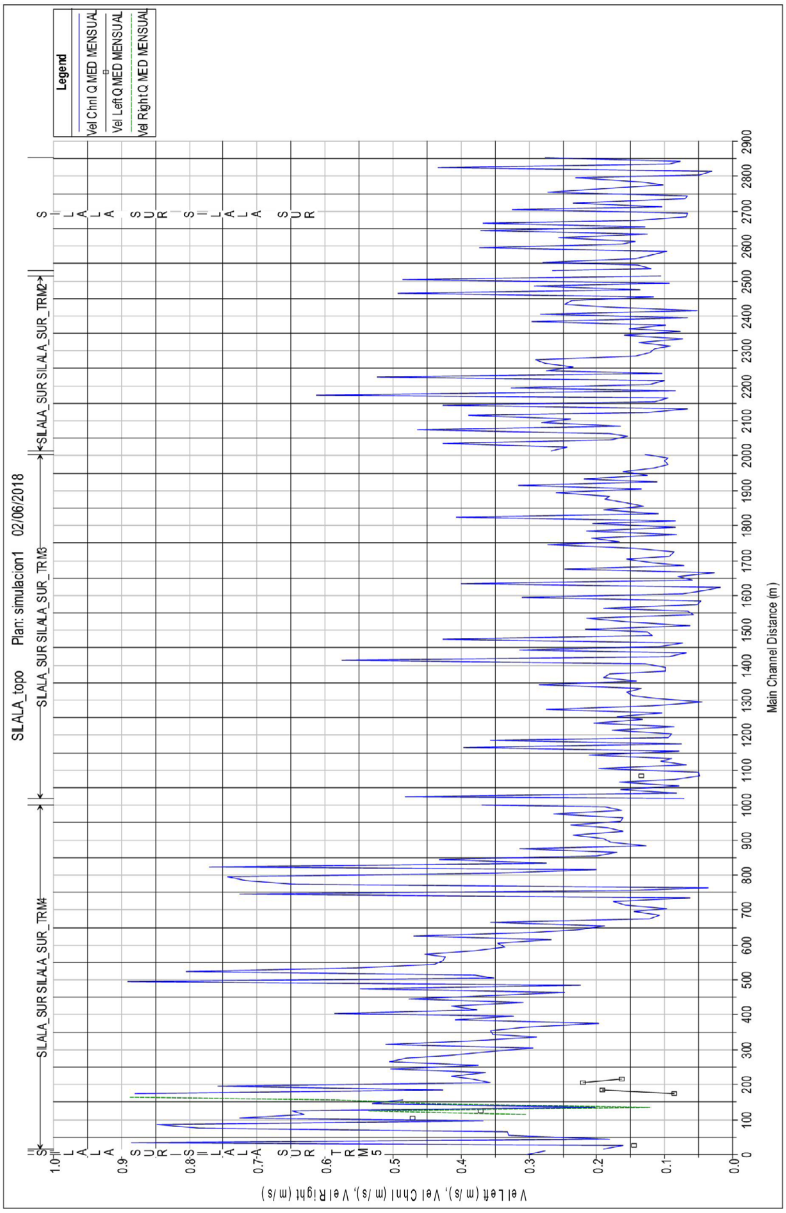


Figure 104. Hydraulic Profile of the velocities in the South Branch of the Silala in HEC-RAS

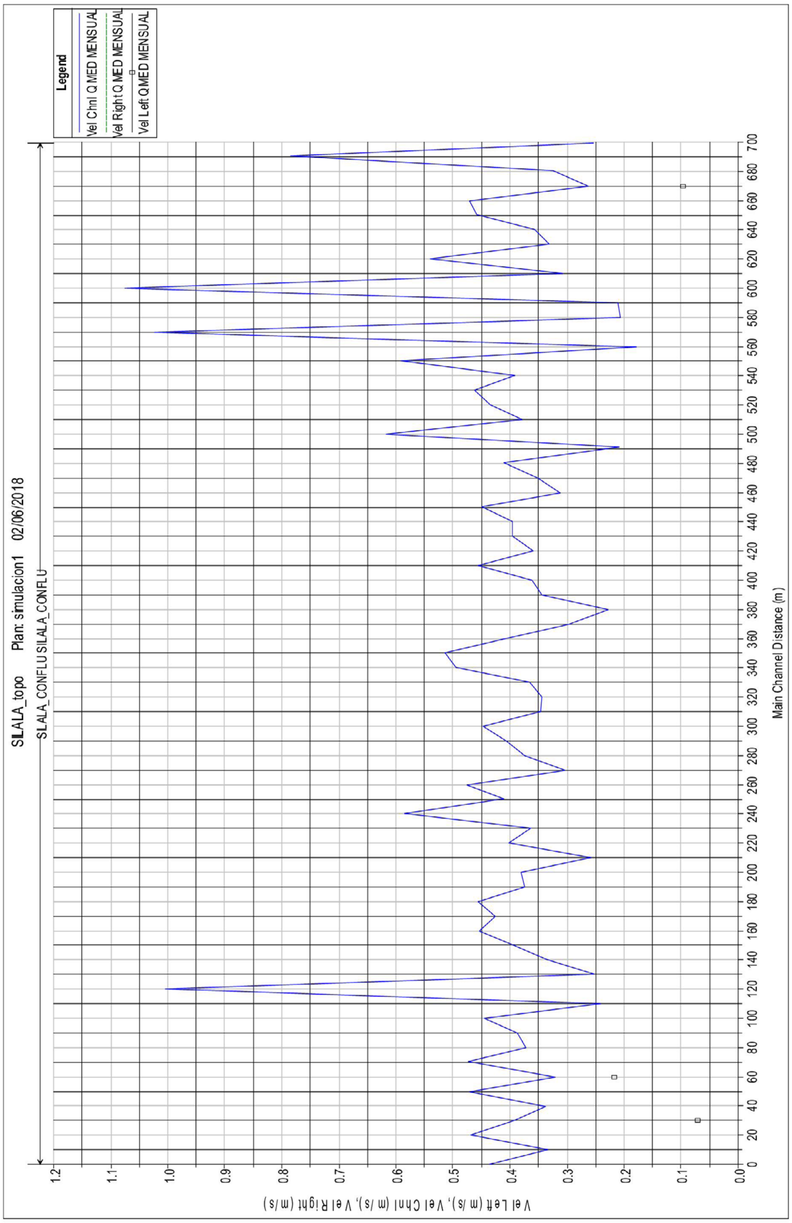


Figure 105. Hydraulic Profile of the velocities in the Confluence Branch of the Silala at HEC-RAS

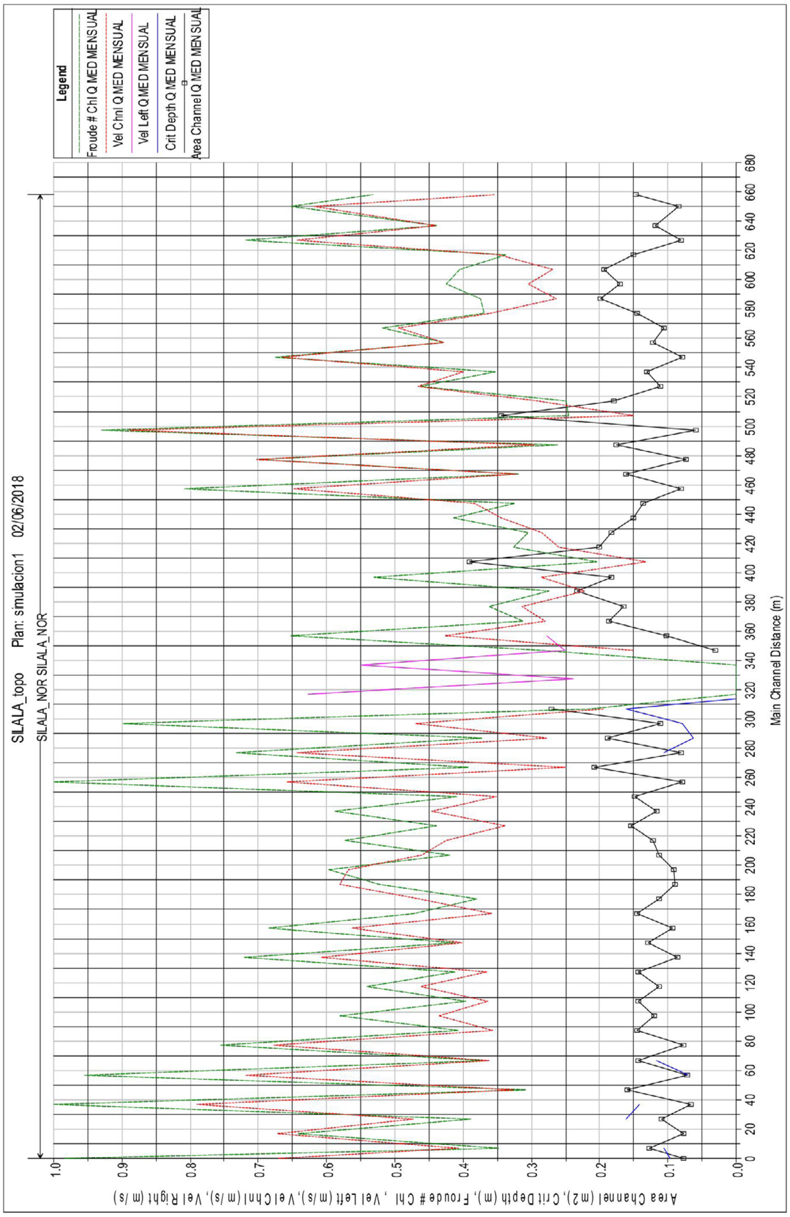


Figure 106. Hydraulic Profile of the Froude Number and Velocities in the North Branch of the Silala in HEC-RAS

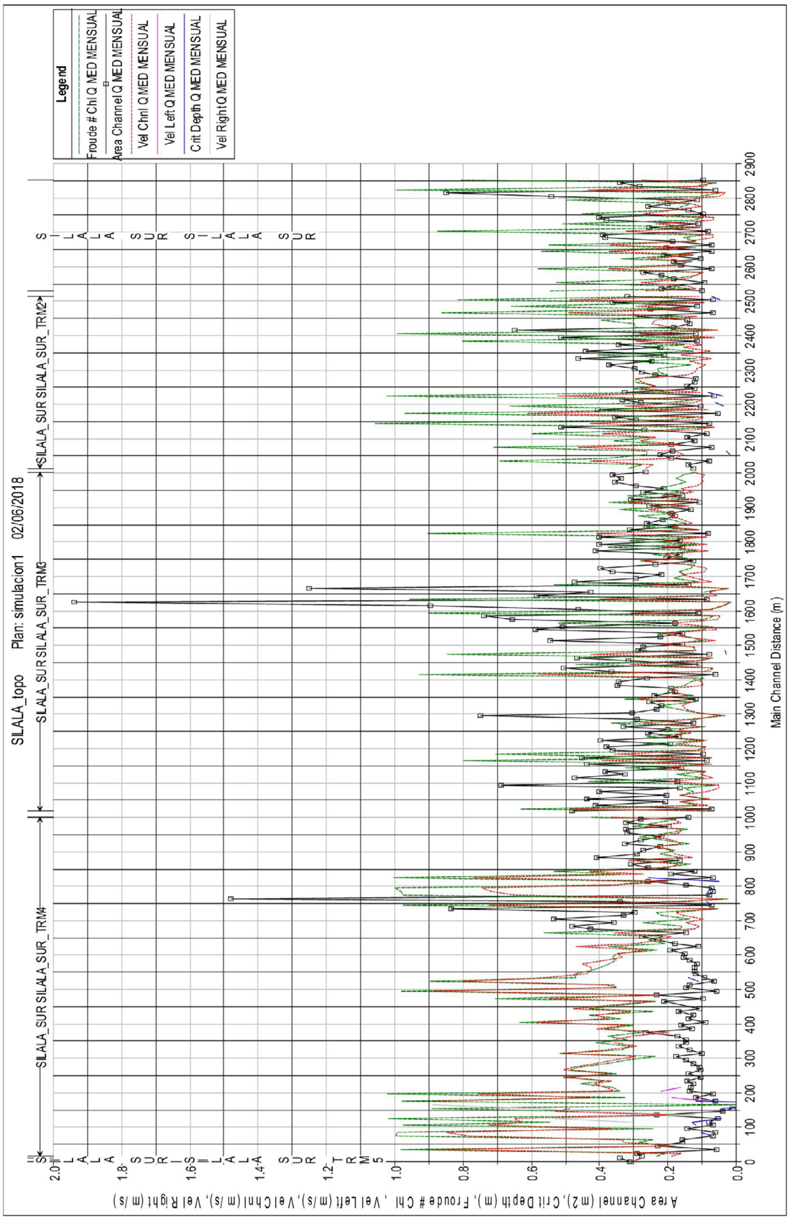


Figure 107. Hydraulic Profile of the Froude Number and Velocities in the South Branch of the Silala in HEC-RAS

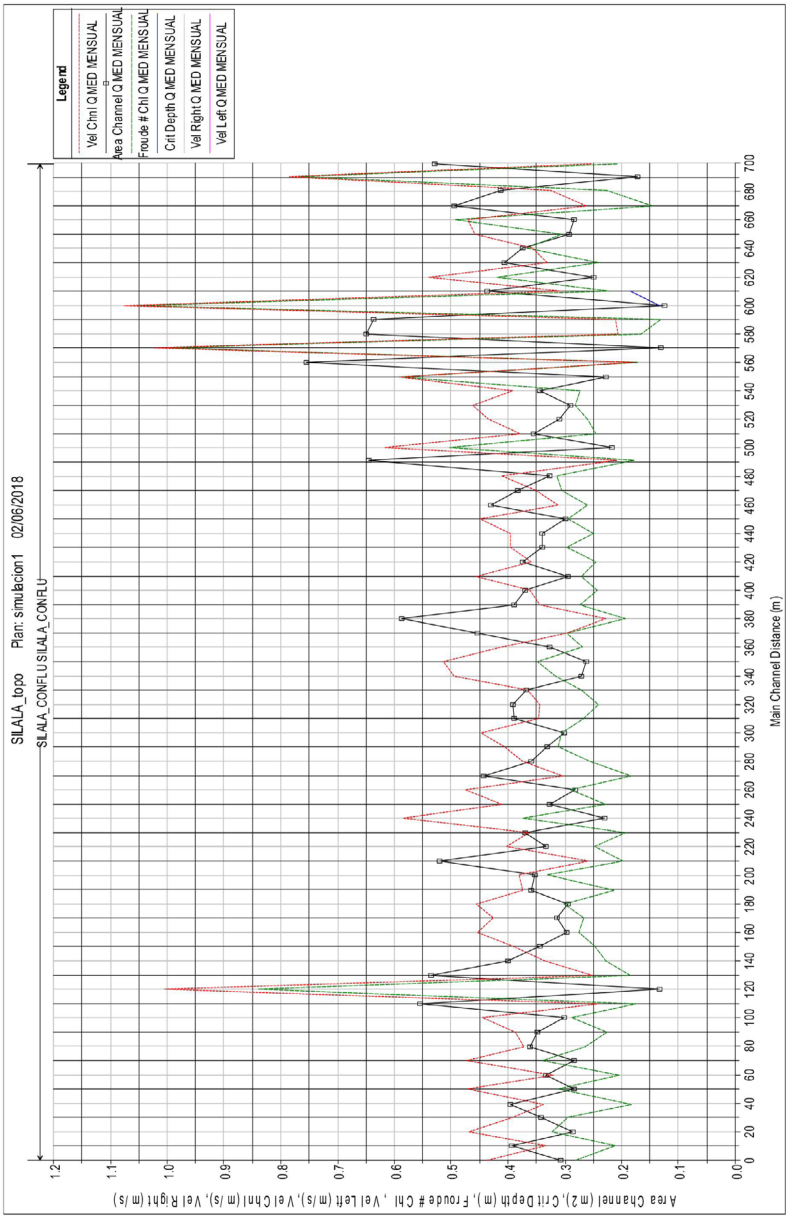


Figure 108. Hydraulic Profile of the Froude Number and Velocities in the Confluence Branch of the Silala in HEC-RAS

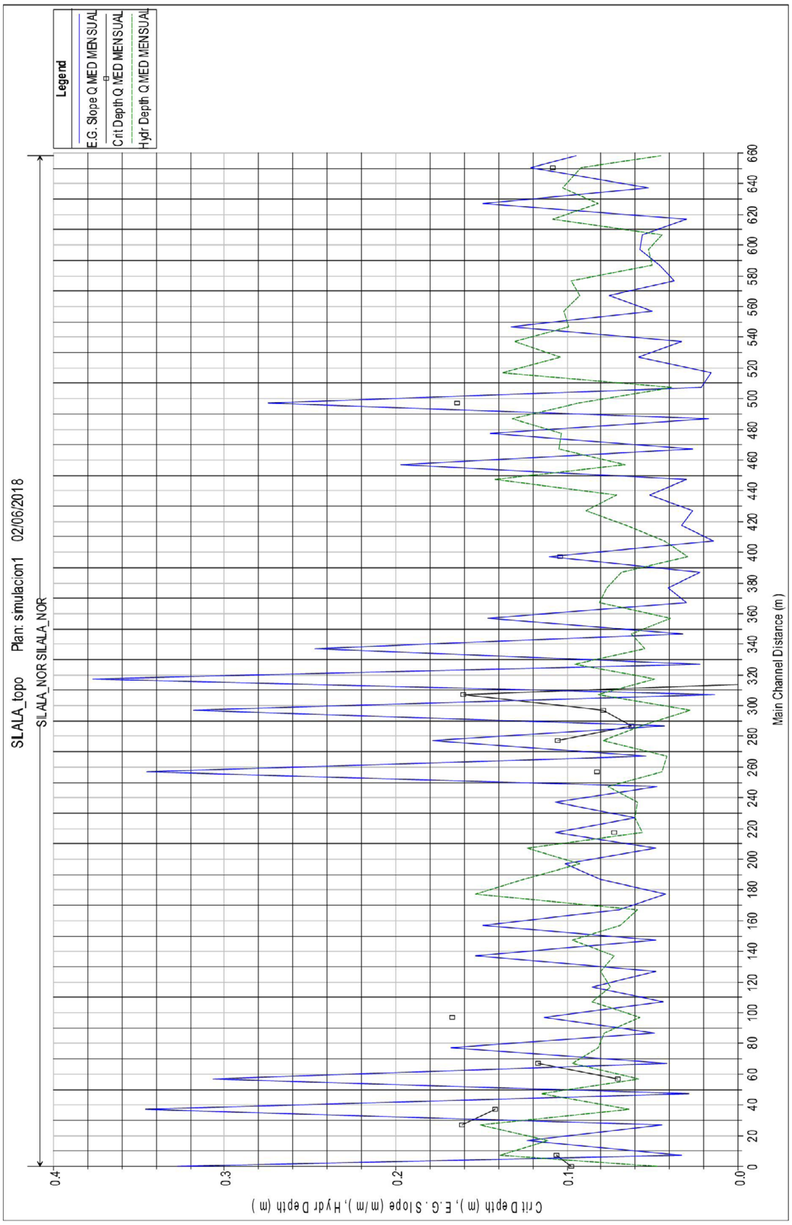


Figure 109. Profile of the Gradient, Energy Line, and Depth in the North Branch of the Silala in HEC-RAS

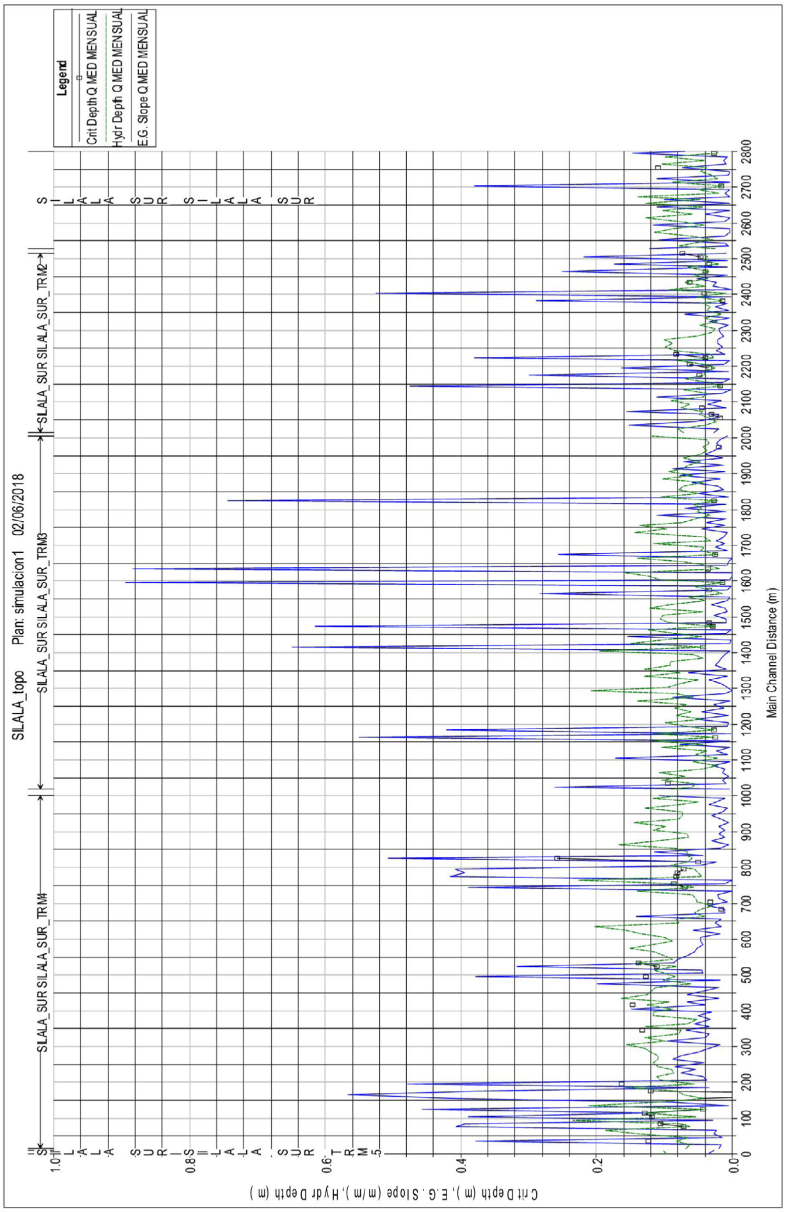


Figure 110. Profile of the Gradient, Energy Line, and Depth in the South Branch of the Silala in HEC-RAS

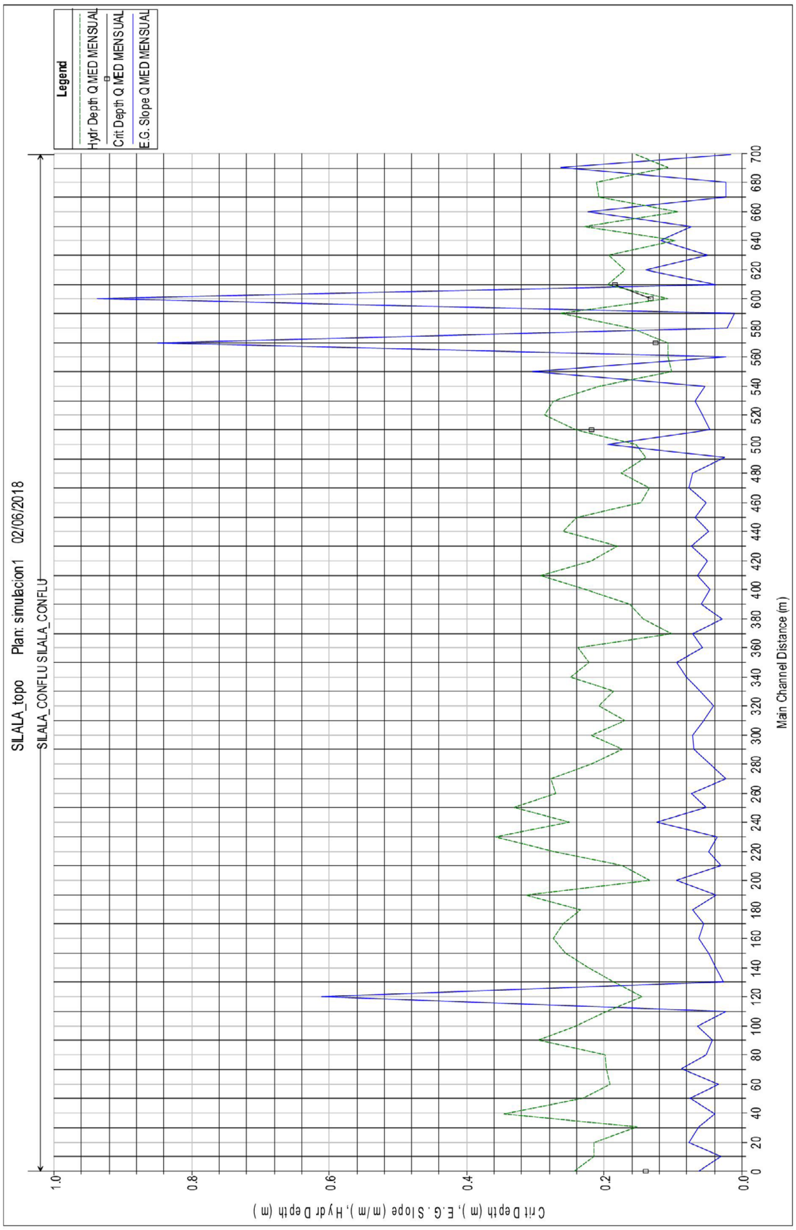


Figure 111. Profile of the Gradient, Energy Line, and Depth in the Confluence Branch of the Silala in HEC-RAS

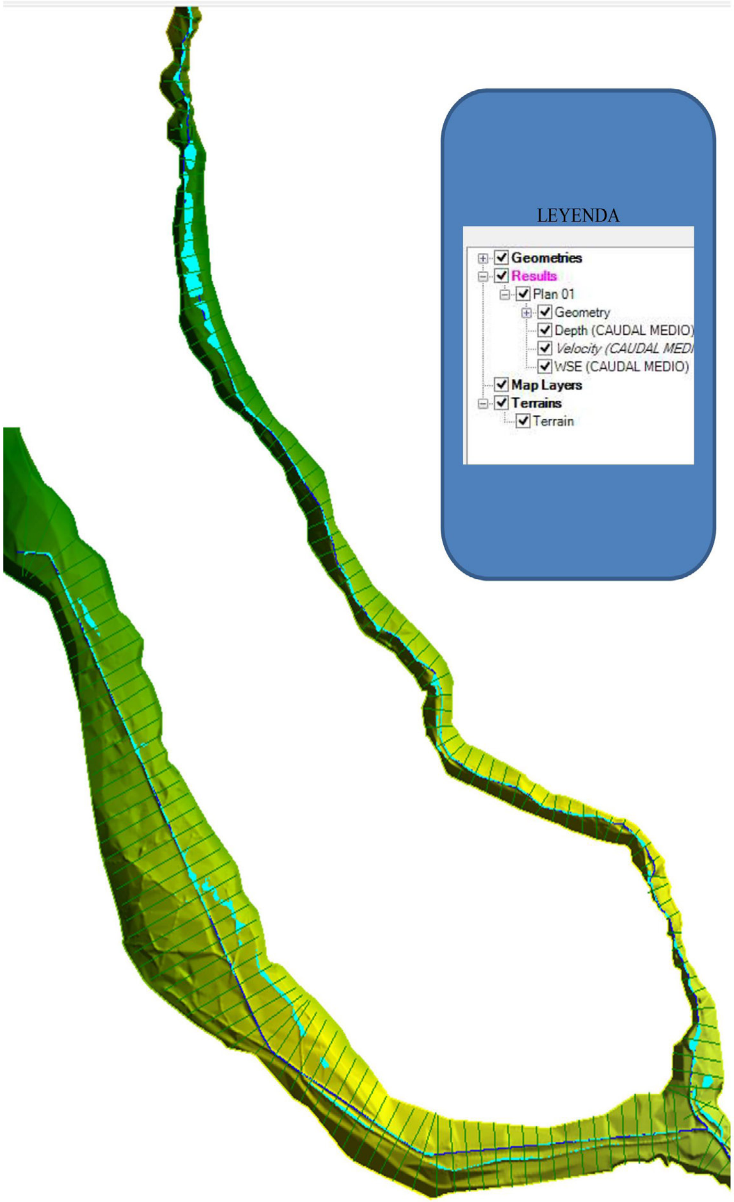


Figure 112. Hydraulic Simulation in Ras Mapper for the North Branch of the Silala in HEC-RAS

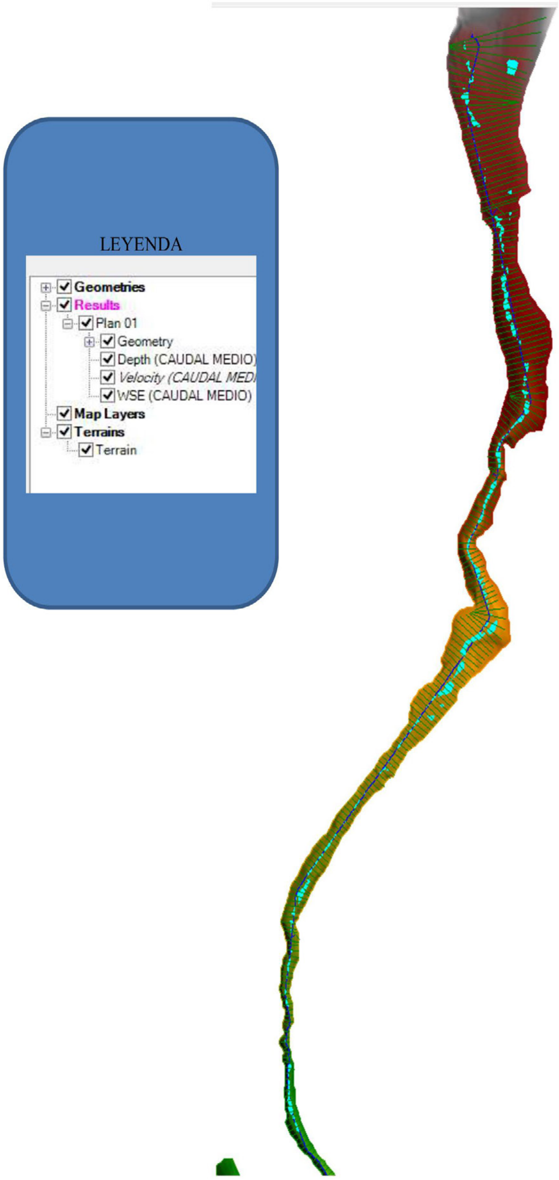


Figure 113. Hydraulic Simulation in Ras Mapper for the South Branch of the Silala in HEC-RAS

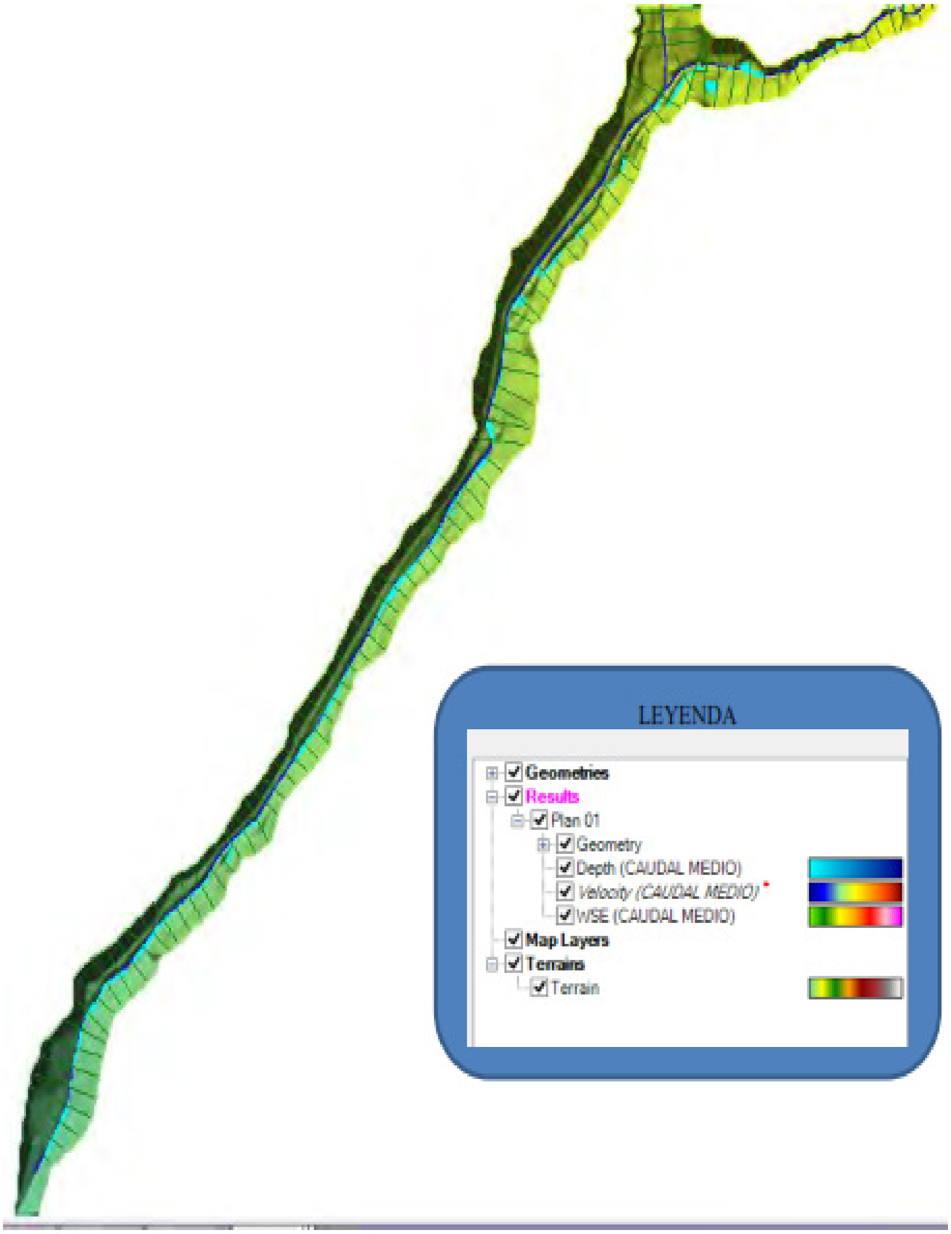


Figure 114. Hydraulic Simulation in Ras Mapper for the Confluence Branch of the Silala in HEC-RAS

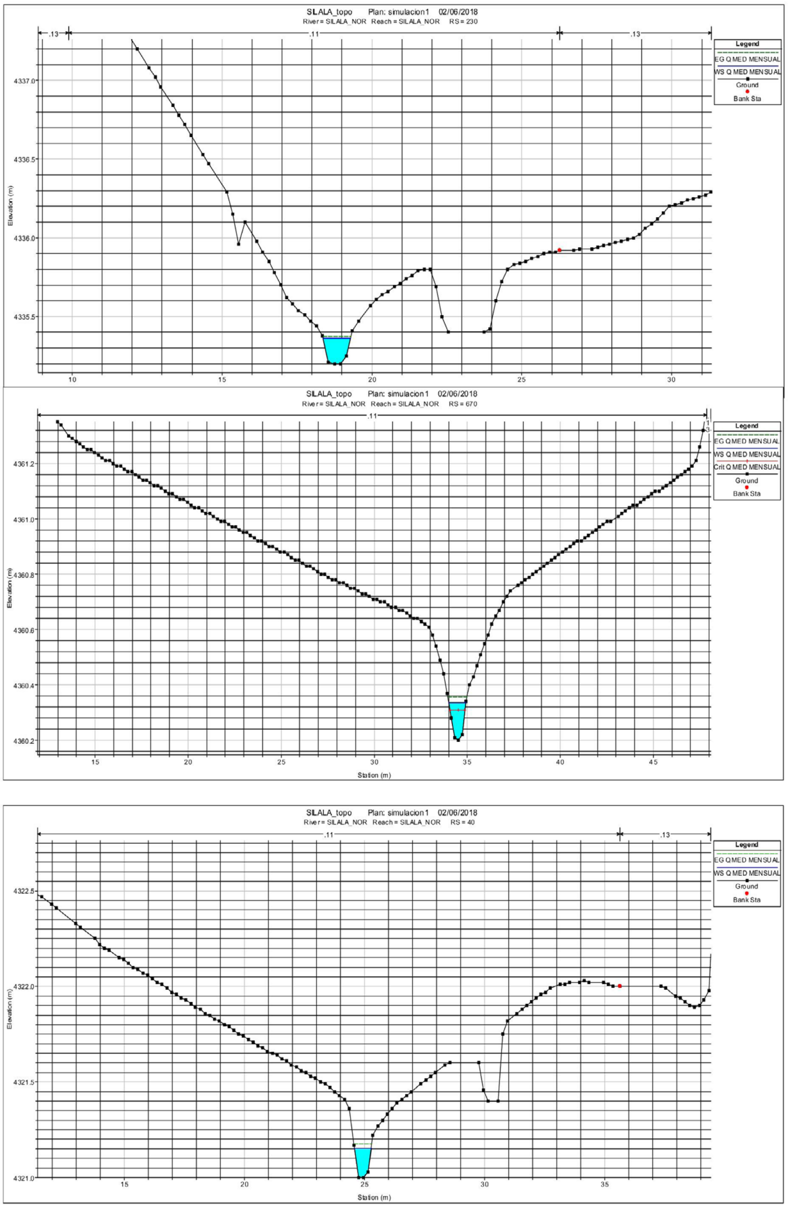


Figure 115. Cross-sections of the North Branch of the Silala in HEC-RAS

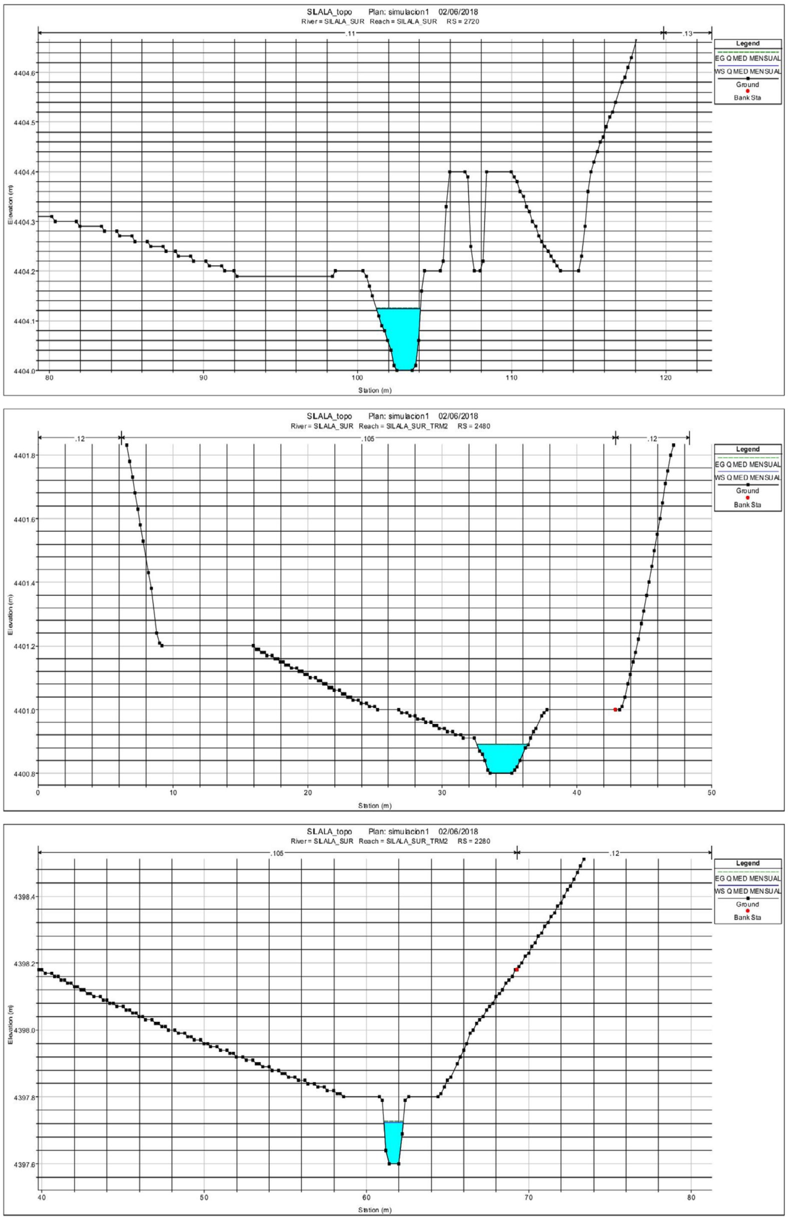


Figure 116. Cross-sections of the South Branch of the Silala in HEC-RAS

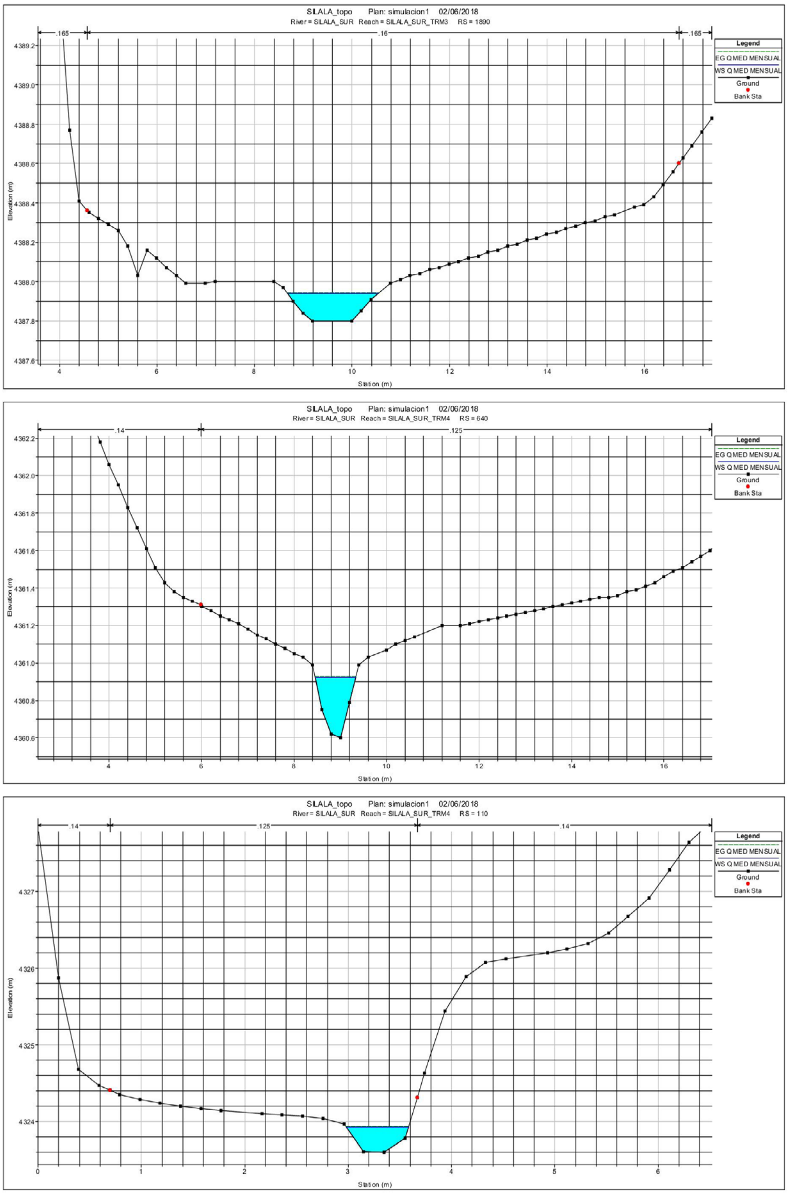


Figure 117. Cross-sections of the South Branch of the Silala in HEC-RAS (Continued)

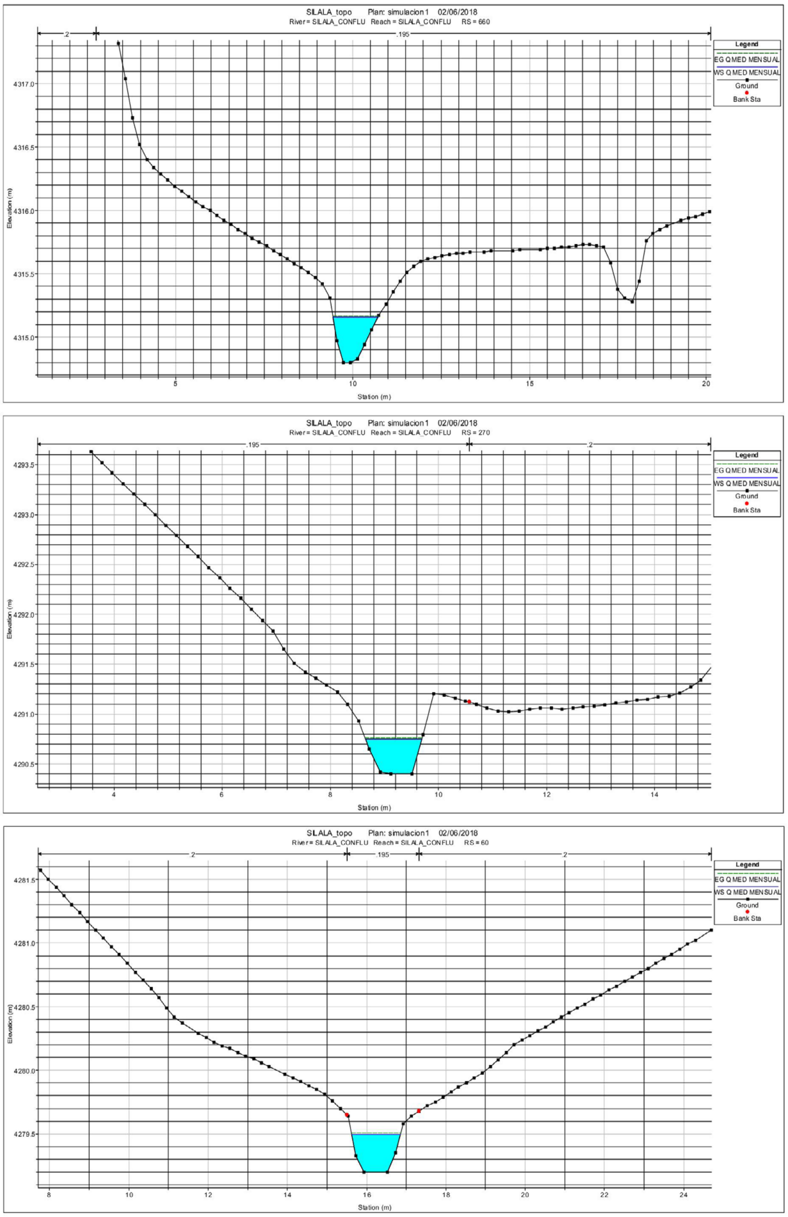


Figure 118. Cross-sections of the Confluence Branch of the Silala in HEC-RAS

SIMULACIÓN HIDRÁULICA DE FLUJO SUPERFICIAL DELSISTEMA SILALA

River	Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
SILALA	SILALA_SUR	2860	Q MED	0.03	4406.2	4406.2	4406.2	4406.2	0.474	0.28	0.10	8.02	0.81
SILALA	SILALA_SUR	2850	Q MED	0.03	4405.6	4405.9		4405.9	0.001	0.08	0.34	1.75	0.06
SILALA	SILALA_SUR	2840	Q MED	0.03	4405.8	4405.9		4405.9	0.007	0.09	0.28	4.95	0.12
SILALA	SILALA_SUR	2830	Q MED	0.03	4405.6	4405.6	4405.6	4405.6	0.613	0.43	0.06	3.14	1.00
SILALA	SILALA_SUR	2820	Q MED	0.03	4405.4	4405.5		4405.5	0.001	0.03	0.85	19.43	0.05
SILALA	SILALA_SUR	2810	Q MED	0.03	4405.4	4405.4		4405.4	0.007	0.05	0.54	26.93	0.11
SILALA	SILALA_SUR	2800	Q MED	0.03	4405.2	4405.2	4405.2	4405.2	0.147	0.23	0.11	5.20	0.50
SILALA	SILALA_SUR	2790	Q MED	0.03	4404.8	4404.9		4404.9	0.007	0.13	0.20	2.03	0.13
SILALA	SILALA_SUR	2780	Q MED	0.03	4404.8	4404.9		4404.9	0.012	0.10	0.26	6.20	0.16
SILALA	SILALA_SUR	2770	Q MED	0.03	4404.6	4404.7		4404.7	0.009	0.19	0.14	1.35	0.19
SILALA	SILALA_SUR	2760	Q MED	0.03	4404.4	4404.5	4404.5	4404.6	0.074	0.27	0.10	2.58	0.45
SILALA	SILALA_SUR	2750	Q MED	0.03	4404.4	4404.5		4404.5	0.003	0.07	0.40	8.73	0.10
SILALA	SILALA_SUR	2740	Q MED	0.03	4404.2	4404.4		4404.4	0.006	0.07	0.38	12.63	0.13
SILALA	SILALA_SUR	2730	Q MED	0.03	4404.2	4404.2		4404.2	0.110	0.24	0.11	5.12	0.51
SILALA	SILALA_SUR	2720	Q MED	0.03	4404.0	4404.1		4404.1	0.003	0.10	0.25	2.87	0.11
SILALA	SILALA_SUR	2710	Q MED	0.03	4404.0	4404.0	4404.0	4404.0	0.379	0.32	0.08	5.84	0.88
SILALA	SILALA_SUR	2700	Q MED	0.03	4403.8	4403.9		4403.9	0.003	0.07	0.39	7.89	0.10
SILALA	SILALA_SUR	2690	Q MED	0.03	4403.8	4403.8		4403.8	0.010	0.07	0.38	18.71	0.15
SILALA	SILALA_SUR	2680	Q MED	0.03	4403.6	4403.8		4403.8	0.004	0.14	0.19	1.33	0.12
SILALA	SILALA_SUR	2670	Q MED	0.03	4403.6	4403.7		4403.7	0.101	0.37	0.07	1.55	0.55
SILALA	SILALA_SUR	2660	Q MED	0.03	4403.4	4403.6		4403.6	0.003	0.13	0.20	1.60	0.12
SILALA	SILALA_SUR	2650	Q MED	0.03	4403.4	4403.5		4403.5	0.111	0.37	0.07	1.64	0.57
SILALA	SILALA_SUR	2640	Q MED	0.03	4403.2	4403.3		4403.3	0.004	0.12	0.21	2.04	0.12
SILALA	SILALA_SUR	2630	Q MED	0.03	4403.1	4403.3		4403.3	0.039	0.26	0.10	1.75	0.34
SILALA	SILALA_SUR	2620	Q MED	0.03	4403.0	4403.2		4403.2	0.004	0.14	0.18	1.44	0.13
SILALA	SILALA_SUR	2610	Q MED	0.03	4403.0	4403.1		4403.1	0.010	0.16	0.16	2.04	0.18
SILALA	SILALA_SUR	2600	Q MED	0.03	4402.8	4402.9		4402.9	0.117	0.37	0.07	1.69	0.58
SILALA	SILALA_SUR	2590	Q MED	0.03	4402.6	4402.8		4402.8	0.003	0.10	0.27	3.18	0.10
SILALA	SILALA_SUR	2580	Q MED	0.03	4402.6	4402.7		4402.7	0.003	0.12	0.22	1.92	0.11
SILALA	SILALA_SUR	2570	Q MED	0.03	4402.6	4402.7		4402.7	0.011	0.14	0.18	3.04	0.18
SILALA	SILALA_SUR	2560	Q MED	0.03	4402.4	4402.4		4402.4	0.108	0.28	0.09	3.25	0.53
SILALA	SILALA_SUR	2550	Q MED	0.03	4402.1	4402.2		4402.2	0.011	0.14	0.19	3.29	0.19
SILALA	SILALA_SUR	2540	Q MED	0.03	4402.0	4402.1		4402.1	0.005	0.12	0.22	2.76	0.14
SILALA	SILALA_SUR	2530	Q MED	0.03	4402.0	4402.0		4402.0	0.122	0.27	0.10	4.06	0.54
SILALA	SILALA_SUR_TRM2	2520	Q MED	0.03	4401.6	4401.8	4401.7	4401.8	0.009	0.11	0.32	7.09	0.16
SILALA	SILALA_SUR_TRM2	2510	Q MED	0.03	4401.5	4401.5	4401.5	4401.5	0.219	0.49	0.07	1.93	0.82
SILALA	SILALA_SUR_TRM2	2500	Q MED	0.03	4401.2	4401.3		4401.3	0.006	0.09	0.36	8.51	0.14
SILALA	SILALA_SUR_TRM2	2490	Q MED	0.03	4401.1	4401.1	4401.1	4401.1	0.173	0.29	0.12	5.77	0.66
SILALA	SILALA_SUR_TRM2	2480	Q MED	0.03	4400.8	4400.9		4400.9	0.008	0.14	0.25	3.80	0.17
SILALA	SILALA_SUR_TRM2	2470	Q MED	0.03	4400.6	4400.6	4400.6	4400.7	0.251	0.49	0.07	2.07	0.86
SILALA	SILALA_SUR_TRM2	2460	Q MED	0.03	4400.3	4400.4		4400.4	0.007	0.12	0.29	5.31	0.16
SILALA	SILALA_SUR_TRM2	2450	Q MED	0.03	4400.2	4400.3		4400.3	0.053	0.24	0.14	4.02	0.40
SILALA	SILALA_SUR_TRM2	2440	Q MED	0.03	4399.8	4399.9	4399.9	4399.9	0.024	0.25	0.14	1.97	0.30
SILALA	SILALA_SUR_TRM2	2430	Q MED	0.03	4399.6	4399.7		4399.7	0.028	0.19	0.18	4.52	0.30
SILALA	SILALA_SUR_TRM2	2420	Q MED	0.03	4399.4	4399.6		4399.6	0.001	0.05	0.65	6.90	0.05
SILALA	SILALA_SUR_TRM2	2410	Q MED	0.03	4399.6	4399.6	4399.6	4399.6	0.525	0.28	0.12	14.43	0.99
SILALA	SILALA_SUR_TRM2	2400	Q MED	0.03	4399.2	4399.3		4399.3	0.003	0.07	0.51	9.99	0.09
SILALA	SILALA_SUR_TRM2	2390	Q MED	0.03	4399.2	4399.2	4399.2	4399.2	0.289	0.30	0.11	8.31	0.80
SILALA	SILALA_SUR_TRM2	2380	Q MED	0.03	4398.9	4399.0		4399.0	0.007	0.10	0.34	7.85	0.15
SILALA	SILALA_SUR_TRM2	2370	Q MED	0.03	4398.8	4398.8		4398.8	0.026	0.15	0.22	7.03	0.27
SILALA	SILALA_SUR_TRM2	2360	Q MED	0.03	4398.7	4398.8		4398.8	0.005	0.08	0.44	11.65	0.13
SILALA	SILALA_SUR_TRM2	2350	Q MED	0.03	4398.6	4398.6		4398.6	0.071	0.16	0.21	13.25	0.41
SILALA	SILALA_SUR_TRM2	2340	Q MED	0.03	4398.5	4398.5		4398.5	0.004	0.07	0.46	11.12	0.11
SILALA	SILALA_SUR_TRM2	2330	Q MED	0.03	4398.4	4398.4		4398.4	0.035	0.14	0.25	11.47	0.30
SILALA	SILALA_SUR_TRM2	2320	Q MED	0.03	4398.2	4398.3		4398.3	0.005	0.09	0.37	7.79	0.13
SILALA	SILALA_SUR_TRM2	2310	Q MED	0.03	4398.0	4398.2		4398.2	0.020	0.11	0.30	11.82	0.23
SILALA	SILALA_SUR_TRM2	2300	Q MED	0.03	4398.0	4398.0		4398.0	0.018	0.12	0.28	9.32	0.23
SILALA	SILALA_SUR_TRM2	2290	Q MED	0.03	4397.8	4397.9		4397.9	0.012	0.14	0.24	4.63	0.20
SILALA	SILALA_SUR_TRM2	2280	Q MED	0.03	4397.6	4397.7		4397.7	0.021	0.29	0.12	1.18	0.29
SILALA	SILALA_SUR_TRM2	2270	Q MED	0.03	4397.4	4397.5		4397.5	0.022	0.28	0.12	1.39	0.30
SILALA	SILALA_SUR_TRM2	2260	Q MED	0.03	4397.2	4397.3		4397.3	0.014	0.23	0.14	1.46	0.24
SILALA	SILALA_SUR_TRM2	2250	Q MED	0.03	4397.0	4397.2		4397.2	0.023	0.27	0.12	1.46	0.30
SILALA	SILALA_SUR_TRM2	2240	Q MED	0.03	4396.8	4397.0	4396.9	4397.0	0.012	0.10	0.33	10.05	0.18
SILALA	SILALA_SUR_TRM2	2230	Q MED	0.03	4396.6	4396.6	4396.6	4396.7	0.381	0.52	0.06	2.44	1.02
SILALA	SILALA_SUR_TRM2	2220	Q MED	0.03	4396.2	4396.4		4396.4	0.003	0.10	0.34	4.16	0.11
SILALA	SILALA_SUR_TRM2	2210	Q MED	0.03	4396.2	4396.3	4396.3	4396.3	0.012	0.12	0.28	7.24	0.20
SILALA	SILALA_SUR_TRM2	2200	Q MED	0.03	4396.0	4396.0	4396.0	4396.0	0.164	0.33	0.10	4.20	0.66
SILALA	SILALA_SUR_TRM2	2190	Q MED	0.03	4395.6	4395.7		4395.7	0.006	0.08	0.41	10.03	0.13
SILALA	SILALA_SUR_TRM2	2180	Q MED	0.03	4395.4	4395.5	4395.5	4395.5	0.299	0.61	0.06	1.36	0.97
SILALA	SILALA_SUR_TRM2	2170	Q MED	0.03	4395.0	4395.1		4395.1	0.004	0.10	0.35	5.24	0.12

SIMULACIÓN HIDRÁULICA DE FLUJO SUPERFICIAL DELSISTEMA SILALA

River	Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
SILALA	SILALA_SUR_TRM2	2160	Q MED	0.03	4395.0	4395.0		4395.0	0.014	0.12	0.29	8.73	0.20
SILALA	SILALA_SUR_TRM2	2150	Q MED	0.03	4394.6	4394.6	4394.6	4394.6	0.475	0.43	0.08	4.80	1.06
SILALA	SILALA_SUR_TRM2	2140	Q MED	0.03	4394.4	4394.5		4394.5	0.002	0.07	0.51	7.10	0.08
SILALA	SILALA_SUR_TRM2	2130	Q MED	0.03	4394.4	4394.4		4394.4	0.014	0.13	0.27	7.06	0.21
SILALA	SILALA_SUR_TRM2	2120	Q MED	0.03	4394.0	4394.1		4394.1	0.111	0.39	0.09	2.01	0.60
SILALA	SILALA_SUR_TRM2	2110	Q MED	0.03	4393.6	4393.7		4393.7	0.016	0.24	0.14	1.60	0.26
SILALA	SILALA_SUR_TRM2	2100	Q MED	0.03	4393.4	4393.5		4393.5	0.036	0.28	0.12	1.93	0.36
SILALA	SILALA_SUR_TRM2	2090	Q MED	0.03	4393.2	4393.3	4393.3	4393.3	0.009	0.17	0.21	2.82	0.19
SILALA	SILALA_SUR_TRM2	2080	Q MED	0.03	4393.0	4393.1		4393.1	0.157	0.46	0.07	1.68	0.71
SILALA	SILALA_SUR_TRM2	2070	Q MED	0.03	4392.6	4392.7	4392.6	4392.7	0.020	0.18	0.19	3.82	0.26
SILALA	SILALA_SUR_TRM2	2060	Q MED	0.03	4392.4	4392.4	4392.4	4392.4	0.023	0.15	0.22	6.35	0.26
SILALA	SILALA_SUR_TRM2	2050	Q MED	0.03	4392.0	4392.1		4392.1	0.054	0.18	0.19	8.26	0.38
SILALA	SILALA_SUR_TRM2	2040	Q MED	0.03	4391.5	4391.5		4391.5	0.153	0.43	0.08	2.04	0.69
SILALA	SILALA_SUR_TRM2	2030	Q MED	0.03	4391.0	4391.1		4391.1	0.020	0.24	0.14	1.73	0.28
SILALA	SILALA_SUR_TRM2	2020	Q MED	0.03	4390.8	4390.9		4390.9	0.027	0.27	0.13	1.77	0.32
SILALA	SILALA_SUR_TRM3	2010	Q MED	0.03	4390.6	4390.8		4390.8	0.008	0.13	0.26	2.25	0.12
SILALA	SILALA_SUR_TRM3	2000	Q MED	0.03	4390.6	4390.6		4390.6	0.018	0.09	0.36	9.58	0.16
SILALA	SILALA_SUR_TRM3	1990	Q MED	0.03	4390.4	4390.4		4390.4	0.024	0.10	0.34	9.93	0.18
SILALA	SILALA_SUR_TRM3	1980	Q MED	0.03	4390.2	4390.2	4390.2	4390.2	0.015	0.10	0.36	8.24	0.15
SILALA	SILALA_SUR_TRM3	1970	Q MED	0.03	4390.0	4390.0		4390.0	0.027	0.12	0.29	7.79	0.19
SILALA	SILALA_SUR_TRM3	1960	Q MED	0.03	4389.7	4389.7		4389.7	0.039	0.16	0.21	4.46	0.24
SILALA	SILALA_SUR_TRM3	1950	Q MED	0.03	4389.4	4389.5		4389.5	0.014	0.13	0.27	3.79	0.15
SILALA	SILALA_SUR_TRM3	1940	Q MED	0.03	4389.2	4389.3		4389.3	0.071	0.22	0.16	3.31	0.32
SILALA	SILALA_SUR_TRM3	1930	Q MED	0.03	4388.9	4389.0		4389.0	0.012	0.11	0.31	4.84	0.14
SILALA	SILALA_SUR_TRM3	1920	Q MED	0.03	4388.6	4388.7		4388.8	0.087	0.32	0.11	1.49	0.37
SILALA	SILALA_SUR_TRM3	1910	Q MED	0.03	4388.4	4388.5		4388.5	0.011	0.13	0.25	2.71	0.14
SILALA	SILALA_SUR_TRM3	1900	Q MED	0.03	4388.2	4388.3		4388.3	0.077	0.26	0.13	2.24	0.34
SILALA	SILALA_SUR_TRM3	1890	Q MED	0.03	4387.8	4387.9		4387.9	0.018	0.18	0.19	1.86	0.18
SILALA	SILALA_SUR_TRM3	1880	Q MED	0.03	4387.6	4387.7		4387.7	0.059	0.19	0.18	4.13	0.29
SILALA	SILALA_SUR_TRM3	1870	Q MED	0.03	4387.2	4387.3		4387.3	0.022	0.16	0.22	2.99	0.19
SILALA	SILALA_SUR_TRM3	1860	Q MED	0.03	4387.0	4387.1		4387.1	0.013	0.13	0.26	3.34	0.15
SILALA	SILALA_SUR_TRM3	1850	Q MED	0.03	4386.8	4386.9		4386.9	0.050	0.19	0.18	3.63	0.27
SILALA	SILALA_SUR_TRM3	1840	Q MED	0.03	4386.6	4386.8		4386.8	0.006	0.11	0.31	2.93	0.11
SILALA	SILALA_SUR_TRM3	1830	Q MED	0.03	4386.5	4386.6	4386.6	4386.6	0.744	0.41	0.08	4.04	0.90
SILALA	SILALA_SUR_TRM3	1820	Q MED	0.03	4386.2	4386.3		4386.3	0.008	0.08	0.40	7.07	0.11
SILALA	SILALA_SUR_TRM3	1810	Q MED	0.03	4386.0	4386.1		4386.1	0.069	0.21	0.17	3.66	0.31
SILALA	SILALA_SUR_TRM3	1800	Q MED	0.03	4385.8	4385.9		4385.9	0.010	0.09	0.40	7.68	0.12
SILALA	SILALA_SUR_TRM3	1790	Q MED	0.03	4385.6	4385.7		4385.7	0.111	0.21	0.16	4.80	0.38
SILALA	SILALA_SUR_TRM3	1780	Q MED	0.03	4385.4	4385.5		4385.5	0.009	0.08	0.41	7.57	0.11
SILALA	SILALA_SUR_TRM3	1770	Q MED	0.03	4385.2	4385.3		4385.3	0.037	0.21	0.16	2.23	0.25
SILALA	SILALA_SUR_TRM3	1760	Q MED	0.03	4384.8	4385.1		4385.1	0.011	0.17	0.21	1.50	0.14
SILALA	SILALA_SUR_TRM3	1750	Q MED	0.03	4384.8	4384.9		4384.9	0.045	0.27	0.13	1.29	0.28
SILALA	SILALA_SUR_TRM3	1740	Q MED	0.03	4384.6	4384.8		4384.8	0.008	0.14	0.24	1.66	0.12
SILALA	SILALA_SUR_TRM3	1730	Q MED	0.03	4384.6	4384.7		4384.7	0.013	0.09	0.40	9.58	0.13
SILALA	SILALA_SUR_TRM3	1720	Q MED	0.03	4384.4	4384.5		4384.5	0.022	0.09	0.36	11.45	0.17
SILALA	SILALA_SUR_TRM3	1710	Q MED	0.03	4384.2	4384.3		4384.3	0.012	0.16	0.22	1.88	0.15
SILALA	SILALA_SUR_TRM3	1700	Q MED	0.03	4384.1	4384.2		4384.2	0.024	0.12	0.29	7.03	0.18
SILALA	SILALA_SUR_TRM3	1690	Q MED	0.03	4384.0	4384.1		4384.1	0.008	0.07	0.47	10.27	0.11
SILALA	SILALA_SUR_TRM3	1680	Q MED	0.03	4383.8	4383.8	4383.8	4383.8	0.256	0.25	0.14	6.34	0.53
SILALA	SILALA_SUR_TRM3	1670	Q MED	0.03	4383.4	4383.7		4383.7	0.000	0.03	1.25	8.91	0.02
SILALA	SILALA_SUR_TRM3	1660	Q MED	0.03	4383.6	4383.7		4383.7	0.005	0.08	0.42	5.75	0.09
SILALA	SILALA_SUR_TRM3	1650	Q MED	0.03	4383.6	4383.6		4383.6	0.007	0.06	0.58	15.66	0.10
SILALA	SILALA_SUR_TRM3	1640	Q MED	0.03	4383.4	4383.4	4383.4	4383.4	0.883	0.40	0.09	4.83	0.96
SILALA	SILALA_SUR_TRM3	1630	Q MED	0.03	4382.9	4383.1		4383.1	0.000	0.02	1.94	12.26	0.01
SILALA	SILALA_SUR_TRM3	1620	Q MED	0.03	4383.0	4383.1		4383.1	0.001	0.04	0.90	7.38	0.03
SILALA	SILALA_SUR_TRM3	1610	Q MED	0.03	4383.0	4383.1		4383.1	0.003	0.07	0.46	4.39	0.07
SILALA	SILALA_SUR_TRM3	1600	Q MED	0.03	4383.0	4383.0	4383.0	4383.0	0.894	0.31	0.11	9.19	0.90
SILALA	SILALA_SUR_TRM3	1590	Q MED	0.03	4382.8	4382.9		4382.9	0.003	0.05	0.74	13.43	0.06
SILALA	SILALA_SUR_TRM3	1580	Q MED	0.03	4382.7	4382.8	4382.8	4382.8	0.007	0.05	0.65	20.31	0.09
SILALA	SILALA_SUR_TRM3	1570	Q MED	0.03	4382.6	4382.6		4382.6	0.282	0.19	0.18	13.22	0.52
SILALA	SILALA_SUR_TRM3	1560	Q MED	0.03	4382.4	4382.5		4382.5	0.004	0.07	0.51	7.81	0.08
SILALA	SILALA_SUR_TRM3	1550	Q MED	0.03	4382.2	4382.4		4382.4	0.006	0.06	0.59	14.67	0.09
SILALA	SILALA_SUR_TRM3	1540	Q MED	0.03	4382.2	4382.3		4382.3	0.030	0.22	0.16	1.74	0.23
SILALA	SILALA_SUR_TRM3	1530	Q MED	0.03	4382.0	4382.1		4382.1	0.011	0.15	0.22	1.83	0.14
SILALA	SILALA_SUR_TRM3	1520	Q MED	0.03	4382.0	4382.1		4382.1	0.007	0.06	0.55	12.91	0.10
SILALA	SILALA_SUR_TRM3	1510	Q MED	0.03	4381.8	4381.9		4381.9	0.026	0.22	0.16	1.52	0.22
SILALA	SILALA_SUR_TRM3	1500	Q MED	0.03	4381.6	4381.8		4381.8	0.008	0.13	0.27	2.55	0.12
SILALA	SILALA_SUR_TRM3	1490	Q MED	0.03	4381.6	4381.7	4381.6	4381.7	0.009	0.12	0.29	3.11	0.12
SILALA	SILALA_SUR_TRM3	1480	Q MED	0.03	4381.4	4381.4	4381.4	4381.4	0.614	0.43	0.08	3.11	0.85
SILALA	SILALA_SUR_TRM3	1470	Q MED	0.03	4381.0	4381.1		4381.1	0.002	0.07	0.47	3.75	0.07

SIMULACIÓN HIDRÁULICA DE FLUJO SUPERFICIAL DELSISTEMA SILALA													
River	Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
SILALA	SILALA_SUR_TRM3	1460	Q MED	0.03	4381.0	4381.1		4381.1	0.008	0.11	0.32	3.79	0.12
SILALA	SILALA_SUR_TRM3	1450	Q MED	0.03	4380.8	4380.9		4380.9	0.154	0.31	0.11	2.39	0.47
SILALA	SILALA_SUR_TRM3	1440	Q MED	0.03	4380.6	4380.8		4380.8	0.002	0.07	0.51	4.89	0.07
SILALA	SILALA_SUR_TRM3	1430	Q MED	0.03	4380.6	4380.8		4380.8	0.003	0.09	0.37	2.44	0.08
SILALA	SILALA_SUR_TRM3	1420	Q MED	0.03	4380.6	4380.6	4380.6	4380.7	0.650	0.58	0.06	1.52	0.93
SILALA	SILALA_SUR_TRM3	1410	Q MED	0.03	4380.2	4380.5		4380.5	0.004	0.13	0.26	1.34	0.09
SILALA	SILALA_SUR_TRM3	1400	Q MED	0.03	4380.2	4380.4		4380.4	0.012	0.10	0.34	5.96	0.13
SILALA	SILALA_SUR_TRM3	1390	Q MED	0.03	4380.2	4380.3		4380.3	0.016	0.10	0.35	8.05	0.15
SILALA	SILALA_SUR_TRM3	1380	Q MED	0.03	4380.0	4380.1		4380.1	0.021	0.18	0.19	2.04	0.19
SILALA	SILALA_SUR_TRM3	1370	Q MED	0.03	4379.7	4379.9		4379.9	0.025	0.19	0.18	1.96	0.20
SILALA	SILALA_SUR_TRM3	1360	Q MED	0.03	4379.6	4379.8		4379.8	0.008	0.14	0.24	1.86	0.13
SILALA	SILALA_SUR_TRM3	1350	Q MED	0.03	4379.4	4379.6		4379.6	0.065	0.28	0.12	1.54	0.33
SILALA	SILALA_SUR_TRM3	1340	Q MED	0.03	4379.2	4379.4		4379.4	0.007	0.13	0.25	1.96	0.12
SILALA	SILALA_SUR_TRM3	1330	Q MED	0.03	4379.2	4379.3		4379.3	0.034	0.16	0.22	4.35	0.22
SILALA	SILALA_SUR_TRM3	1320	Q MED	0.03	4378.9	4379.0		4379.0	0.017	0.15	0.23	3.01	0.17
SILALA	SILALA_SUR_TRM3	1310	Q MED	0.03	4378.8	4378.9		4378.9	0.008	0.11	0.30	3.17	0.12
SILALA	SILALA_SUR_TRM3	1300	Q MED	0.03	4378.6	4378.9		4378.9	0.000	0.05	0.75	3.59	0.03
SILALA	SILALA_SUR_TRM3	1290	Q MED	0.03	4378.8	4378.9		4378.9	0.010	0.12	0.29	3.51	0.13
SILALA	SILALA_SUR_TRM3	1280	Q MED	0.03	4378.6	4378.7		4378.7	0.088	0.27	0.12	2.16	0.36
SILALA	SILALA_SUR_TRM3	1270	Q MED	0.03	4378.4	4378.6		4378.6	0.004	0.10	0.33	2.36	0.09
SILALA	SILALA_SUR_TRM3	1260	Q MED	0.03	4378.4	4378.5		4378.5	0.027	0.17	0.20	2.98	0.21
SILALA	SILALA_SUR_TRM3	1250	Q MED	0.03	4378.2	4378.3		4378.3	0.012	0.13	0.26	3.05	0.15
SILALA	SILALA_SUR_TRM3	1240	Q MED	0.03	4378.0	4378.1		4378.1	0.044	0.20	0.17	2.72	0.26
SILALA	SILALA_SUR_TRM3	1230	Q MED	0.03	4377.8	4378.0		4378.0	0.005	0.09	0.40	4.80	0.09
SILALA	SILALA_SUR_TRM3	1220	Q MED	0.03	4377.8	4377.9		4377.9	0.054	0.18	0.19	4.50	0.27
SILALA	SILALA_SUR_TRM3	1210	Q MED	0.03	4377.6	4377.7		4377.7	0.005	0.09	0.38	3.83	0.09
SILALA	SILALA_SUR_TRM3	1200	Q MED	0.03	4377.6	4377.7		4377.7	0.008	0.09	0.36	5.18	0.11
SILALA	SILALA_SUR_TRM3	1190	Q MED	0.03	4377.4	4377.4	4377.4	4377.4	0.421	0.36	0.10	3.65	0.71
SILALA	SILALA_SUR_TRM3	1180	Q MED	0.03	4377.2	4377.3		4377.3	0.003	0.08	0.45	3.89	0.07
SILALA	SILALA_SUR_TRM3	1170	Q MED	0.03	4377.2	4377.2	4377.2	4377.2	0.551	0.40	0.09	3.46	0.80
SILALA	SILALA_SUR_TRM3	1160	Q MED	0.03	4377.0	4377.1		4377.1	0.003	0.08	0.44	3.66	0.07
SILALA	SILALA_SUR_TRM3	1150	Q MED	0.03	4377.0	4377.1		4377.1	0.077	0.21	0.16	3.79	0.33
SILALA	SILALA_SUR_TRM3	1140	Q MED	0.03	4376.8	4376.9		4376.9	0.004	0.09	0.38	3.67	0.09
SILALA	SILALA_SUR_TRM3	1130	Q MED	0.03	4376.8	4376.9		4376.9	0.023	0.11	0.32	8.72	0.17
SILALA	SILALA_SUR_TRM3	1120	Q MED	0.03	4376.3	4376.7		4376.7	0.007	0.07	0.50	9.21	0.09
SILALA	SILALA_SUR_TRM3	1110	Q MED	0.03	4376.5	4376.6		4376.6	0.172	0.20	0.17	8.23	0.44
SILALA	SILALA_SUR_TRM3	1100	Q MED	0.03	4376.4	4376.5		4376.5	0.003	0.05	0.69	12.00	0.07
SILALA	SILALA_SUR_TRM3	1090	Q MED	0.03	4376.4	4376.4		4376.4	0.028	0.05	0.36	16.51	0.15
SILALA	SILALA_SUR_TRM3	1080	Q MED	0.03	4376.2	4376.3		4376.3	0.011	0.08	0.40	8.81	0.13
SILALA	SILALA_SUR_TRM3	1070	Q MED	0.03	4376.0	4376.1		4376.1	0.015	0.17	0.21	1.92	0.16
SILALA	SILALA_SUR_TRM3	1060	Q MED	0.03	4375.8	4376.0		4376.0	0.006	0.08	0.44	6.29	0.09
SILALA	SILALA_SUR_TRM3	1050	Q MED	0.03	4375.8	4376.0		4376.0	0.015	0.16	0.21	1.98	0.16
SILALA	SILALA_SUR_TRM3	1040	Q MED	0.03	4375.6	4375.8	4375.7	4375.8	0.009	0.08	0.41	7.80	0.11
SILALA	SILALA_SUR_TRM3	1030	Q MED	0.03	4375.5	4375.6		4375.6	0.261	0.48	0.07	1.18	0.63
SILALA	SILALA_SUR_TRM3	1020	Q MED	0.03	4375.4	4375.5		4375.5	0.003	0.07	0.48	5.35	0.08
SILALA	SILALA_SUR_TRM4	1010	Q MED	0.05	4375.2	4375.3		4375.3	0.107	0.37	0.14	1.80	0.42
SILALA	SILALA_SUR_TRM4	1000	Q MED	0.05	4375.0	4375.1		4375.1	0.010	0.19	0.28	2.38	0.18
SILALA	SILALA_SUR_TRM4	990	Q MED	0.05	4374.9	4375.0		4375.0	0.023	0.16	0.32	6.51	0.23
SILALA	SILALA_SUR_TRM4	980	Q MED	0.05	4374.6	4374.7		4374.7	0.033	0.26	0.20	2.56	0.30
SILALA	SILALA_SUR_TRM4	970	Q MED	0.05	4374.4	4374.6		4374.6	0.006	0.16	0.32	2.48	0.14
SILALA	SILALA_SUR_TRM4	960	Q MED	0.05	4374.4	4374.5		4374.5	0.014	0.16	0.32	4.35	0.19
SILALA	SILALA_SUR_TRM4	950	Q MED	0.05	4374.2	4374.3		4374.3	0.030	0.24	0.22	3.00	0.28
SILALA	SILALA_SUR_TRM4	940	Q MED	0.05	4373.9	4374.1		4374.1	0.016	0.19	0.28	3.56	0.21
SILALA	SILALA_SUR_TRM4	930	Q MED	0.05	4373.8	4374.0		4374.0	0.006	0.16	0.32	2.24	0.13
SILALA	SILALA_SUR_TRM4	920	Q MED	0.05	4373.8	4373.9		4373.9	0.020	0.24	0.22	2.25	0.24
SILALA	SILALA_SUR_TRM4	910	Q MED	0.05	4373.6	4373.8		4373.8	0.010	0.19	0.27	2.35	0.18
SILALA	SILALA_SUR_TRM4	900	Q MED	0.05	4373.5	4373.6		4373.6	0.019	0.18	0.29	4.45	0.22
SILALA	SILALA_SUR_TRM4	890	Q MED	0.05	4373.4	4373.5		4373.5	0.010	0.13	0.41	6.37	0.16
SILALA	SILALA_SUR_TRM4	880	Q MED	0.05	4373.2	4373.3		4373.3	0.031	0.31	0.17	1.50	0.30
SILALA	SILALA_SUR_TRM4	870	Q MED	0.05	4372.9	4373.2		4373.2	0.006	0.17	0.31	1.84	0.13
SILALA	SILALA_SUR_TRM4	860	Q MED	0.05	4373.0	4373.1		4373.1	0.018	0.20	0.26	3.10	0.22
SILALA	SILALA_SUR_TRM4	850	Q MED	0.05	4372.6	4372.8		4372.8	0.115	0.43	0.12	1.83	0.54
SILALA	SILALA_SUR_TRM4	840	Q MED	0.05	4372.0	4372.1		4372.1	0.044	0.27	0.19	2.84	0.34
SILALA	SILALA_SUR_TRM4	830	Q MED	0.05	4370.8	4371.0	4371.0	4371.1	0.508	0.77	0.07	1.13	1.01
SILALA	SILALA_SUR_TRM4	820	Q MED	0.05	4370.2	4370.3	4370.2	4370.3	0.023	0.20	0.26	3.90	0.25
SILALA	SILALA_SUR_TRM4	810	Q MED	0.05	4369.8	4370.0		4370.0	0.048	0.35	0.15	1.60	0.37
SILALA	SILALA_SUR_TRM4	800	Q MED	0.05	4368.8	4368.9	4368.9	4368.9	0.409	0.74	0.07	1.24	1.00
SILALA	SILALA_SUR_TRM4	790	Q MED	0.05	4367.7	4367.7	4367.7	4367.8	0.394	0.72	0.08	1.50	0.98
SILALA	SILALA_SUR_TRM4	780	Q MED	0.05	4363.7	4363.8	4363.8	4363.8	0.416	0.65	0.08	1.79	0.98
SILALA	SILALA_SUR_TRM4	770	Q MED	0.05	4362.9	4363.2		4363.2	0.000	0.04	1.48	6.58	0.02

SIMULACIÓN HIDRÁULICA DE FLUJO SUPERFICIAL DELSISTEMA SILALA													
River	Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
SILALA	SILALA_SUR_TRM4	760	Q MED	0.05	4363.0	4363.2	4363.1	4363.2	0.010	0.15	0.34	3.99	0.17
SILALA	SILALA_SUR_TRM4	750	Q MED	0.05	4362.8	4362.9	4362.9	4362.9	0.389	0.72	0.07	1.28	0.98
SILALA	SILALA_SUR_TRM4	740	Q MED	0.05	4362.4	4362.7		4362.7	0.001	0.06	0.83	5.99	0.05
SILALA	SILALA_SUR_TRM4	730	Q MED	0.05	4362.6	4362.7		4362.7	0.021	0.18	0.30	5.06	0.23
SILALA	SILALA_SUR_TRM4	720	Q MED	0.05	4362.4	4362.5		4362.5	0.019	0.16	0.33	6.15	0.22
SILALA	SILALA_SUR_TRM4	710	Q MED	0.05	4362.3	4362.4	4362.3	4362.4	0.008	0.10	0.53	10.19	0.14
SILALA	SILALA_SUR_TRM4	700	Q MED	0.05	4362.2	4362.2		4362.2	0.036	0.15	0.36	12.15	0.27
SILALA	SILALA_SUR_TRM4	690	Q MED	0.05	4362.0	4362.1	4362.0	4362.1	0.011	0.11	0.48	10.23	0.16
SILALA	SILALA_SUR_TRM4	680	Q MED	0.05	4361.9	4361.9		4361.9	0.011	0.12	0.43	7.69	0.17
SILALA	SILALA_SUR_TRM4	670	Q MED	0.05	4361.6	4361.7		4361.7	0.141	0.36	0.15	3.56	0.56
SILALA	SILALA_SUR_TRM4	660	Q MED	0.05	4361.2	4361.3		4361.3	0.016	0.19	0.28	3.37	0.21
SILALA	SILALA_SUR_TRM4	650	Q MED	0.05	4361.0	4361.1		4361.1	0.024	0.23	0.23	2.92	0.26
SILALA	SILALA_SUR_TRM4	640	Q MED	0.05	4360.6	4360.9		4360.9	0.016	0.29	0.18	0.88	0.21
SILALA	SILALA_SUR_TRM4	630	Q MED	0.05	4360.4	4360.7		4360.7	0.057	0.47	0.11	0.71	0.38
SILALA	SILALA_SUR_TRM4	620	Q MED	0.05	4360.2	4360.4		4360.4	0.018	0.27	0.20	1.46	0.23
SILALA	SILALA_SUR_TRM4	610	Q MED	0.05	4359.9	4360.1		4360.1	0.046	0.35	0.15	1.51	0.35
SILALA	SILALA_SUR_TRM4	600	Q MED	0.05	4359.5	4359.6		4359.6	0.047	0.34	0.16	1.78	0.36
SILALA	SILALA_SUR_TRM4	590	Q MED	0.05	4359.0	4359.2		4359.2	0.042	0.38	0.14	1.17	0.35
SILALA	SILALA_SUR_TRM4	580	Q MED	0.05	4358.5	4358.7		4358.7	0.052	0.45	0.12	0.77	0.37
SILALA	SILALA_SUR_TRM4	570	Q MED	0.05	4358.0	4358.2		4358.2	0.055	0.42	0.12	1.07	0.40
SILALA	SILALA_SUR_TRM4	560	Q MED	0.05	4357.4	4357.6		4357.6	0.066	0.43	0.12	1.23	0.43
SILALA	SILALA_SUR_TRM4	550	Q MED	0.05	4356.7	4356.9		4356.9	0.080	0.44	0.12	1.35	0.47
SILALA	SILALA_SUR_TRM4	540	Q MED	0.05	4355.8	4356.0	4355.9	4356.0	0.087	0.55	0.09	0.66	0.47
SILALA	SILALA_SUR_TRM4	530	Q MED	0.05	4354.3	4354.5	4354.5	4354.5	0.318	0.80	0.06	0.79	0.90
SILALA	SILALA_SUR_TRM4	520	Q MED	0.05	4353.4	4353.6		4353.6	0.044	0.38	0.14	1.19	0.36
SILALA	SILALA_SUR_TRM4	510	Q MED	0.05	4353.0	4353.1		4353.1	0.043	0.35	0.15	1.47	0.35
SILALA	SILALA_SUR_TRM4	500	Q MED	0.05	4352.0	4352.1	4352.1	4352.2	0.379	0.89	0.06	0.70	0.98
SILALA	SILALA_SUR_TRM4	490	Q MED	0.05	4351.3	4351.5		4351.5	0.018	0.22	0.23	2.26	0.22
SILALA	SILALA_SUR_TRM4	480	Q MED	0.05	4351.0	4351.1		4351.1	0.199	0.55	0.10	1.55	0.71
SILALA	SILALA_SUR_TRM4	470	Q MED	0.05	4350.4	4350.6		4350.6	0.019	0.25	0.21	1.86	0.24
SILALA	SILALA_SUR_TRM4	460	Q MED	0.05	4349.8	4350.0		4350.0	0.066	0.48	0.11	0.87	0.43
SILALA	SILALA_SUR_TRM4	450	Q MED	0.05	4349.4	4349.7		4349.7	0.020	0.31	0.17	1.03	0.24
SILALA	SILALA_SUR_TRM4	440	Q MED	0.05	4349.2	4349.3		4349.4	0.066	0.41	0.13	1.35	0.43
SILALA	SILALA_SUR_TRM4	430	Q MED	0.05	4348.6	4348.8	4348.8	4348.9	0.040	0.38	0.14	1.10	0.34
SILALA	SILALA_SUR_TRM4	420	Q MED	0.05	4348.0	4348.1		4348.1	0.148	0.59	0.09	1.02	0.63
SILALA	SILALA_SUR_TRM4	410	Q MED	0.05	4347.4	4347.5		4347.5	0.031	0.32	0.16	1.38	0.30
SILALA	SILALA_SUR_TRM4	400	Q MED	0.05	4347.0	4347.1		4347.2	0.051	0.41	0.13	1.10	0.38
SILALA	SILALA_SUR_TRM4	390	Q MED	0.05	4346.6	4346.8		4346.8	0.032	0.20	0.26	5.13	0.28
SILALA	SILALA_SUR_TRM4	380	Q MED	0.05	4346.2	4346.3		4346.3	0.055	0.30	0.17	2.56	0.38
SILALA	SILALA_SUR_TRM4	370	Q MED	0.05	4345.7	4345.9		4345.9	0.035	0.36	0.15	1.15	0.32
SILALA	SILALA_SUR_TRM4	360	Q MED	0.05	4345.2	4345.4	4345.3	4345.4	0.069	0.35	0.15	1.96	0.41
SILALA	SILALA_SUR_TRM4	350	Q MED	0.05	4344.8	4344.9		4344.9	0.035	0.29	0.19	2.38	0.31
SILALA	SILALA_SUR_TRM4	340	Q MED	0.05	4344.4	4344.6		4344.6	0.039	0.38	0.14	1.07	0.34
SILALA	SILALA_SUR_TRM4	330	Q MED	0.05	4343.8	4344.0		4344.0	0.097	0.51	0.10	1.03	0.52
SILALA	SILALA_SUR_TRM4	320	Q MED	0.05	4343.4	4343.6		4343.6	0.019	0.29	0.18	1.13	0.24
SILALA	SILALA_SUR_TRM4	310	Q MED	0.05	4343.2	4343.4		4343.4	0.034	0.36	0.15	1.13	0.32
SILALA	SILALA_SUR_TRM4	300	Q MED	0.05	4342.8	4343.0		4343.0	0.050	0.41	0.13	1.05	0.38
SILALA	SILALA_SUR_TRM4	290	Q MED	0.05	4342.2	4342.4		4342.4	0.076	0.48	0.11	0.99	0.46
SILALA	SILALA_SUR_TRM4	280	Q MED	0.05	4341.4	4341.5		4341.6	0.087	0.51	0.10	0.94	0.49
SILALA	SILALA_SUR_TRM4	270	Q MED	0.05	4340.8	4341.0		4341.0	0.042	0.37	0.14	1.19	0.35
SILALA	SILALA_SUR_TRM4	260	Q MED	0.05	4340.2	4340.4		4340.4	0.085	0.50	0.10	0.95	0.49
SILALA	SILALA_SUR_TRM4	250	Q MED	0.05	4339.6	4339.7		4339.7	0.053	0.36	0.14	1.60	0.39
SILALA	SILALA_SUR_TRM4	240	Q MED	0.05	4339.0	4339.1		4339.1	0.075	0.41	0.13	1.48	0.45
SILALA	SILALA_SUR_TRM4	230	Q MED	0.05	4338.4	4338.5		4338.5	0.043	0.38	0.14	1.25	0.36
SILALA	SILALA_SUR_TRM4	220	Q MED	0.05	4338.0	4338.1		4338.1	0.038	0.36	0.15	1.45	0.34
SILALA	SILALA_SUR_TRM4	210	Q MED	0.05	4337.1	4337.2	4337.2	4337.2	0.478	0.76	0.07	1.22	1.02
SILALA	SILALA_SUR_TRM4	200	Q MED	0.05	4335.5	4335.8		4335.8	0.035	0.43	0.13	0.81	0.33
SILALA	SILALA_SUR_TRM4	190	Q MED	0.05	4334.8	4334.9	4334.9	4335.0	0.373	0.88	0.06	0.73	0.98
SILALA	SILALA_SUR_TRM4	180	Q MED	0.05	4334.2	4334.0	4334.0	4334.0	0.566		0.06	0.82	0.00
SILALA	SILALA_SUR_TRM4	170	Q MED	0.05	4331.2	4331.2	4331.2	4331.2	0.411	0.49	0.09	2.09	0.89
SILALA	SILALA_SUR_TRM4	160	Q MED	0.05	4329.0	4329.2		4329.2	0.090	0.53	0.11	0.97	0.46
SILALA	SILALA_SUR_TRM4	150	Q MED	0.05	4328.8	4329.0		4329.0	0.005	0.20	0.27	1.29	0.14
SILALA	SILALA_SUR_TRM4	140	Q MED	0.05	4328.8	4328.8	4328.8	4328.9	0.457	0.65	0.09	2.26	1.02
SILALA	SILALA_SUR_TRM4	130	Q MED	0.05	4326.8	4327.0	4326.9	4327.0	0.116	0.63	0.09	0.66	0.54
SILALA	SILALA_SUR_TRM4	120	Q MED	0.05	4324.9	4325.0	4325.0	4325.1	0.389	0.73	0.07	1.35	0.98
SILALA	SILALA_SUR_TRM4	110	Q MED	0.05	4323.6	4323.9		4323.9	0.028	0.37	0.14	0.60	0.24
SILALA	SILALA_SUR_TRM4	100	Q MED	0.05	4323.1	4323.2	4323.2	4323.2	0.394	0.85	0.06	0.82	0.99
SILALA	SILALA_SUR_TRM4	90	Q MED	0.05	4321.8	4321.9	4321.9	4321.9	0.407	0.79	0.07	1.05	1.00
SILALA	SILALA_SUR_TRM4	80	Q MED	0.05	4320.4	4320.6		4320.6	0.023	0.33	0.16	0.84	0.25
SILALA	SILALA_SUR_TRM4	70	Q MED	0.05	4320.2	4320.4		4320.4	0.027	0.33	0.16	1.17	0.29

SIMULACIÓN HIDRÁULICA DE FLUJO SUPERFICIAL DELSISTEMA SILALA

River	Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
SILALA	SILALA_SUR_TRM4	60	Q MED	0.05	4320.1	4320.2		4320.2	0.015	0.18	0.33	5.02	0.20
SILALA	SILALA_SUR_TRM4	50	Q MED	0.05	4319.6	4319.7	4319.7	4319.8	0.378	0.89	0.06	0.71	0.98
SILALA	SILALA_SUR_TRM4	40	Q MED	0.05	4319.1	4319.2		4319.2	0.016	0.16	0.33	5.16	0.21
SILALA	SILALA_SUR_TRM4	30	Q MED	0.05	4318.9	4319.1		4319.1	0.020	0.19	0.27	3.99	0.23
SILALA	SILALA_SUR_TRM5	20	Q MED	0.09	4318.6	4318.9		4318.9	0.027	0.28	0.34	3.32	0.27
SILALA	SILALA_SUR_TRM5	10	Q MED	0.09	4318.3	4318.6		4318.6	0.035	0.30	0.31	3.20	0.31
SILALA	SILALA_NOR	680	Q MED	0.05	4361.2	4361.3		4361.3	0.095	0.35	0.15	3.28	0.53
SILALA	SILALA_NOR	670	Q MED	0.05	4360.2	4360.3	4360.3	4360.4	0.121	0.62	0.08	0.91	0.65
SILALA	SILALA_NOR	660	Q MED	0.05	4359.2	4359.3		4359.4	0.052	0.44	0.12	1.15	0.44
SILALA	SILALA_NOR	650	Q MED	0.05	4358.4	4358.5		4358.5	0.149	0.64	0.08	0.99	0.72
SILALA	SILALA_NOR	640	Q MED	0.05	4357.8	4357.9		4357.9	0.030	0.35	0.15	1.38	0.34
SILALA	SILALA_NOR	630	Q MED	0.05	4357.4	4357.5		4357.6	0.056	0.27	0.19	4.33	0.41
SILALA	SILALA_NOR	620	Q MED	0.05	4356.9	4357.0		4357.0	0.057	0.31	0.17	3.24	0.42
SILALA	SILALA_NOR	610	Q MED	0.05	4356.4	4356.5		4356.5	0.046	0.26	0.20	3.94	0.37
SILALA	SILALA_NOR	600	Q MED	0.05	4355.9	4356.1		4356.1	0.037	0.36	0.14	1.48	0.37
SILALA	SILALA_NOR	590	Q MED	0.05	4355.4	4355.6		4355.6	0.076	0.49	0.11	1.14	0.52
SILALA	SILALA_NOR	580	Q MED	0.05	4354.8	4354.9		4354.9	0.050	0.43	0.12	1.19	0.43
SILALA	SILALA_NOR	570	Q MED	0.05	4354.0	4354.2		4354.2	0.133	0.66	0.08	0.80	0.68
SILALA	SILALA_NOR	560	Q MED	0.05	4353.4	4353.6		4353.6	0.033	0.40	0.13	1.00	0.35
SILALA	SILALA_NOR	550	Q MED	0.05	4353.0	4353.1		4353.2	0.058	0.47	0.11	1.07	0.46
SILALA	SILALA_NOR	540	Q MED	0.05	4352.6	4352.9		4352.9	0.016	0.29	0.18	1.31	0.25
SILALA	SILALA_NOR	530	Q MED	0.05	4352.6	4352.7		4352.7	0.021	0.15	0.34	8.97	0.25
SILALA	SILALA_NOR	520	Q MED	0.05	4351.8	4352.0	4352.0	4352.0	0.275	0.89	0.06	0.63	0.93
SILALA	SILALA_NOR	510	Q MED	0.05	4351.4	4351.6		4351.6	0.017	0.30	0.18	1.34	0.26
SILALA	SILALA_NOR	500	Q MED	0.05	4351.0	4351.2		4351.2	0.145	0.70	0.07	0.72	0.70
SILALA	SILALA_NOR	490	Q MED	0.05	4350.5	4350.7		4350.7	0.027	0.32	0.16	1.55	0.32
SILALA	SILALA_NOR	480	Q MED	0.05	4350.0	4350.1		4350.1	0.197	0.65	0.08	1.22	0.81
SILALA	SILALA_NOR	470	Q MED	0.05	4349.2	4349.5		4349.5	0.030	0.38	0.14	0.96	0.32
SILALA	SILALA_NOR	460	Q MED	0.05	4349.0	4349.1		4349.1	0.051	0.34	0.15	2.14	0.41
SILALA	SILALA_NOR	450	Q MED	0.05	4348.6	4348.7		4348.7	0.026	0.28	0.18	2.06	0.31
SILALA	SILALA_NOR	440	Q MED	0.05	4348.2	4348.5		4348.5	0.033	0.26	0.20	3.07	0.33
SILALA	SILALA_NOR	430	Q MED	0.05	4348.0	4348.2		4348.2	0.014	0.13	0.39	9.03	0.20
SILALA	SILALA_NOR	420	Q MED	0.05	4347.8	4347.9	4347.9	4347.9	0.110	0.29	0.18	6.19	0.53
SILALA	SILALA_NOR	410	Q MED	0.05	4347.4	4347.5		4347.5	0.022	0.22	0.23	3.44	0.27
SILALA	SILALA_NOR	400	Q MED	0.05	4347.0	4347.2		4347.2	0.041	0.31	0.17	2.16	0.36
SILALA	SILALA_NOR	390	Q MED	0.05	4346.6	4346.9		4346.9	0.030	0.28	0.19	2.30	0.31
SILALA	SILALA_NOR	380	Q MED	0.05	4346.2	4346.3		4346.3	0.146	0.43	0.13	3.38	0.65
SILALA	SILALA_NOR	370	Q MED	0.05	4345.6	4345.7		4345.7	0.033	0.15	0.22	3.52	0.28
SILALA	SILALA_NOR	360	Q MED	0.05	4345.0	4344.9		4344.9	0.248		0.09	1.73	0.00
SILALA	SILALA_NOR	350	Q MED	0.05	4344.4	4344.4	4344.3	4344.4	0.023		0.22	2.28	0.00
SILALA	SILALA_NOR	340	Q MED	0.05	4344.0	4343.9	4343.9	4343.9	0.377		0.08	1.71	0.00
SILALA	SILALA_NOR	330	Q MED	0.05	4343.2	4343.4	4343.3	4343.4	0.014	0.19	0.27	3.31	0.22
SILALA	SILALA_NOR	320	Q MED	0.05	4342.9	4343.0	4343.0	4343.0	0.318	0.47	0.11	3.99	0.90
SILALA	SILALA_NOR	310	Q MED	0.05	4342.0	4342.1	4342.1	4342.1	0.043	0.28	0.19	3.31	0.37
SILALA	SILALA_NOR	300	Q MED	0.05	4341.2	4341.3	4341.3	4341.3	0.178	0.64	0.08	1.03	0.73
SILALA	SILALA_NOR	290	Q MED	0.05	4340.4	4340.5		4340.5	0.054	0.25	0.21	5.02	0.39
SILALA	SILALA_NOR	280	Q MED	0.05	4339.2	4339.3	4339.3	4339.3	0.345	0.66	0.08	1.79	1.00
SILALA	SILALA_NOR	270	Q MED	0.05	4338.2	4338.3		4338.3	0.048	0.35	0.15	1.96	0.41
SILALA	SILALA_NOR	260	Q MED	0.05	4337.5	4337.6		4337.6	0.107	0.45	0.12	2.00	0.59
SILALA	SILALA_NOR	250	Q MED	0.05	4336.7	4336.8		4336.9	0.060	0.34	0.15	2.55	0.44
SILALA	SILALA_NOR	240	Q MED	0.05	4336.0	4336.1	4336.0	4336.1	0.107	0.43	0.12	2.18	0.57
SILALA	SILALA_NOR	230	Q MED	0.05	4335.2	4335.4		4335.4	0.048	0.46	0.11	0.92	0.42
SILALA	SILALA_NOR	220	Q MED	0.05	4334.5	4334.7		4334.7	0.101	0.57	0.09	0.99	0.60
SILALA	SILALA_NOR	210	Q MED	0.05	4333.6	4333.8		4333.8	0.080	0.58	0.09	0.71	0.52
SILALA	SILALA_NOR	200	Q MED	0.05	4333.0	4333.2		4333.2	0.043	0.46	0.11	0.73	0.38
SILALA	SILALA_NOR	190	Q MED	0.05	4332.6	4332.7		4332.7	0.069	0.36	0.15	2.47	0.47
SILALA	SILALA_NOR	180	Q MED	0.05	4331.6	4331.7		4331.7	0.149	0.56	0.09	1.34	0.68
SILALA	SILALA_NOR	170	Q MED	0.05	4330.8	4330.9		4330.9	0.048	0.40	0.13	1.34	0.41
SILALA	SILALA_NOR	160	Q MED	0.05	4330.0	4330.1		4330.1	0.153	0.61	0.09	1.18	0.72
SILALA	SILALA_NOR	150	Q MED	0.05	4329.2	4329.3		4329.3	0.048	0.37	0.14	1.78	0.41
SILALA	SILALA_NOR	140	Q MED	0.05	4328.6	4328.7		4328.7	0.085	0.46	0.11	1.51	0.54
SILALA	SILALA_NOR	130	Q MED	0.05	4328.0	4328.1		4328.1	0.044	0.36	0.14	1.68	0.40
SILALA	SILALA_NOR	120	Q MED	0.05	4327.2	4327.4	4327.4	4327.4	0.113	0.44	0.12	2.08	0.58
SILALA	SILALA_NOR	110	Q MED	0.05	4326.6	4326.7		4326.7	0.049	0.36	0.15	1.86	0.41
SILALA	SILALA_NOR	100	Q MED	0.05	4325.8	4325.9		4325.9	0.168	0.68	0.08	0.94	0.76
SILALA	SILALA_NOR	90	Q MED	0.05	4325.0	4325.2	4325.1	4325.2	0.041	0.36	0.14	1.49	0.37
SILALA	SILALA_NOR	80	Q MED	0.05	4324.2	4324.3	4324.3	4324.3	0.307	0.72	0.07	1.25	0.95
SILALA	SILALA_NOR	70	Q MED	0.05	4323.4	4323.6		4323.6	0.029	0.33	0.16	1.39	0.31
SILALA	SILALA_NOR	60	Q MED	0.05	4322.7	4322.8	4322.8	4322.9	0.346	0.79	0.07	1.04	1.00
SILALA	SILALA_NOR	50	Q MED	0.05	4321.6	4321.9	4321.8	4321.9	0.045	0.47	0.11	0.73	0.39

SIMULACIÓN HIDRÁULICA DE FLUJO SUPERFICIAL DELSISTEMA SILALA

River	Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
SILALA	SILALA_NOR	40	Q MED	0.05	4321.0	4321.2		4321.2	0.123	0.67	0.08	0.70	0.64
SILALA	SILALA_NOR	30	Q MED	0.05	4320.4	4320.6	4320.5	4320.6	0.033	0.41	0.13	0.92	0.35
SILALA	SILALA_NOR	20	Q MED	0.05	4319.9	4320.0	4320.0	4320.1	0.328	0.67	0.08	1.64	0.98
SILALA	SILALA_CONFLU	710	Q MED	0.13	4317.8	4318.1		4318.1	0.017	0.25	0.53	3.41	0.21
SILALA	SILALA_CONFLU	700	Q MED	0.13	4317.4	4317.6		4317.7	0.263	0.78	0.17	1.59	0.76
SILALA	SILALA_CONFLU	690	Q MED	0.13	4316.8	4317.1		4317.1	0.023	0.32	0.41	1.96	0.23
SILALA	SILALA_CONFLU	680	Q MED	0.13	4316.4	4316.9		4316.9	0.023	0.26	0.55	2.63	0.15
SILALA	SILALA_CONFLU	670	Q MED	0.13	4316.2	4316.3		4316.3	0.224	0.47	0.28	3.04	0.49
SILALA	SILALA_CONFLU	660	Q MED	0.13	4314.8	4315.2		4315.2	0.073	0.46	0.29	1.27	0.31
SILALA	SILALA_CONFLU	650	Q MED	0.13	4314.0	4314.2		4314.2	0.118	0.36	0.38	3.90	0.37
SILALA	SILALA_CONFLU	640	Q MED	0.13	4313.2	4313.5		4313.5	0.051	0.33	0.41	2.10	0.24
SILALA	SILALA_CONFLU	630	Q MED	0.13	4312.4	4312.7		4312.7	0.139	0.54	0.25	1.47	0.42
SILALA	SILALA_CONFLU	620	Q MED	0.13	4311.6	4312.1	4311.8	4312.1	0.038	0.31	0.44	2.23	0.22
SILALA	SILALA_CONFLU	610	Q MED	0.13	4310.8	4310.9	4310.9	4311.0	0.937	1.07	0.12	1.16	1.05
SILALA	SILALA_CONFLU	600	Q MED	0.13	4310.0	4310.4		4310.4	0.011	0.21	0.64	2.41	0.13
SILALA	SILALA_CONFLU	590	Q MED	0.13	4309.8	4310.2		4310.2	0.022	0.21	0.65	4.04	0.16
SILALA	SILALA_CONFLU	580	Q MED	0.13	4309.4	4309.5	4309.5	4309.6	0.850	1.02	0.13	1.22	1.00
SILALA	SILALA_CONFLU	570	Q MED	0.13	4308.4	4308.7		4308.7	0.024	0.18	0.75	6.99	0.17
SILALA	SILALA_CONFLU	560	Q MED	0.13	4307.9	4308.1		4308.1	0.305	0.59	0.23	2.20	0.59
SILALA	SILALA_CONFLU	550	Q MED	0.13	4306.7	4307.0		4307.0	0.054	0.39	0.34	1.65	0.27
SILALA	SILALA_CONFLU	540	Q MED	0.13	4306.0	4306.4		4306.4	0.069	0.46	0.29	1.06	0.28
SILALA	SILALA_CONFLU	530	Q MED	0.13	4305.4	4305.8		4305.8	0.057	0.43	0.31	1.08	0.26
SILALA	SILALA_CONFLU	520	Q MED	0.13	4304.8	4305.3	4305.0	4305.3	0.047	0.38	0.35	1.47	0.25
SILALA	SILALA_CONFLU	510	Q MED	0.13	4304.2	4304.4		4304.4	0.195	0.62	0.22	1.41	0.50
SILALA	SILALA_CONFLU	500	Q MED	0.13	4303.4	4303.9		4303.9	0.026	0.21	0.64	4.64	0.18
SILALA	SILALA_CONFLU	490	Q MED	0.13	4303.2	4303.5		4303.5	0.071	0.41	0.33	1.87	0.31
SILALA	SILALA_CONFLU	480	Q MED	0.13	4302.4	4302.7		4302.7	0.076	0.35	0.38	2.86	0.31
SILALA	SILALA_CONFLU	470	Q MED	0.13	4301.8	4302.1		4302.1	0.052	0.31	0.43	2.91	0.26
SILALA	SILALA_CONFLU	460	Q MED	0.13	4301.2	4301.5		4301.5	0.068	0.45	0.30	1.25	0.29
SILALA	SILALA_CONFLU	450	Q MED	0.13	4300.6	4300.9		4300.9	0.048	0.40	0.34	1.31	0.25
SILALA	SILALA_CONFLU	440	Q MED	0.13	4300.0	4300.4		4300.4	0.073	0.40	0.34	1.87	0.30
SILALA	SILALA_CONFLU	430	Q MED	0.13	4299.2	4299.8		4299.8	0.051	0.36	0.37	1.71	0.24
SILALA	SILALA_CONFLU	420	Q MED	0.13	4298.7	4299.2		4299.2	0.065	0.46	0.29	1.01	0.27
SILALA	SILALA_CONFLU	410	Q MED	0.13	4298.2	4298.6		4298.6	0.047	0.36	0.37	1.63	0.24
SILALA	SILALA_CONFLU	400	Q MED	0.13	4297.7	4298.1		4298.1	0.058	0.34	0.39	2.41	0.27
SILALA	SILALA_CONFLU	390	Q MED	0.13	4297.4	4297.7		4297.7	0.028	0.23	0.59	4.09	0.19
SILALA	SILALA_CONFLU	380	Q MED	0.13	4297.0	4297.3		4297.3	0.073	0.30	0.45	4.46	0.30
SILALA	SILALA_CONFLU	370	Q MED	0.13	4296.2	4296.6		4296.7	0.057	0.41	0.33	1.38	0.27
SILALA	SILALA_CONFLU	360	Q MED	0.13	4295.6	4295.9		4295.9	0.095	0.51	0.26	1.18	0.35
SILALA	SILALA_CONFLU	350	Q MED	0.13	4294.7	4295.0		4295.1	0.081	0.50	0.27	1.09	0.32
SILALA	SILALA_CONFLU	340	Q MED	0.13	4294.0	4294.3		4294.4	0.061	0.36	0.37	1.98	0.27
SILALA	SILALA_CONFLU	330	Q MED	0.13	4293.6	4293.9		4293.9	0.040	0.34	0.39	1.87	0.24
SILALA	SILALA_CONFLU	320	Q MED	0.13	4293.0	4293.4		4293.4	0.055	0.35	0.39	2.27	0.27
SILALA	SILALA_CONFLU	310	Q MED	0.13	4292.4	4292.8		4292.8	0.071	0.45	0.30	1.38	0.31
SILALA	SILALA_CONFLU	300	Q MED	0.13	4291.8	4292.0		4292.1	0.071	0.41	0.33	1.90	0.31
SILALA	SILALA_CONFLU	290	Q MED	0.13	4291.2	4291.5		4291.5	0.047	0.37	0.36	1.65	0.26
SILALA	SILALA_CONFLU	280	Q MED	0.13	4290.8	4291.2		4291.2	0.024	0.30	0.44	1.59	0.18
SILALA	SILALA_CONFLU	270	Q MED	0.13	4290.4	4290.8		4290.8	0.073	0.48	0.28	1.04	0.29
SILALA	SILALA_CONFLU	260	Q MED	0.13	4289.6	4290.2		4290.2	0.051	0.41	0.33	0.99	0.23
SILALA	SILALA_CONFLU	250	Q MED	0.13	4289.0	4289.4		4289.4	0.124	0.59	0.23	0.92	0.37
SILALA	SILALA_CONFLU	240	Q MED	0.13	4288.2	4288.8		4288.8	0.036	0.36	0.37	1.03	0.19
SILALA	SILALA_CONFLU	230	Q MED	0.13	4288.0	4288.4		4288.4	0.049	0.40	0.33	1.23	0.25
SILALA	SILALA_CONFLU	220	Q MED	0.13	4287.6	4288.0		4288.0	0.031	0.26	0.52	2.98	0.20
SILALA	SILALA_CONFLU	210	Q MED	0.13	4287.1	4287.5		4287.5	0.095	0.38	0.35	2.61	0.33
SILALA	SILALA_CONFLU	200	Q MED	0.13	4286.4	4286.9		4286.9	0.038	0.37	0.36	1.14	0.21
SILALA	SILALA_CONFLU	190	Q MED	0.13	4286.0	4286.4		4286.4	0.072	0.46	0.29	1.26	0.30
SILALA	SILALA_CONFLU	180	Q MED	0.13	4285.4	4285.8		4285.8	0.056	0.43	0.31	1.21	0.27
SILALA	SILALA_CONFLU	170	Q MED	0.13	4284.8	4285.2		4285.2	0.063	0.45	0.30	1.08	0.28
SILALA	SILALA_CONFLU	160	Q MED	0.13	4284.2	4284.6		4284.6	0.048	0.39	0.34	1.34	0.25
SILALA	SILALA_CONFLU	150	Q MED	0.13	4283.8	4284.2		4284.2	0.038	0.33	0.40	1.81	0.23
SILALA	SILALA_CONFLU	140	Q MED	0.13	4283.4	4283.9		4283.9	0.026	0.25	0.54	2.87	0.19
SILALA	SILALA_CONFLU	130	Q MED	0.13	4282.9	4283.1		4283.2	0.611	1.01	0.13	0.92	0.84
SILALA	SILALA_CONFLU	120	Q MED	0.13	4282.0	4282.5		4282.5	0.023	0.24	0.56	2.82	0.17
SILALA	SILALA_CONFLU	110	Q MED	0.13	4281.8	4282.1		4282.1	0.064	0.45	0.30	1.25	0.29
SILALA	SILALA_CONFLU	100	Q MED	0.13	4281.2	4281.6		4281.6	0.042	0.39	0.35	1.17	0.23
SILALA	SILALA_CONFLU	90	Q MED	0.13	4280.8	4281.2		4281.2	0.053	0.37	0.36	1.82	0.27
SILALA	SILALA_CONFLU	80	Q MED	0.13	4280.2	4280.5		4280.5	0.088	0.47	0.28	1.44	0.34
SILALA	SILALA_CONFLU	70	Q MED	0.13	4279.6	4280.0		4280.0	0.034	0.32	0.46	2.40	0.20
SILALA	SILALA_CONFLU	60	Q MED	0.13	4279.2	4279.5		4279.5	0.076	0.47	0.28	1.23	0.31
SILALA	SILALA_CONFLU	50	Q MED	0.13	4278.2	4278.9		4278.9	0.039	0.34	0.40	1.14	0.18
SILALA	SILALA_CONFLU	40	Q MED	0.13	4278.2	4278.5		4278.5	0.062	0.39	0.35	2.29	0.29
SILALA	SILALA_CONFLU	30	Q MED	0.13	4277.4	4277.8		4277.8	0.078	0.47	0.29	1.33	0.32
SILALA	SILALA_CONFLU	20	Q MED	0.13	4277.0	4277.3		4277.3	0.030	0.33	0.42	1.94	0.21
SILALA	SILALA_CONFLU	10	Q MED	0.13	4276.6	4276.9	4276.7	4276.9	0.062	0.44	0.31	1.26	0.28

ANNEX 3: WATER QUALITY MEASUREMENT SHEETS IN THE CANALS OF THE SILALA SPRINGS

CODE	SAMPLING POINT	Temperature	pH	Electric Conductivity	Dissolved Oxygen	Dissolved Oxygen	Turbidity	Salinity	Dissolved Solids	Calcium	Magnesium	Sodium	Potassium	Chlorides	Sulfates	Carbonates	Bicarbonates	Nitrates	Silica	Suspended Solids	Total Hardness	Iron	Ammonium	Phosphates	DQO	$\delta^{2}H_{VSMOW}$	$\delta^{18}O_{VSMOW}$	Escherichia Coli	Total Coliforms
		° C		µS/cm	mg/L	% Sat	NTU	0/00	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	0/00	0/00	UFC/100 ml	UFC/100 ml
SIT-1	TAIKA-POZO HOTEL	6.1	7.34	189.3	7.17	101.2	0.00	0.0	177.83	11.06	10.52	10.48	1.33	7.54	9.80	0.00	103.33	2.77	19.83	0.0	68.47	0.10	0.06	0.38	5.0	-91.2	-10.50	-	-
SI-1	NORTH SPRING BOFEDAL	14.4	8.25	114.2	5.84	98.3	0.23	0.0	106.12	9.04	1.46	9.38	1.82	4.94	7.74	0.00	56.62	2.60	17.11	3.0	35.41	0.07	0.03	0.23	< 2,0	-91.2	-11.66	-	-
SI-2	SOUTH SPRING BOFEDAL	14.0	7.75	246.0	6.01	99.0	0.20	0.0	231.80	16.31	6.13	19.08	2.80	6.14	8.98	0.00	142.96	2.22	21.02	0.0	62.74	0.10	0.03	0.39	< 2,0	-95.7	-12.03	-	-
SI-3	SOUTH SPRING BOFEDAL	14.6	7.41	260.0	6.01	100.4	0.25	0.0	237.75	17.04	7.05	19.08	3.10	6.61	8.98	0.00	145.79	2.32	22.04	4.0	79.57	0.06	0.03	0.34	< 2,0	-95.6	-12.13	-	-
SI-4	SPRING OF THE SOUTH BOFEDAL	12.2	7.80	226.0	6.48	103.7	0.15	0.0	208.11	14.61	5.40	18.09	2.80	5.34	7.74	0.00	127.39	2.39	20.26	2.0	68.74	0.08	0.02	0.32	< 2,0	-97.0	-12.18	-	-
SI-5	SOUTH BOFEDAL CANAL	10.9	8.40	283.0	7.06	110.0	2.32	0.0	261.88	19.57	8.97	19.08	3.59	4.74	8.98	0.00	165.61	0.81	22.21	8.0	85.79	0.17	0.03	0.22	2.7	-96.1	-12.09	7.00E+02	7.00E+02
SI-6	SILALA NORTH BOFEDAL	16.3	8.16	115.4	5.89	102.5	0.25	0.0	102.30	8.41	1.51	9.68	1.82	4.54	6.91	0.00	55.20	2.05	17.45	2.0	29.45	0.08	0.03	0.30	< 2,0	-90.8	-11.55	-	-
SI-7	NORTH BOFEDAL CANAL	15.7	8.01	139.0	5.92	101.9	0.15	0.0	113.18	9.48	1.95	10.68	1.92	5.20	7.46	0.00	60.86	2.13	17.62	1.0	31.69	0.19	0.03	0.25	< 2,0	-92.1	-11.74	-	-
SI-8	SILALA SOUTH BOFEDAL	14.5	7.59	404.0	5.4	92.5	0.33	0.1	359.79	32.32	15.81	21.07	5.45	5.47	10.08	0.00	225.05	2.07	31.79	3.0	141.37	0.73	0.05	0.29	2.8	-95.6	-12.26	-	-
SI-9	BOFEDAL OF THE NORTH CANAL	15.5	8.03	124.7	6.19	105.3	0.17	0.0	113.84	8.48	1.56	10.48	1.92	5.07	7.05	0.00	63.69	2.13	16.40	0.0	29.58	0.11	0.03	0.23	< 2,0	-92.3	-11.72	-	-
SI-10	BOFEDAL OF THE NORTH CANAL	14.9	8.08	96.3	6.22	103.6	0.48	0.0	84.39	7.52	1.13	7.89	1.82	4.24	6.01	0.00	43.88	1.81	17.59	3.0	25.63	0.14	0.04	0.20	< 2,0	-90.1	-11.41	-	-
SI-11	BOFEDAL OF THE NORTH PIEZOMETER	14.9	8.21	87.7	6.04	99.5	0.25	0.0	75.32	7.50	0.94	7.29	1.92	4.14	5.94	0.00	36.80	1.73	17.36	2.0	24.58	0.12	0.10	0.19	2.1	-90.2	-11.83	-	-
SI-12	SILALA NORTH BOFEDAL	13.8	8.31	173.7	6.41	105.1	1.39	0.0	152.24	12.66	3.73	13.10	2.51	4.87	6.91	0.00	89.17	1.36	18.16	2.0	48.76	0.12	0.03	0.25	3.6	-92.4	-11.72	0.00E+00	0.00E+00
SI-13	NORTH BOFEDAL CANAL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00E+00	0.00E+00
SI-14	NORTH BOFEDAL CANAL	14.8	8.19	121.7	6.22	104.6	0.70	0.0	113.63	9.20	1.83	10.18	1.92	4.80	6.63	0.00	63.69	1.94	16.06	2.0	33.21	0.08	0.03	0.25	< 2,0	-92.0	-11.58	0.00E+00	0.00E+00
SI-15	SOUTH BOFEDAL CANAL	12.3	8.44	217.0	6.31	101.5	2.55	0.0	201.59	15.87	5.93	15.10	2.90	5.20	8.15	0.00	123.14	1.66	18.95	7.0	66.33	0.12	0.08	0.25	3.8	-93.4	-11.65	1.00E+03	1.00E+03
SI-16	SOUTH BOFEDAL CANAL	13.4	8.44	302.0	7.28	118.0	0.52	0.1	268.31	22.22	10.27	19.08	3.88	5.40	6.63	0.00	168.44	1.17	18.30	4.0	98.77	0.12	0.05	0.17	10.6	-	-	1.00E+02	1.00E+02
SI-17	SOUTH BOFEDAL	13.5	9.00	248.0	8.18	137.6	0.47	0.0	189.02	17.41	7.20	21.07	3.10	5.74	7.32	20.88	83.51	0.63	18.55	4.0	74.63	0.18	0.03	0.19	8.2	-	-	3.00E+02	3.00E+02
SI-18	SOUTH LIPEZ PROVINCE	14.3	8.98	256.0	6.73	113.1	0.33	0.0	205.43	17.12	7.18	18.58	3.15	5.17	6.98	14.62	107.57	0.94	20.04	3.0	72.54	0.16	0.07	0.25	3.6	-	-	0.00E+00	0.00E+00
LCE-1	LAGUNA COLORADA SPRING SOUTH LIPEZ PROV.	14.1	8.24	957.0	4.97	83.8	0.31	0.4	449.54	9.67	4.42	103.78	13.21	174.48	43.17	0.00	46.71	1.83	35.06	4.0	44.35	0.07	0.04	0.44	< 2,0	-86.0	-11.45	-	-
LCS-1	LAGUNA COLORADA SPRING SOUTH LIPEZ	16.7	8.35	998.0	4.86	84.6	0.35	0.4	382.32	10.34	4.81	112.74	13.70	88.07	39.86	0.00	66.53	1.81	33.74	4.0	46.32	0.05	0.04	0.38	13.8	-	-	-	-
LCMAC-1	LAGUNA COLORADA VIEWPOINT	19.1	8.03	510.0	5.54	102.4	0.36	0.2	391.52	8.68	3.22	55.95	9.28	203.17	18.35	0.00	45.29	1.72	35.74	3.0	35.86	0.06	0.03	0.43	< 2,0	-95.3	-12.58	-	-

Annex 23.2

C. Barrón, "Study of Georeferencing, Topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs", May 2018

(English Translation)

PLURINATIONAL STATE OF BOLIVIA

FINAL REPORT

"STUDY OF GEOREFERENCING, TOPOGRAPHIC SURVEY AND DETERMINATION OF THE INFILTRATION CAPACITY IN THE EVENT OF POSSIBLE SURFACE RUNOFF IN THE AREA OF THE SILALA SPRINGS"

Modality: Consultancy by Product - Supreme Decree N° 3131 - Specific Regulation of Direct Contracting of Goods, General Services and Consulting Services Article 7, numeral II, sub-paragraph a)

PRESENTED TO:

DIREMAR

May – 2018

La Paz – Bolivia

STUDY OF GEOREFERENCING, TOPOGRAPHIC SURVEY AND DETERMI-NATION OF THE INFILTRATION CAPACITY IN THE EVENT OF POSSIBLE SURFACE RUNOFF IN THE AREA OF THE SILALA SPRINGS"

1. BACKGROUND. -

The Political Constitution of the Plurinational State of Bolivia, approved by Referendum of 25 January 2009 and promulgated on 7 February 2009, establishes in its Article 349 that: "I. Natural resources are property and direct, indivisible and imprescriptible domain of the Bolivian people, and will correspond to the State its administration based on the collective in-terest."

Paragraph II of Article 373 of the constitutional text states that: "II. Water resources in all its states, surface and underground, are finite, vulnerable, strategic resources and fulfill a social, cultural and environmental function. These resources cannot be subject to private ap-propriations and both they and their services will not be granted in concession and are sub-ject to a regime of licenses, registrations and authorizations in accordance with the Law."

In order to study the legal alternatives to assume the defense of the Silala springs and other water resources before the competent international instances, by means of Supreme Decree N° 2760 of 11 May 2016 the Strategic Office for the Defense of the Silala Springs and all Water Resources in the Border with the Republic of Chile (DIRESILALA).

On 6 June 2016, the Republic of Chile filed a claim with the International Court of Justice against the Plurinational State of Bolivia, regarding the dispute over the Status and Use of the Silala waters (Chile vs. Bolivia), establishing the deadline of 3 July 2018 for the presentation of the Counter-Memorial of Bolivia.

In this context, the Government of the Plurinational State of Bolivia, through Supreme Decree N° 3131 of 29 March 2017, determined the merger of the Strategic Office foe the Maritime Claim (DIREMAR) with the Strategic Office for the Defense of the Silala Springs and all Water Re-sources in the Border with the Republic of Chile (DIRESILALA), constitut-ing the Strategic Office for the Maritime Claim, Silala and International Water Resources, maintaining the institutional acronym DIREMAR.

Supreme Decree N° 3131 provides for the extension of the compe-tences and powers of the Maritime Vindication Council, of the State Agent before international tribunals, as well as of the DIREMAR. There-fore, for the fulfillment of the objectives of DIREMAR, the aforementioned Supreme Decree modifies paragraph I of Article 8 of Supreme Decree N°1747 of 2 October 2013, establishing in Article 5, paragraph V, the following attributions: "The direct contracting of goods is authorized, as well as multidisciplinary and individual consultancy services (line or product), translators and national and/or foreign professionals in various areas for advice on the processing and legal defense of the maritime claim and, other services for all the necessary legal and procedural steps on any diplomatic, jurisdictional, administrative or emergent communication action of the maritime claim; or of any other claim related to the Silala springs and/or international water resources; be in national or abroad."

With the purpose of structuring the technical and procedural defense of the waters from the Silala springs, a study with two important sections is required. The first aims to carry out the georeferencing and detailed topographic survey of the hydraulic infrastructure, springs, piezometers and referential points of interest in the Silala area. The second to know the properties of the infiltration from the hydrological characteristics of the soil in the Silala Ravines and surrounding areas, in order to determine the capacity of surface runoff formation in the topographic basin based on the hydraulic characteristics of the soil and the rainfall that occur in the area, in order to have evidence about the behavior of the basin at the surface level and the conditions that would contribute to the loss of flow in the Main Ravine.

Therefore, the DIREMAR, within the framework of its competences, requires the hiring of the Consulting Services by Product, of a nationally recognized entity dedicated to the field of topography, water and soils, with experience in technical studies in the field of hydraulic works in order to conclude the Consultancy by product "Study of georeferencing, topographic survey and determination of the infiltration capacity in the event of possible surface runoff in the area of the Silala springs."

- Study to which the Consulting Company "Campos Barron SRL Engineering & Construction Technical Consultants" access, after passing evaluations and re-views of the institutional and professional experience of the assigned team.

- Evaluation carried out by the technical, administrative and legal team of the DIREMAR, which is the team that assumes the Study Supervision.

2. OBJECTIVES

2.1 General Objective

- The general objective of the study is to carry out the georeferencing, topographic survey and the determination of the infiltration capacity and properties of the soil in the area of the Silala springs.

This will be done through the intervention of two specialized teams, one in the field of topography and geodesy and anoth-er specialized in the field of geology and soils.

2.2 Specific Objective

- Carry out the georeferencing and the detailed topographic survey of the hydraulic infrastructure, springs, piezometers and referential points of interest in the area of the Silala springs by means of dual frequency GPS C/A P Phase and Total Station.

- Determine the maximum infiltration capacity and physical properties from field trials in the Silala Ravines and surrounding areas, in order to determine the formation of sur-face runoff in the basin.

3. ACTIVITIES FULFILLED

a) Georeferencing – Topography

- The purchase of information from the Military Geographical Institute (MGI) of precision coordinates for Georeferencing was made.
- The topographic survey of precision was carried out under the concept of a georeferenced inventory of springs, wells, piezometers, weirs, water intakes and other referential points of interest on the hydrology and hydraulic infrastructure of the Silala area.
- Landmarks have been materialized in the BM points, to serve as a permanent reference for the purposes of any required redefinition.
- The detailed longitudinal and transversal topographic survey of the main and secondary canal network has been carried out.
- The topographic survey of the base of the south, north and main ravines has been carried out.
- The topographic survey of the terrain has been carried out on an area of 16 hectares from the border line.
- 37 plant layouts, profile, cross sections and maps in CAD formats ready for printing have been prepared.
- Attached in CHAPTER I is the Specialized Report of the activi-ties, field report, methodology and results.

b) Determination of the Infiltration Capacity and analy-sis of a possible runoff.

- The location of the 15 field sampling points that represent each hydrological unit has been defined through desk work (13 hydro-logical units, 1 sampling point per unit and 2 points distributed in the Main Ravine. Of these, 11 are in the area of the Near Field and 4 in the Far Field).

- 15 prospect pits have been made with depths of 1 to 2 meters deep.

Samples have been taken for field testing and sampling in order to obtain the physical and hydraulic properties of the different hydrological units of the soil at
the surface level.

• The soil samples have been collected and have been subjected tests in order to determine the physical and hydraulic properties.

to laboratory

• All the samples obtained have been interpreted by processing the data collected in the field.

• The evaluation and analysis of the basin characteristics and other properties required during the desk work have been carried out.

• **Attached in CHAPTER II is the Specialized Report of the activities, field report, methodology and results.**

STAFF OF THE CONSULTANT ASSIGNED TO THE STUDY

NAME	POSITION
Eng. Estanislao Aliaga Flores	Head of the Study
Lic. Juan Jose Quispe Lopez	Head of Surveying
Eng. German Guaygua Aguilar	Head of Geology and Soils
Arch. Marvin Rodrigo Rico Suarez	Legal Representative

Signatures:

CHAPTER I

GEOREFERENCING TOPOGRAPHICAL SURVEY
SILALA SPRINGS

Index

Content

TOPOGRAPHIC SURVEY STUDY:
"STUDY OF GEOREFERENCING, TOPOGRAPHIC SURVEY AND DETERMINA-TION OF THE INFILTRATION CAPACITY IN THE EVENT OF POSSIBLE SUR-FACE RUNOFF IN THE AREA OF THE SILALA SPRINGS"

1. BACKGROUND

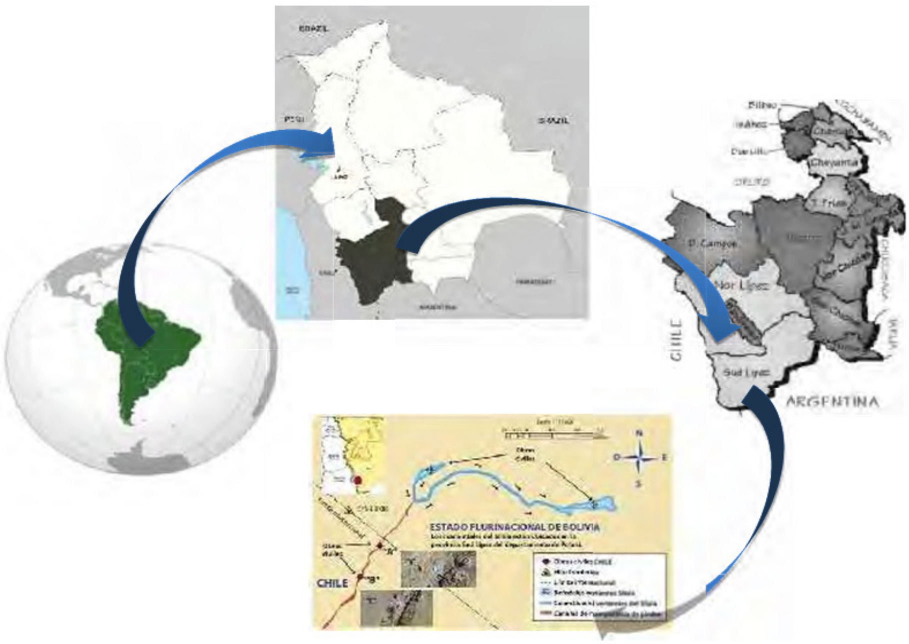
In order to comply with the part corresponding to the georeferencing and topographic survey, the topography and geodesy technical team is constituted in the region of Lipez in order to carry out the geodesic data location works, boundary markers (BMs) of the Geometric Military Institute (MGI), leveling of elevations and other fundamental aspects to be able to install the equipment and carry out the work commissioned as requested in the terms of reference (TDRs) of the Study.

2. STUDY COMPONENTS AND THEIR LOCATION

2.1. Study location
A. Physical location

The study is located in the Municipality of San Pablo de Lipez, South Lipez Province in the Department of Potosi.

FIGURE 1. MAP OF THE STUDY LOCATION



B. Geographic location.

The Study area is located at the following coordinates 7566060.00m North, 600794.00m East, Da-tum WGS-84 Zone 19 South, said coordinates referring to the Equator and the central meridian in the Universal Transverse Mercator (UTM) metric grid. This representation is used in the national geographic system for topographic surveys

The representation of the study in geodetic coordinates is between meridians of latitude 22°0’25.73”S, longitude 68° 1’24.59”W.

2.2. SATELLITE VIEW

Satellite view of the study area
FIGURE 2. SATELLITE PHOTOGRAPH OF THE STUDY AREA WITH THE LOCATION OF THE BOUNDARY MARKERS (BMs)

2.3. TOPOGRAPHIC RELIEF

The relief of the Municipality of San Pablo has extensive plains, which include steep mountains with high altitude elevations, mountainous areas with considerable slopes and extensive plains with less rough topography.

- High Mountains: They fluctuate from 3,500 to 6,008 meters above sea level, represented by the elevations of Uturuncu and San Pablo de Lipez. They present a strong slope as in the hills of Bonete and San Matias, south of San Pablo de Lipez, and moderate as in the volcanic cones on the border with Chile, Soniquera, Licancabur and Zapaleri.

- The middle mountains have altitudes from 3,900 to 5,500 meters above sea level. They have a moderate slope of 15 and 65%.

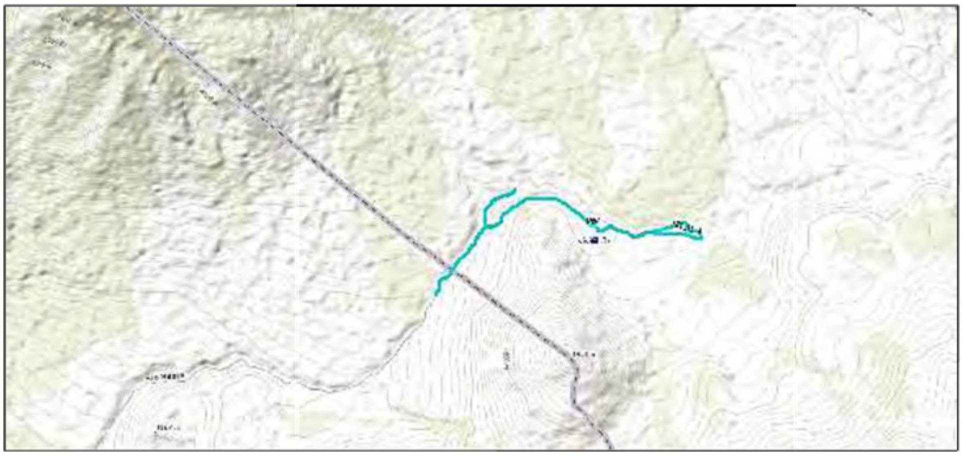
• High and medium hills located from 3,800 to 5,000 meters above sea level, with a moderate slope of 30 to 60%, modeled on rocks formed by andesites, rhyolites and dacites, and medium rocks.

• The high hills reach heights from 3,800 to 6,000 meters above sea level, represented by the hills of San Pablo de Lipez.

• The plains vary between 3,700 and 4,100 meters above sea level, with slight slopes of 2 to 5%, with great coverage of scrublands, tola formations and gramineae.

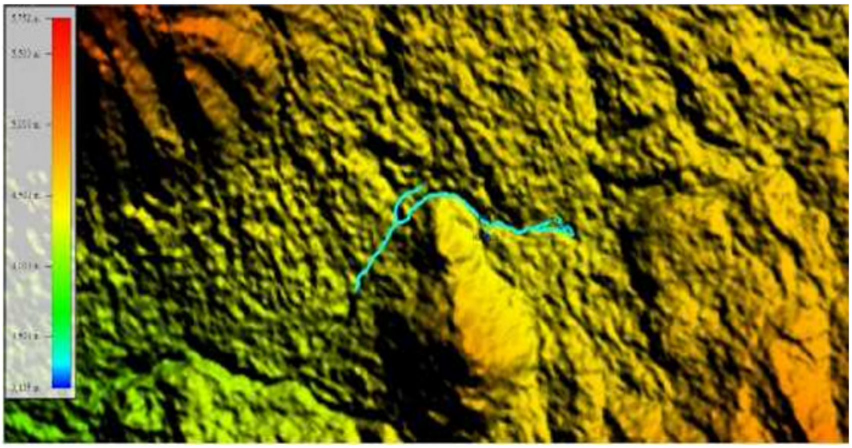
• Extensive plains with light and moderate erosion surfaces.

FIGURE 3. IMAGE OF THE TOPOGRAPHIC RELIEF OF THE STUDY AREA



The study area presents an irregular topography with moderate slopes, classified within the high hills.

FIGURE 4. DIGITAL MODEL OF THE STUDY AREA TERRAIN



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3. STUDY SCOPE.

The scope of the work is based on the following activities:

- Inspection of the intervention area
- Tracing the polygonal base
- Establishing of boundary markers (BMs) in the field
- Geodetic survey (georeferencing of boundary markers (BMs))
- Geometric leveling
- Tacheometric surveying in detail
- Office work
- Preparation of the final report containing a Monograph of Boundary Markers (BMs), topographic book, photographs, plans in editable format.

4. TOPOGRAPHIC METHODS

For the development of the study different methods were take into account such as survey-ing, geodetic survey, tachometric and geometric leveling, throughout the length of the network of springs and canals, after carrying out an inspection of the area:

- **GEOREFERENCING.** Georeferencing of the boundary markers (BMs) was carried out with-in the current system and established by the Military Geographical Institute WGS-84. (It will be
defined if it will be done in UTM or Geographical coordinates).

- **POLYGONAL**. A polygonal base was established, with the geo-referenced points, us-ing observation and calculations of successive vertices, along the entire length of ca-nals and work areas.

- **RADIATION.** The detailed surveys of radiation planimeters will be used in all closed are-as, organized based on the priority of the client.

- **CROSS SECTIONS.** The cross sections were used in all canal networks, taking detailed data
of each existing slope. Performing a section at an average of 10 measurements in the curves.

meters and smaller

- **GEOMETRIC LEVELING.** The geometric leveling was performed with the precision speci-fied by the Bolivian norm of drinking water NB-689.

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5. WORK PLAN FOR GEOREFERENCING AND TOPOGRAPHY

The technical department of topography in coordination with the technical management developed a planningof the methodologies of measure-ment in the field, using the GOOGLE EARTH software and the CIVIL 3d software, a Digital Terrain Model and the altimetric database of the entire study area were obtained.

Data was bought from the Military Geographic Institute (GMI), of the measurements made by them; data that allow us to carry out the work with the required precisions for the study.

Once the coordination of the works to be developed was carried out, the work brigades were planned and organized, both in the field and in the office, who were responsible for surveying and processing the data obtained in the field.

The qualified personnel complied with all the required requirements in accordance with the needs and field expertise, as well as selecting the tech-nical instruments and logistical material used to carry out the activities and ensuring that the information obtained during the survey complies with the indispensable requirement of quality for the designs.

The organization of all activities and topographic surveys were carried out as follows:

a) INSPECTION OF THE INTERVENTION AREA.

b) DEMARCATION OF BOUNDARY MARKERS (BMs) FOR THE POLYGO-NAL BASE.

c) GEOREFERENCING OF CONTROL POINTS.

d) DETAILED TACHEOMETRIC SURVEY.

e) INFORMATION PROCESSES IN OFFICE WORK.

a) INSPECTION OF THE INTERVENTION AREA

The reconnaissance and field inspections were developed before starting the topographic works, in the company of the topographic brigade, making a tour of the whole area, locating the limits of the study areas and identifying the critical points, location of the canals, piezometers, water springs, roads, equipment areas and all the most relevant data of the area of influence to the study.

Based on high-resolution satellite photographs, which were worked on during the planning pro-cess, the points where the polygonal boundary markers (BMs) would be located were marked.

In a preliminary way, a planimetric survey of the location for due reconnaissance was carried out with a GPS Navigator of the GARMIN Ltd. line. The preliminary inspection was carried out in a coordinated manner between the surveying brigades and those responsible for the study.

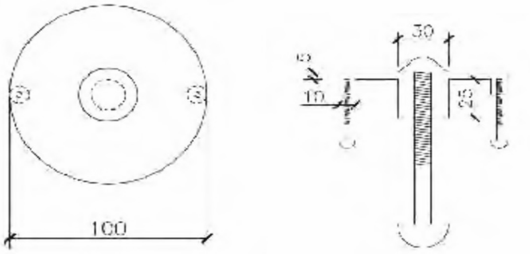
b) DEMARCATION OF BOUNDARY MARKERS (BMs) FOR THE POLYGONAL BASE.

Once the field inspection was carried out, the control points (boundary markers) were materialized, performing an in situ excavation with the excavation of 0.40 meters deep in an area of 0.30x0.30, incrusting in the head of the boundary marker an aluminum bolt, of which we detail in figure 5 its characteristics.

According to the initial planning there would be 8 control points, which was increased based on the control points found in the field and establisheby the Military Geographic Institute (GMI). This number was evaluated according to the precisions required by the study, forming part of
the main polygonal a pair was materialized every 1 km in the entire canal network.

For the fulfillment of the technical specifications of topographic surveys, aluminum bolts were made, previously designed and approved by the technical department of the company.

FIGURE 5. ALUMINUM BOLT DESIGN



For the emplacement of the Boundary Markers (BMs) of the entire polygon, the following criteria were taken into account:

- Visibility between the control points,
- Location of the Control Point, in a way that allows the most accurate and highest performance survey
- That they do not run risks of removal of their location.
- That they meet the technical specifications.

c) GEOREFERENCING OF CONTROL POINTS AND DETAILS

The geodesic networks of the study were carried out,according to the location of geographical areas, in this case 19 south of the UTM WGS 84 System.

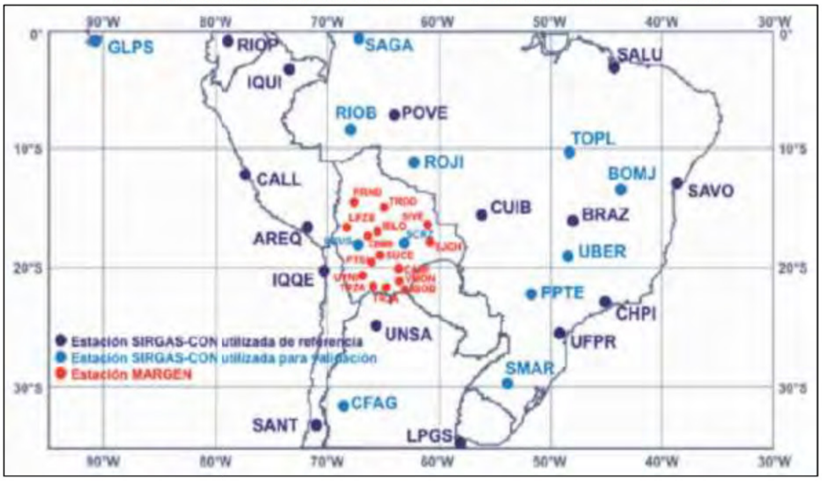
The basic works carried out were: Determination of the base triangulation, using the GPS- IGM-01, which was geo-referenced based on the continuous station located in Uyuni, the georeferencing of the study polygonal and the detailed survey of piezometers, water springs, weirs and canals, were measured with the Boundary Markers (BMs) located
Pag 6

in the field.

Based on the georeferencing of the base and polygonal triangulation of the study, the precise geographic positions of each structure contemplated in the terms of reference (TDRs) were obtained, the detailed topographic surveys were executed with a total station, which, starting from two geo-referenced points previously known, gives us as results the exact locations of piezometers, water springs, weirs and canals, which are described in the maps based on the study sup-porting polygonal.

The National Geodetic Reference Framework (MARGEN) of Bolivia is made up of a GPS network of continuous operation of 8 stations, which are linked to the continental geodesic network: Geocentric Reference System for the Americas (SIRGAS). The results obtained in this report are obtained from the advanced processing of the Engineering Manual “GEODETIC AND CONTROL SURVEYING EM 1110-1-1004” of the US Engineers Corps.

FIGURE 6. SIRGAS AND MARGEN REFERENCE STATIONS IN BOLIVIA.



The applied analysis is based on the double-difference method supported by the following processing characteristics.

1) The known values are introduced, that is, the satellite orbits, the terrestrial orientation parameters and the corrections to the Satellite atomic clocks calculated by the IGS (International GNSS Service).
2) The variations of the phase centers of the GPS antennas used in the occupation of the network are corrected by applying the absolute values obtained by the Military Geographic Institute (GMI).
3) The ambiguities of the L1 and L2 waves are determined by QIF (Quasi Ionosphere- Free) strategy, including the ionospheric models of the process software.

4) The periodic movements generated by the oceanic load on the stations are reduced ac-cording to the ocean tide model Finite Element Solution (FES 2004).
5) The delay caused by tropospheric refraction (moisture component of the troposphere) is estimated within the adjustment of the network at 2 hour intervals.
6) For traverse calculations, GPS devices Promark 100 of the Thales brand are established, which generate measurements at intervals of 15 seconds.

For the survey, the post-process and office work adjustment method used to determine the coordinates of the points in the static differential mode was used, to then place Auxiliary Control Points that formed our control polygon, throughout the study area.

d) GEOMETRIC LEVELING

In order to start the leveling activities, the data from the work done in 2017 by the Military Geographical Institute were obtained, from which the follow-ing form is obtained, level that was dragged from Laguna Colorada to the door of the Silala Military Post.

SUMMARY OF FIRST ORDER LEVELING

STUDY: FIRST ORDER LEVELING OF THE SILALA AREA		**ESTIMATOR**: SOF. 1ST. BERNARDO CALLE
DEPARTMENT: POTOSI	**HEAD OF STUDY** :	**INSTRUMENT**: Ni - 2 Y SOKKIA DIGITAL
PROVINCE: SOUTH LIPEZ	**HEAD OF COMMISSION** :	**RULES**: TAQUIMETRIC AND IMBAR

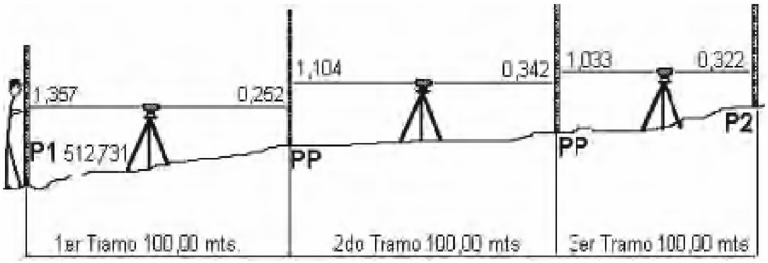
YEAR: 2017 DATE: NOV.	DESIGNATION OF THE POINT	DEPARTURE REC.	DIST. Km.	LEVELING DIFFERENCE m.	CLOSURE mm.	AVERAGE LEVELING m.	DESIGNATION OF THE PUNTO	ELEVATION OF THE POINT m.	OBSERVATIONS
	BM-BP-45-I						BM-BP-45-J	4294.0206	MGI DATA
	BM-BP-45-J	I	1.82	-1.7159					
	BPS-01	R	1.82	1.7162	0.3	-1.7161	BPS-01	4292.3046	
	BPS-01	I	1.86	5.1682					
	BPS-02	R	1.86	-5.167	1.2	5.1676	BPS-02	4297.4722	
	BPS-02	I	1.47	-5.2568					
	BPS-03	R	1.47	5.2567	-0.1	-5.2568	BPS-03	4292.2154	
	BPS-04	I	1.42	6.9776					
	BPS-05	R	1.42	-6.9770	0.6	6.9773	BPS-05	4297.6367	
	BPS-05	I	2.02	31.7883				[illegible]	

BPS-04	I	1.42	6.9776					
BPS-05	R	1.42	-6.9770	0.6	6.9773	BPS-05	4297.6367	
BPS-05	I	2.02	31.7883					
BPS-06	R	2.02	-31.7878	0.5	31.7881	BPS-06	4329.4248	
BPS-06	I	1.87	31.8231					
BPS-07	R	1.87	-31.8213	1.8	31.8222	BPS-07	4361.2470	
BPS-07	I	1.86	62.1468					
BPS-08	R	1.86	-62.1438	3.0	62.1453	BPS-08	4423.3923	
BPS-08	I	1.90	-1.3408					
BPS-09	R	1.91	1.3440	3.2	-1.3424	BPS-09	4422.0499	
BPS-09	I	2.07	52.1305					
BPS-10	R	2.08	-52.1264	4.1	52.1285	BPS-10	4474.1783	
BPS-10	I	1.57	42.4986					
BPS-11	R	1.5745	-42.4962	2.4	42.4974	BPS-11	4516.6757	
BPS-11	I	1.81	8.4974					
BPS-12	R	1.81	-8.4928	4.6	8.4951	BPS-12	4525.1708	
BPS-12	I	2.38	33.9430					
BPS-13	R	2.4	-33.9417	1.3	33.9424	BPS-13	4559.1132	
BPS-13	I	2.58	37.5773					
BPS-14	R	2.58	-37.5789	-1.6	37.5781	BPS-14	4596.6913	
BPS-14	I	2.18	-12.0484					
BPS-15	R	2.18	12.0534	5.0	-12.0509	BPS-15	4584.6404	
BPS-15	I	2.22	-12.9446					
BPS-16	R	2.21	12.9455	0.9	-12.9451	BPS-16	4571.6953	
BPS-16	I	2.07	-12.2621					
BPS-17	R	2.07	12.2633	1.2	-12.2627	BPS-17	4559.4326	
BPS-17	I	2.73	0.4777					
BPS-18	R	2.74	-0.4739	3.8	0.4758	BPS-18	4559.9084	
BPS-18	I	2.20	-1.3659					
BPS-19	R	2.20	1.3644	-1.5	-1.3652	BPS-19	4558.5433	
BPS-19	I	2.35	-35.0891					
BPS-20	R	2.36	35.0938	4.7	-35.0915	BPS-20	4523.4518	
BPS-20	I	2.06	-96.6782					
BPS-21	R	2.06	96.6755	-2.7	-96.6769	BPS-21	4426.7750	
BPS-21	I	2.14	-39.6221					
BPS-22	R	2.13	39.6198	-2.3	-39.6210	BPS-22	4387.1540	

The geometric leveling consisted of measuring the unevenness of the ground between two points. The Boundary Markers (BM) polygonal link methodology was carried out back and forth, so it started from a point and the route was closed in it.

While traveling through the polygon, intermediate readings were made between both stadia and changes of station that allow successive readings, inside which all the Boundary Markers (BMs) that are located along the polygonal were stepped on, for the proper altimetric adjustment. As seen in the image.

FIGURE 9. REPRESENTATION OF THE GEOMETRIC LEVELING



The leveling of the Boundary Markers (BMs) was carried out in three reaches; the first reach started from MRGV-BPS-22 located in the Silala Military Post in the direction of BM01 located at the head of the bofedales of the South Canal; the second leveling reach was made starting from MRGV-BPS-22 towards BM-03 in the northeast direction, performing visualizations of intermediate reaches in an average of 45 meters in length, making readings of the sights, which are equidistant from the equip-ment, until reaching each Boundary Marker (BM) to give the final height to the control point. And finally, the third leveling reach was made towards the border between Bolivia and Chile, where BM-08 is located, thus providing definitive heights of all the Boundary Markers (BMs) that are part of our main polygonal.

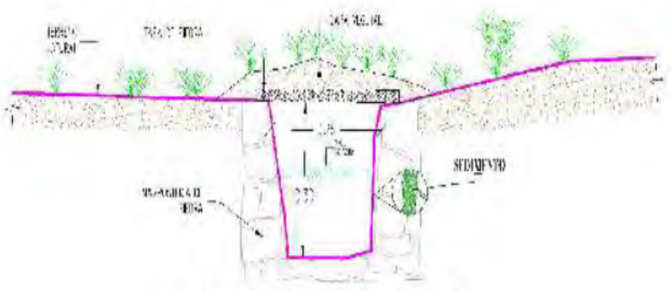
e) DETAILED TACHEOMETRIC SURVEY

Once the 10 points of the main polygonal were geo-referenced, a detailed measurement of the water springs was carried out, making the first station at the GPS-IGM-01 point, and making the reference (Back Sight) in BM-01 starting with coordinates and final heights.

During the field tests carried out on the cross sections, the canal points were measured, ap-proximately every 10 meters, taking points on the upper part of the left margin and on the lower part of the right margin, identifying the sole heights and the canal axes with the great-est detail where required. The strip that was maintained to make the measurements is taken according to the characteristics of the terrain, taking as reference the minimum of the terms of reference (TDRs), which was expanded, based on the field data, determining the limits of the bofedal.

From the surveys carried out, it is shown that not only is there a Main Canal, but also that from the location of the water springs, the contributing branches are different, reason why a north or south BRANCH coding is defined respectively, and also the length, slope,corresponding numbering and the type of material in the reach (RAMAL-SUR-01 MºPª).

In the case of the measurements of canals and water springs in the north –where the largest number of canals are available– it can be evidenced that the greater amount of the network of contributing branches is covered with flat stones, so the coding for this case is (CT) covered canals. This prevents to carry out a precise measurement since it prevents the intermediate readings in the canal's sole heights, and also in the cover because of the grown vegetation.



SECCION TIPO CANAL TAPADO (CT)
CANALES NORTE

- GEOREFERENCING OF WATER SPRINGS.

The georeferencing of water springs was measured as we moved forward from northeast to southeast, thanks to the points that were identified with iron rods ø6 and the respective description for each water spring; we proceeded to the location in the field with leveled prisms.

These rods not only indicated the location of the water spring, it also showed that they are the headwaters of the canals, forming a network of branches that contribute to the Main Canal. It was these rods that helped in the surveying of the northern canals, which showed us the direction taken by the branches towards the Main Canal. These data is described in the maps.

From the measurements taken, the following table is obtained.

TABLE OF COORDINATES OF WATER SPRINGS

Nº	EAST	NORTH	HEIGHT	DESCRIPTION
1	601004.544	7566387.533	4362.229	OCN-001
2	600985.782	7566363.324	4359.189	OCN-002
3	600973.792	7566340.893	4357.365	OCN-003
4	600946.944	7566336.212	4356.413	OCN-004
5	600944.534	7566335.288	4356.214	OCN-005
6	600933.758	7566329.499	4355.491	OCN-006
7	600912.584	7566318.922	4353.973	OCN-007
8	600905.533	7566314.891	4353.440	OCN-008
9	600887.195	7566319.743	4354.531	OCN-009
10	600868.939	7566288.900	4352.144	OCN-010

12	600857.769	7566279.831	4351.532	OCN-012
13	600843.492	7566281.723	4350.329	OCN-013
14	600815.795	7566308.965	4351.314	OCN-014
15	600818.669	7566308.507	4351.469	OCN-015
16	600824.052	7566299.541	4351.181	OCN-016
17	600827.840	7566289.794	4349.595	OCN-017
18	600837.328	7566274.457	4350.175	OCN-018
19	600834.213	7566264.670	4350.124	OCN-019
20	600834.050	7566259.363	4349.909	OCN-020
21	600831.075	7566255.795	4350.588	OCN-021
22	600808.046	7566264.598	4348.464	OCN-022
23	600780.313	7566316.415	4356.656	OCN-023
24	600785.647	7566299.008	4351.264	OCN-024
25	600789.643	7566274.248	4348.582	OCN-025
26	600804.937	7566255.481	4348.465	OCN-026
27	600812.020	7566247.491	4349.305	OCN-027
28	600798.869	7566240.125	4347.929	OCN-028
29	600804.295	7566234.130	4350.011	OCN-029
30	600795.766	7566236.855	4348.251	OCN-030
31	600796.786	7566235.969	4348.631	OCN-031
32	600795.748	7566233.711	4348.875	OCN-032
33	600779.592	7566225.654	4348.037	OCN-033
34	600777.333	7566225.604	4347.107	OCN-034
35	600775.867	7566223.661	4347.082	OCN-035
36	600769.064	7566220.103	4347.163	OCN-036
37	600764.964	7566312.969	4356.875	OCN-037
38	600761.069	7566300.161	4353.516	OCN-038
39	600756.852	7566293.710	4352.478	OCN-039
40	600747.900	7566285.386	4351.900	OCN-040
41	600768.589	7566280.901	4349.457	OCN-041
42	600759.106	7566273.416	4349.809	OCN-042
43	600695.264	7566302.487	4359.439	OCN-043
44	600742.966	7566306.587	4355.814	OCN-044
45	600728.596	7566289.055	4354.177	OCN-045
46	600737.949	7566282.983	4351.350	OCN-046
47	600744.099	7566275.703	4350.624	OCN-047
48	600727.619	7566268.254	4350.456	OCN-048
49	600731.974	7566263.909	4349.914	OCN-049
50	600734.470	7566260.435	4349.869	OCN-050
51	600720.510	7566264.516	4350.566	OCN-051
52	600716.269	7566257.545	4349.552	OCN-052
53	600722.648	7566254.320	4348.694	OCN-053
54	600708.418	7566246.405	4348.574	OCN-054

55	600702.570	7566239.523	4348.401	OCN-055
56	600724.633	7566244.980	4347.394	OCN-056
57	600730.122	7566245.309	4347.768	OCN-057
58	600738.392	7566239.061	4347.166	OCN-058
59	600749.759	7566215.851	4345.634	OCN-059
60	600721.771	7566195.333	4343.622	OCN-060
61	600719.769	7566180.766	4342.630	OCN-061
62	600616.363	7566052.493	4330.602	OCN-062
63	600627.259	7565973.262	4324.874	OCN-063
64	600632.839	7565963.152	4323.778	OCN-064
65	600633.059	7565948.857	4322.566	OCN-065
66	600632.125	7565947.583	4322.826	OCN-066
67	600633.270	7565932.574	4321.437	OCN-067
68	600667.561	7565950.108	4323.444	OCN-068
69	600671.985	7565942.388	4323.587	OCN-069
70	600654.709	7565908.625	4318.880	OCN-070
71	600647.828	7565895.779	4317.921	OCN-071
72	600652.987	7565892.572	4318.449	OCN-072
73	603126.569	7565889.025	4407.202	OCS-001
74	603127.121	7565886.623	4407.239	OCS-002
75	603126.869	7565884.497	4407.177	OCS-003
76	603127.180	7565882.402	4407.192	OCS-004
77	603120.132	7565914.779	4407.015	OCS-005
78	603119.407	7565913.194	4407.034	OCS-006
79	603103.142	7565925.585	4406.530	OCS-007
80	603108.546	7565911.391	4406.500	OCS-008
81	603111.952	7565906.932	4406.601	OCS-009
82	603107.460	7565905.251	4406.450	OCS-010
83	603109.038	7565902.452	4406.429	OCS-011
84	603090.410	7565914.361	4406.013	OCS-012
85	603095.138	7565896.176	4405.979	OCS-013
86	603049.766	7565915.344	4405.357	OCS-014
87	602888.255	7565873.423	4403.261	OCS-015
88	602859.281	7565864.999	4402.737	OCS-016
89	602899.772	7565804.806	4403.426	OCS-017
90	602884.890	7565796.700	4403.314	OCS-018
91	602838.104	7565800.543	4402.686	OCS-019
92	602821.778	7565792.503	4402.420	OCS-020
93	602823.481	7565819.617	4402.390	OCS-021
94	602819.729	7565812.613	4402.445	OCS-022
95	602807.569	7565824.628	4402.524	OCS-023
96	602796.781	7565848.828	4402.452	OCS-024
97	602779.062	7565847.371	4402.153	OCS-025
98	602719.606	7565833.768	4400.697	OCS-026

99	602396.794	7565817.515	4393.448	OCS-027
100	602389.873	7565827.341	4393.273	OCS-028
101	601872.071	7565993.441	4381.969	OCS-029
102	601874.336	7566011.758	4382.540	OCS-030
103	601867.989	7566015.965	4382.505	OCS-031
104	601863.955	7566019.885	4382.364	OCS-032
105	601859.428	7566013.346	4380.876	OCS-033
106	601839.820	7566027.084	4381.128	OCS-034
107	601835.224	7566041.740	4381.621	OCS-035
108	601815.606	7566043.096	4381.218	OCS-036
109	601806.665	7566042.564	4381.066	OCS-037
110	601802.673	7566040.206	4381.157	OCS-038
111	601803.756	7566056.919	4380.520	OCS-039
112	601801.526	7566058.052	4380.515	OCS-040
113	601803.084	7566076.577	4381.764	OCS-041
114	601784.900	7566080.619	4380.204	OCS-042
115	601726.083	7566142.507	4379.052	OCS-043
116	601678.955	7566171.187	4378.674	OCS-044
117	601098.128	7566236.748	4361.597	OCS-045
118	601099.556	7566235.399	4360.919	OCS-046
119	601090.150	7566227.478	4360.915	OCS-047
120	601076.898	7566214.600	4360.468	OCS-048
121	601071.981	7566212.142	4360.513	OCS-049
122	601067.719	7566204.669	4360.108	OCS-050
123	601053.024	7566195.428	4359.328	OCS-051
124	601054.451	7566192.521	4357.934	OCS-052
125	601047.395	7566193.591	4359.399	OCS-053
126	601050.437	7566189.943	4357.808	OCS-054
127	601017.103	7566179.338	4357.007	OCS-055
128	601009.408	7566182.002	4358.841	OCS-056
129	601007.843	7566164.832	4352.210	OCS-057
130	601004.736	7566172.525	4355.470	OCS-058
131	600996.865	7566173.561	4356.768	OCS-059
132	600997.687	7566170.193	4355.087	OCS-060
133	600991.968	7566169.799	4356.442	OCS-061
134	600987.699	7566157.647	4351.816	OCS-062
135	600961.715	7566148.822	4352.839	OCS-063
136	600957.475	7566138.324	4350.200	OCS-064
137	600927.906	7566103.407	4348.495	OCS-065
138	600742.414	7565912.805	4323.728	OCS-066

- **GEOREFERENCING OF PIEZOMETERS.**

For this work, the same route as the water springs was covered. As we move forward, the piezometers were measured at the ground level in three of the four corners of the concrete cast, in order to obtain a correct triangulation during the creation of the maps. And to obtain the coordinates, which are points in the center of the concrete block, the following coordinates are obtained.

TABLE OF PIEZOMETER COORDINATES

Nº	EAST	NORTH	HEIGHT	DESCRIPTION
1	7565638.267	603083.175	4413.853	DS-10
2	7565691.913	603374.338	4409.740	DS-09
3	7565735.316	603478.704	4413.204	DS-06
4	7565860.828	603354.328	4413.140	DS-5T
5	7565865.855	603347.686	4413.141	DS-5P
6	7565919.779	603298.671	4412.711	DS-4P
7	7565923.225	603290.299	4412.583	DS-4S
8	7565794.747	603205.219	4407.605	DS-08
9	7565848.430	603066.526	4406.165	DS-07
10	7565838.313	602931.083	4403.539	DS-38S
11	7565836.840	602928.850	4403.542	DS-39D
12	7565755.957	602857.718	4406.091	DS-11
13	7565687.533	602580.935	4403.634	DS-13
14	7565826.716	602553.722	4401.512	DS-12
15	7566099.265	601874.032	4389.470	DS-17
16	7566047.439	601810.947	4380.994	DS-16
17	7565991.959	601747.359	4391.670	DS-18
18	7566208.233	600937.747	4382.978	DS-30
19	7566311.810	600860.885	4353.255	DS-24S-24P
20	7566378.659	601038.486	4362.799	DS-23
21	7566489.069	600808.672	4398.895	DS-25
22	7566349.674	600598.464	4368.499	DS-27
23	7565902.205	600638.318	4318.399	DS-37
24	7565453.930	600290.512	4283.862	DS-35
25	7565433.564	600279.457	4281.596	DS-31
26	7565433.893	600270.321	4281.764	DS-32

- GEOREFERENCING OF WEIRS.

For the georeferencing of weirs, the same cross-sectional procedure was followed, so the following table was obtained.

TABLE OF WEIR COORDINATES

Nº	EAST	NORTH	HEIGHT	PROGRESSIVE	DESCRIPTION
1	7565891.227	603033.528	4404.453	0+099.08	V-01
2	7565843.271	602786.879	4401.495	0+353.14	V-02
3	7565832.136	602322.829	4390.766	0+850.68	V-03
4	7566263.134	601470.873	4374.972	1+868.32	V-04
5	7565911.234	600659.920	4318.587	2+861.37	V-05

6	7565910.262	600652.384	4318.599	0+680.62	V-06
7	7565879.255	600625.175	4316.364	2+908.94	V-07
8	7565600.381	600439.746	4293.574	3+255.75	V-08
9	7565406.459	600264.800	4279.309	3+522.00	V-09

The weirs and hydraulic gauges were measured in their width and depth, as we moved forward in the canal surveying, therefore their locations are accurate. For the description of the weirs we will put the progressive and the coordinates in the detailed maps.

PHOTOGRAPH OF WEIRS

f) INFORMATION PROCESSES THROUGH OFFICE WORK.

The office data processing was developed within the following stages:

Review and download of information

•For precision GPS: Transfer of raw data from the GPS memory to the hard disk of a computer, through a mini USB cable connection interface.

•From these data, RINEX files will be generated, standard exchange data format compatible with various processing programs and coordinates adjustment. The software that will be used for this work will be, GNSS Solutions v3.10.11, and Map Source, respectively for each team.

•**FOR TOTAL STATIONS,** the transfer of topographic equipment information (Total Stations and engineer levels) is carried out through specialized programs by each SOKKIA LINK team.

• **Migration, transcription and calculation of field data**

The field data (North and East coordinates and Height) stored in the topographic equipment was migrated to a computer, and using the appropriate software, we will proceed to make the adjustments of each reach between Border Markers (BMs), by means of a predesigned spreadsheet in Excel and the calculation of field data.

All compensations, both angular and altimetric, will be verified daily at the end of the working day for the verification of data.

• **Drawing of Topographic Maps and Adjustments**

A transfer of the North, East and Height coordinates was made adjustments, thanks to the predesigned spreadsheets.with the necessary

As for the subsequent processing of the data obtained, the updated spreadsheets were created for the transfer of data to a graphic processor software (CIVIL 3D 2018).

And we proceeded to the drawing of coordinates, heights, contour lines, ravines, roads, canals, etc., thus creating topographic maps for the study report.

• **Spreadsheets and Final Data**

From the processes and adjustments made, the following was obtained: the leveling calculation spreadsheet, the Polygon Adjustment Spread-sheets, the list of the East, North and Height coordinates in digital format of the entire topographic survey carried out.

• **RESULTS**

The compilation and systematization of this information will allow having a document that identifies the topographic conditions of the terrain.

6. REFERENCE REGULATIONS

The reference regulations for the development of the study are adopted according to the measurement methodology, the calculations made for the final worksheets that are shown in the annexes of the document.

6.1. TECHNICAL PARAMETERS

- Ellipsoid: GLOBAL
- Semi-major axis: 6378137.000 m
- Reverse crush: 298.257223563

• Horizontal Datum: WGS-84
• Vertical Datum MRGV-EPB (Vertical Geodetic Reference Framework – Plurinational State of Bolivia)
• Projection: U.T.M.
• Grid: C.U.T.M.
• Zone: 19s
• Central Meridian: 69º 00’ 00.0000” West
• False East: 500000.000 m
• False North: 1000000.000 m

6.2. TAQUIMETRIC SURVEYS.

For the precisions required for this survey, we use as reference the Bolivian Regulations for Drinking Water Systems NB-689, as it is the closest to the concept of this study, adopting the following parameters.

Angular error:

$$E = \varphi_f - \varphi_f$$

Where:
E = A e
φ_f = C a h i d d
φ_f = S a h i d d

Permissible angular error for the closing of main polygonal:

$$E = 15'' \sqrt{N}$$

Where:
E = A e i s
N = N o a o the P

Permissible angular error for the closing of secondary polygonal:

$$E = 20'' \sqrt{N}$$

Where:
E = A e i s
N = N o a o the P

Angular compensation:

$$C = -\frac{E}{N}$$

Where:
C = A co
E = A e
N = N o a o the P

For the precisions required for this survey, we use as reference the Bolivian Regulations for Drinking Water Systems NB-689, as it is the closest to the concept of this study, adopting the following parameters.

Longitudinal Error:

$$E_L = \sqrt{E\Delta N^2} + E\Delta E^2$$

Where:

$E_L = L \quad e$

$E\Delta N = L \quad E \quad t\ the\ N \quad h$

$E\Delta E = L \quad E \quad t\ the\ E$

Permissible Longitudinal Error:

$$E_L = 0.020\sqrt{\sum L}$$

Where:

$E_L = P \quad L \quad T$

$L = T \quad H \quad D$

Permissible longitudinal error for closing of main polygonal:

$$E_{l_i} = 1:5000$$

Where:

$E_{l_i} = P \quad lo \quad e$

Permissible longitudinal error for closing of secondary polygonal:

$$E_{l_i} = 1:3000$$

Where:

$E_{l_i} = P \quad lc \quad e$

Longitudinal Compensation:

$$C_L N_i = -\left(\frac{E\Delta N}{\sum L_i}\right) L$$

$$C_L E_i = -\left(\frac{E\Delta E}{\sum L_i}\right) L$$

Where:

$C_L N_i = N \quad h\ L \quad C$

$C_L E_i = E \quad L \quad C$

$E\Delta N = L \quad E \quad t\ the\ N \quad h$

$E\Delta E = L \quad E \quad t\ the\ E$

$L_i = H \quad D \quad p \quad p$

$L = T \quad ho \quad d$

The results of the compensation made are presented in the adjustment spreadsheets of the Polygon Adjustments Annex.

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6.3. FUNDAMENTAL PARAMETERS FOR THE CALCULATION OF THE COMBINED FACTOR OF ATMOSPHERIC PRECISION

CALCULATION OF THE SCALE FACTOR

SCALE FACTOR = E

Formula - E = Ko*(1+(XVIII)q^2+0.00003q^4)

q = 0.000001 * x'

Ko = 0.9996 Scale factor in the central meridian

Merid.Cent =	**500000.000**
x' =	**77939.423**
q =	**0.0779394**
q*2-	**0.0060746.**
q*3-	**0.0004734**
qM-	**0.0000369**
XVIII =	**0.0123700**
(XVIII) q^2 =	**0.0000751**
(0.00003) qM =	**1.10701E-09**
Ko = 0.9996*(1 +	**7.51433E-05**
Ko =	**0.9996751**

6.4. GEOMETRIC LEVELING.

According to NB-689, the precisions required for the adjustment of the leveling data must have the following limits:

Permissible error of direct leveling of main polygonal:

$$E = 10m \sqrt{L}$$

Where:
$E = D$ p le e ,in m
$L = L$ le h (N° o k)

Permissible error of direct leveling of secondary polygons:

$$E = 20m \sqrt{L}$$

Where:
$E = D$ p r le e ,in m
$L = L$ le h (N° o k)

Permissible leveling error for polygonal link with BM:

$$E = 10m \quad L$$

Where:
$E = D$ p le e ,in m
$L = L$ le h (N° o k)

Leveling compensation for polygonal link with BM:

Leveling compensation for polygonal link with BM:

$$C = \frac{\sum L_p}{L_t} * E$$

Where:

C = E cc e

L_p = P le h le

L_t = T le h le

E = E in le ,in m

The results of the leveling performed are presented in the adjustment spreadsheets of the Annex on Leveling.

7. EQUIPMENT DESCRIPTION.

For the topographic survey, all the necessary instruments and equipment were used, both for the field and for office work. Simultaneously, said instruments and equipment will be detailed below:

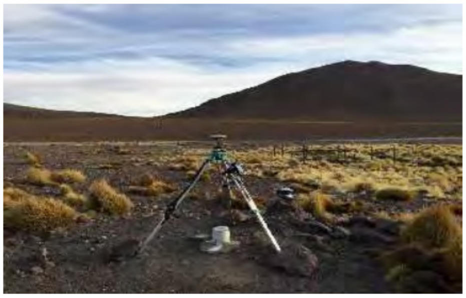
7.1 2 LAPTOPS

o ASUS brand
o i7 processor
o RAM memory of 16Gb
o Storage Solid 500 GB SDD

7.2. ELECTRONIC DISTANCE METER

o Measurement range from 0.05 to 50 meters
o Accuracy of +/- 1.5 mm
o Measuring time of 0.5s min; max. 4s
o Size 100x58x32 mm

7.3. PRECISION GPS



o Promark 100 model of the THALES line
o Of 14 parallel canals for signal reception L1
o Update rate of 1Hz
o Horizontal precision of 0.005 m + 1ppm
o Vertical precision of 0.01 m + 2ppm
o Observation time goes from 4 to 40 minutes according to distance
o PDOP <4

7.4. GPS NAVIGATOR

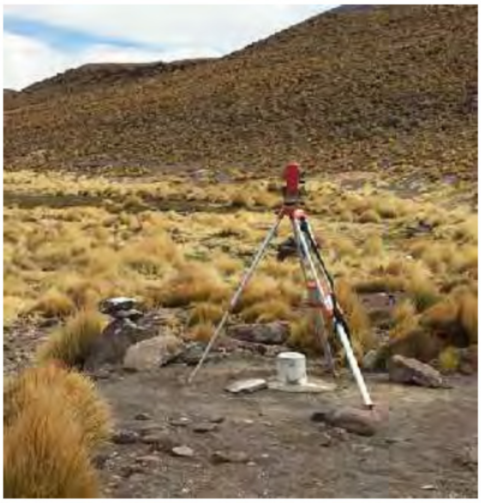
o GARMIN of the GARMIN Line Ltda.
o Model GPSMAP 76CSx
o Accuracy 3 – 5 meters with typical 95%
o Speed of 0.05 m/s in continuous state
o 128Mb of storage in micro SD

7.5. TOTAL STATION

o SOKKIA SET-510
o Precision 5”
o Fine Prism +/- 2mm + 2ppm * D
o Visual scope of measurement with prism of 5 km
o Visual scope of measurement without prism of 0.50 to 50 meters
o 45mm opening (EDM: coaxial)
o Atmospheric correction and terrestrial curvature
o 30x magnification

7.6. DIGITAL LEVEL

o SOKKIA Japanese Line
o Model SDL 50
o Precision of 1km of double leveling 1.0 mm
o Compensation range of +/- 15' min.
o Measuring range 1.6 to 100 meters.



7.7. PRISMS, STADIMETRIC RETICLES

o Two prisms with carbon wires
o Two milestones expandable to 3 meters
o Two stadimetric reticles for digital level with bar code
o Precision metric tapes
o Measuring tapes

7.8. ANNEXES

For information regardingprocessing spreadsheets, georeferencing, polygon adjustmens and other details, see the Topographic Annexes.

CHAPTER II

DETERMINATION OF THE INFILTRATION CAPACITY IN THE EVENT OF POSSIBLE SURFACE RUNOFF IN THE AREA OF THE SILALA SPRINGS

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"GEOREFERENCING AND TOPOGRAPHIC SURVEY, AND DETERMINATION OF THE INFILTRATION CAPACITY IN THE EVENT OF AN EVENTUAL SURFACE RUNOFF IN THE AREA OF THE SILALA SPRINGS"

SAN PABLO DE LIPEZ MUNICIPALITY – POTOSI DEPARTMENT

1. INTRODUCTION

The present technical report contains the information obtained from the field surveys completed by gathering information on the surface, excavating fifteen (15) open trial pits, at a depth of 1.50 meters, and taking soil samples to attain knowledge on the granulometric characteristics of the soils in different areas of the Silala Springs, where the granular materials are exposed. This survey also comprised the completion of infiltration tests necessary to determine the maximum infiltration capacity and hydraulic properties of the soils on basis of field tests and laboratory data-processing to then analyze the occurrence of surface runoff in the basin found within the limits of the San Pablo de Lipez municipality, Potosi Department (Figure No. 1).

Figure No. 1. Area surveyed where the trial pits where excavated and the infiltration tests completed

Figure No. 2 below presents a satellite image taken from Google Earth where it is possible to have a glance at the location of the fifteen (15) sampling and test points assigned in the field as a function of the distribution of the soils' hydrological units. Most of the granular materials of the area surveyed can be classified as silt-matrix sands, the sub-rounded to rounded characteristics of which give them a high infiltration rate that allows water to infiltrate from the surface and reach the underlying rocks.

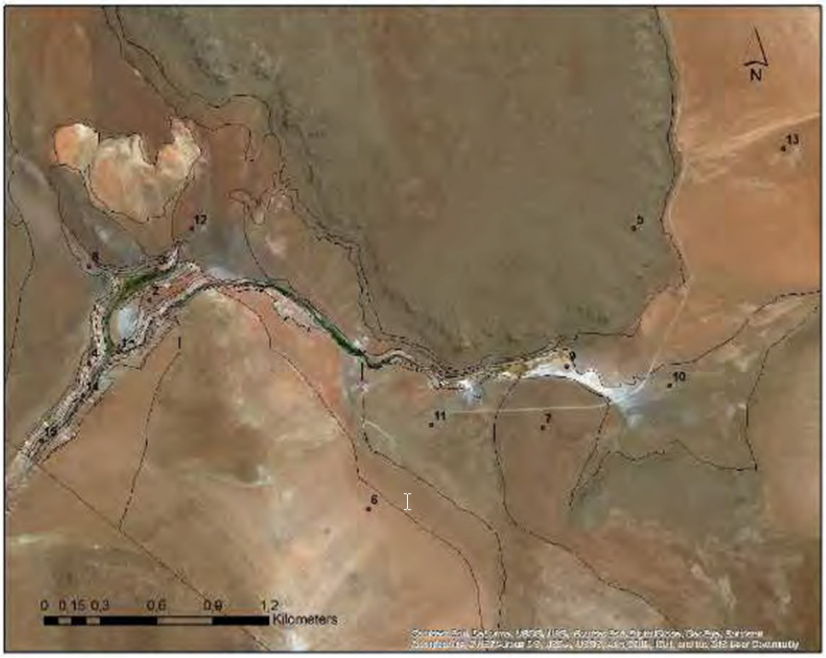

Figure No. 2. Area surveyed. Location of the trial pits and infiltration tests

2. OBJECTIVE

The main objective of the present survey is to determine the maximum infiltration capacity and physical properties of the materials contained within the fifteen assigned points on

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basis of field tests (excava-tion of open trial pits) in the area of the Silala Springs and the vicinities so as to as-sess the occurrence of surface runoff.

3. SPECIFIC OBJECTIVES

- To excavate fifteen open trial pits
- To identify the soil types of the area by means of the SUCS System soil classification
- To take samples and perform tests in the field to identify the physical and hydraulic properties of the different hydrological units of the soil at the surface level.

4. METHODOLOGY

The initial stage comprehended an identification of the hydraulic characteristics of the granular materials in the field by completing infiltration tests with the double ring methods and an examination of the subsurface materials.

Figure No. 3. Middle section of the Silala bofedals. This area comprises thin thickness gravel, sands, and organic silt and clay development which form bofedals due to the fact that these materials allow water to infiltrate and reach the underlying rocks before infiltrating further

The subsurface examination is intended to obtain a representative picture of the different soil types that each surveyed point is likely to present. After excavation was completed, altered soil samples were taken to perform different tests at the Consultant's Soil Laboratory. The different soil horizons of the fifteen points surveyed were then described, classifying the different areas where roots were found (Figure No. 4).

The laboratory works were completed to determine the content of natural humidity in the samples taken, to classify their granulometry and identify their Atterberg limits, including the porous elements that allow surface water infiltration. Test were completed to determine the humidity content in the soil samples in terms of the latter's weight in dry conditions.

Figure No. 4. Trial pit excavation, SLL-15, on colluvial fan deposits composed of sands that contain clast fragments. One of the sections where infiltration tests were completed.

The liquid and plastic limits are intended to identy and classify the soils. The gran-ulometric analysis test serves to determine the relative proportions of the different grain sizes of a specific soil mass. In the practice, the materials are grouped by size ranges. A specific amount of material is obtained by sieving it from large to mi-nor diameter screens. The amount retained bears a relation with the sample weighted.

5. LOCATION OF THE TEST SITES

The location of observation points responds to a preliminary geological appraisal that takes into consideration the units that might present infiltration conditions that are likely to create surface runoff. The fifteen trial pits were excavated to perform a clerical comparison with the infiltration tests completed with the double-ring method (Figure No. 5).

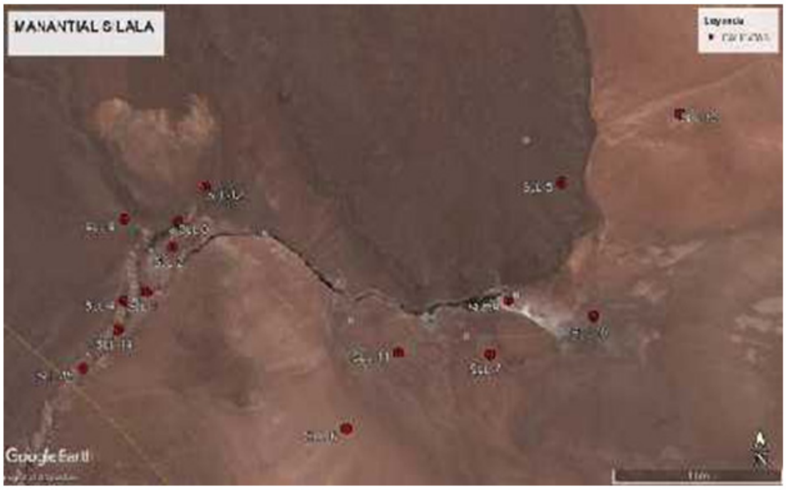

Figure No. 5. Location of the fifteen open trial pits excavated

The coordinates of the excavated trial pits where samples were taken for their laboratory analysis are presented below

TRIAL PIT	***U.T.M. EAST COORDINATE***	***U.T.M. SOUTH COORDINATE***
TRIAL PIT S L-1	600702 m E	7565914 m S
TRIAL PIT S L-2	600869 m E	7566190 m S
TRIAL PIT S L-3	600903 m E	7566350 m S
TRIAL PIT S L-4	600545 m E	7565857 m S

TRIAL PIT S L-5	603457 m E	7566566 m S
TRIAL PIT S L-6	602038 m E	7565089 m S
TRIAL PIT S L-7	602967 m E	7565516 m S
TRIAL PIT S L-8	600546 m E	7566366 m S
TRIAL PIT S L-9	603096 m E	7565843 m S
TRIAL PIT SLL-10	603645 m E	7565740 m S
TRIAL PIT SLL-11	602375 m E	7565532 m S
TRIAL PIT SLL-12	601092 m E	7566563 m S
TRIAL PIT SLL-13	604251 m E	7566988 m S
TRIAL PIT SLL-14	600515 m E	7565685 m S
TRIAL PIT SLL-15	600290 m E	7565449 m S

Table No. 1. Location of the fifteen (15) trial pits excavated to define the infiltration capacity in the event of surface runoff in the area of the Silala Springs (DIREMAR, 2018)

6. DESCRIPTION OF THE DOUBLE-RING TESTS COMPLETED IN THE FIELD

Infiltration in porous media isdefined as the process through which water infiltrates from the surface and reaches underlying layers. Many factors related with soil structure affect infiltration and the movement of water with-in. If water is poured on a specific soil surface at a constant and uniform velocity, the water eventually reaches a point in which the inpouring ve-locity exceeds the soils capacity to absolve water, accumulating the latter on the surface and forming runoff if the gradient conditions so permit[1].

Infiltration velocity depends on several factors, such as the thickness of water used for irrigation— or that of rain—water temperature, and the soil, struc-ture, compaction, texture, stratification, content of humidity, aggregation and microbial activities.

1 [sic] No footnote is actually inserted.

It should also be reminded that water infiltration has a fundamental role in runoff processes as a response of a specific event precipitation in a given basin. Depending on their scale, rains of simi-lar intensities can produce different flowrates; this is of great practical importance given that their velocity generally determines the amount of water that runs off on the surface and the risk of "hydric erosion."

The double-ring method serves to determine infiltration in granular soils. It consists in saturating a soil portion limited by two concentric rings to measure the variations in the water level within the inner ring. The time it will take to reach final saturation conditions depends on the initial humidity, texture, soil structure, the thickness of the horizon through which the water moves, and the height of water inside the inner ring.

During the tests completed for this survey, the saturation times lower when:

- A rock mass was found near SLL-2, SLL-3, SLL-4, SLL-5 and SLL-13;
- The individual size of soil particles (texture) sands silt matrix had a higher percentage [sic].
- Greater thickness of the soil horizon through which water circulates, in the exactions made these levels surpasses the 1.60 meters of depth.
- The altitude exceeded the water film in the inner ring.

Infiltration velocity is when the water penetrates the soil through the surface. Normally, it is expressed in mm/h and its maximum value is consistent with the hydraulic conductivity of the saturated soil (Figure No. 6).

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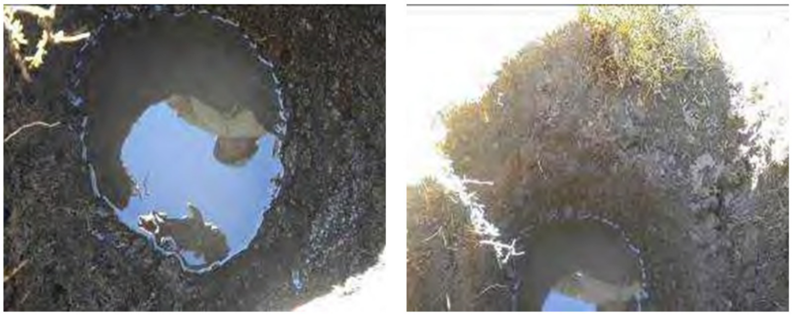

Figure No. 6. Infiltration test completed in the SLL-1 trial pit. It did not present a drop in the water level during the first fifteen minutes of the test.

The following aspects were taken into account to perform the nine tests described herein:

- The best location choice for the rings within the different points identified.
- Carefulness when driving the rings into the soil, filling them with water, taking measures at different time intervals.
- Caution not to locate the rings on compacted areas. Areas that have been compacted by vehicles or people present a reduced infiltration rate in comparison to surrounding areas (particularly in fine texture soils). Care was taken not to compact the soil with stomped-on samples, both when choosing the proper sites and driving the rings into the soil.

The rings used are made of iron in consideration of the high presence of sands in the sectors surveyed. In the most accepted model, the equipment consists of two ring sets. The diameter of the smaller ring is of 30.5 cm and that of the external ring is of 43 cm. A leveler to keep the rings in horizontal position, a rubber mallet and a thermometer (Figure No. 8).

Figure No.7. Infiltration test completed in the SLL-4 trial pit, in silt-matrix sands, using a single ring due to the problems experimented when trying to set up the double ring infiltrometer

With the materials described above, nine infiltration tests were completed in locations with similar granulometric characteristics. The tests for the SLL-2 and SLL-5 sites were interrupted due to the fact that the water seeped inside the rings because of the ground-ring contact, perhaps as a result of the presence of a rock mass. The trial pits were excavated at a separation distance of 10.00 centimeters [sic] close to the trial pits described, making detailed information on the soil profiles available (Figure No. 9).

The clerical work consisted of calculating the instant infiltration velocity and the accumulated infiltration on basis of the data collected from the nine tests completed (SLL-6, SLL-7, SLL-8, SLL-9, SLL-9, SLL-10, SLL-11, SLL-12, SLL-14, and SLL-15 [sic].

6.1. DRIVING THE DOUBLE-RING INFILTROMETERS INTO THE SOIL, FILLING THE RINGS WITH WATER AND TAKING THE MEASUREMENTS

These three operations had to be completed without altering the soil, avoiding to alter the natural porosity. As these are factors that determine the soil absorption capacities are manifold and easily altered, it is convenient to perform the operations by following a set of basic rules, namely:

1. Driving the rings into the chosen location ensuring that neither rocks nor roots are present below, as they might easily deform them.

2. Ensuring that the inner ring is completely anchored in the exterior.

3. The rings are driven into the ground at the same depth throughout their perimeter and at the same time. Rings thatare inclined or that have not been driven into the ground homogeneously present a higher risk of water leakage. Both the outer ring and the inner ring must reach up to 5.00 cm in depth (preventing lateral leakage to a greater extent).

4. After driving the rings into the ground, they must be carefully filled with water, always starting from the outside and protecting their base with a plastic bag, preventing the water from having a direct impact on the bare ground and from causing the particles to unclog and seal the pores.

5. Ensuring that there are no water leaks caused by the presence of oversize in the surroundings [sic].

6. The same water level must be maintained inside both rings; a 10-centimeter water-column must initially be filled and the level must be prevented from dropping below the 5 cm.

7. The measurements were made at regular intervals of either time or water-film decline inside the rings, making it easier to identify when the absorption rate remains constant (Figure No
9).

Figure No. 9. Infiltration test completed in the SLL-10 trial pit.

7. SUBSURFACE RESEARCH TRIAL PITS

The geotechnical appraisal of materials began with a site visit to identify the different test and sampling points and coordinate the work to be completed by excavating fifteen trial pits with a final depth of 1.50 meters. The topographical characteristics of the area surveyed presents different gradients where the fifteen (15) subsurface research trial pits are located. The physical properties of the soils were determined by testing their samples, which were taken at a depth of 1.50, at the Campos Firm Soil Laboratory (Figure No 10).

Figure No. 10: SLL-1 trial pit, excavated at the convergence of a tributary river that presents organic alluvial-to-lake materials.

The location of the exploration wells in the study area presents almost horizontal surfaces and medium gradients where manual excavations were completed to obtain soil samples and identify the granular soils' physical properties. The exploration wells needed to be excavated at different depths due to the presence of a bedrock composed of lava and volcanic tuffs.

Based on the identification of the materials completed, variable depths ranging between 0.40 m and 1.60 m were reached. In order to obtain knowledge on the materials, the trial pits' lithological profiles were studied up to a depth of 1.80 m.

During the excavation works, the standard procedures were followed to extract and prepare the fifteen representative samples to complete the tests at the consultant's soil laboratory.The methodology followed in the field works included the description and identification of soils (visual and manual procedure), and ASTM D2488 to differentiate gravel, sand, silt and clay. The soil samples (ASTM D4220) identified were preserved and transported after being wrapped in plastic bags to prevent them from losing their natural moisture for the extraction and preparation of soil samples (ASTM C75 AASHTO T2).

Methodology to quart the soil samples (ASTM C702 AASHTO T248), methodolo-gy to determine the content of crumbly particles (ASTM C142 AASHTO T1 12), dry preparation of soil samples for their granulometric analysis and determination of physical constants (ASTM D421 - ASTM D2217 AASHTO T87) referred to the dry preparation of soil samples as received from the field [sic]. Preparation of soil samples for granulometric analysis and determination of physical constants ASTM D2217). Laboratory determination of water content (moisture) of the soils (ASTM D2216), granulometric analysis by sieving (ASTM D422 AASHTO T88), granulometric analysis with hydrometers (ASTM D422), determination of the soils' liquid limits (ASTM D4318 AASHTO T89), determination of the plastic limit and plasticity index (ASTM D4318 AASHTO T90).

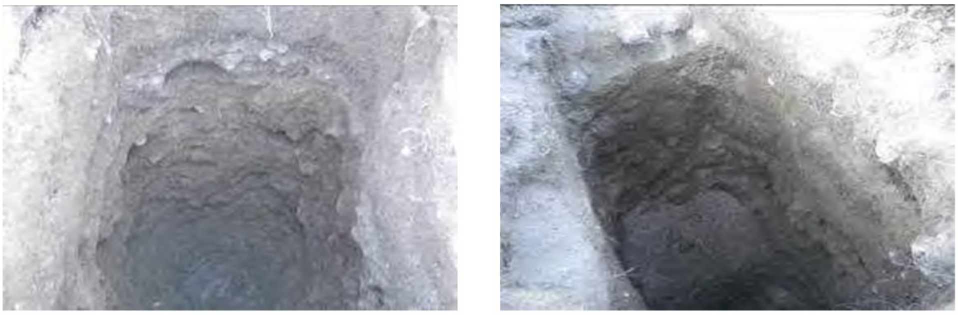

Figure No. 11. Subsurface research trial pit SLL-11, where sandy silt-to-clay matrix materials are found up to a depth of 1.60 m

With the analysis of the field and laboratory results, the materials were identified and grouped on basis of the Soil Laboratory result forms. The soils of the area studied correspond to sedimentary colluvial and colluvial-cone deposits. The materials identified belong to the mixtures of gravel, sand of silt matrixes, marshy clays and the bedrock (Figure No. 12).

Figure No. 12. Manual excavation of the SLL-12 trial pit on an ancient alluvial plain of a reduced thickness of 0.40 m. a highly fractured bedrock is found below.

7.1. PHYSICAL CHARACTERISTICS OF THE SOILS

The fifteen samples taken in the field during the subsoil exploration phase and processed in the laboratory are grouped in the range of the sands; the grains pass through sieve No 10 (2 mm), are retained in sieve No 40 (0.425 mm), and fine sand when re-tained in the No. 200 sieve [sic]. The sands are conceptualized when more than 50 percent of the coarse grains passes through sieve No. 4 (1 mm) and are silty when they present more than 12 percent of fine materials. Silt-matrix (SM) sands are the most representative with respect to silty to clayey matrix sands (SM-SC). Sandy silt- matrix (SM) materials are permeable to semipermea-ble.

According to the SUCS material classification that the most of the materials comprise mid to fine grain materials where the predominance is composed of silt-matrix sand mixtures and, to a lesser degree, a clay matrix arranged in variable proportions as a function of the sector in which they are identified.

7.2. Silt sands – SM

The main characteristic of these materials is the presence of rounded to sub-rounded clasts as op-posed to flat particles due to the majoritarian presence of silt in their matrix. The material has a percentage of fine gravels and coarse silts composed mostly by sizes larger than sieve No. 4.

These sandy silty matrix materials are composed of mixtures of coarse gravel and coarse grains, with variable proportions that depend on their formation thereof, providing varying behav-iors that bear a direct relation with the granulometric characteristics of the samples, with complex physical- mechanical behaviors.

These are generally permeable materials, depending on the content of fine materials in their composition. They can have average permeability values in the event that the silt particles have medium to high consistency limits and act as impermeable agents. In the case of the present study, it is observed that the materials identified do not present any plasticity and, due to their content of larger clasts, they have high permeability values and are categorized as permeable materials.

Figure No. 13 shows the percentual relationship of sandy materials and their variants as a function of their fine content (silt and clay) in granular soils. A predominance of silt-matrix silty sand (SM) with a 60 percent [sic]; sandy loamy to clayey (SM-SC) materials in second place with a percentage of 26.67 and very sparse samples of sands with a clayey matrix (SC) and low plasticity (ML) sands with 6.67 percent for each type of material [sic].

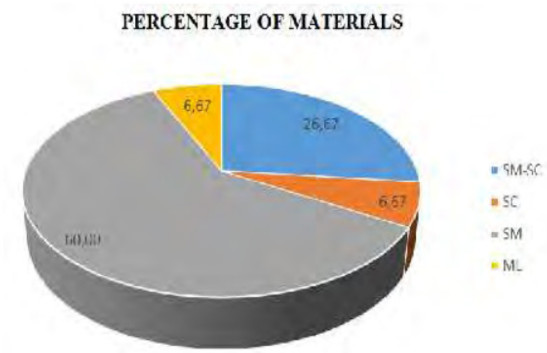

Figure No. 13. Percentual ratio of the fifteen samples analyzed and identified in the soil laboratory

7.3. CLAYEY SANDS, CS

The characteristic of clay-based sandy materials is the presence of mixtures of low-plasticity inorganic sands and clays in very variable proportions, where the charac-teristic is the type of matrix that contains them. The behavior of this type of mate-rial is subject to the content of clay minerals in its composition, modifying the fabric-type in some occasions. It should be considered that due to the character-istics of the materials that compose them, these soils present medium to low per-meability characteristics in their composition.

Figures 16 and 17 below show the different types of soils obtained from the fifteen pits and soil samples taken in the field. The geotechnical profile is based on a classification of soils under the SUCS system.

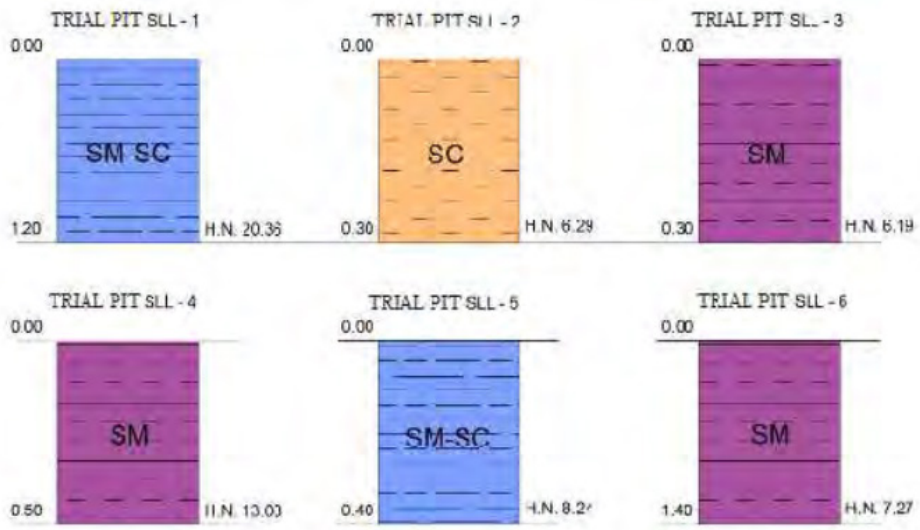

Figure No. 14. Geotechnical profiles of the SLL -1 to SLL-6 trial pits (Prepared by the authors).

Once the field works were completed taking into account the excavation of trial pits, taking soil samples to be processed in the soil laboratory, and obtaining soil classifications for the present work through the SUCS classification system with the granulometric material results, in addition to the limits of their consistency (Table No. 2) [sic].

TABLA RESUMEN ENSAYOS CLASIFICACION DE SUELO						
SISTEMA S.U.C.S.						
POZO	PROFUNDIDAD (m)	HUMEDAD NATURAL %	L.L.	L.P.	I.P.	CLASIFICACIÓN SUCS
DETERMINACIÓN DE LA CAPACIDAD DE INFILTRACIÓN ANTE UN POSIBLE ESCURRIMIENTO SUPERFICIAL EN LA ZONA DE LOS MANANTIALES DEL SILALA						
POZO 1	1,20	20,36	23,12	18,28	4,84	SM-SC
POZO 2	0,30	6.29	29,43	21,28	8.15	SC
POZO 3	0,30	6.19	NP	NP	NP	SM
POZO 4	0,50	13.08	NP	NP	NP	SM
POZO 5	0,40	8.24	23,61	19,11	4.50	SM-SC
POZO 6	1,40	7.27	NP	NP	NP	SM
POZO 7	1,60	9.31	NP	NP	NP	SM
POZO 8	1,60	7.28	NP	NP	NP	SM
POZO 9	1,60	8.68	NP	NP	NP	SM
POZO 10	1,15	7.67	NP	NP	NP	SM
POZO 11	1,60	11.05	21,86	15,72	6.14	SM-SC
POZO 12	1,00	8.30	NP	NP	NP	SM
POZO 13	0,30	6.44	NP	NP	NP	SM
POZO 14	0,70	8.05	23,66	17,01	6.66	SM-SC
POZO 15	1,60	8,37	NP	NP	NP	ML

Table N° 2. Values that correspond to the natural humidity of the fifteen (15) samples and the low plasticity indexes that they present (Own elaboration).

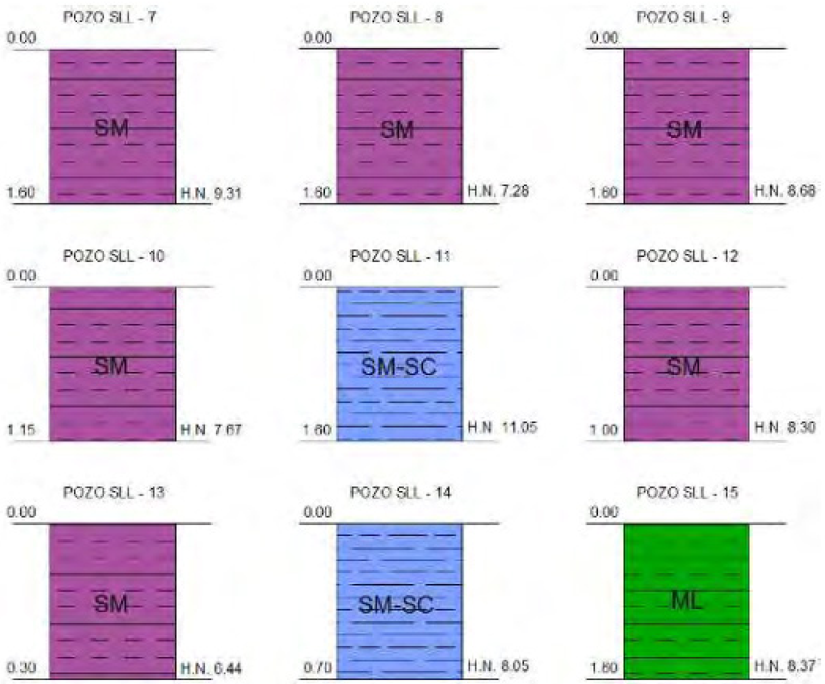

Figure N° 15. Geotechnical profiles of the trial pits SLL-7 to SLL-15 (Own Source).

Figure N° 16. Presence of the almost surface rocky basement in the SLL-13 trial pit, where there is the presence of sandy materials with a silty matrix.

In Table N° 3, corresponding to natural humidity, there is homogeneity in the values, where the samples present values of 6.19 percent in well 3 to

9.31 percent in well 7, as the most characteristic. Well 11 presents a high percentage of hu-midity, 11.05 percent due to the depth where the sample was taken —1.60 meters. Well 5 that reached a maximum depth of 0.40 meters presents a natural humidity of 13.08 percent and finally well 1 presents a high humidity due to the geological characteristics that it presents (bofedal) with a mixture of sands with silty to clayey matrix and also a water table from 1.00 meters.

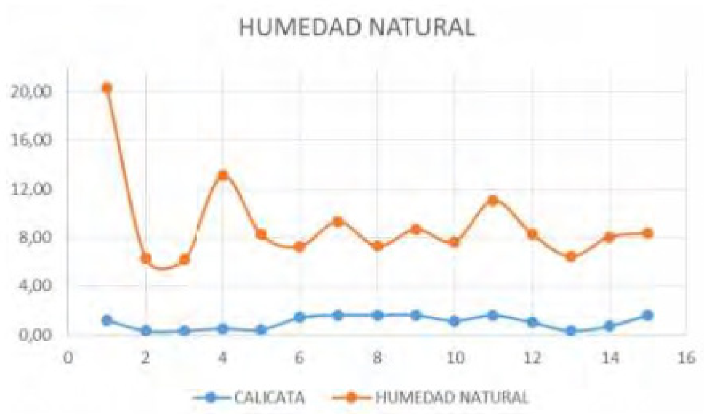

Chart N° 3. Relation of natural humidity in the samples of the fifteen trial pits (Own Source).

The values in the natural humidity content of the fifteen (15) soil samples correspond to granular materials in the range of sands, mostly associated with silts (SM). There are sandy materials of silty to loamy to clayey (SM-SC) content. The samples obtained have a humidity range where the minimum value corresponds to 6.19% for silty sands (SM) and a maximum value equal to 20.36% for sands with loamy to clay matrix (SM-SC), at depths greater than 1.00 meters. These values indicate that the soils are in a saturation, below a plastic behavior.

TABLA RESUMEN ENSAYOS CLASIFICACION DE SUELO						
SISTEMA S.U.C.S.						
POZO	PROFUNDIDAD (m)	% QUE PASA EN PESO				CLASIFICACIÓN SUCS
		N° 4	N° 10	N° 40	N° 200	
DETERMINACIÓN DE LA CAPACIDAD DE INFILTRACIÓN ANTE UN POSIBLE ESCURRIMIENTO SUPERFICIAL EN LA ZONA DE LOS MANANTIALES DEL SILALA						
POZO 1	1,20	73,60	62,30	43,60	36,90	SM-SC
POZO 2	0,30	79,80	75,10	57,10	40,20	SC
POZO 3	0,30	79,50	69,80	51,60	36,10	SM
POZO 4	0,50	79,70	70,60	58,80	42,00	SM
POZO 5	0,40	92,60	84,00	68,00	49,10	SM-SC
POZO 6	1,40	83,10	70,10	55,60	42,40	SM
POZO 7	1,60	80,90	72,60	55,50	37,10	SM
POZO 8	1,60	76,20	65,90	51,00	30,10	SM
POZO 9	1,60	78,00	69,30	57,60	46,90	SM
POZO 10	1,15	78,30	66,10	49,00	34,90	SM
POZO 11	1,60	72,70	63,50	52,30	39,60	SM-SC
POZO 12	1,00	74,80	66,10	48,20	37,00	SM
POZO 13	0,30	81,90	73,10	55,20	45,00	SM
POZO 14	0,70	96,50	84,80	69,40	49,70	SM-SC
POZO 15	1,60	99,60	94,30	77,20	57,50	ML

Table N° 4. Values in the granulometric analysis of the fifteen samples (Own Source).

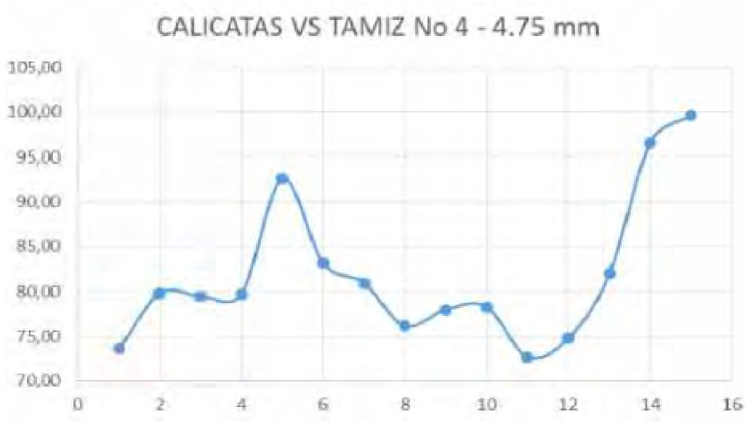

Chart N° 5. Representation of the percentages obtained in the fifteen soil samples through sieve N° 4 (Own Source).

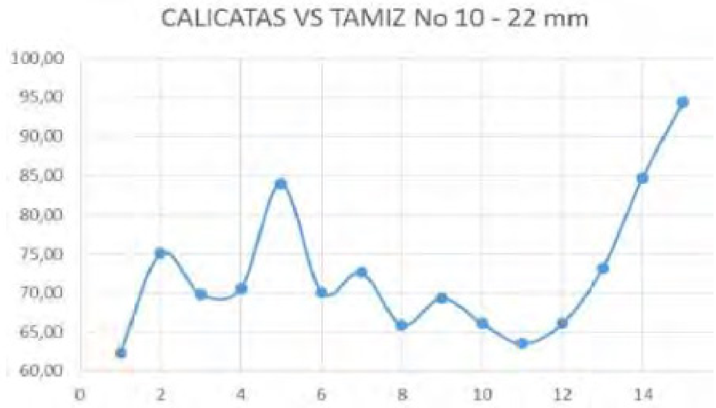

Chart N° 6. Representation of the percentages obtained in the fifteen soil samples through sieve N° 10 (Own Source).

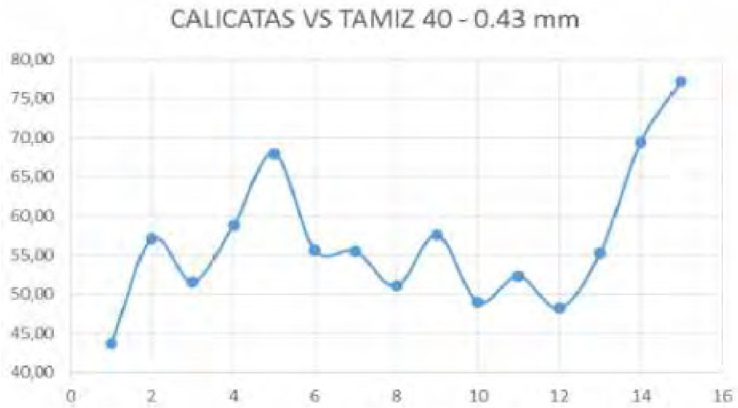

Chart N° 7. Representation of the percentages obtained in the fifteen soil samples through sieve N° 40 (Own Source).

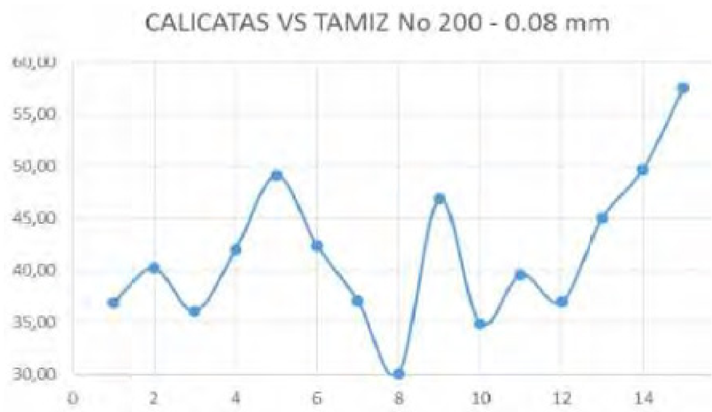

Chart N° 8. Representation of the percentages obtained in the fifteen soil samples through sieve N° 200 (Own Source).

Once the four main sieves of the fifteen samples were quantified, a similarity in the behavior of the grains in their composition of sandy materials can be observed. When dealing with sandy materials the granulometric characteristics belong with constant values and with percentages that are similar as shown in the following Chart N° 9.

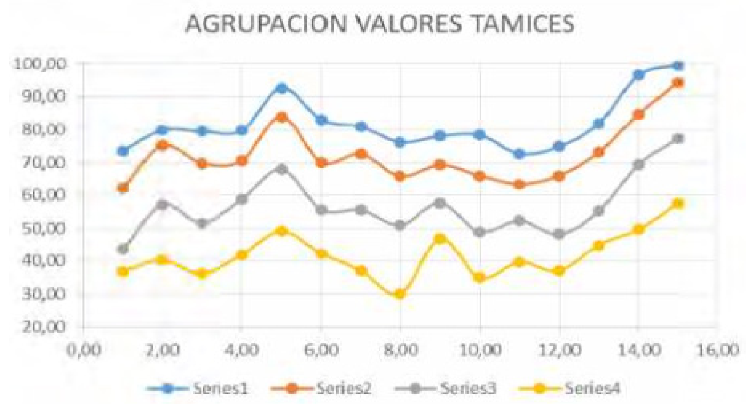

Chart N° 9. Curves interpolated with the data of the sieves N° 4, N° 10, N° 40 and N° 200 (Own Source).

The forms presented with the data obtained in the field in wells SLL-6, SLL-7, SLL-8, SLL- 9, SLL-10, SLL-11, SLL-12, SLL-14 and SLL-15, with mostly sandy silty matrix (SM) materials. Once the different probes were concluded, infiltration tests were carried out, with which the infiltration velocity parameters and the accumulated infiltration of the sandy materials present in the Silala spring can be estimated. The test is based on the introduction of a known flow in the soils and the observation of the behavior of the piezometric level over time (Figure N° 17).

Figure N° 17: Infiltration velocity measurement in SLL-15 trial pit.

The reaches tested cross a sand-silty matrix lithology (SM). In its highest percentage, infiltration occurs directly by the action of gravity. In order to calculate the hydraulic conductivity of the soils from the time and flow measurements –obtained during the field stage– a basic infiltration results table has been prepared, which is when the passage of water to the ground enters constantly.

Table N° 10 presents the values of the basic infiltration based on the graphical method of the forms of Infiltration Velocities (IV) and Infiltration Accumulation (IA) in relation to time. In the graphs of Figure N° 6, we observe that the Infiltration Velocity (IV) tends to become constant over time. At that velocity it is called “Basic Infiltration” (BI), which is the passage of water on the soil. The calculation of the basic infiltration can be done graphically, being evident that the basic infiltration begins at approximately 15 minutes.

CALCULO DE LA INFILTRACION BASICA (Ib) - METODO GRAFICO				
CALICATA	SUCS	VELOCIDAD DE INFILTRACION (cm/h)	TIEMPO (min)	RANGO VARIACION (mm/h)
SLL-6	SM	25	12	Arena 25 - 50
SLL-7	SM	24	15	
SLL-8	SM	50	12	
SLL-9	SM	30	5	
SLL-10	SM	40	8	
SLL-11	SM-SC	24	12	
SLL-12	SM	60	7	
SLL-14	SM-SC	22	3	
SLL-15	ML	60	3	

Table N° 10. Different values calculated by the graphical method based on the basic infiltration of soils (Own Source).

Table N° 11 presents a list of materials and their agronomic characteristics as soils before the infiltration of water.

Textura del suelo	Infiltración básica. Rango de Variación (mm/h)	Ib promedio (mm/h)
Arena	25 - 50	50
Franco-arenoso	13 – 75	25
Franco	7.5 – 20	12,5
Franco-limoso	2 - 15	7,5
Arcillo- limoso	0.2 5	2,6
Arcilla	0,1 - 1	0,5

Table N° 11. Values of basic soil infiltration (mm/h).

The different tests carried out have as objective to know the Infiltration Velocity (IV) or amount of water that enters per unit of surface and time. Since the texture of the soils is mostly sandy, they are more susceptible to a greater infiltration that will also depend on the humidity content of the soils at the time of the tests. A dry soil absorbs water quickly but as time passes, the soil gradually becomes saturated and the infiltration rate decreases until reaching a constant value, called basic or stabilized infiltration velocity (Figure N° 18).

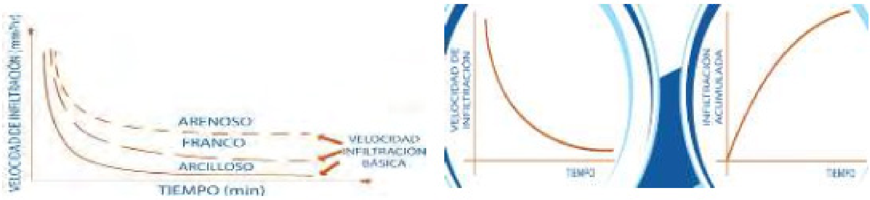

Figure N° 18. Behavior of the infiltration velocity according to the texture of the soils.

The graphs of the results of the different tests carried out are plotted according to the curves of the infiltration velocity (IV) and the accumulated infiltration (AI). The first left vertical axis (infiltration velocity) will tend to decrease in time while the right vertical axis (accumulated infiltration) will increase as a function of time.

The double-ring method was not easy to carry out in the field due to water leaks from the outside ring to the three-centimeter [pipe] jacking from the surface. Although the outer ring has the function of preventing the horizontal infiltration of water below the inner cylinder so that the measurements correspond to a vertical flow.

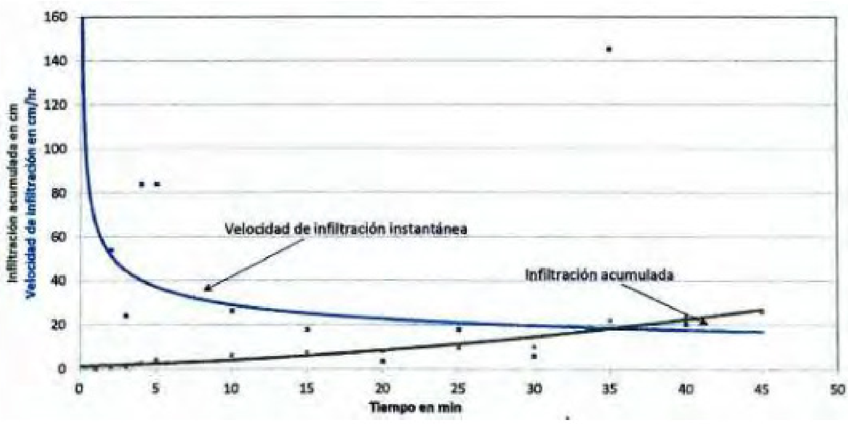

Chart N° 12. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-6 trial pit.

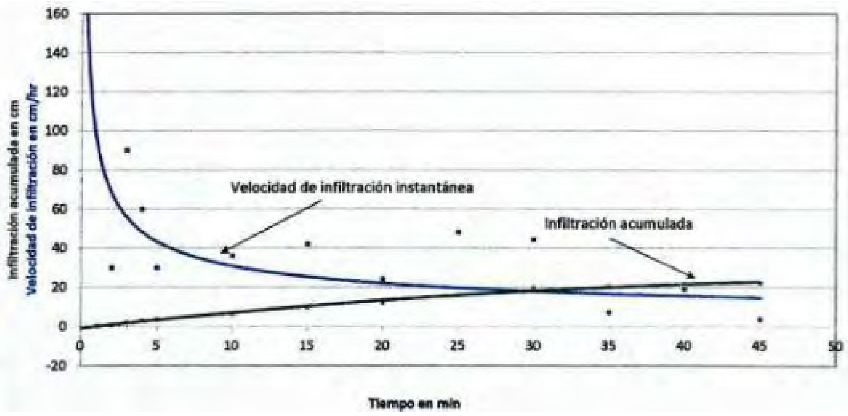

Chart N° 13. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-7 trial pit.

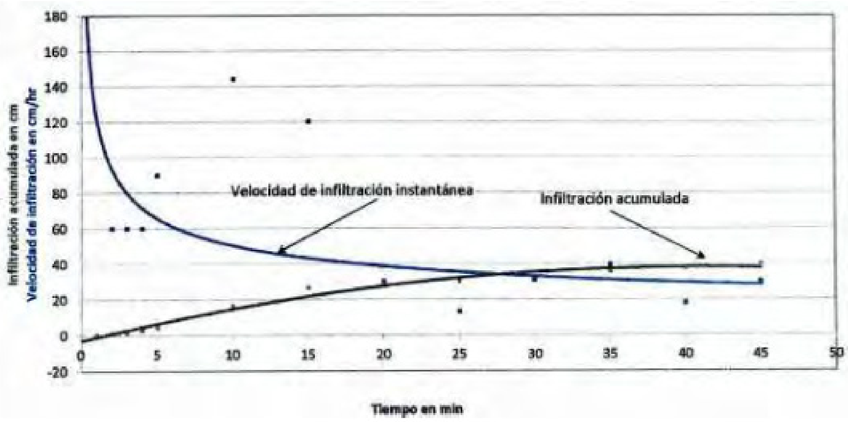

Chart N° 14. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-8 trial pit.

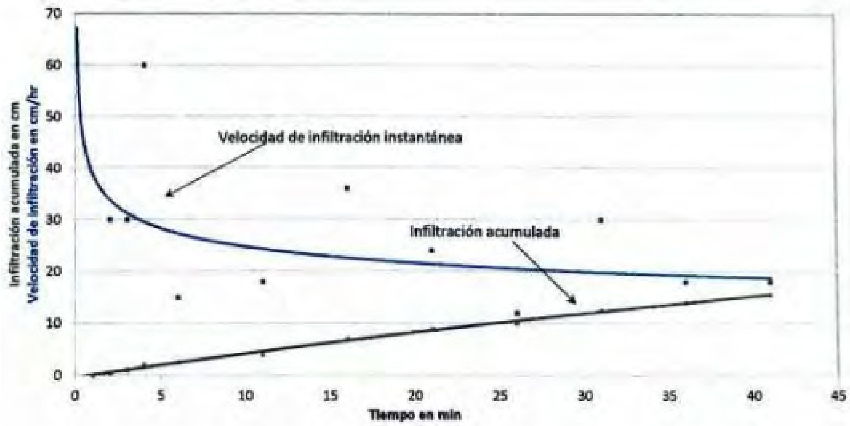

Chart N° 15. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-9 trial pit.

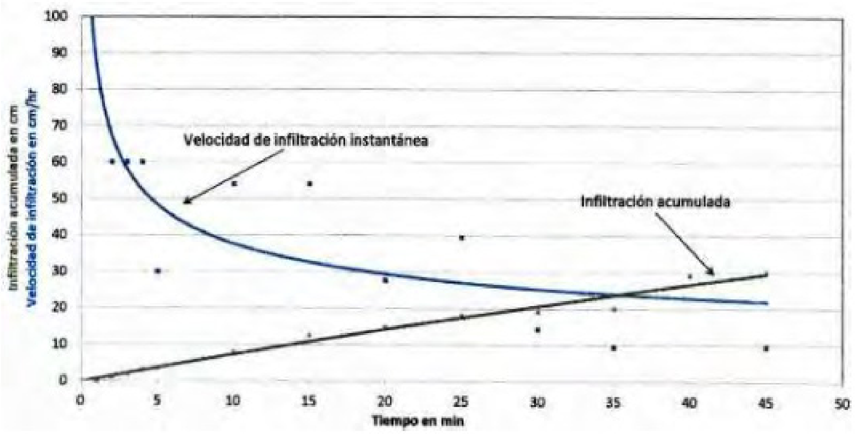

Chart N° 16. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-10 trial pit.

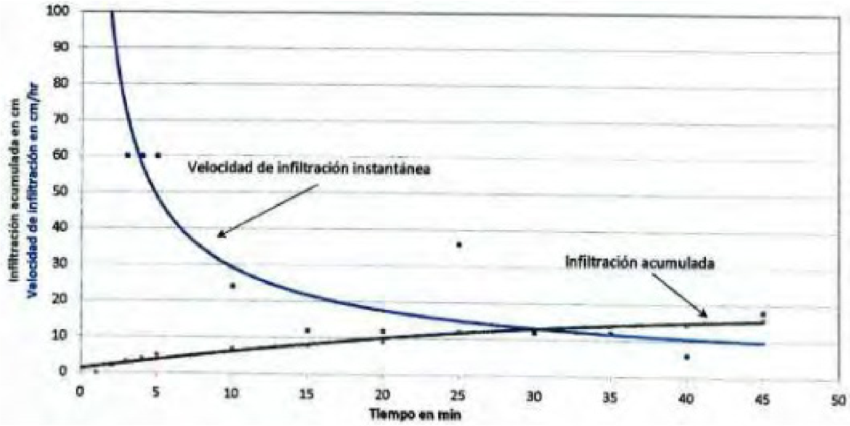

Chart N° 17. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-11 trial pit.

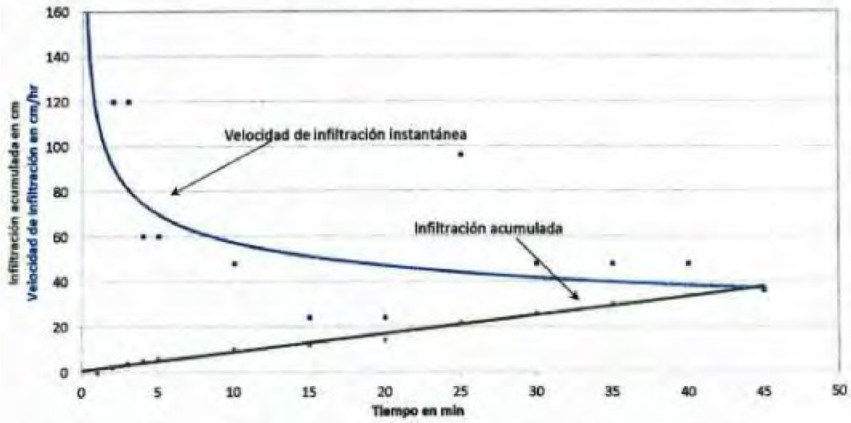

Chart N° 18. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-12 trial pit.

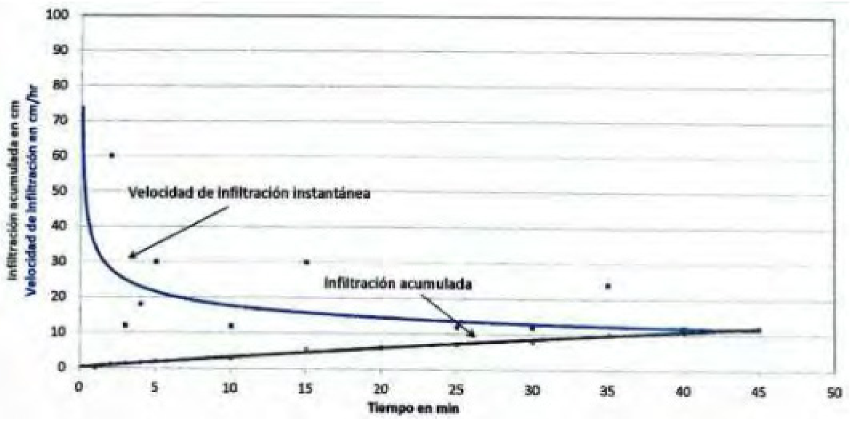

Chart N° 19. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-14 trial pit.

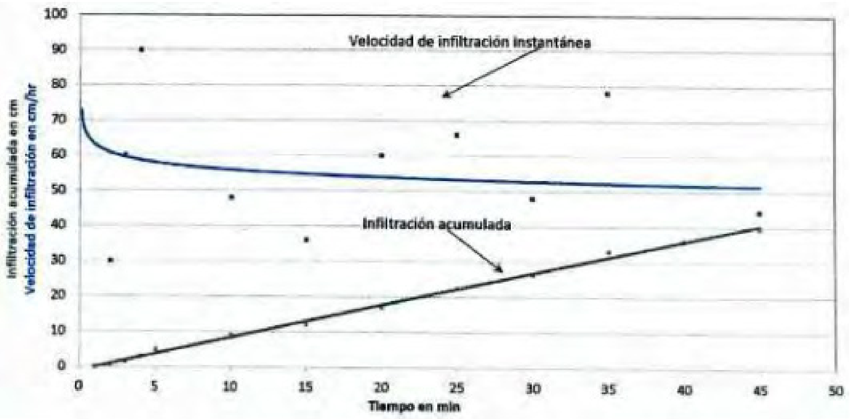

Chart N° 20. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-15 trial pit.

Chart N° 21. Infiltration velocity (blue line) curve and accumulated infiltration (black line) as a function of time in minutes in the SLL-15 trial pit.

8. CONCLUSIONS

The study area in the Silala springs presents outcrops of igneous rocks of tertiary age, lithologically composed of lava and Silala tuff of fine grain porphyritic composition of light brown and dark gray colors. It presents phases of alluvial sedimentation, colluvial cones, alluvial terraces where sands with a silty matrix (SM) have been identified to the greatest extent, sands with silty to clayey matrix (SM-SC), clay sands (SC) and low plasticity silts (ML) with clasts of sub-rounded and rounded forms.

1. The degree of jointing in igneous rocks presents up to two systems of preferential joints whose planes are arranged in a normal (perpendicular) way, which gives the area of rocky materials a secondary permeability, therefore a flow below the sandy materials.

2. It does not present areas of erosion that could be a problem for sandy materials. It presents slopes with apparent stability due to the quality of the rock presented by families of discontinuity.

3. Fifteen research points were carried out by digging open trial pits with depths greater than 1.50 meters and some with less depth due to the presence of the rock mass. The identified materials show heterogeneity in the natural humidity and some soil samples have no consistency limits, so they are considered non- plastic soils with a high infiltration velocity.

4. Once the fifteen open-pit excavations were carried out, it was possible to observe the presence of a single water table in depth in the SLL-1 trial pit, developed in sandy materials that have a silty to clayey matrix very close to a continuous water flow.

5. The predominant presence of sandy materials in its four variants (SP, SW, SM and SC) throughout the study area and due to its granular characteristics, they are highly permeable and with a high infiltration rate. Due to the absence of permeable levels (silts and clays) in depth, it causes rainwater to enter greater granular thicknesses until contact with the rock mass.

6. The fine materials (silts and clays to a lesser degree) are restricted to the lower part of the basin, where the two important flows converge and the bofedales develop. In the upper part, the development is very punctual. During the excavation of the fifteen underground prospect pits, up to a final depth that exceeded in some cases 1.60 meters, it was not possible to identify fine deposits (silts and clays) except for well SLL-1, which is on the eastern margin and that coincides with a plain where the bofedal is located, presenting silts and clays of dark brown color with high organic content.

7. The percentage ratio of sandy materials and their variants depending on the content of fines (silts and clays) shows a predominance of silty sands of silty matrix (SM) with 60 percent, the sandy materials of silty to clayey matrix (SM-SC) in second place with a percentage of 26.67 percent and very sporadic samples of sands with clayey matrix (SC) and low plasticity (ML) silts with 6.67 percent for each type of material.

8. The natural humidity also presents a universe of similar samples,

except for some high values due to the topographic location at the time of the study.

9. The presence of sandy materials of silty matrix in the wells SLL-2, SLL-3, SLL-4, SLL-5 and SLL-13 that had a lower development in thickness with respect to the other wells, presenting the rock mass that has planes of joints. The materials that exceeded 1.60 meters in thickness are identified in wells SLL-1, SLL-6, SLL-7, SLL-8, SLL-9, SLL-10, SLL-11, SLL-12, SLL-14 and SLL-15, identifying sands with less presence of granules larger than 3 centimeters in diameter.

10.Nine tests were carried out in order to measure the infiltration velocity and the accumulated infiltration in the sandy materials, obtaining the graphs where the basic infiltrations for the different samples analyzed were calculated using the graphical method.

11. It was not possible to establish the presence of water tables in depth in any of the excavated wells, nor in the trial pits excavated to a depth of more than 1.60 meters, nor in those that reached the rocky mass, therefore the infiltration is deeper in the research points.

9. BIBLIOGRAPHIC REFERENCES

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10. PHOTOGRAPHIC REPORT

Fractures (Joints)

When the rocks on the surface are subjected to the pressure of a force that increases in intensity, it suffers a series of deformations in response to the effort to which is subjected. The rocks of igneous nature, which presents pseudo stratification based on the observation of the dynamic phenomena that have affected the materials of the earth's crust, have joints that are fractures without displacement of the affected blocks. The joints usually have several lengths from a centimeter to a dozen meters. The joints are usually open on the surface and closed in depth, which gives the rock mass a secondary permeability and therefore an underground flow according to the preferential direction of the fracture system.

Classification according to their degree of separation:

- Latent: they are not observable to the naked eye.
- Closed: the walls are in close contact.
- Open: there is a certain degree of separation and well exposed fractures in the vertical walls.

Classification according to their size:

- Inter-formational: small, within a layer or formation.
- Inter-sectant: large, cut to several layers.

Classification according to its origin:

- Tectonic.
- Hydraulic: when they are formed by high fluid pressure.
- By decompression: they require the existence of pre-existing structures.

-By discharge: They are formed as a consequence of the erosion of the overlying sediments.

Figure N° 19. Measurements of planes of joints that present the igneous rocks through which the surface waters that infiltrate the granular materials flow.

Figure N° 20. Geological-structural mapping of the joint maps presented by igneous rocks where the surface waters that infiltrate the granular materials flow.

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Figure N° 21. Ignimbrites that present a high degree of fracturing, presenting a secondary

SILALA – 1 TRIAL PIT

Figure N° 22: General view of the rock mass widely exposed in the sector of the ravine that presents a flow of water.

Figure N° 23: General view of the rock mass widely exposed in the sector of the ravine that presents a flow of water.

SILALA – 2 TRIAL PIT

Figure N° 24: General view of the rock mass widely exposed in the sector of the SLL-2 trial pit.

Figure N° 25: Rocky mass exposed very superficially.

SILALA – 3 TRIAL PIT

Figure N° 26: General view of point SLL-3.

Figure N° 27: Excavation of the trial pit.

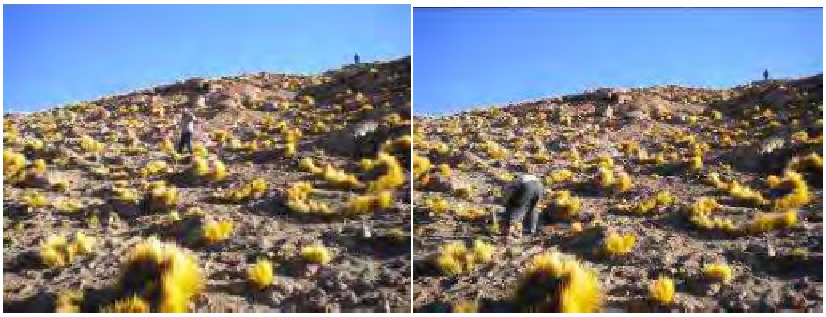

Figure N° 28: Excavation works in the SLL-3 trial pit.

SILALA – 4 TRIAL PIT

Figure N° 29: Measurement of joints in the rock mass.

Figure N° 30: Excavation works in the SLL-4 trial pit.

Figure N° 31: Presence of the rock mass; conclusion of the excavation works in the SLL-4 trial pit.

SILALA – 5 TRIAL PIT

Figure N° 32: Identification of the SLL-5 point.

Figure N° 33: Excavation works of the SLL-5 trial pit.

Figure N° 34: Presence of the rock mass; conclusion of the excavation works in the SLL-5 trial pit.

SILALA – 6 TRIAL PIT

Figure N° 35: Identification of the SLL-6 point.

Figure N° 36: Excavation works in the SLL-6 trial pit.

SILALA – 7 TRIAL PIT

Figure N° 37: Identification of the SLL-7 point.

Figure N° 38: Excavation works in the SLL-7 trial pit.

Figure N° 39: Final excavation of the SLL-7 well.

SILALA – 8 TRIAL PIT

Figure N° 40: Identification of the SLL-8 point.

Figure N° 41: End of the excavation works in the SLL-8 trial pit.

Figure N° 42: Stratigraphic profile of the SLL-8 well.

SILALA – 9 TRIAL PIT

Figure N° 43: Identification of the SLL-9 point.

Figure N° 44: Excavation works in the SLL-9 trial pit.

Figure N° 45: Stratigraphic profile of the SLL-9 well.

SILALA – 10 TRIAL PIT

Figure N° 46: Identification of the SLL-10 point.

Figure N° 47: End of the excavation works in the SLL-10 trial pit.

Figure N° 48: Stratigraphic profile of the SLL-10 well.

SILALA – 11 TRIAL PIT

Figure N° 49: Identification of the SLL-11 point.

Figure N° 50: End of the excavation works in the SLL-11 trial pit.

Figure N° 51: Stratigraphic profile of the SLL-11 well.

SILALA – 12 TRIAL PIT

Figure N° 52: Start of excavation works in the SLL-12 trial pit.

Figure N° 53: Stratigraphic profile in the SLL-11 trial pit.

SILALA – 13 TRIAL PIT

Figure N° 54: Start of excavation works in the SLL-13 trial pit.

Figure N° 55: Stratigraphic profile in the SLL-13 trial pit.

SILALA – 14 TRIAL PIT

Figure N° 56: Excavation works in the SLL-14 trial pit.

Figure N° 57: Main Canal near the SLL-14 trial pit.

SILALA – 15 TRIAL PIT

Figure N° 58: Excavation works in the SLL-15 trial pit.

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Figure N° 59: Stratigraphic profile in the SLL-15 trial pit.

DOUBLE RING

Figure N° 60. Infiltration test in the SLL-4 trial pit in silty matrix (SM) sands, using a single ring due to the problems presented when the double ring was armed.

Figure N° 61. Infiltration test by means of the double ring in trial pit N° 7, which did not yield the expected results due to the excessive leakage of water through the lateral walls of the external ring to the required 3 cm [pipe] jacking.

Figure N° 62. Infiltration test in SLL-8 trial pit.

Figure N° 63. Infiltration test in SLL-10 trial pit.

Figure N° 64. Infiltration test in the SLL-12 trial pit in sands with a silty matrix with a maximum thickness of 1.00 meters in depth, where there is the presence of rocky basement composed of ignimbrites and lavas (Sangueza 2018).

Figure N° 65. Excavation of the SLL-15 trial pit, carrying out the infiltration test using a ring in highly