



CRHIAM  
CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA

# ANNUAL REPORT

Water Research Center for Agriculture and Mining

# 2016





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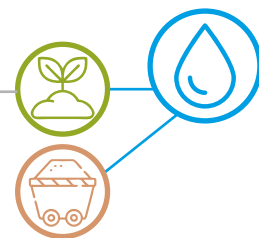
# 2016





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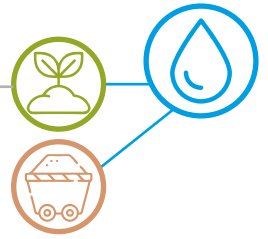
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## I. DIRECTOR'S REPORT

Water scarcity and climate change have become the new reality in which our society and industries must subsist. They are still not completely understood phenomena, which challenge us to find new paths to carry on our various activities and face the future.

In its first three years of work, CRHIAM has acknowledged the importance of this framework and focused its efforts on developing high-level multidisciplinary research to contribute to the pursuit of solutions to the issues associated with this uncertain scenario.

Finding new sources to improve the availability of water in various sectors, looking for new processes and technologies for treating and reusing it, promoting the efficient use of water in

industries and society in general and fostering the development of appropriate public policies have made up the core of our activities.

Therefore, we have built an outstanding team composed of researchers, technicians, students and professionals from different fields, all of whom work toward accomplishing our goals.

We would like to thank our team for its excellent performance during these three years and encourage them to keep going along this challenging yet inspiring path.

At CRHIAM, we know that sustainable development will be possible only if we consciously work toward it and we are committed to doing so in the years still to come.

Fernando Concha  
Director

Eduardo Holzapfel  
Deputy Director

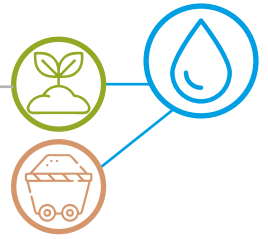


# CRHIAM

CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA







## II. EXECUTIVE SUMMARY

CRHIAM has finished its third year of operation. This is a great time to celebrate because in May 2016 we hosted an international evaluation committee composed of Dr. Teresa Eileen Jordan of Cornell University and Ole Wendroth of the University of Kentucky, Carmen Gallo Stegmaier of the Universidad Austral and José Cembrano Perasso of the Universidad de Chile, a member of the Fondecyt Council, and María Eugenia Camelio, head of Fondap, which had the objective of deciding if CRHIAM should continue operating to its 5th year. The following is an extract of their findings, the complete version of which is attached to this report.

*"The overall impression we gained from the site visit and report is that CRHIAM is doing a magnificent job. Relative to our own experiences with multidisciplinary research centers, we feel that the extent of integration achieved over only two years is admirable. This is due in part to the personalities and vision of the directors, and in part to the talents and good will of the research team. It seems apparent that the universities' administrators are supportive of CRHIAM's complicated work, and that FONDAP has acted constructively to assist CRHIAM to conquer the inevitable challenges they faced while forming an interdisciplinary center from disciplinary roots. We are pleased to find the students to be well integrated as a group and enthused to be contributing to achievement of the broad objectives of CRHIAM. They find themselves to be appreciated and, in turn, several of them have been inspired to continue to deepen their training. All the elements needed for long term success exist."*

The center's vision is to become an authority on the management of water resources in Chile and worldwide. Its mission is to contribute to the solution of problems related to water resources in agriculture and mining, promote the harmonic extraction of natural resources and optimize their use, leading to sustainable development in each of these economic sectors.

CRHIAM has three main objectives: (1) to promote research, create knowledge and develop technologies in water resources, optimize their management and consumption, find new water resources and develop standards to regulate the interaction of relevant actors; (2) to train researchers at the undergraduate and especially graduate and postdoctoral levels in order to address the lack of advanced human resources in the country and (3) to create links with other national and international research institutions and the public or private sectors to benefit from common research and technology transfer.

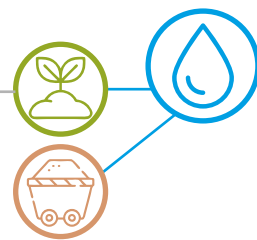
### PERFORMANCE

We have strategic lines of research: (1) Efficient use of water in agriculture and mining; (2) Seawater as a new water source for agriculture, mining and communities; (3) Water availability, hydrology and climate change; (4) Technology for water treatment and environmental remediation and (5) Water governance, ecosystem services and sustainability. In 2017, we plan to add a new research line: 6)

Groundbreaking research, which defies established trends and in some cases common logic (for example, the study of mineral processing without water).

During 2016, CRHIAM published two books, nine book chapters, 68 articles in ISI journals and 4 in non-ISI journals, made 19 conference presentations and completed 20 technology transfer projects. Two patents were awarded and one was submitted. Five internal seminars and six national seminars were organized. During 2016, a total of 86 students joined CRHIAM to do their research projects on water-related subjects, nine at the postdoctoral level, 24 at the PhD level, 15 at the master's level and 41 at the undergraduate level. In addition, 431 professionals were trained in short courses. CRHIAM has links with 32 international universities and research institutions, is associated with three national universities and has links with two others. Twenty-seven international researchers visited CRHIAM to conduct several activities with their Chilean partners and 10 CRHIAM researchers visited international institutions to carry out research activities.





## RESEARCH HIGHLIGHTS

In the five lines of research, the following were the research highlights. See Chapter V for more information on the results.

### Efficient water use in agriculture and mining:

- AQUASAT platform for field-scale water management based on remote-sensing technologies.
- Methodology for variable-rate water application in pivot irrigation systems.
- Risk and economic assessment of water scarcity conditions in central Chile.
- Economic assessment of climate change impacts on agricultural yields.
- New automatic method of roping detection for hydrocyclones in the mining industry.
- Development of a rational approach for optimizing surface irrigation with the use of an automatic irrigation controller.
- Development of an automatic system for surface irrigation models.
- New method for predicting the void fraction distribution in sediments with multi-particle size distribution.

### Seawater as a source for mining, agriculture and communities:

- The use of water with high salt content in processing requires deep knowledge of the interaction of electrolytes with reagents and mineral and gangue. New results are available (i) at lab scale and (ii) from molecular simulation.
- A molecular simulation of a nanoscale capillary water bridge between two mineral surfaces was used to determine the force between the surfaces. These results are related to adhesion, agglomeration and consolidation and are of importance in mining and agriculture.

- Progress has been made in the development of a hybrid methodology for studying particulate systems by combining different simulation techniques to address different spatial and temporal scales.
- The use of seawater may be questioned if the scales are not controlled in pipes/equipment. Progress has been made in inhibiting calcite and gypsum. The subject is crucial in mining as well as in agriculture in irrigation systems.
- Relevant results were obtained on the effect of seawater salts on the flotation process. New collectors for copper flotation in seawater have been tested. In addition, the effect of clays was studied in the presence of high salt concentration.

### Treatment of effluents and environmental remediation:

- Conceptual design of a nanofiltration plant capable of treating the acid mine drainage generated by the Andina Division of Codelco.
- Demonstration at lab scale of the ability of such a process to remove ions from tailings dam water.
- Forward osmosis membranes show good levels of retention for the most common ions present in acid mine drainage.
- The results of the application of the microbial-induced carbonate precipitation process for heavy metal removal show a potential capacity to remove copper from liquid samples.
- The toxicity of acid mine drainage was evaluated by wastewater quality and land use bioassays.
- Sewage concentration by forward osmosis was studied at lab scale using different membranes (microfiltration, ultrafiltration, forward osmosis) for increased organics concentration, enabling direct application of anaerobic digestion.
- Optimization of biogas production from sludge by pre-treatment processes before anaerobic



digestion can be applied to promote sewage sludge disintegration.

- Adaptation of non-conventional technologies such as constructed wetlands can be a very good alternative for rural areas of Chile.
- Feasibility of reuse of wastewater treated by non-conventional technology.
- Wastes to develop substrate to improve the water holding capacity and plant nutrient uptake in degraded areas.
- The biobed is a biopurification system for pesticide degradation to mitigate point source contamination by agricultural pesticides.

#### Hydrology, water availability and climate change:

- Integrated assessment to understand hydrological dissimilarity in neighboring volcanic mountainous basins located in the Andean region of south-central Chile, specifically in the Nevados del Chillán volcanic complex.
- Negative glaciological mass balance values indicate that Glaciar Universidad is losing mass and is not in a state of equilibrium. The ice accumulation in the upper part is not enough to

balance the high rates of ablation presented in the lower part.

- The current drought conditions affecting the extratropical region of Chile could reduce mass balance not only through decreasing snow accumulation, but also through increased ablation resulting from an earlier exposure of the ice surface in the ablation zone and a corresponding decrease in albedo.

#### Water governance, ecosystem services and sustainability:

- Invitation by the Chilean Supreme Court to explain our analysis of the water conflicts in Chile.
- Advice given to the Agriculture Committee of the Chilean Senate to discuss the current draft of the water law reform.
- Participation as speakers at different high-level conferences such as the United Nations Environment Assembly UNEA-2 and several international congresses and workshops aimed at making the work of the CRHIAM more visible.
- A geography of water conflicts in Chile.





### III. CHRIAM ORGANIZATION



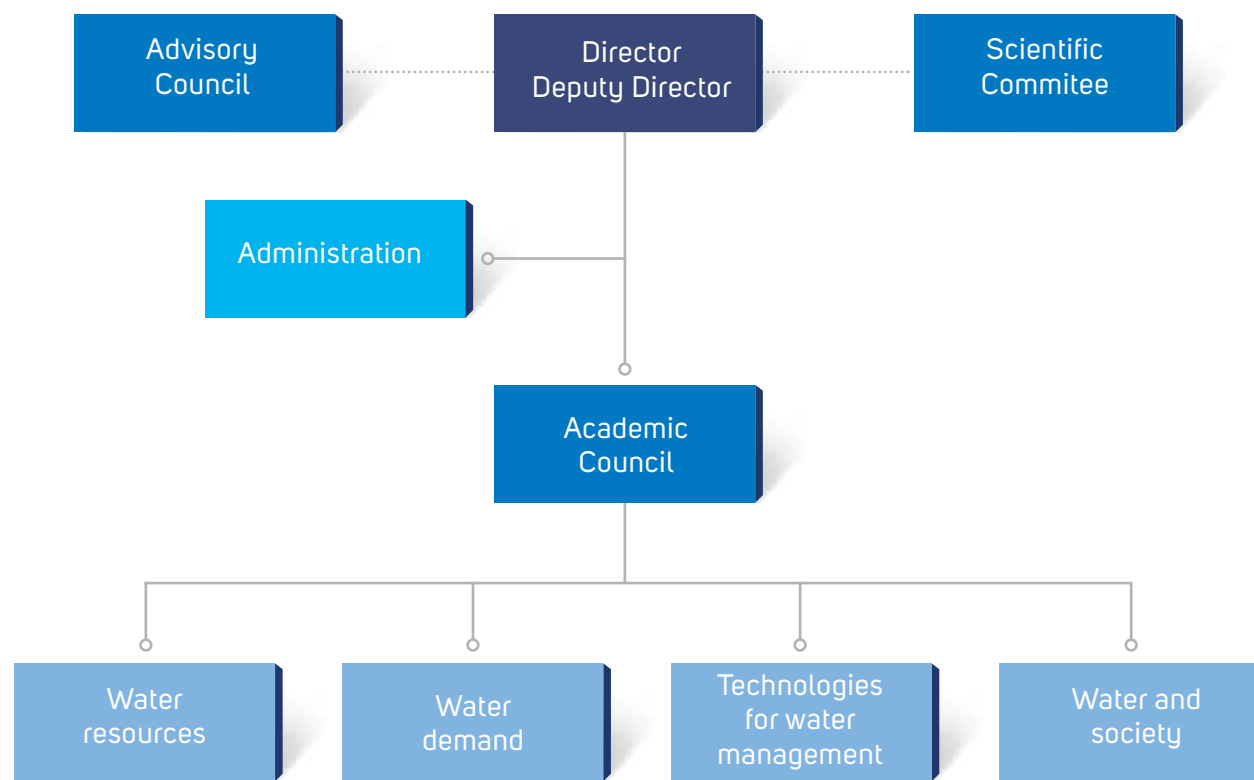


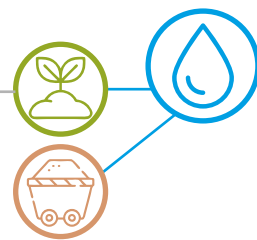
## ORGANIZATION

The administration of CRHIAM includes a director, a deputy director, two administrative officers, two journalists and a secretary. Eight principal investigators constitute the Academic Committee responsible for the center's operation and research progress. The Scientific Committee is in charge of recommending general research guidelines, the evaluation of the advances of current research performed at the center and the suggestion of new lines when necessary. The Advisory Council aligns the center with the country's public and private sectors and society in general to ensure that the center's activity benefits the country.

Researchers are grouped into four clusters: (1) Water Resources, (2) Water Demand, (3) Technology for Water Management and (4) Water and Society. Each cluster includes researchers from various departments and specialties of the three participating universities: UdeC, UDD and UFRO.

### 1. ORGANIZATIONAL CHART





## 2. ADMINISTRATION



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## 3. SCIENTIFIC COMMITTEE

The Scientific Committee is in charge of recommending general research guidelines, evaluating the advances of ongoing research at the center and suggesting new lines when necessary. The committee includes the director, deputy director and seven members from prestigious international universities:

- Elías Fereres, Universidad de Córdoba, Spain.
- Jan Hopman, University of California, Davis, USA.
- Mark Servos, University of Waterloo, Canada.
- Niel McIntire, University of Queensland, Australia.
- Peter Scale, University of Melbourne, Australia.
- Reyes Sierra-Álvarez, University of Arizona, USA.
- Alejandro López Valdivieso, Universidad Autónoma de San Luis Potosí, Mexico.



Photo: Scientific Committee participation in a field trip to Chillán, 2016.





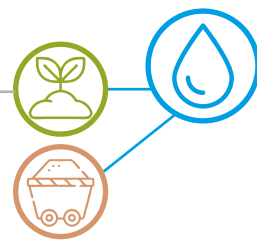
#### 4. ADVISORY COUNCIL

The Advisory Council aligns the center with the country's public and private sectors and society in general to ensure that the center's activity benefits the country. Its members are:



- Maria Eugenia Camelio Acting Director, Fondap Program, CONICYT
- Alex Chechilnitzky Z. President, AIDIS
- Álvaro Hernández Director of Water Management, Codelco, Chile.
- José Luis Soler President, Copefrut
- Álvaro Prieto Operations Manager, Iansa
- Patricio Crespo President, National Agriculture Society
- María Loreto Mery Executive Secretary, National Commission of Irrigation
- Juan Pablo López Executive Director, CIREN
- Xaviera De la Vega Executive Secretary, Commission for Water Sustainability, National Council of R&D and Innovation
- Óscar Castro Tailings Planning and Development, Caserones, Lumina Copper Chile S.A.





## 5. ACADEMIC COMMITTEE

The Academic Committee is responsible for the center's operation and research progress. It is composed of eight principal investigators and is chaired by its director, Professor Emeritus Fernando Concha.

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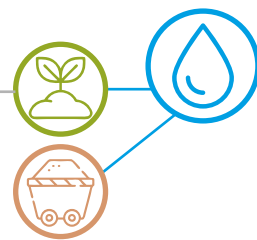
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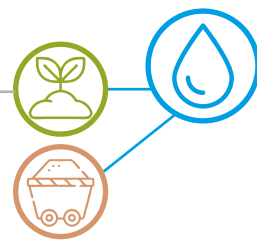
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- **Loreto Acevedo**  
Support engineer
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Support lawyer
- **Francisco Flores**  
Support staff
- **Álvaro Paredes**  
Support staff
- **Carlos Cea**  
Support engineer
- **Roberto Rozas**  
Support engineer
- **Jorge Saavedra**  
Support engineer
- **Javier Quispe**  
Support engineer
- **Felipe de la Hoz**  
Water Center engineer
- **Denisse Álvarez**  
Laboratory coordinator
- **Gerson Valenzuela**  
Chemical engineer
- **Patricio Leonelli**  
Technician
- **Joshua Parra Medel**  
Support engineer
- **Pamela Villalón**  
Support staff
- **María Fernanda Saavedra**  
Support staff
- **Norma Pérez**  
Support engineer
- **Viviana Gavilán**  
Support engineer
- **Pablo Pedreros**  
Biologist
- **Niela Araneda**  
Technician
- **Brígida Catalina Monardes**  
Technician
- **Sujey Hormazábal Méndez**  
Support engineer
- **Mario Sepúlveda Mardones**  
Support engineer
- **María José Ortega Silva**  
Laboratory technician
- **Pamela Sanhueza**  
Laboratory technician



## 8. ADMINISTRATIVE STAFF

- **Alejandra de las Mercedes Fajardo Yañez**  
Secretary
- **Aurora Elcira Varela Avendaño**  
Janitor
- **Héctor Ramírez**  
Administrator
- **Héctor Reinaldo Guzmán Aravena**  
Janitor
- **Leonora Hidalgo Cayo**  
Secretary
- **Marianela Carreño Ramírez**  
Administrator
- **Matías José Vejar Oróstica**  
Accountant
- **Paul Gutiérrez Ruíz**  
Accountant
- **Ronald Burgos**  
IT technician

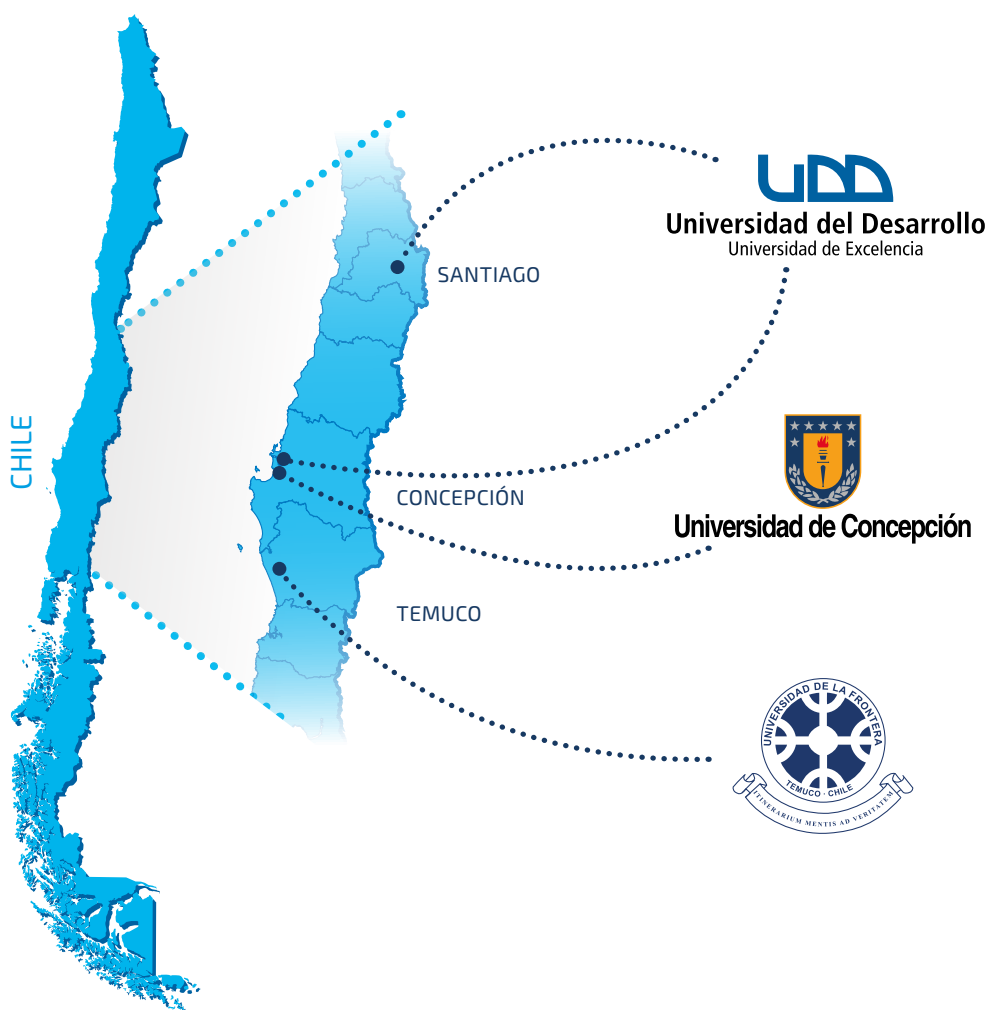




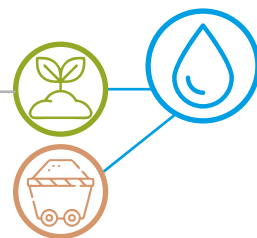
# IV. NATIONAL AND INTERNATIONAL NETWORKING



Two Chilean universities, the Universidad de la Frontera (UFRO) and the Universidad Del Desarrollo (UDD), participate in CRHIAM. The center also has associations with the Universidad del Bío-Bío and the Universidad Católica del Norte. Other associated institutions are BMBF in Germany, INOVAGRI in Brazil and AGSI and CNR in Chile.







1. The University of Arizona 2. Water Resources Research Institute 3. Colorado School of Mines 4. The University Melbourne 5. The University of Queensland 6. Universiteit Gent 7. Leibniz Universität Hannover 8. Instituto de Diagnóstico Ambiental y Estudios del Agua (IDAEA) 9. University of Waterloo 10. York University 11. University of California-Davis 12. Universidad Politécnica de Madrid 13. Lund University.

1. Colorado School of Mines (USA), (<https://www.mines.edu/>)
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3. Lund University (Sweden), (<http://www.lunduniversity.lu.se/>)
4. New Mexico Water Resource Research Institute(USA), (<https://nmwrri.nmsu.edu/>)
5. Sustainable Minerals Institute (SMI), University of Queensland (Australia), (<http://www.smi.uq.edu.au/>)
6. University of Arizona (USA), (<http://www.arizona.edu/>)
7. University of Melbourne (Australia), (<http://www.unimelb.edu.au/>)
8. University of California, Davis, (USA), (<https://www.ucdavis.edu/>)
9. Ghent University (Belgium), (<http://www.ugent.be/>)
10. Universidad Politécnica de Madrid (Spain), (<http://www.upm.es/>)
11. Leibniz Universität Hannover (Germany), (<https://www.uni-hannover.de/>)
12. University of Waterloo (Canada), (<https://uwaterloo.ca/>)
13. York University (Canada), (<http://www.yorku.ca/>)

During 2016, international cooperation played a key role in the development of the CRHIAM science program. As we hosted numerous international colleagues over the course of the year, there was a clear emphasis on the fact that such visits allow the development of new research and that CRHIAM may increase its impact on research through international cooperation.

One of the keystones this year was the development of the CRHIAM-INNOVAGRI meeting (October 2016), which allowed more than 150 researchers, mainly from Brazil and Chile, but also from other parts of the world, to come to Concepción and share their research results in the field of water management and new technologies for



efficient use of water in agriculture and mining and to discuss issues regarding water and society.

Training was another component of international cooperation this year, starting with the visit of our colleagues from the University of Idaho, who, together with CRHIAM researchers and partners from other local universities, offered the course "International Water Issues: adaptation to change in water resources research." This course was attended by Chilean and US PhD students, and consisted of lectures, field trips and a research project done by students and supported by the lecturers. This course was made possible by the support of the National Science Foundation IGERT program.

Visitors from the University of New Mexico and the University of California, Davis, completed a series of activities on both the Chillán and Concepción campuses. Both universities have been associated with CRHIAM since the beginning and strive to continue cooperating with CRHIAM through the development of new scientific initiatives.

CRHIAM also allowed associate researchers and principal investigators to travel internationally to attend scientific meetings and workshops and carry out short- and long-term research stays abroad. The results of these visits demonstrate the success of the CRHIAM "trips for papers" policy, which is an important way of stimulating scientific productivity and has a positive impact on the center's scientific research.

The attempt to broaden our international scientific cooperation network is also seen through the visits of colleagues from other international universities who wanted to establish research and training cooperation initiatives, such as our colleagues from the University of Nebraska (USA). The development of international links should be based on the center's increasing

maturity and its growing international recognition. As the network widens in the coming years we expect that scientific production with international colleagues will grow accordingly.

CRHIAM also has associated PhD programs, which are instrumental in the development of the scientific research and human capital component within the center's objectives. These programs include not only Chilean students, as in 2016 two foreign students also joined the center. One is Jason Walters, a PhD candidate from the University of Idaho, who is completing his research on systems thinking and water resources in the Biobío River basin. The other is master's student Prajna Kasargodu, who completed his Master of Science at Leibniz Universität Hannover in Germany based on work in the Laja River basin. The center is also becoming an attractive international research center for developing high-quality research in Chile.

Another important project initiated this year was an interdisciplinary thematic network for "transnational changes, social inequalities, cultural exchanges and aesthetic manifestations: The example of the Chilean Patagonia," led by the Friedrich Schiller of the University of Jena in Germany with the participation of an associate researcher of CRHIAM (Dr. Jorge Rojas).

The results of the international cooperation and relationships established so far by CRHIAM researchers allow us to predict that in the near future more relationships will be established as a result of the international impact of the center's research of excellence.

Finally, a German PhD recently joined the center as a postdoctoral fellow, working under the direction of Dr. Pedro Toledo, PI of CRHIAM.

# V. RESEARCH





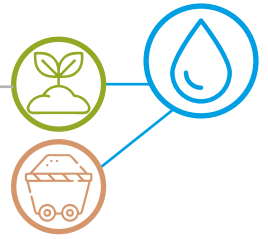


**PRIORITY RESEARCH LINES:**

- 1 | EFFICIENT USE OF WATER IN AGRICULTURE AND MINING
- 2 | SEAWATER AS A NEW WATER SOURCE FOR AGRICULTURE, MINING AND COMMUNITIES
- 3 | TECHNOLOGY FOR WATER TREATMENT AND ENVIRONMENTAL REMEDIATION
- 4 | HYDROLOGY, WATER AVAILABILITY AND CLIMATE CHANGE
- 5 | WATER GOVERNANCE, ECOSYSTEM SERVICES AND SUSTAINABILITY







# 1 | EFFICIENT USE OF WATER IN AGRICULTURE AND MINING

The combination of increased water demands and the periodic occurrence of droughts throughout Chile has brought tensions to many mining processes and irrigated agricultural areas, which must respond to water limitations in a still unknown fashion. This line of research aims to identify the key issues for the optimization of water use and reuse in mineral concentrators and irrigated agriculture.



## 1.1 | EFFICIENT USE OF WATER IN AGRICULTURE

### Satellite imagery to support agricultural water management

The aim of this research is to develop and validate an integrated service for site-specific management of irrigation water, considering spatio-temporal variability in the estimation of water demand for crops and orchards.

### Effects of wetted area and water application in orchards under drip irrigation

This line of research aims at evaluating the most effective and efficient manner of applying water under drip irrigation in orchards to produce optimum yields and avoid contamination. Knowing the best position to apply water in micro-irrigation permits



## 1 EFFICIENT USE OF WATER IN AGRICULTURE AND MINING

a better use of water and associated applications in the irrigation process such as chemigation and avoids contamination of the aquifer and soil. This topic is relevant for the design and management of micro-irrigation systems.

### Effects of irrigation regime on fruit yield and quality in carménère vine

In Chile, vineyards are typically grown under irrigated conditions. Therefore, irrigation is an important management factor to ensure the quality of grapes used in wine production. The objective of this research is to analyze the effects of different levels of water application (0%, 20%, 40%, 75% and 100%, 1,400 to 9,400 m<sup>3</sup> ha<sup>-1</sup> water per season) on the production of grapes and wine quality in a carménère vineyard located in the Cachapoal Valley (Chile) with the presence of a water table during three irrigation seasons. The water table depth had no substantial effect on the measured parameters. The level of water application in the presence of the water table had no substantial effect on the measured parameters, although grape production in the treatment without irrigation was significantly reduced.

### Effects of wetted area on apple production and root extraction under micro-irrigation

There has been considerable research in Chile on the issue of irrigation; however, there have been no conclusive studies linking the optimum level of the percentage of wetted area under micro-irrigation and its effects on apple production. The objectives of this study are to evaluate the effects of the location of water and the percentage of wetted area on the production of 'Brookfield' apple

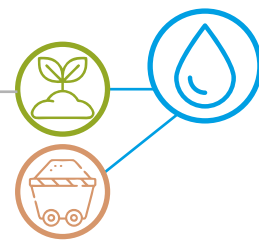
orchards, analyze the relationship between wetted and evapotranspiration areas, identify areas of root extraction through wetted area and evaluate the effects of soil wetting patterns on yield.

### Effects of irrigation level on avocado performance in Chile

Chile is a major avocado producer. The effects of four irrigation regimes on fruit production and size were evaluated for three seasons in a mature 'Hass' avocado orchard (*Persea americana* Mill). The orchard was located in the Central Valley of Chile in a sandy clay loam soil at the surface to sandy loam at a depth of 0.9 m. The study considered four applied water treatments, 25%, 50%, 75% and 100% of the theoretical water volume required ( $V_{tr}$ ) based on daily reference evapotranspiration. The optimum level is 75% of  $V_{tr}$ .

### Water footprint in cultivated blueberries with drip irrigation systems (Concordia, Argentina)

The use of indicators is fundamental in order to reach sustainability and improve irrigation water management. The water footprint, which includes direct and indirect use of water to produce goods or services during a certain period, is a good indicator of water use efficiency in different processes. The objective of this work was to determine the water footprint in cultivated blueberries (*Vaccinium corymbosum* L.) of the 'Snowchaser' variety under drip irrigation in Colonia Aguí, Concordia, Entre Ríos, Argentina. From 2010 to 2015, we analyzed different uniformity coefficients to design the irrigation system and irrigation management approach.



### Soil water balance for oranges grafted with different rootstocks (Bahia, Brazil)

We assessed new relationships between canopy and rootstocks under different planting densities by monitoring processes in the soil-plant-atmosphere. We performed a water balance in the soil over time for combinations of 'Pera' orange with TSKC x rootstocks (LCR x TR) - 059, LVK x LCR - 038, TSKC x CTSW - 041, 'Rangpur Santa Cruz' lime, 'Sunki Tropical' tangerine and 'Riverside' citrandarin, with an emphasis on internal drainage in the soil water recharge period.

### Pivot management decisions for spatial applications

Center pivot irrigation has recently increased significantly in Chile, as it allows large areas of intensive annual crop and/or vegetable production to be watered with high uniformity and high application efficiency. However, not all the areas under this irrigation system are irrigated adequately. A center pivot with a precision irrigation system (wireless control of valves and sprinklers and a positioning device) allows producers to have multiple crops under the pivot, with areas defined by the farmer, optimizing water use and increasing production in areas where problems are currently expected. The objective of this research is to develop and evaluate a decision support system for real-time spatial management of irrigation, reducing water losses (surface runoff and deep percolation) resulting from excessive or inadequate irrigation rates.

### Linear Variable Rate Irrigation System

For studies on crop water demand, crop water stress and the effects of irrigation and chemigation on agricultural crops, it is typically necessary to design an experiment with replications randomly located on the field. This situation forces the design of a complex and expensive hydraulic network to apply the required amount of water or fertilizer to each experimental unit. One solution to this problem is equipment that allows the application of the right amount of water required by the crop according to the experimental design and the application of the water and fertilizer required for more than one experiment at the same time. This project proposes the acquisition of this system, commercially known as the Linear System with Variable Rate Irrigation. The objective of this Fondecap project is to acquire scientific equipment for research purposes in agricultural water resources.

### Soil analysis and evaluation for irrigation system design

Irrigation system design and irrigation management require appropriate spatially homogeneous zoning, especially in terms of soil hydrophysical properties. In Chile, agrological studies are currently being used as a basis for orchard design as well as to determine the homogeneity of soil units, land capability classes and land capability

for tree fruit production. These studies use a number of soil characteristics, which do not include the hydrophysical properties essential for irrigation zoning. Therefore, it is necessary to establish a methodology to objectively evaluate soils based on a quantitative analysis of the hydrophysical parameters required for irrigation system design and management. We aim to evaluate two different methodologies to obtain soil maps for the same purposes through a case study. In addition, the Saxton-Rawls method will be evaluated and calibrated to estimate soil water characteristics.

## 1.2 | AGRICULTURAL AND MINING DEMAND FOR WATER

### A | Water scarcity and impact of the mining and agricultural sectors of Chile

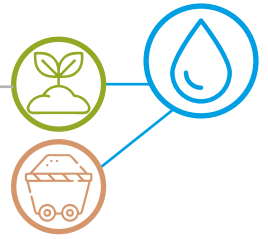
Water scarcity index values were calculated for the central and northern regions of Chile. Very high values of up to 52 (Region of Antofagasta) were determined when environmental flow requirements were considered. Values of 15 and 11 were calculated for the V and III regions, respectively. These values suggest very high levels of scarcity and unsustainable use of water in the northern regions. Agriculture was calculated to be the dominant water user in all regions except Antofagasta, where mining was calculated to account for 64% of water use. The use of more efficient irrigation was determined to have a considerable impact on water scarcity in all regions (up to 20% reduction in WSI values). Water use reduction in mining via tailings dewatering and evaporation reduction was calculated to minimize the WSI value in Antofagasta by up to 48%.

### B | Cost-effectiveness of strategies to reduce water consumption in the copper mining industry

A water balance model was developed to determine the cost-effectiveness of various strategies to reduce water consumption in the copper mining industry. Dewatering and dust suppression strategies were focused on. Considering the net present value and water reduction effectiveness of the various strategies, values of \$/m<sup>3</sup> of water saved were calculated. The most cost-effective strategy for water consumption reduction was calculated to be the application of road dust suppressant. Tailings dewatering was calculated to provide considerably higher values of water saved but with a lower cost-effectiveness value. The most cost-effective technology was calculated to be high-rate thickening of the tailings with flocculation.







### 1.3 | WATER RECOVERY FROM TAILINGS THICKENERS AND TAILINGS DAMS

#### A | Ultra-flocculation reactors

Research on ultra-flocculation technology was recently introduced to thickening research in Chile by the University of Concepción with the collaboration of the Academy of Science of Ukraine. This technology aims at improving thickening operation by increasing the settling velocity of a suspension, reducing flocculant consumption and making it possible to treat very fine suspensions in an efficient way. Using the SediRack on-line, a specially designed on-line instrument at the university, a 50% increase in the settling velocity of  $1 \times 10^{-3}$  m/s of suspension of quartz with  $P_{80} = 18 \mu\text{m}$  was achieved when the shear rate of the ultra-flocculation reactor was increased from 120 to  $500 \text{ s}^{-1}$ , maintaining the suspension concentration and the flocculant dosage.

#### B | Numerical approximation of the sedimentation of polydisperse suspensions

This work focuses on the numerical approximation of multi-species kinematic flow model solutions. These models are strongly coupled nonlinear first-order conservation laws with various applications such as sedimentation of a polydisperse suspension in a viscous fluid. Since the eigenvalues and eigenvectors of the corresponding flux Jacobian matrix have no closed algebraic form, this is a challenging issue. A new class of simple schemes based on a Lagrangian-Eulerian decomposition (the so-called Lagrangian-remap (LR) schemes) was recently advanced to models of polydisperse sedimentation. These schemes are supported by a partial numerical analysis when only one species is considered and turned out to be competitive with several existing schemes in both accuracy and efficiency. Since they are only first-order accurate, the purpose of this contribution is to propose an extension to second-order accuracy using quite standard MUSCL and Runge-Kutta techniques. Numerical illustrations are proposed for both applications, involving eleven (sedimentation) and nine species (traffic), respectively.



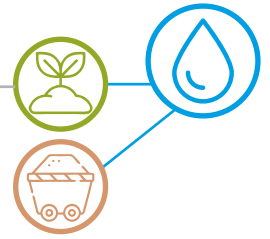
## C | Sediment formation under a strongly degenerate polydisperse sedimentation model

Implicit-explicit (IMEX) Runge-Kutta (RK) methods are suitable for the solution of nonlinear, possibly strongly degenerate, convection-diffusion problems, since the stability restrictions, coming from the explicitly treated convective part, are much less severe than those that would be deduced from an explicit treatment of the diffusive term. A particularly efficient variant of these schemes, so-called linearly implicit IMEX-RK schemes, arise from discretizing the diffusion terms in a way that more carefully distinguishes between stiff and nonstiff dependence, such that in each time step only a linear system needs to be solved. These schemes provide an efficient tool for the numerical exploration of sediment formation and composition under a strongly degenerate polydisperse sedimentation model.

## D | One-dimensional models of gravity-driven sedimentation of polydisperse suspensions

One-dimensional models of gravity-driven sedimentation of polydisperse suspensions with particles belonging to  $N$  size classes give rise to systems of  $N$  strongly coupled, nonlinear first-order conservation laws for the local solids volume fractions. As the eigenvalues and eigenvectors of the flux Jacobian have no closed algebraic form, characteristic-wise numerical schemes for these models become involved. Alternative simple schemes for this model directly utilize the velocity functions and are based on splitting the system of conservation laws into two different first-order quasi-linear systems, which are solved successively for each time iteration, namely, the Lagrangian and remap steps (so-called Lagrangian-remap [LR] schemes). This approach was advanced in (Bürger, Chalons, and Villada, SIAM J Sci Comput 35 (2013), B1341–B1368) for a multiclass Lighthill–Whitham–Richards traffic model with nonnegative velocities.





## **E** | Antidiffusive Lagrangian-remap schemes for models of polydisperse sedimentation

By incorporating recent antidiffusive techniques for transport equations, a new version of these Lagrangian-antidiffusive remap (L-AR) schemes for the polydisperse sedimentation model is constructed. These L-AR schemes are supported by a partial analysis for  $N = 1$ . They are total variation diminishing under a suitable CFL condition and therefore converge to a weak solution. Numerical examples illustrate that these schemes, including a more accurate version based on MUSCL extrapolation, are competitive with several existing schemes in accuracy and efficiency.

## **F** | Polynomial viscosity methods for multispecies kinematic flow models

Multispecies kinematic flow models are defined by systems of strongly coupled, nonlinear first-order conservation laws. They arise in various applications including sedimentation of polydisperse suspensions and multiclass vehicular traffic. Their numerical approximation is a challenge since the eigenvalues and eigenvectors of the corresponding flux Jacobian matrix have no closed algebraic form. Polynomial viscosity matrix (PVM) methods have the advantage that they only need some information about the eigenvalues of the flux Jacobian, and do not require spectral decomposition of a Roe matrix. The PVM methods are competitive with several existing methods in accuracy and efficiency, including the Harten, Lax and van Leer method and a spectral weighted essentially non-oscillatory scheme that is based on the same interlacing property.

## **G** | Computational uncertainty quantification for a clarifier-thickener model with several random perturbations

Continuous sedimentation processes in a clarifier-thickener unit can be described by a scalar nonlinear conservation law whose flux density function is discontinuous with respect to the spatial position. In the applications of this model, the rate and composition of the feed flow cannot be given deterministically. Efficient numerical simulation is required to quantify the effect of uncertainty in these control parameters in terms of the response of the clarifier-thickener system. Thus, the problem at hand is one of uncertainty quantification for nonlinear hyperbolic problems with several random perturbations. The presented hybrid stochastic Galerkin method is devised so as to extend the polynomial chaos approximation by multiresolution discretization in the stochastic space. This approach leads to a deterministic hyperbolic system, which is partially decoupled and therefore suitable for efficient parallelization. Stochastic adaptivity reduces the computational effort. Several numerical experiments are presented.



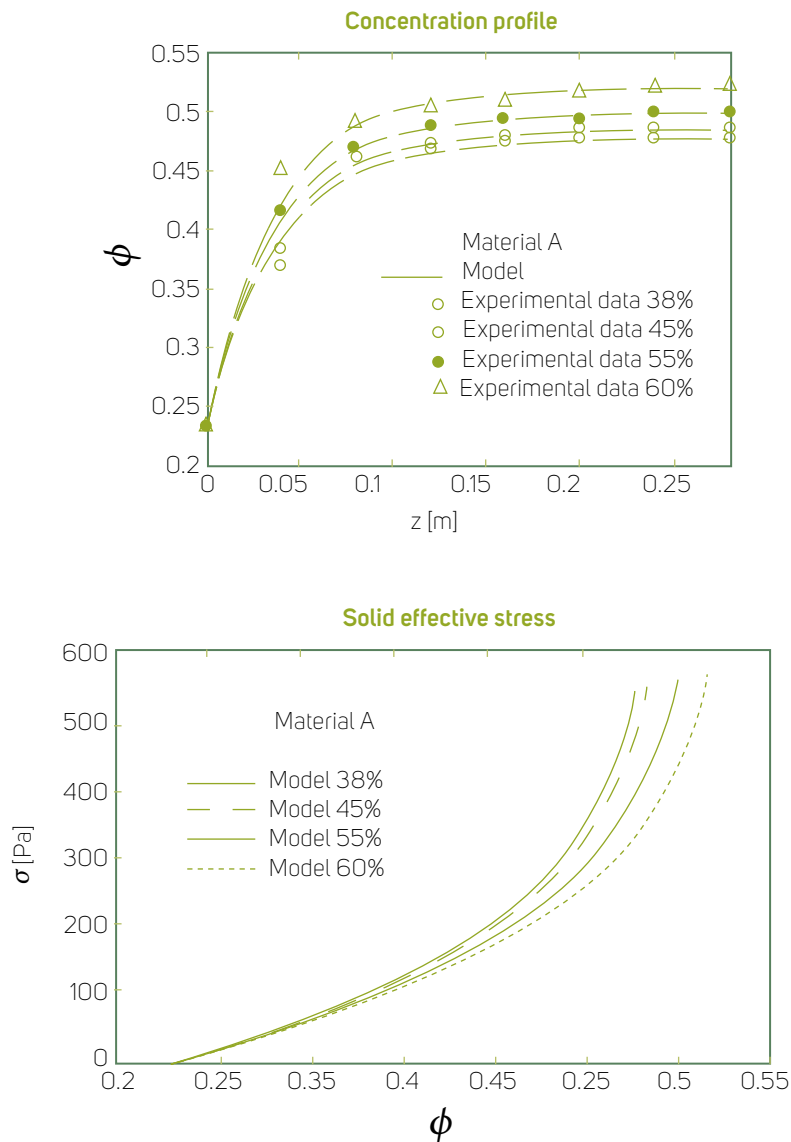


## H Formation of sediment of multi-sized incompressible particles

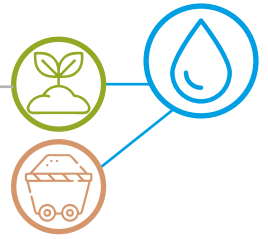
The objective of this work is to determine the concentration profile of a saturated polydisperse particulate system, such as those found in mine tailings dams and soils in agriculture. A method to solve the balance of effective solid stress and concentration profile and a new constitutive equation for the volume solids fraction were developed.

$$\frac{d\phi}{d\sigma} = c_0 e^{-k_c \sigma} ; \quad \sigma_0 \leq \sigma \leq \sigma_H$$

As a result, a nonlinear model to estimate the axial concentration and effective stress distribution profile was obtained as a function of the parameter  $k_c$  that characterizes the material.







## 1.4 | MULTIPHASE FLOW IN HETEROGENEOUS POROUS MEDIA IN AGRICULTURE AND MINING

### A | Discontinuous approximation of viscous two-phase flow in heterogeneous porous media

Runge–Kutta Discontinuous Galerkin (RKDG) and Discontinuous Finite Volume Element (DFVE) methods are applied to a coupled flow–transport problem describing the immiscible displacement of a viscous incompressible fluid in a non-homogeneous porous medium, such as the soil in agriculture or filtration of concentrates in mineral processing. The model problem consists of nonlinear pressure–velocity equations (assuming Brinkman flow) coupled to a nonlinear hyperbolic equation governing the mass balance (saturation equation). The mass conservation properties inherent to finite volume-based methods motivate a DFVE scheme for the approximation of the Brinkman flow in combination with a RKDG method for the spatio-temporal discretization of the saturation equation. The stability of the uncoupled schemes for the flow and saturation equations is analyzed and several numerical experiments illustrate the robustness of the numerical method.

### B | Multi-dimensional porous media flow without capillarity

In this work, we derive a numerical technique based on finite-difference WENO schemes for the simulation of multi-dimensional multiphase flows in a homogeneous porous medium. The key idea is to define a compatible discretization for the fluxes of the convective term in order to maintain their divergence-free character not only in the continuous setting but also in the discrete setting, ensuring the conservation of the sum of the saturations through time evolution. The one-dimensional numerical technique is derived in detail for the case of neglected capillarity effects. Numerical results obtained with one- and two-dimensional standard tests of multiphase flow in a homogeneous porous medium are shown.





## 2 | SEAWATER AS A NEW SOURCE FOR AGRICULTURE, MINING AND COMMUNITIES

The projected increase in the capacity of copper mining companies and new plants by 2025 requires significant additional quantities of process water. The mining industry currently consumes  $14.7 \text{ m}^3/\text{s}$  of fresh water and will require  $24.6 \text{ m}^3/\text{s}$  by 2025. There is not enough fresh water available in the northern regions of Chile to meet this demand. Thus, mining companies, the agricultural sector and communities are considering seawater as a new water resource. Seawater is necessary but harmful to almost all processes if applied directly. Its negative effects are well known but their mechanisms have not been completely elucidated. Thus, scientific unknowns should be solved, technologies adapted and new technologies created.



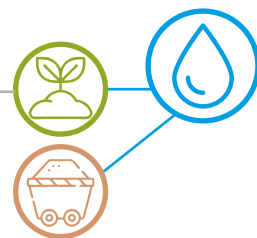
### Flocculation and rheological behavior of particle suspensions with seawater ions

We used macroscopic modeling in two cases with special attention to the physical meaning of the parameters depending on the chemical environment: (a) a population balance model to describe the time evolution of aggregate size distribution in turbulent shear flow during flocculation and (b) a new empirical three-parameter visco-elastic model for describing

the rheological behavior of linear and nonlinear suspensions and sediments.

### New empirical three-parameter visco-elastic model

We developed a new empirical three-parameter visco-elastic model to describe the rheological behavior of linear and nonlinear materials. The nonlinear behavior at the beginning of the creep response of our suspensions shows that an almost



instantaneous viscoelastic response occurs, followed by a long quasi-stationary state or gradual retarded deformation, which makes it very complex to fit conventional linear models for viscoelastic solids. We proposed a new ansatz to represent the creep curves in the whole time domain.

### Molecular dynamics simulation of the mineral-water interface in the presence of seawater ions and polyelectrolytes

The use of water with high salt content in mineral processing requires deep knowledge of the interaction of electrolytes with polyelectrolytes (reagents) and solid surfaces (mineral and gangue). Moreover, it is known that similar electrolytes produce dramatically different effects on the structure, and therefore the properties, of water and suspensions as well as the shielding intensity of local electric fields emanating from polarized or ionic sites on polyelectrolytes and solid surfaces. Seawater contains numerous ions such as Na, Ca, Mg, K and others of lesser quality. It is crucial to comprehend how these ions interact with solids in mineral suspensions. Here, we used molecular simulation to study the mineral-water interface in the presence of salts from seawater and macromolecules used as reagents; of interest are mineral oxides (quartz, alumina, titania) and sulfides (pyrite and chalcopyrite) contained in copper concentrates and tailings in the processing of copper ores. The methodology and results are also relevant in soil physics and thus in agriculture.

### Nanoforce-distance curves between two flat substrates in different media from molecular simulation and enhancement from a continuum model

A molecular dynamics simulation of a nanoscale capillary water bridge between two planar substrates (particles) was used to determine the

resulting force between the substrates without arbitrariness regarding the geometry and location of the free surface (meniscus) of the bridge. For now, the substrates are moderately hydrophilic. Research on replacing water with saline water has started. In addition, in 2015, we formulated and solved a continuum model of the system.

### Hybrid simulation methodology that allows the study of particulate systems

In an effort to better explain the underlying physics of fitting parameters, a new idea began to germinate: to develop a hybrid simulation methodology that allows the study of particulate systems by combining different simulation techniques to address their different spatial and temporal scales. The specific objectives are to (a) estimate, by molecular simulation, bulk liquid phase properties such as density and viscosity and their dependence on temperature and pressure, (b) identify, by molecular simulation, interfacial tension of liquid-liquid and liquid-solid systems through analysis of capillary waves and thermodynamic integration, (c) determine the characteristics of the simulations of the smoothed particle hydrodynamics (SPH) by simulating flow problems where solutions are known, (d) develop models of flocculation and sedimentation to be simulated with SPH using parameters obtained from molecular simulations and (e) study the hydrodynamics of colloidal systems by simulation with SPH and extension of these concepts to sedimentation and flocculation. We are currently testing such models.

### Partial desalination of seawater (pre-treatment)

Seawater mainly affects the grade of copper concentrates, but also significantly diminishes the recovery of molybdenum, gold and silver. This effect



## 2 SEAWATER AS A NEW SOURCE FOR AGRICULTURE, MINING AND COMMUNITIES

is generally attributed to the salt content of seawater. However, as demonstrated at the laboratory level at the University of Concepción, salinity conceived as common salt concentration is not a problem for the flotation of copper ores and their by-products. It was shown that the negative effect of seawater is due mainly to the presence of Ca and Mg; therefore, their removal prior to flotation by partial desalting or pre-treatment produces process water of good metallurgical quality—even better than that of fresh water—for the recovery of copper and molybdenite. The removal of these ions makes desalination unnecessary, decreasing capital and operating expenses associated with reverse osmosis. This technology has been tested in the laboratory but requires pilot-scale studies. The objective of this project is to build and operate a seawater pre-treatment and a flotation pilot plant.

### Economic evaluation of producing process water from seawater

In an analysis of 25 reverse osmosis plants in operation, installed in and/or planned for Chile, we calculated the total investment in US dollars necessary to produce one cubic meter per day of desalinized water from seawater and the cost of one cubic meter of process water. We compared the costs of process water from seawater from reverse osmosis desalination and pre-treatment, showing the contributions of CAPEX and OPEX in US\$/m<sup>3</sup> to the costs of producing water from seawater at the plant and at a mining operation 160 km from the plant and several elevations in meters above sea level.

### Scaling and bio-fouling mechanisms and inhibitors

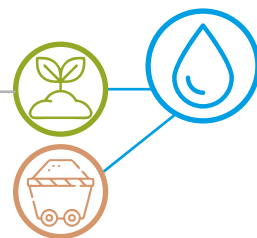
The availability of water and its efficient use are priorities for the regions from Arica to Atacama, not

only in mineral processing, but also in sectors such as agriculture, the development of cities and rural communities and tourism. The idea of incorporating new technologies based on seawater and brackish water sources to ensure the availability and efficient use and reuse of water has emerged. We are working along two lines of research, (a) setting up a lab-scale system to generate inorganic scales and test scale inhibitors, more specifically to measure the kinetics of scaling with/without inhibitors for the selection of the best inhibitor and optimum dose for each particular situation of water to be treated, and (b) developing a protocol to extend the life of membranes and expand the use of reverse osmosis systems to bring quality water to all productive sectors, especially in remote communities, including a test kit for early warning of bio-fouling potential and strategies for the prevention, control and cleaning of membrane fouling.

### Reagents for copper flotation in saline and seawater

In seawater flotation, problems arise in the cleaning stage, where the unwanted pyrite and mineral by-products are depressed with lime at pH between 11.0 and 11.5. It is ultimately the depressant effect of lime that impairs the recovery of molybdenite and gold. To recover molybdenite and gold, pH should be corrected to a lower value, which implies that an alternative to lime depression of pyrite must be found for seawater or brackish water. There are also problems in the cleaning stage with foaming, which are due to excess lime and changes in bubble coalescence. In seawater and saline water, there is an incompatibility between lime and foam quality. Minera Centinela is a copper mine that uses sodium metabisulfite to depress pyrite ions industrially at pH 8. Unfortunately, copper ores containing pyrite in amounts greater than 5% cannot be used in this process. For these ores, it is necessary to





find new reagents to replace sodium metabisulfite. Work is underway that suggests that the chemical composition of seawater favors depression of pyrite in alkaline media and that metal cations (e.g., Cu ions) play an active role as oxidizing agents.

### Effect of kaolinite on the floatability of chalcopyrite using seawater

Another goal in year 2 was to evaluate the depressing effect of kaolinite on the floatability of chalcopyrite using distilled water (0.01 M NaCl), seawater and solutions containing Ca, Mg, Na and K ions at the concentrations at which they appear in seawater in the pH range of 8 to 11. A chalcopyrite sample was obtained from Ward's Natural Science Establishment. The chalcopyrite content of the sample was 98.9%, with minor amounts of quartz (0.8%) and pyrite (0.3%). The size ranged from 40 to 210 microns. The kaolinite sample was provided by the Clay Minerals Society Source Clays Program. X-ray diffraction analysis indicates a mineralogical composition of 96% kaolinite, 3% anatase and 1% other impurities. The measured mean particle size for kaolinite was 8.9 microns, with 100% of the particles below 21 microns. The study thus far has focused on the effect of seawater vs. fresh water on the recovery of CPY, CPY-bubble induction times and turbidity. The analysis of the results confirms that slime coating is an important mechanism of depression of chalcopyrite in the presence of kaolinite. The presence of ions in solution is a variable that has to be taken into account to explain the interactions between clay minerals and chalcopyrite. In seawater, the depressing effect of kaolinite on chalcopyrite may be related to the action of hydrolyzed species of magnesium and calcium, which could induce hetero-coagulation between kaolinite and chalcopyrite. The phenomenon of clay-coated bubbles was confirmed in this work by

image analysis and it is proposed as a mechanism that might explain the depressing effect of clays on the floatability of chalcopyrite.

### Economic evaluation of producing process water from seawater

An economic analysis of the CAPEX and OPEX costs of three options for using seawater in mineral processing plants was carried out. The options evaluated were: (a) seawater desalinated by reverse osmosis (SWRO), (b) seawater pre-precipitated by lime and (c) raw seawater (non-desalinated). The main factors taken into account were the elevation or altitude of the mining operation and the distance from the coast to the mineral processing plant. The unit cost of the treated seawater (USD/m<sup>3</sup>) delivered to the mineral processing plant was calculated assuming a concentrator located 160 km from the coast with a water demand of 100,000 m<sup>3</sup>/d (1,157 L/s). The study, based on data from 25 reverse osmosis plants in operation in, installed in or planned for Chile, yielded a calculated total investment of US\$ 600 million for a reverse osmosis seawater desalinization plant, US\$420 million for a pre-treated seawater plant and US\$380 million for a raw seawater plant. These investment totals, necessary to produce one cubic meter of process water per day, resulted in costs of US\$6.00, US\$ 4.20 and US\$4.00 per cubic meter 160 km from the plant and 3,500 meters above sea level.



### 3 | TECHNOLOGY FOR WATER MANAGEMENT

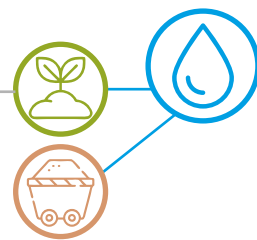
Water is used intensely in all productive sectors based on extraction and processing of natural resources. In Chile in particular, the mining sector uses 4% of the total, while agriculture uses more than 75% of the available freshwater in the country.

The water stress that is affecting Chile as a result of global climate change has generated a new scenario for water management in the country in which its use must be prioritized and a circular economy promoted in the productive sector. This new notion of productive behavior employs integrated management of water and its use and reuse.

The technologies involved in this water management approach are varied and meet the objective of acting on water quality in production processes and surface water ecosystems.

The aim of this line of investigation is to assess the performance and/or adaptation of different physical, chemical and/or biological technologies or a sequence of them that can intervene in processes related to mining and agriculture and their relationship with the environment to reduce contamination and close production cycles.





## 3.1 | ACID MINE DRAINAGE AND REMEDIATION

### Use of membrane processes for water reclamation from acid mine drainage (AMD)

Acid mine drainage (AMD) is generated from waste rock and tailings and contaminates soils, surface water and groundwater. AMD can be a source of valuable metals, the recovery of which can partially or totally offset the cost of treatment. Passive and active technologies can be employed to treat AMD. Membrane filtration, still considered an emerging technology for the active treatment of mine water, has a relatively small footprint and does not involve significant dosing with chemicals or the generation of chemical sludge.

#### Nanofiltration

Two chemical engineering thesis reports were obtained in which the objective was to evaluate the AMD treatment by nanofiltration (NF) and reverse osmosis (RO) at pilot scale. The performances of two commercial spiral-wound membranes—NF99 and RO98pHt, both from Alfa Laval—were compared. The results showed a high ion removal, which reached 92% for the NF99 membrane and 98% for the RO98pHt membrane. With respect to sulfate, removal reached 97% and 99% for NF99 and RO98pHt, respectively. In the case of copper, aluminum, iron and manganese, the removal percentage surpassed 95% in both membranes.

In addition, the results of the study of nanofiltration as an alternative to reverse osmosis in seawater desalination were published and patented. The objective of the study was to obtain drinking water from seawater using two alternatives. Optimal operating conditions for nanofiltration

are a temperature of 10°C and a feed flow of 1,325 L/h. However, one step of nanofiltration at 40 bar was unable to remove the required Cl and ion concentrations to meet the Chilean and World Health Organization (WHO) drinking water standards; therefore, it is necessary to carry out a second stage of ion exchange.

#### Forward Osmosis

Forward osmosis is a novel technology when it comes to mining wastewater. Research conducted this year has been oriented toward the determination of rejection factors for several metals using a forward osmosis process with different draw solutions. Results show that forward osmosis membranes can have good levels of retention for the most common ions present in acid mine drainage. An international MSc student (from the Czech Republic) did her thesis on this subject during 2016. Results are being analyzed in order to prepare a publication that is expected to be submitted during 2017. Two BSc students have also been working in this field, one of them dedicated to studying the technical feasibility of the process.

### Use of bioprecipitation processes for heavy metal removal from acid mine drainage (AMD)

During 2016, research began on the application of the microbial-induced carbonate precipitation (MICP) process for heavy metal removal. This process has previously been tested for the treatment of soil contaminated with heavy metals, but few reports are available for wastewater. Preliminary results show a potential capacity to remove copper from liquid samples. A BSc student did his graduation project on the subject during 2016 and a PhD student is starting a thesis in this field.



### The environmental risk of acid mine drainage (AMD) using bioassays to test water quality and land use

Heavy metal release into the environment through AMD has occurred continuously and constitutes a severe water pollution problem associated with mining activity. Sulfuric acid and hydrogen ions lower the pH and cause the mobilization of other heavy metals such as Al, Mn, Zn, Pb, Cu, As, Ni, Cd and Co. Heavy metal distribution and bioavailability in sediments and the water column have to be considered in order to obtain a better understanding of environment-organism interactions. A review of this topic was published by Pérez et al. (constructed wetland for mining effluents).

The use of biological methods for evaluating contamination is an important alternative for understanding the potential for residual water to contaminate when discharged into aquatic ecosystems. The aim of this research is to evaluate the toxicity of AMD through water quality and land use bioassays. The results suggest that the environmental risk associated with AMD could be significantly mitigated through relatively cheap and simple measures to reduce metal mobility such as liming.

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## 3.2 | ACID MINE DRAINAGE AND REMEDIATION

### Biogas production by anaerobic treatment of wastewater

Anaerobic digestion can provide a cost-effective conversion of organic matter into biogas, providing a sanitary solution not only for waste disposal, but also for generating biomethane and facilitating nutrient recovery. Sewage is normally diluted, and this

condition, when combined with low temperatures, tremendously complicates the application of anaerobic processes. Sewage concentration by forward osmosis was studied at lab scale using different membranes (micro-filtration, ultra-filtration, forward osmosis). Sewage concentration would increase organics concentration, enabling direct application of anaerobic digestion to sewage. The results allowed the publication of a research paper in 2016 (*in Chemical Engineering Journal*) and a platform presentation at an international conference (Latin-American Workshop and Symposium on Anaerobic Digestion, Peru). A second manuscript is being prepared at the moment, which is expected to be submitted during the early months of 2017.

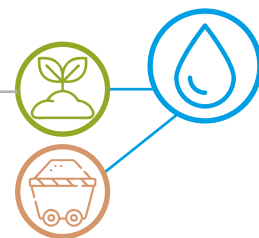
### Optimization of biogas production by anaerobic treatment of sludge

Pre-treatment processes can be applied to promote sewage sludge disintegration before anaerobic digestion. A review regarding pre-treatment was published by Neumann et al. (2016) in *Review in Environmental Science and Bio/Technology*. However, these technologies are generally associated with high costs, as heat, electricity and/or chemical addition are needed to carry out the pre-treatment. The objective of this work is to study the effects of ultrasonic pre-treatment on solubilization, enzymatic activity and anaerobic digestion of sewage sludge.

### Biogas upgrading

Transformation of biogas into a potential substitute for natural gas requires the removal of carbon dioxide and other gases, a process known as biogas upgrading. Research has been conducted on the use of microalgae as a way to add economic value to biogas (see Vergara et al.,





2016, Biodeterioration Biodegradation). A PhD was finished on this subject in 2016. The candidate defended her thesis before an international committee, earning the highest grade. A manuscript was submitted on this subject in 2016, and work has started on two other manuscripts that will be submitted during 2017. The results were also presented at an international conference (Latin-American Workshop and Symposium on Anaerobic Digestion, Peru), earning an award for the best platform presentation of the entire conference.

### Bioflocculation

Improvement of primary separation during sewage treatment can increase biogas production from sludge. Moreover, it would reduce aeration requirements, improving the energy balance of sewage treatment plants. Primary separation can be improved using secondary sludge as a bioflocculating/biosorption agent. Research was conducted in this direction. An MSc thesis was finished on this subject in 2016 and a manuscript was submitted for publication and is under review. Moreover, the results were presented at an international conference (Latin-American Workshop and Symposium on Anaerobic Digestion, Peru). Cooperation on this subject with researchers of the University of Rhode Island (USA) was initiated. Research in the lab was oriented toward studying the fate of nitrogen during bioflocculation of sewage.

### Reuse of wastewater treated by non-conventional technologies (evaluation of organic matter, nutrients and micropollutants)

#### Constructed wetland evaluation

Although 99% of concentrated populations are covered by wastewater treatment systems, rural areas of Chile are low-density nuclei, of

which only 15% have wastewater collection and treatment systems. The adaptation of non-conventional technologies such as constructed wetlands can be a very good alternative for such areas. A horizontal subsurface flow (HSSF) constructed wetland at pilot plant scale and different configurations of vertical subsurface flow at lab scale were evaluated by a PhD and three undergraduate students (one environmental engineer and two bioengineers). The development of and nutrient uptake by *Phragmites australis* (Phr) and *Schoenoplectus californicus* (Sch) in HSSF were evaluated. The results were published by López et al. (2016) in *J Soil Sci. & Plant Nutrition*. Regarding the fiber generated by the constructed wetland, a book entitled "Vegetable fibers and their applications: Innovation in their generation from water purification" was edited by Vidal and Hormazabal (Editions University of Concepción, ISBN 978-956-227-405-0, property registration 272.242 year 2016, 60 pp.).

### Feasibility of reuse of wastewater treated by non-conventional technology

Regarding the parameters considered for the reuse of treated water, the constructed wetland effluent shows concentrations within the standard for water use in irrigation. In addition, the work "Comparative analysis of the perception of the adult population of the rural communities of Hualqui and San Pedro de Atacama regarding the reuse of treated wastewater" is being carried out. Hualqui and San Pedro de Atacama are rural areas. Hualqui is located in the south of Chile, where water is abundant, while San Pedro is in the Atacama Desert, where the population has always lived under water scarcity conditions.



### 3.3 | AGRO-INDUSTRIAL RESOURCES AND AGRICULTURAL REMEDIATION

Agriculture is an important sector in Chile, and the surface area used for agricultural activities has increased by approximately 70% in the last 10 years. More than 60% of the cultivation of cereals in the country takes place in the Araucanía Region, with a commensurate generation of waste (>1,000,000 tons/year). Modern farming and food production require a high quantity of fertilizers and adequate soil conditions to obtain high productivity in soils with high degrees of erosion, and 64% of Chilean territory presents some degree of erosion. In this respect, organic and inorganic wastes can be added to soil to improve its physical and chemical characteristics, especially in soils poor in organic matter such as sandy soils. Although many inorganic and organic materials are extensively used for this purpose, diatomite, perlite and biochar are not commonly used, even when they come from agro-industrial processes.

#### Agro-industrial resources to improve soil properties

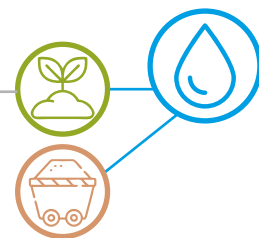
- **Wastes to develop substrate to improve the water holding capacity in degraded areas**

This work involves the evaluation of different waste materials to design agro-industrial substrates (amendments) to increase the water holding capacity (WHC) in sandy soils. In addition, biological activity and microbiological communities were evaluated by molecular techniques. The materials evaluated were perlite from the agar production industry, biochar from a biomass boiler from the wood board industry, filter earth (diatoms) from the brewing industry and sawdust from the wood processing industry. The main results showed that the productivity

of ryegrass increased in all treatments with added agro-industrial wastes compared to the control without amendment, and the chemical properties of the sandy soil were also improved by the addition of the different combinations of agro-industrial wastes. The results were presented at the Fifth International Symposium on Environmental Biotechnology and Engineering (5ISEBE) in Argentina and in the thesis of Silvina Guzman, biochemist.

- **Pig slurry to increase chemical properties in degraded soil and plant nutrient uptake**

Swine production in Chile has intensified, reaching 500,000 tons/year and totaling 8% of all production in South America. Pig slurry, the most important by-product in the pork industry, has been used as fertilizer due to its significant organic matter content. Chile is the second largest producer of pork in South America and produces 6.4 tons/year of pig slurry. This project studied the effect of pig slurry and the microbial consortium constituted by bacteria, fungi and actinomycetes on two degraded soils and ryegrass growth, nutrient uptake and establishment under greenhouse conditions. The combined treatment, involving the microbial consortium and the addition of the pig slurry, had an additive effect, improving the chemical quality of the soil and nutrient uptake by *L. perenne*. The application of beneficial microorganisms to the soil can enhance nutrient uptake and increase the efficiency of organic amendments. In this regard, the combined use of a microbial consortium and pig slurry has a potential role in developing sustainable systems for crop production (Schoebitz and Vidal, 2016, *J. Soil Sci. and Plant Nutrition*).



### Biopurification system for pesticide degradation

An efficient biotechnological tool to mitigate point source contamination by agricultural pesticides is the on-farm biopurification system (biobed). The biopurification system is based on the adsorption and degradation capacity of a biomixture prepared with top soil, straw and peat, with a plant cover.

### Understanding the rhizosphere to improve pesticide degradation in the biopurification system

The objective of this research is to understand the rhizosphere and rhizodegradation of pesticides, the reduction in point source contamination by pesticides using biobed technology and the benefits of the grass layer and its rhizosphere in order to contribute to enhancing the degradation of pesticides compared with unplanted matrix. The rhizosphere effect of a *Lolium perenne*, *Festuca arundinacea* and *Trifolium repens* mixture on the dissipation of a pesticide combination that was composed of atrazine, chlorpyrifos and isoproturon was studied. The results indicated that there was high dissipation of atrazine, chlorpyrifos and isoproturon in the planted pots compared with the unplanted pots. In addition, exudation of oxalic and malic acid in contaminated pots, associated with oxidation of the pesticide mixture in the biomixture of a biobed system, was higher than in the control without pesticides. Therefore, we concluded that the grass layer enhances pesticide removal in biobeds (results published by Urrutia et al., 2015).

### Novel insights into a biopurification system for pesticide mixture dissipation in repeated applications

Pesticide dissipation from planted biomixture increases quickly with respect to non-planted matrices (Urrutia et al., 2015). Plant-microbial interaction increases microbial activity at the root-soil interface where physical, chemical, and/or biological parameters are modified by the action of the root exudates. The objective of this study was to assess the effect of the re-application (0, 30 and 60 days) of a pesticide mixture on the operation of a biopurification system with and without grass cover. The results were submitted to *Environmental Science and Pollution Research* and presented at the XXXV Congreso Interamericano de Ingeniería Sanitaria y Ambiental (AIDIS), Colombia) and in the thesis of Barbara Ravena, agronomist.

### Specific microorganisms (individual and consortium) to degrade specific pesticides

Organophosphorus pesticides (OPs) represent the most important pesticides in the global market, and contamination of soil, water systems, atmosphere and foods has been reported worldwide due to large-scale use of these compounds. The aim of this study was to assess pure cultures of diazinon-degrading *Streptomyces* spp. in order to define a mixed culture capable of removing CP and its main metabolite 3,5,6-trichloro-2-pyridinol (TCP) from liquid media. The results of this study were published by Campos et al. (2016).

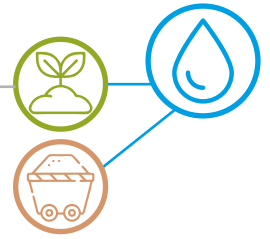


## 4 | HYDROLOGY, WATER AVAILABILITY AND CLIMATE CHANGE



Mountain watersheds play a critical role in the production of the water needed for different productive activities such as mining, energy, and agriculture as well as the drinking water supply and the sustainability of the ecosystems that support these areas. The first research line aims at understanding the hydrological processes that control streamflow generation and how driving forces like the climate and land use change will affect water availability. The second research line is focused on the study of the groundwater processes of recharge, storage and release. This focus was based on the hypothesis that these processes play an important role as resilience mechanisms against the effects of climate change and variability on water resources during low-flow conditions, especially spatially in the volcanic Andean watersheds located throughout Chile.





## 4.1 | MASS BALANCE AND HYDROLOGICAL CONTRIBUTION OF GLACIAR UNIVERSIDAD

Increasing temperatures in the central Chilean Andes, together with the decrease in precipitation in the previous and current decades, have resulted in acute hydrological stress in north-central Chile. As snow and ice represent the water tower of the region, ongoing climate change may strongly impact glacial storage, posing a threat to future water resource availability downstream in the cities and the cultivated lowlands. As glaciers tend to accumulate water in wet years and release it during dry years, reduced glacier storage can also weaken the inter-annual buffering of streamflow by glaciers. The prospect of long-term reduced glacier storage and associated increased inter-annual variability in streamflow may exacerbate conflicts in north-central Chile where water demand is high.

Glaciar Universidad (377942.23E 6160282.2423N) is located in the upper part of the Rapel River basin in the O'Higgins Region. Morphologically, it is a valley glacier with strong frontal retreat in the last 50 years. It is at the union of two continuous sub-basins that face north and west (Lliboutry, 1956; DGA, 2014). Its linear length is around 10 km from the front to the peak of the western sub-basin. The size of the glacier is approximately 27.6 km<sup>2</sup>. The local environmental conditions are semiarid and temperate, and it is located in an area of climate transition. It has an altitudinal range of 2,450 m and a maximum height of approximately 4,550 m in the north basin. Glaciar Universidad was studied in order to determine its current mass balance and hydrological contribution in relation to current climate conditions, with emphasis on the effect of distributed albedo and distributed energy balance, glaciological and geodetic methods and

ice movement. To understand glacier movement, we used Image GeoRectification and Feature Tracking (ImGRAFT). With this package, we carried out georeferencing, georectification and feature tracking of terrestrial oblique images from the glacier area. The glacier-wide mass balance was slightly negative in 2012/13 ( $Ba = -0.32 \pm 0.40$  m w.e. a<sup>-1</sup>), but much lower in 2013/14 ( $Ba = -2.53 \pm 0.57$  m w.e. a<sup>-1</sup>) due to increased summer ablation. The current drought conditions affecting the extratropical region of Chile could reduce mass balance not only through decreasing snow accumulation, but also through increased ablation resulting from an earlier exposure of the ice surface in the ablation zone and a corresponding decrease in albedo.

## 4.2 | MOUNTAIN WATERSHED HYDROLOGY AND VULNERABILITY OF THE WATER SUPPLY AND ECOSYSTEM SERVICES

This research line is focused on the study of the groundwater processes of recharge, storage and release. This focus was based on the hypothesis that these processes play an important role as resilience mechanisms against the effects of climate change and variability on water resources during low-flow conditions, especially spatially in the volcanic Andean watersheds located throughout Chile. This research is a collaborative effort with two Chilean universities and three foreign universities: the Universidad Católica de la Santísima Concepción, the Universidad de la Serena, the University of California, Davis (USA), the Colorado School of Mines (USA) and the Leibniz Universität Hannover (Germany).

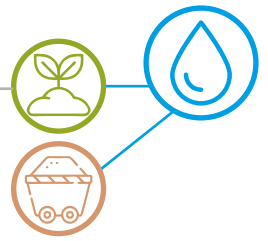


During 2015-2016, we focused on the study of the water balance in order to evaluate water demand and availability in the Laja-Diguillín river system as an experimental watershed. The Laja-Diguillín system lies in the foothills of the Andes Mountains and the main source of water for the catchment is the Laja River, which receives water from the leaks formed through the porous volcanic barrier that dams Lake Laja. Snowmelt from the Andes is one of the main sources of water for the lake. The abundant availability of water in the mountain range has attracted hydropower operations. The basin has five hydropower plants that use water from either Lake Laja or the Laja River in an intricately developed diversion infrastructure. Water from the river is transported through various canals to irrigate the vast fields of the catchment. To combat the water shortage faced in the Diguillín catchment, the Laja-Diguillín Canal was built to transport water from the Laja River to the Diguillín catchment to meet irrigation needs. Different models have been used and compared in the area: SWAT, WEAP and a water balance model developed by the research group. We conclude that WEAP presents significant limitations in the estimation of agricultural water demands and that SWAT presents significant limitations in its applications in Andean watersheds with scarce soil data information. Therefore, we prefer the use of our own parsimonious models, which allow model experiments that improve our knowledge of the watershed to be generated.

## 4.3 | IMPROVEMENT OF WATERSHED GROUNDWATER STORAGE AND RELEASE PROCESSES USING RECESSION ANALYSIS

There is a concern about the impact that global driving forces will have on minimum flow conditions and therefore on water resources availability during high-demand conditions. In addition, it was recently ascertained that groundwater storage systems in mountain watersheds play a critical role in buffering climate variability changes and that these systems can be affected by land use changes or groundwater extraction.

As most of these watersheds have scarce data related to groundwater (very few observation wells are available in central Chile, and none south of Chillán) it is important to develop methodologies that use the available streamflow records to characterize groundwater systems. Markovich et al. (2015) used recession data clouds to study the parameterization of a complex model in two watersheds with different geological conditions: granitic low permeability and volcanic high permeability. In each watershed, different shapes of the recession data clouds represented the different storage and release behaviors of the watersheds. In an ongoing project, we expand on the work of Markovich, studying the recession flows of several Chilean rivers from the Limari watershed to Chiloé Island and finding that there is a relationship between the predominant geological characteristics and the behavior of the recession streamflow. Further research will focus on the analysis of land use and climate change on recession streamflow patterns.



## 4.4 | INTERDECADAL TO LONG-TERM FLUCTUATIONS OF SPECIFIC COMPONENTS OF THE WATER BALANCE

The main interdecadal mode of rainfall in extratropical South America, found by means of EOF analysis and using trendless time series, exhibits a spatial dipole with one pole located at 40–45°S in Chile and the other with the opposite sign in north-central Argentina. This mode seems to be related to the Interdecadal Pacific Oscillation, with

a lag time of five years, providing at a first glance a reliable explanation. More important, several global models used to project climate fluctuations forced by the increase in greenhouse gases in the atmosphere are able to reproduce the main observed interdecadal rainfall pattern. This result provides some confidence in the quality of the very complex processes parameterized by these models and the projections of the future climate, even at decadal time scales.







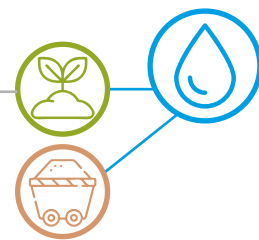
## 5 | WATER GOVERNANCE, ECOSYSTEM SERVICES AND SUSTENTABILITY

This research line seeks to make interdisciplinary contributions to water security from a legal and socio-environmental perspective. To this end, we recognize water security as the capacity of a population to safeguard sustainable access to adequate quantities of water of acceptable quality for sustaining livelihoods, human well-being and socio-economic development, to ensure protection against water-borne pollution and water-related disasters and for the conservation of ecosystems in a context of peace and political stability.

To make this contribution to water security, we have carried out research on six different topics. To improve our understanding of the value of water and water quality, we developed topics related to the perception of the value of water (i) and the impact of different technologies on water (ii). Topics number iii and iv are related to water governance and the final topics (v and vi) are related to the improvement of water resources management by adapting it to global change.







## 5.1 | PERCEPTION OF WATER VALUE

This study is based on the sociological investigation entitled "Perception and civil practices of the value of the water as a natural and social good: human, agricultural and mining consumption in Chile in times of climate change," which was carried out in four regions of the country. The objective of this research is to study the perceptions and citizen practices related to the value of water as a natural good for human, agricultural, mining and energy use in times of climate change. This investigation provided a significant quantity of hard information, which will allow the thinking of the population and water users to be understood. We designed a survey with 37 questions organized into 16 thematic areas : 1) the concept of water, 2) the value of water, 3) water as an element of identity, 4) entitlements to water, 5) precipitation, 6) rivers and reservoirs, 7) water quality, 8) multipurpose water in Chile today, in particular its use in agriculture, mining and energy, 9) disputes over water, 9) nesting water use 10) water scarcity, 11) the current water regulation system in Chilean law, 12) the national and regional system of water management, 13) climate change 14) water shortage, 15) mitigation strategies and adaptation to water scarcity and 16) new sustainable management systems. The survey data underwent a psychometric analysis, yielding a reliability coefficient of 0.74 and a Cronbach's alpha ( $\alpha$ ) of 0.80. The survey was given to a sample of 1,110 people over 18 years of age in the Coquimbo, O'Higgins and Biobío regions as well as in areas of the Metropolitan Region that have different economic profiles, stress levels and uses of water resources. The survey was carried out between the months of April and August of 2015. It had a sampling error of 3%, associated with an assumed confidence level of 95%. Regarding the

stratification criteria, proportional stratified random sampling was done.

## 5.2 | UNDERSTANDING HUMAN SYSTEM IMPACTS FROM TECHNOLOGIES

Since the impacts of technology on water resources and water quality in particular are not well understood, new strategies and tools must be developed to address the issue of water monitoring in Chile. Biomonitoring/bioindicator techniques are being developed to improve analytical capabilities to determine the impacts of pollution from agriculture and mining in rivers and coastal waters.

New developments in monitoring water quality: passive samplers as a tool for the analysis and interpretation of persistent organic pollutants and other emerging contaminants in different ecosystems. The objective of this research is to develop new strategies for monitoring contaminants in surface waters based on passive samplers, a time-weighted approach for measuring pollutants in surface waters with potential application in better water quality monitoring strategies. This approach is based on passive diffusion of pollutants from water to a polymer or other suitable matrix sampler, which will capture pollutants from the water. The system has been assayed in laboratory settings and now fieldwork is being developed in order to identify pesticides and emerging contaminants (pharmaceuticals, personal care products and endocrine-disrupting chemicals) in Chilean rivers. In addition, research is being conducted on the impacts of discharges of complex mixtures of pollutants on the biota in rivers, estuaries and soils using bio-indicators (fish, earthworms and aquatic worms).

## 5.3 | WATER USERS' ASSOCIATIONS IN CHILE

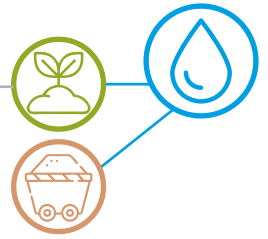
This research focuses on establishing if water users' associations (WUAs) play a central role in Chilean water management. In 2016, CRHIAM researchers participated in high-level government committees to develop administrative tools and regulations and they are working on the development of proposals to allow Chile to advance in integrated water resources management with a consensus about the importance of WUAs.

Agriculture in Chile must cope with the uncertainty resulting from demands for changes in water regulation. These changes are required according to the following arguments (i) the current model is excessively liberal, (ii) it artificially separates water from land and (iii) its model allows water speculation. However, the same model gives farmers security in their water rights and considers the centuries-old Chilean water management tradition represented by water users' associations (WUAs), a tradition that originates in Spain and is quite similar to the existing water use model in the acequia systems of New Mexico and Valencia, among other areas of the Hispanic World.

As agriculture and society change, so do the requirements of markets, raising new issues related to irrigation, water quality and food safety. In recent years, as the scarcity of water resources has increased, new problems have emerged such as competition between users of water energy and irrigation as well as pressures to protect important ecosystem services that support important tourist attractions like Laja Waterfall in the Biobío Region.

Chilean WUAs have developed from fragile farmers' organizations to very important, well-organized groups that incorporate professional administration and include other water users such as hydropower and mining companies and drinking water services. Following that pathway, Chilean WUAs are the future standard for a new approach to water management that blends tradition with the demands of the 21st century.





## 5.4 | WATER AND JUDICIAL PROBLEMS IN CHILE

In Chile, the understanding and resolution of conflicts that arise between individuals, or between them and the state, is entrusted to common and special courts (trial courts, environmental courts, courts of appeals, the Supreme Court, etc.). They manifest their decisions through judgments. Notwithstanding these findings, there is a relative lack of knowledge of how Chilean judges face the implementation of water law. This issue is related to the absence in Chile of a database of these judgments and decisions that is thematically oriented around water resources. The objective of this research was to study every single case regarding water rights conflicts decided during 2013 by a Chilean court (1,009 first instance cases, 42 court of appeals cases and 19 Supreme Court cases). Every case has been examined and translated into a chart (database) designed to obtain relevant legal information. The idea is to provide the legal technical inputs necessary to understand the reasons for conflicts over water rights and supply valuable empirical information to the legal community as well as policy makers. To create the database, the researchers chose to use the open access case law database made available by the judiciary through its institutional website ([www.poderjudicial.cl](http://www.poderjudicial.cl)) as a source of information. This option allows researchers to access a vast amount of court decisions from all over the country. Once the source of information was determined, criteria were set to restrict the number of court decisions. Thus, it was determined that as a pilot project, only the judgments pronounced by trial courts in 2013 would be considered. As the jurisdiction of courts (commune) is determined by law, it also determined the territorial unit of the study.



### Water conflicts in Chile: spatial intensity, challenges and policy

Water demand and climate variability increase competition and tension between water users—agriculture, industry, mining, hydropower—and local communities. Since 1981, the Water Code has regulated water allocation through private individual property rights, fostering markets as the distribution mechanism among users. The volume of court decisions made the task of searching, analyzing, and extracting knowledge from these texts challenging.

We built a representative database with a sample of 1,000 legal records corresponding to decisions issued by the Supreme Court and 17 courts of appeal





throughout the country from 1981 to 2014. Another 3,000 additional records are under analysis. Also, more than 1,000 cases from first-instance judges were used to build a third database.

For geo-tagging, all records were transformed to plain text and analyzed to find words matching the entries of a geographical thesaurus, allowing records to be linked to geographical locations.

**Spatial intensity:** The spatial pattern of the intensity of conflicts related to specific sections of the Water Code is explained in terms of the main geographical, climatic and productive characteristics of Chile. To implement the mapping tools, we combined a geographic information system with a search engine (Elasticsearch) and an analytic dashboard (Kibana).

**Challenges:** Geo-tagging legal records reveals a strong potential for allowing regional water conflict variations to be defined and understood. However, data availability would become a barrier if measures to improve data management were not taken.

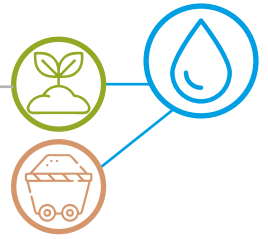
**Policy:** Regarding the institutional framework, the same regulations for water management rules are applied throughout the highly diverse ecosystems of the country, impeding the resolution of conflicts that are strongly related to the local geographical context. This leads to a collision of interests and visions around water resources of a public and private as well as national and international nature involving individuals, aboriginal communities and corporations, especially mining industries, regarding both extractive and non-extractive uses.

Water rights are one of the key components for the implementation and operation of water markets. Ongoing research shows that most of the conflicts reaching courts are related to changes and transfers of water rights. Also, there exists a tension among different information holders—the Real Estate Registry, managed by notaries, and the National Cadastre of Water Resources, managed by the Water Authority.

## 5.5 ADAPTATION TO CHANGE IN WATER RESOURCES: SCIENCE TO INFORM DECISION MAKING ACROSS DISCIPLINES, CULTURES AND SCALES

Climate change and human population dynamics alter water resource systems at many spatial and temporal scales throughout the world. Work from the local to global scales suggests that the effects of human population growth alone on water resources may outweigh those of climate change, and their combined effects are unlike any the human race has experienced in recent history. These two complex stressors are so interrelated, and their effects so wide ranging, that we cannot consider them or address the related problems in disciplinary isolation. The challenge for the water resources community is developing the ability to effectively integrate knowledge across disciplines and extend knowledge beyond the academic setting to policy makers and stakeholders. Water resource challenges in multi-stressor environments comprise the thematic basis for IGERT (Integrative Graduate Education and Research Traineeship, Funded by the National Science Foundation, USA). The research goal is to study the impacts of climate change and population dynamics on physical, ecological and socio-economic systems and





integrate them to formulate proactive adaptation scenarios. The overarching goal is to address system-wide gaps that currently exist for both aspects of this vision. In other words, we will train future scientists to address complex interactions and feedback in physical, ecological and social systems resulting from the combined impacts of climate change and human population dynamics and to develop collaborative skills to formulate adaptation strategies. In 2016, we continued our practice of developing an annual training course held at the Environmental Sciences Center EULA-Chile, where

PhD students in water resources at the University of Idaho and Chilean students from the Environmental Sciences program addressed two major issues in the Biobío basin. The event combined field trips, discussions with stakeholders, lectures and a large amount of time devoted to discussion.

### During 2016, the project “Systems Thinking

and Systems Dynamics in the Biobío Basin,” which is part of the PhD thesis of Jason Waters and Caitlin Eastman from the University of Idaho, was developed. This project has been supported by the INFEWS Program of the U.S. National Science Foundation. It incorporates a holistic systems thinking framework in order to better understand the dynamic interrelationships between various aspects of the socio-environmental system in the Central Valley of the Biobío River basin, which is the center of a food-water-energy nexus that is crucial to the economic production of the region. System dynamics modeling will be employed to provide tangible representations of the system structure and the interactions between and among its socio-economic, cultural, and biophysical aspects. A final web-based version will serve as a decision support tool for testing future scenarios against system behavior. Themes to be investigated through the modeling include climate change, dam operations, domestic and international markets, subsidies and investment, natural disasters, population dynamics, forestry production, crop selection, sediment dynamics and infrastructure improvements.

## 5.6 DEVELOPING WATER RESOURCES MANAGEMENT STRATEGIES BETTER ADAPTED TO THE CHILEAN MODEL

This line of research has been evolving from the initial goal of establishing the concept of ecosystem services as a keystone in the water management system in Chile to the analysis of gaps related to Chilean water law.

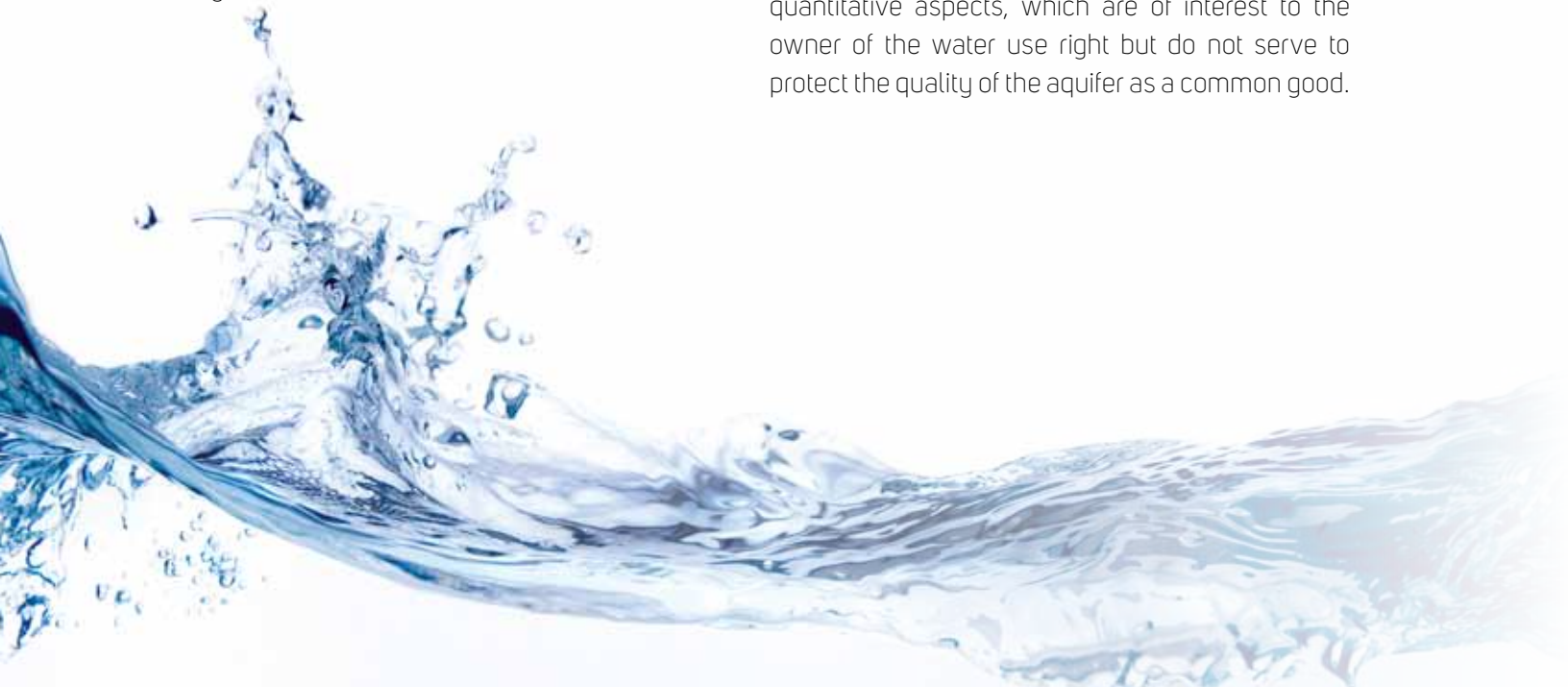
Important gaps addressed in 2016 were ecosystem services, desalinization and use of raw sea water for mining, human rights to water access, groundwater protection areas and the inclusion of environmental concepts in Chilean water law.

Continuing research initiated in 2013, we have demonstrated the importance of the concept of ecosystem services today in Chilean legislation and environmental justice, especially in lawsuits and penalties for environmental damage. It is proposed that the concept serves as a criterion to determine active legitimization in these trials when natural components of the environment or ecosystems are damaged.

We conclude that use of sea water in mining and desalination does not have a judicial framework in current Chilean legislation; therefore, the comparative study of international legislation is developed to propose modifications to Chilean legislation.

Regarding human water rights, conceptual research is conducted through the study of compared models to propose a legal modification that establishes a priority use of water that could contribute to the regulation of water according to international experience.

In Chile, there is no legal protection of groundwater quality even though it is the main source of drinking water for the population and is therefore vulnerable to pollution from dangerous activities near catchments. In the absence of such a regulation, the Water Code (and the new by-law of 2014), which considers a fixed protection area for water use rights, is applied. We reviewed the purpose of this area and how it is determined by comparing it with the special regulation of mineral water and drinking water. In summary, this aspect of the code is insufficient because it only considers quantitative aspects, which are of interest to the owner of the water use right but do not serve to protect the quality of the aquifer as a common good.





## VI. ADVANCED HUMAN RESOURCES TRAINING

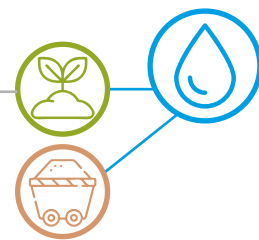




One of the center's main objectives is to train researchers at the undergraduate and especially graduate and postdoctoral levels in order to address the lack of advanced human resources in the country.







Human resources training is one of the key activities for CRHIAM. The importance of this activity was made explicit in the second goal of the project: "To train researchers at the undergraduate and especially graduate and postdoctoral levels to address the lack of advanced human resources in the country."

Following that goal, the center has maintained constant activity in human resources training that is conducted through the graduate and undergraduate programs associated with the center and the establishment of different educational activities conducted to coordinate the students that belong to the different programs associated with the center around research on water resources.

## 1. GRADUATE PROGRAMS ASSOCIATED WITH CRHIAM

The researchers of CRHIAM are part of different graduate and undergraduate programs and bring many students to the center through their teaching, student supervision and research.

### Doctoral programs

At the doctoral level, CRHIAM researchers are part of six programs: i) Environmental Sciences with a concentration in Continental Aquatic Systems, ii) Engineering Sciences with a concentration in Chemical Engineering, iii) Energy, iv) Metallurgical Engineering, v) Applied Sciences with a concentration in Mathematical Engineering and vi) Agricultural Engineering with a concentration in Water Resources in Agriculture. The first five programs are accredited by the National Accreditation Commission (CNA).

As a result of the change in accreditation status of the Doctoral Program in Agricultural Engineering, it has undergone modifications that will include a new curriculum, the incorporation of the area of energy and a name change to "Doctorate in Water Resources and Energy in Agriculture." The Doctoral Program in Environmental Sciences with a concentration in Continental Aquatic Systems is currently in the process of obtaining a new accreditation, which will be received in January 2017.

### Master's programs

The researchers of CRHIAM are part of five scientific master's programs, all of which require the completion of a thesis and publication. They are the master's programs in: i) Agricultural Engineering with a concentration in Agro-industry, Energy and Water Resources, ii) Engineering Sciences with a concentration in Civil Engineering, iii) Science in Engineering with a concentration in Chemical Engineering, iv) Metallurgical Engineering and v) Regional Sciences. The Master's in Agricultural Engineering is accredited by the National Accreditation Commission (CNA).

### Undergraduate programs

The researchers of CRHIAM are professors in the various departments that make up the center and therefore participate in the development of 10 undergraduate programs: Bachelor in Mathematics, Law, Geophysics, Environmental Engineering, Civil Engineering, Agricultural Engineering, Mining Engineering, Metallurgical Engineering, Chemical Engineering and Sociology.

Seniors of these undergraduate programs directly benefit from their participation in seminars and workshops and the development integrated final projects.



### Certification programs

Certification programs are important activities to transfer new knowledge to professional engineers whose work involves water resources-related issues. Following this principle, CRHIAM, through its associated units, has been developing new certification programs. It is important to clarify that because CRHIAM is a center in development, according to University of Concepción regulations, human resources training programs must be created by one of the associated units of the university.

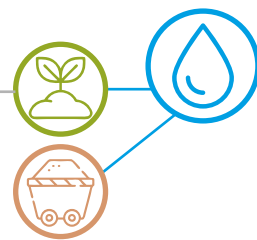
In October 2014, the Department of Water Resources of the University of Concepción submitted to CONICYT a grant proposal to offer a program entitled "Certification in Water Resources Management in the Agricultural-Food Industry." This proposal was granted by CONICYT in September 2016, started with 42 students in March 2015 and finished in October 2016.

### Coordination of training activities in water resources

According to its creation mandate, CRHIAM contributes to the formation of human capital through different activities such as teaching and graduate and undergraduate theses. At the same time, CRHIAM contributes to the delivery of a series of specialized courses with different clusters that have defined the center. In addition to these courses, several internal workshops involving students and researchers from different clusters were offered during the year to promote transdisciplinary discussion of relevant problems.

Undergraduate Students	61
Master's Students	16
PhD. Students	35
Postdoctoral Fellows	15
<b>TOTAL</b>	<b>127</b>





## Graduate programs

1. Doctorate in Agriculture Engineering, Water Resources, UdeC.
2. Doctorate in Environmental Sciences, Aquatic Systems, UdeC.
3. Doctorate in Electrical Engineering, UdeC.
4. Doctorate in Chemical Engineering, UdeC.
5. Doctorate in Metallurgical Engineering, UdeC.
6. Doctorate in Engineering Mathematics, UdeC.
7. Doctorate in Natural Resources, UFRO.
8. Doctorate in Food Engineering, UBB.

- 
1. Master of Agricultural Engineering with concentrations in Agro-industry, Mechanization and Energy and Water Resources, UdeC.
  2. Master of Environmental Management with concentrations in Labor Risks and Corporate Social Responsibility, UDD.
  3. Master of Science in Electrical Engineering, UdeC.
  4. Master of Metallurgical Engineering, UdeC.
  5. Master of Natural Resources Economy and environment, UdeC.
  6. Master of Science in Chemical Engineering, UdeC.
  7. Master of Science in Civil Engineering, UdeC.
  8. Master of Sustainability Management, UDD.
  9. Master of Science in Biotechnology, UFRO.
  10. Master of Science in Food Engineering, UBB.

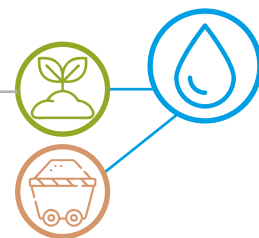
## Undergraduate programs

1. Electrical, Chemical, Metallurgical, Civil and Mathematical Engineering, UdeC.
2. Agricultural Engineering, UdeC.
3. Environmental Engineering, UdeC.
4. Legal and Social Science, UdeC.
5. Environmental Engineering, UFRO.
6. Food Engineering, UBB.



2. POSTDOCTORAL FELLOWS		
Name	RESEARCH TOPIC	ADVISER'S NAME
Alvaro Torres	PHA production from wastewater	David Jeison
Juan Carlos Ortega	Forward osmosis for water recovery from mining wastewater	David Jeison
Soledad Chamorro	Evaluación del riesgo ambiental de drenajes ácido de mina a través de bioindicadores de calidad de agua y uso de suelo	Gladys Vidal
Carolina Reyes Conteras	Evaluation of organic micropollutants, nutrients and organic matter removal contained on domestic wastewater treated by constructed wetlands	Gladys Vidal
Daniela López	Reuso de agua servida tratada mediante humedales construidos	Gladys Vidal
Heidi Schalchli	Valorización de residuos agroindustriales. Obtención de productos de valor agregado	M. Cristina Diez
Sudarshan Kumar Kennetinkara	Numerical Analysis of Partial Differential Equations	Raimund Bürger
Maria del Carmen Martí Raga	Numerical Analysis of Partial Differential Equations	Raimund Bürger
Cristina Alejandra Villamar	Valorización de residuos agrícolas	Diego Rivera
Yessica Rivas	Water availability in Coastal watersheds	Diego Rivera
Douglas Aitken	Water use in mining	Alex Godoy
Robinson Torres	La Hidro-Modernidad de lo Común: Una Ecología Política de los Nuevos Movimientos Sociales por el Agua en Chile	Jorge Rojas/ Ricardo Barra/ J.L.Arumí
Felipe Tucca Díaz	Monitoreo de compuestos orgánicos hidrofóbicos en agua mediante dispositivos de muestreo pasivo: una aproximación hacia el conocimiento de la calidad del agua en sistemas fluviales	Ricardo Barra
Viviana Almanza	Limnología	Roberto Urrutia
Gerson Valenzuela	Surface force between two surfaces separated by few nanometers	Pedro Toledo





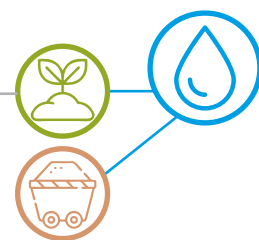
3. PHD STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING DEGREE
Leslie Meier	Biogas purification by microalgae	David Jeison	Universidad de La Frontera
Carla Duarte	Precipitation of heavy metals on mining wastewater through microbial induced carbonate precipitation (MICP) process	David Jeison	Universidad de La Frontera
Francisco Cabrera	Development of strategies for polyhydroxyalcanoate production in mixed microbial cultures by online control of oxygen and pH variations.	David Jeison	Universidad de La Frontera
Barbara Vital	Treatment of acid mine drainage by forward osmosis: Rejection of selected metals	Jan Bartacek University of Chemistry and Technology, (Prague, Czech Republic)/ David Jeison	University of Chemistry and Technology, Prague, Czech Republic
Daniela López	Evaluación estacional de humedales construidos de flujo horizontal subsuperficial para la depuración de aguas servidas en zonas rurales: implicancias en la generación de metano	Gladys Vidal	U. De Concepción
Patricio Neumann	Digestión anaerobia avanzada de biosólidos sanitarios: implicancias energéticas y ambientales	Gladys Vidal	U. De Concepción
Jorge Cornejos	Identificación y caracterización de híbridos de Populus spp. asociados a la tolerancia de cobre y cadmio como una aproximación biotecnológica y mecanismos de fitorremediación	Jaime Tapia / Gladys Vidal	U. de Talca



### 3. PHD STUDENTS

NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING DEGREE
Thais González	Comportamiento de un humedal artificial acoplado con sistemas bioelectroquímicos para potenciar su eficiencia en la depuración de aguas residuales rurales	Gladys Vidal	U. de Concepción
María Venegas	Influencia de la tecnología sobre la calidad de lodos estabilizados provenientes de la depuración de aguas servidas	Gladys Vidal	U. de Concepción
María Vanessa Gutierrez	Modelación fenomenológica de Espesamiento en pasta	Fernando Betancourt	U. De Concepción
Alonso Pereira	Desarrollo y validación de estrategias de control para espesadores	Fernando Betancourt	U. De Concepción
Diana Celi	Basic studies for water balances in tailing dams	C. Goñi	U. De Concepción
Elvis Gavilán	Mathematical Modelling and Numerical Simulation of Spatio-Temporal Models of Vector-Borne Disease	R. Bürger / Gerardo Chowell-Puente	U. De Concepción
Lihki Rubio	Métodos de Alta Resolución con Matrices de Viscosidad Polinomiales y Refinamiento de Malla Adaptativo para Modelos de Flujo Cinemático Multi-Especies	Raimund Bürger	U. De Concepción
Camilo Mejías	Advanced Numerical Techniques for Convection-Diffusion-Reaction Problems Arising in Secondary Settling Tanks and Related Applications	Raimund Bürger	U. De Concepción





3. PHD STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING DEGREE
Víctor Osoreo	Modelamiento Matemático y Simulación Numérica de un Sistema de Shallow Water Multicapa con Sedimentación Polidispersa en Dos Dimensiones Horizontales, Ing. Civil Matemática, UdeC, started September 2013; defended March 31, 2015; supervised (jointly with Enrique D. Fernández-Nieto, U. de Sevilla, Spain).	R. Bürger / Enrique D. Fernández-Nieto, U. de Sevilla, Spain	U. De Concepción
Alejandro Panunzio	Manejo de agua en arándanos	Eduardo Holzapfel	Universidad de Buenos Aires
Jorge Espinosa	Vulnerabilidad hídrica en cuencas andinas: la cuenca del Río Ángel, Ecuador	Diego Rivera	U. De Concepción
Claudia Sangüesa	Patrones espaciales y temporales de intensidad de precipitación en Chile Central	Diego Rivera	U. De Concepción
Francisco Zambrano Bigiarini	Mapas de riesgo de sequía agrícola a escala regional.	Mario Lillo	U. De Concepción
Angel García Pedrero		Mario Lillo	Universidad Politécnica de Madrid.
Daniel Inzunza Herrera	Métodos Implícitos-Explícitos para Problemas de Convección-Difusión-Reacción no Lineales y no Locales	Raimund Bürger	U. De Concepción
Javier Camaño	Estudio del comportamiento hidrológico de techos verdes y su aplicación para climas mediterráneos/ Evaluación de riesgo de inundación usando desagregación temporal	José Luis Arumí	U. De Concepción

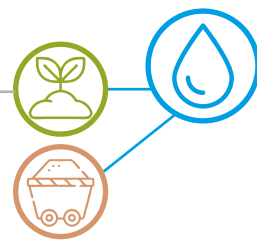


### 3. PHD STUDENTS

NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING DEGREE
Julieth Galdamez	Desde supervivencia hasta thriving ("prosperabilidad") sustentabilidad de los recursos hídricos para la producción de alimentos en Chile	José Luis Arumí	U. De Concepción
Vanessa Novoa	Contabilidad de la huella hídrica de la cuenca del río Cachapoal para la evaluación de la Sostenibilidad	José Luis Arumí	U. De Concepción
Benigno Andiranel Banegas Medina	Importancia ecológica de un río intermitente para la biota acuática, que sirva como un modelo para entender posibles escenarios de cambio climático	Ricardo Figueroa	U. De Concepción
Katherine Markovich	Water resource vulnerability to climate change in a permeable alpine system	Graham Fogg/R. Maxwell / José Arumi	University of California Davis
Andrés Ramírez Madrid	Interacción de filosilicatos con especies sulfuradas en la flotación de minerales de cobre en medios acuosos de distinta salinidad	Leopoldo Gutierrez	U. De Concepción
Enrique Wagemann Herrera	Mitigación de pérdidas hidrodinámicas en Nanoporos y Nanocanales	Pedro Toledo	U. De Concepción
Gonzalo Quezada	Solid-liquid interaction in the presence of electrolytes and polyelectrolytes	Pedro Toledo	U. De Concepción
Maria Jose Climent M.	Evaluación de riesgo ambiental por plaguicidas organofosforados en agua superficial y aire en una cuenca con intensa actividad agrícola: Cuenca del Río Cachapoal (Chile Central)	Roberto Urrutia	U. De Concepción







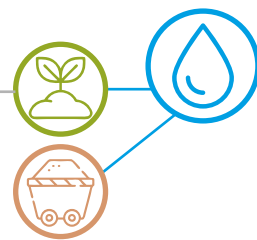
3. PHD STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING DEGREE
Carlos Mendoza M.	Variabilidad Glacio-Hidrológica y Sensibilidad Climática del Glaciar Universidad (34°40'S, 70°20'W), Chile	Roberto Urrutia	U. De Concepción
Isis Montes R.	Reconstrucción de eventos de floraciones de cianofitas durante los últimos 1000 años basado en Pigmentos Sedimentarios y ADN: Buscando evidencias de eventos climáticos y alteraciones Antrópicas	Roberto Urrutia	U. De Concepción
Lina Uribe Velez	Flotabilidad de pirita en agua de mar	Leopoldo Gutierrez	UdeC
Rodrigo Yepsen	Comportamiento de la Enargita en el proceso de flotación utilizando agua de mar	Leopoldo Gutierrez	UdeC



#### 4. MASTER'S STUDENTS

NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Camilo Segura	Dynamics of microalgae inhibition by ammonia	David Jeison	Universidad de La Frontera
Michael Araneda	Biofloculación en la sedimentación primaria como estrategia para aumentar la producción de biogás en plantas de tratamiento de aguas servidas	David Jeison	Universidad de La Frontera
Fernanda Pinto	Efecto de la concentración de metales traza (Fe, Co, Ni y Ba), sobre la velocidad de producción de metano en la digestión anaerobia de muestras de alperujo fresco y alperujo pretratado	David Jeison	Universidad de La Frontera
Francisco Lecaros	Effect of water application in apple	Eduardo Holzapfel	U. De Concepción
Julio Mendoza	Water management at farm scale through a spatially distributed programming service,	M. Lillo	U. De Concepción
Karla Silva	Riego en Cítricos	Eduardo Holzapfel	Universidad de Recocavo de Bahia
Daniel Pèrez	Numerical simulation of a hydricyclone using a granular model	Pablo Cornejo	U. De Concepción
Viviana Gavilán	Evapotranspiración desde pivotes	Mario Lillo	U. De Concepción
Marco Del Rio	Simulación numérica de un ultrafiltrador	Pablo Cornejo	U. De Concepción





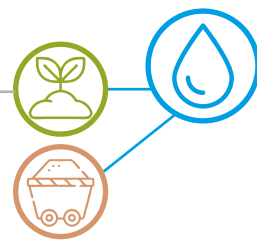
4. MASTER'S STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Daniel Páez	Análisis de caudales de recesión y caracterización de la relación entre escorrentía superficial y agua subterránea en cuencas del sistema hidrogeológico de Chiloé	José Luis Arumí	U. De Concepción
Katerina Wernekinck	Propuesta de manejo al problema de crecimiento de plantas acuáticas en canales de riego	J.Arumí/ Roberto Urrutia	U. De Concepción
Prajna Kasargodu Anebagilu	Simulation of water availability and demand in the Laja-Diguillin river system with weap.	Jorg Dietrich/ José Luis Arumi	Leibnitz Universität Hannover
Vincent Vorgel	Field investigations about soil and sediment parameters and implications to improve an eco-hydrological model of the Itata catchment in Chile	Jorg Dietrich/ José Luis Arumi	Leibnitz Universität Hannover
Kim Etcheverría	La necesidad de una regulación especial sobre el proceso de desalinización en Chile.	Verónica Delgado	U. De Concepción
Alvaro paredes	Zeta potential of pyrite in the presence of seawater salts	Pedro Toledo	U. De Concepción
Cristian Romero	Viscoelastic behavior of silica suspensions	Pedro Toledo	U. De Concepción



5. UNDERGRADUATE STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Sebastián Sepúlveda	Bioprecipitación de metales pesados en efluentes mineros usando precipitación de calcita inducida microbiológicamente (MICP)	Alvaro Torres	U. de La Frontera
Andrés Huirilef	Evaluación de condiciones hidrodinámicas en el proceso de recuperación de agua de relaves mineros por osmosis directa	Juan Carlos Ortega	U. Católica de Temuco
Ignacio Castillo	Evaluación técnico-económica de la escalabilidad de un proceso de ósmosis directa para la recuperación de aguas de relaves mineros	Juan Carlos Ortega	U. Católica de Temuco
Madeleine Aguilera	Factibilidad técnica de concentración de jugo de arándanos por osmosis directa	David Jeison	U. de La Frontera
Benjamín Luza	Start up and operation of bioflocculation SBR	David Jeison	U. de La Frontera
Ana María Leiva	Evaluación del proceso de Nitrificación de Aguas Servidas mediante Humedales Construidos de Flujo Vertical Subsuperficial	Gladys Vidal	U. de Concepción
Mario Sepúlveda	Producción de metano en el tratamiento de aguas servidas por humedales de flujo horizontal subsuperficial utilizando Phragmites australis y Schoenoplectus californicus: composición de las comunidades microbianas	Gladys Vidal	U. de Concepción
Ariel Rivas	Determinación del costo exergético del tratamiento de aguas servidas del humedal construido de Hualqui	Gladys Vidal	U. de Concepción







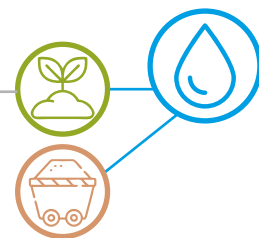
5. UNDERGRADUATE STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Gloria Gómez	Determinación del costo exergético del tratamiento de aguas servidas del humedal construido de Hualqui	Gladys Vidal	U. de Concepción
Pilar Rivera	Obtención de biogás a partir de materia orgánica contenida en efluentes de celulosa kraft mediante un consorcio metanogénico en un reactor UASB	Gladys Vidal	U. Pablo de Olavide, Sevilla, Spain
Leonardo Peña	Reutilización de las aguas residuales en el riego o en el propio proceso de fabricación del aceite de oliva	Gladys Vidal	U. De Concepción
Romina Nuñez	Transformación de materia orgánica mediante humedales construidos acoplados a celdas combustibles microbianas	Gladys Vidal	U. De Concepción
Carol Burgos	Evaluación de humedales construidos en régimen de policultivo y monocultivo de plantas ornamentales para la depuración de aguas servidas	Gladys Vidal	U. de Concepción
Adrián Albarrán	Identificación y Evaluación de la Toxicidad (TIE) de drenaje ácido de mina, mediante bioindicadores de calidad de agua	Gladys Vidal	U. De Concepción
Marcela Levio	Reuso de aguas servidas en la agricultura, tratada mediante humedales construidos	M. Cristina Diez	U. De La Frontera
Barbara Ravana	Operación de un reactor de lecho empacado con biomezcla para la remoción de atrazine	M. Cristina Diez	U. De La Frontera



5. UNDERGRADUATE STUDENTS

NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Daniela Segura	Análisis comparativo de la percepción y aceptación de la población adulta de las comunidades rurales de Hualqui y San Pedro de Atacama respecto al reuso de aguas servidas tratadas, para ser utilizadas con propósitos potables y no potables	Gladys Vidal	U. De Concepción
Felipe Barriga	Influencia de pre-tratamiento combinado sobre la producción de biogás y calidad de lodos secundarios estabilizados mediante digestión anaerobia	Gladys Vidal	U. De Concepción
Javier Cartes	Alternativas de gestión energética en la industria sanitaria y su impacto ambiental	Gladys Vidal	U. De Concepción
Javier Andalaft	Control del ensuciamiento durante la nanofiltración de drenaje ácido	A. Schwarz/ Rodrigo Borquez	U. De Concepción
José Suárez Figueroa	Biorreactor para tratamiento de DAM y recuperación de Metales	Alex Schwarz/ José Vargas	U. De Concepción
Mauricio Montalva	Electrodíálisis de Drenaje Ácido	A. Schwarz/ Rodrigo Borquez	U. De Concepción
Alejandra Morales	Estimación de demanda de agua en áreas verdes urbanas.	D. Rivera	U. De Concepción
Andrés Pérez	Estimación de evaporación en lagos	O. Lagos/D. Rivera	U. De Concepción
Camila Palma	Uso eficiente del agua en la agricultura	C. Goñi	U. De Concepción





5. UNDERGRADUATE STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Grace Rivera	Study of the effect of the flocculants on the consolidation of copper tailings using Seditest equipment	F. Betancourt	U. De Concepción
Julián Ravanal	Estudio de floculantes para sedimentación de relaves con alto contenido de arcillas. DIMET	Fernando Betancourt	U. De Concepción
Sebastián Carrasco	Estudio de sedimentación de relaves de minera Caserones utilizando equipo Sedirack Online. DIMET	Fernando Betancourt	U. De Concepción
Daniela Aguayo	Modelo para el pronóstico de caudales mediante Minería de Datos.	Mario Lillo	U. De Concepción
Nicolás Muñoz	Riego en Manzanos	Eduardo Holzapfel	U. De Concepción
Jonathan Labrín	Implementation and evaluation of a methodology for automatic co-registration of multimodal satellite images	Mario Lillo	U. De Concepción
Bárbara Flores	Relationship between the state of El Yali wetland and climate variability	Diego Rivera	U. De Concepción
Jonathan Venegas	Relationship between flow and water rights of river boards	Diego Rivera	U. De Concepción
Fernando Matus	Experimental analysis of reagents used for thickening of copper tailings	F. Betancourt	U. De Concepción
Joshua Parra	Tailings sedimentation study using Sedirack online equipment	F. Betancourt	U. De Concepción
Edgar Faúndez	Experiments of ultraflocculation using a cylindrical reactor	F. Concha	U. De Concepción

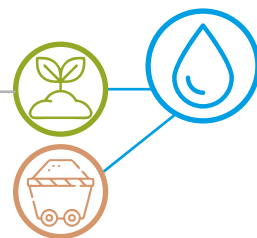


## 5. UNDERGRADUATE STUDENTS

NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Marco Salazar	Experiments of ultraflocculation using a hydrocyclone-type reactor	F.Concha	U. De Concepción
Julio Careaga	Modelamiento Matemático y Simulación Numérica de Sedimentadores con Área Variable en Planta de Tratamiento de Aguas Servidas	R. Bürger	U. De Concepción
Mathias Kuschel	Análisis de Ciclo de Vida en producción agrícola	Diego Rivera	U. De Concepción
Alvaro Galindo Morales	Aspectos Jurídicos relevantes de la NCH 409, sobre agua potable en Chile	V. Delgado	U. De Concepción
Constanza Guajardo Urra	Trade-off ecosistémicos: ¿Qué es lo que se pierde por generar hidroelectricidad?	R.Figueroa	U. De Concepción
Cristian Gonzalez	Recarga Artificial de acuíferos en Derecho comprado"	V. Delgado	U. De Concepción
Daniel Inzunza	La efectividad del sistema jurídico de aguas, en el Derecho Internacional de los Derechos Humanos, frente a situaciones de escasez hídrica.	A. Alvez	U. De Concepción
Ignacio Codelia Contreras	Respuesta funcional de los macroinvertebrados bentónicos a la sustitución de bosques nativos por plantaciones exóticas.	R.Figueroa	U. De Concepción
Joselinne Carrasco	Aspectos Constitucionales de los Recursos Hídricos	A. Alvez	U. De Concepción
Laura Carrillo Barra	Planes de descontaminación asociado a norma de calidad secundaria río Bío - Bío.	V. Delgado	U. De Concepción







5. UNDERGRADUATE STUDENTS			
NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Ma. José Carrasco Cartes	Recarga artificial de acuífero en el derecho comprado Europeo	V. Delgado	U. De Concepción
Paula Hoffer Garcés	El reciclaje de las aguas en el marco constitucional del derecho a vivir en un medioambiente libre de contaminación	A. Alvez	U. De Concepción
Yaritza Burgos Vergara	Comunidad de MIB asociados a vegetación nativa y exótica en ríos de cabecera en la zona Centro-Sur de Chile	R.Figueroa	U. De Concepción
Natalia Andrea Ramírez Fernández	Determinación de la existencia de Fármacos en aguas del Río Biobío, mediante monitoreos pasivos con la utilización de SDB (Styrene Divinyl Benzene).	R. Barra	U. De Concepción
Gabriela Alvarez de Araya	Evaluación del Riesgo de Contaminación de Suelos y Aguas Suterraneas por plaguicidas en un viñedo	R Barra	U. De Concepción
Luis Higuera	Hidrología del Secano Interior	José Luis Arumí	U. De Concepción
Eric Osorio	Calibración de un muestreador pasivo de etilvinilacetado (EVA) para la monitorización de distintos pesticidas en un medio acuático superficial	José Luis Arumí/Felipe Tucca	U. De Concepción
Patricio Silva	Impacto Social de la escasez hídrica en el secano interior de la región del Bío Bío	Jorge Rojas	U. De Concepción
Francisco Alarcón	Cinética de floculación de alúmina	Pedro Toledo	U. De Concepción



## 5. UNDERGRADUATE STUDENTS

NAME OF STUDENT	THESIS TITLE	ADVISER'S NAME	UNIVERSITY CONFERRING THE DEGREE
Millaray San Martín	Viscoelastic behavior of clay suspensions	Pedro Toledo	U. De Concepción
Francisco Ortiz	Estudio de la evolución temporal de las crecidas en cuencas de la VII, VIII y IX región	José Vargas	U. De Concepción
Nicolas Rojas	Hidrología de Wadis	José Vargas	U. De Concepción
Pablo Vidal	Análisis de la precipitación en el Norte Grande de Chile, para determinar posibles zonas propensas a Wadis.	José Vargas	U. De Concepción
Yoshihiro Kawaguchi	Análisis comparativo de caudales máximos estimados a través de series históricas de caudales. Aplicación zona centro-sur de Chile.	José Vargas	U. De Concepción
Erick Rebolledo	Dispersantes para mejorar flotabilidad de molibdenita en agua de mar	Leopoldo Gutierrez	UdeC

# VII.PUBLICATIONS





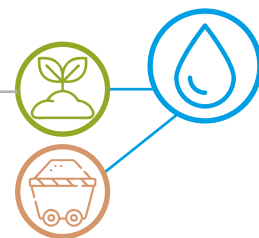


CRHIAM was active in publications during 2016 through books, scientific publications and presentations at national and conferences.

The total number of papers published in 2016 in ISI journals was 68. Out of these, 56 were of the highest rank (from Q3 to Q1) relevant to CRHIAM activities, six more than the number of publications committed to for 2016 (the 3rd year of the project), and 12 were Q4. CRHIAM researchers also published four non-ISI papers.







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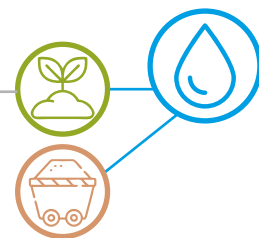


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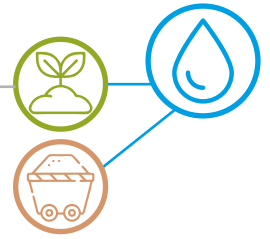


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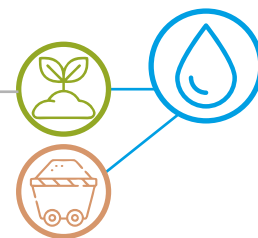




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#### 5. PATENTS

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# VIII. TECHNOLOGY AND KNOWLEDGE TRANSFER





## 1 | TECHNOLOGY TRANSFER

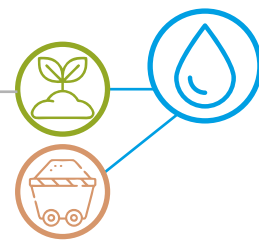
Within the framework of the knowledge transfer and dissemination activities carried out in the CRHIAM project, we can highlight two broad lines of activities.

### Knowledge transfer and extension

The first line, knowledge transfer and extension, is related to different transfer activities established in the framework of technological and innovation projects. Among these, the “Transfer Model” project has been implemented; its main activity was to establish the transfer model of knowledge and dissemination developed by the Water Center

with the support of the University of California, Davis. This project focuses on strengthening the capacities of leaders and users of different water users’ associations of the O’Higgins Region through training activities in irrigation technologies, legal, financial, accounting and organizational aspects and ICT tools that ensure improved management and administration of water resources. In total, 40 conferences with a total of 160 teaching hours and the participation of 407 people were carried out in the third year of CRHIAM within the framework of line one.

The second line of knowledge transfer and extension is characterized by transfer activities designed according to the requirements of stakeholders. The target audience for transfer activities was centered on farmers and professionals from public and private institutions. Among the different types of activities carried out in this second



line, we can highlight certification courses, short courses, workshops and talks. Seven activities were carried out with a total of 116 teaching hours and the participation of 166 people.

### **“Innovative Solutions ExpoAgro Aysén” Technology Fair**

The Water Center participated in the “Innovative Solutions ExpoAgro Aysén” Technology Fair at the request of the Seremi (Regional Ministerial Secretary) of Agriculture. On this occasion, Dr. Felipe De la Hoz made a presentation on integrated water resources management, highlighting the work of CRHIAM and the Water Center in this line. It also participated through a stand in which dissemination material was provided. The activity was organized by the Seremi of Agriculture and Corriedale Breeders Trade Association and financed by the Regional Government of Aysén and the Foundation for Agrarian Innovation (FIA).

### **Regional Technology Fair for Irrigation in the Fifth Region of Chile**

The Semilla Foundation, in Hijuelas in the V region, held the First Regional Technology Fair for Irrigation, organized by AGRYD and Hidroamb. The event presented the irrigation services and technologies of different companies and included talks by experts in the field. Among them was Dr. De la Hoz, who lectured on “Management of Water Resources Information,” a project executed by the Water Center in collaboration with CRHIAM. This fair sought to promote the efficient use of water resources, with an emphasis on environmental protection, the use of renewable energy and energy efficiency, favoring the development of sustainable productive agriculture in the country.

TECHNOLOGY AND KWNOWLEDGE TRANSFER SUMMARY OF ACTIVITIES		
TYPE OF ACTIVITY	TOTAL DURING 2016	NUMBER OF PARTICIPANTS
Training Courses	48	568
Workshops	3	134
Conferences	2	102
International Congresses	3	362







## 2 | CONTRIBUTION TO PUBLIC POLICY DEVELOPMENT

Members of CRHIAM participated in various commissions as advisers and supported the management of certain topics as well as fairs related to water resources.

CRHIAM participated actively in the National Council of Innovation for Development (CNID) for Water Resources Sustainability with the objective of contributing its research to the report entitled "Science and Innovation for Water Challenges in Chile," which was delivered on Tuesday, December 20 to President Michelle Bachelet. The document, presented by CNID Director Gonzalo Rivas, provides a strategy for research, development and innovation in water resources. Fernando Concha and Eduardo Holzapfel participated actively in the National Council of Innovation for Water Resources Sustainability. Doctors Diego Rivera, Jose Luis Arumí and Alex Godoy also participated in the information and research subcommittees.

In addition, under the umbrella of CNID, CRHIAM led the creation of the Chilean Network of Water Resources Centers, with a significant contribution from Eduardo Holzapfel and the participation of Felipe de la Hoz. The document was presented by CNID Director Gonzalo Rivas.

Dr. Felipe de la Hoz participates as member of CRHIAM in the Water and Environment Committee, a multi-sectoral initiative that emerged in 2011, bringing together economic, academic, non-governmental and citizen organizations in order to advance toward a comprehensive vision of water resources problems and their social, economic and environmental implications. The members of this committee delivered to the president and ministers the "Manifesto of Agreements of the Water and Environment Bureau," a document summarizing in 11 points the concerns on the lack of information for sustainable management and informed decision making and the dispersion of authority among various agencies and institutions in the public sector. Figure 2 shows the act of delivery of the document to President Michelle Bachelet.



## IX. OUTREACH





## 1 | EXTENSION AND OUTREACH

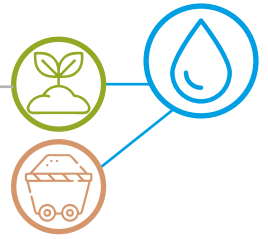
Outreach activities are of paramount importance to support growth and increases in productivity. As noted by the Chilean Ministry of Agriculture, new knowledge and technological innovations have impacts on productivity when there are strong links between research institutions and stakeholders. In order to make knowledge and technology available to industries, there must be a combination of actions—extension, technology dissemination and technology transfer—and an established network of information flow. Current opinion in technology transfer highlights the need to build bridges between research centers and industries in order to achieve high degrees of

cooperation such as co-generation of knowledge and joint investment in technological projects.

CRHIAM has a strong commitment to establishing reliable links among its researchers and industry stakeholders. Building this network is a long-term process and requires actions at different levels such as outreach and extension activities, i.e., enhancing the access of producers and industries to knowledge and technologies, and technology transfer, i.e., the co-creation of products or processes applicable to solve industrial problems. Within this long-term process, the first actions are related to outreach and extension in order to install the center as a potential partner and also to identify technological needs.

Thus, the center has been working on internal and outreach activities such as newsletters,





workshops and scientific meetings as well as participating in international events.

CRHIAM publishes a monthly newsletter that summarizes the activities organized by the center and taken part in by our team. The Water and Society cluster compiles news summaries, which include information on various topics related to water covered in national and international media.

It is important for CRHIAM to spread knowledge to Chilean society. This year, therefore, our center focused on organizing activities with local schools. We organized several conferences about topics related to water and took part in different activities. For example, we enhanced the school science fairs in the village of Llico, where members of our team developed workshops and conferences for more than 130 students between

the ages of 12 and 15. These fairs were a joint effort of both CRHIAM and the Fondap Project Interdisciplinary Center for Aquaculture Research (INCAR).

In addition, during 2016, CRHIAM started working with social media, where we got to connect with society in general and provide information about our activities and relevant information about water resources. We have a Facebook fan page and a Twitter account.

In December 2016, our Facebook fan page had 466 followers, 379 posts and an average of 93 visits per month; we reach an average of 3,478 people per month with our posts. Meanwhile, our Twitter account had 145 followers, 327 posts and 69 likes.

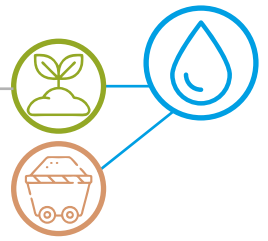




## 2 | EVENTS ORGANIZED

- 1 Seminar: 18th Seminar on Water Resources and Environmental Management. March 13-17, 2016.
- 2 Conference: Ingeniería Ambiental para la Sustentabilidad, led by Dr. Ramón Méndez. May 4, 2016.
- 3 Internal seminar: Students of the Water and Society cluster present their work. May 19, 2016
- 4 Internal workshop: Agua para el consumo humano: Perspectivas y desafíos. June 1, 2016.
- 5 Conference: Agriculture and Innovation in Brazil, led by Dr. Silvio Carlos Ribeiro Vieira Lima. June 22, 2016.
- 6 Internal workshop: Communication Skills and Techniques, for CRHIAM students. July 6, 2016.
- 7 Conference: Seeing things differently: Rethinking the relationship between data, models, and decision-making, by Dr. Ty Ferre, Distinguished Darcy Lecturer for 2016. August 1, 2016.
- 8 Internal Seminar: Students of the Water and Society Cluster present their work. August 10, 2016.
- 9 Academic Conference: Contaminación ambiental: Nuestra agua como receptor de contaminantes, led by Dr. Felipe Tucca. August 29 and 30, 2016.
- 10 Scientific meeting: Technology Cluster. Dr. Gladys Vidal and Dr. David Jeison. September 9, 2016.
- 11 Scientific meeting: Dry Mining group. September 30, 2016.
- 12 Workshop: Uso del recurso hídrico en la actividad forestal. September 30, 2016.
- 13 Scientific visit to University of Concepción with students of local schools. October 19, 2016.
- 14 CRHIAM-INOVAGRI International Congress 2016, a joint effort of both countries, with CRHIAM from Chile as organizing institution and the INOVAGRI Institute and the National Institute of Science and Technology in Irrigation Engineering (INCT-EI) of Brazil. October 24-26, 2016.
- 15 Internal workshop: Students meeting, cluster Technologies for Water Management. November, 14, 2016.
- 16 Academic Science Fair: Agua y Sustentabilidad: Ciencia para la Vida, November 22-24, 2016.
- 17 Forum: First Water Forum. November, 25, 2016.
- 18 Seminar: Evaluación crítica de la implementación de nuevas tecnologías para el tratamiento de aguas servidas. December, 2, 2016.
- 19 International Seminar: Nuevas Tecnologías para la protección del medio ambiente. December 6, 2016.





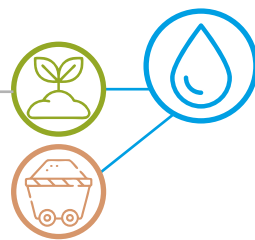
## 3 SUMMARY OF ACTIVITIES

- SEMINARS, WORKSHOPS AND CONFERENCES



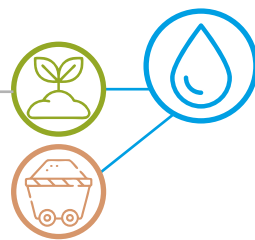










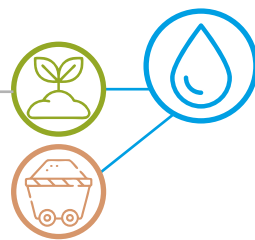




- SCIENTIFIC MEETINGS





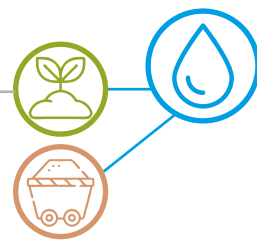




- SCIENTIFIC COMMITTEE ANNUAL MEETING





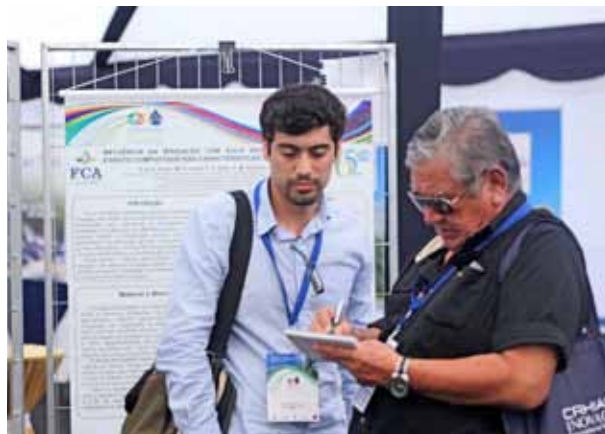
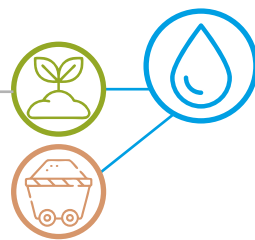




- CRHIAM-INOVAGRI INTERNATIONAL CONGRESS





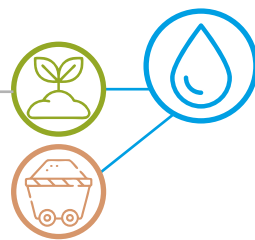




- INTERNAL ACTIVITIES



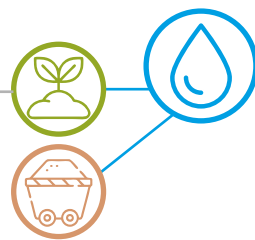






- FIRST WATER FORUM





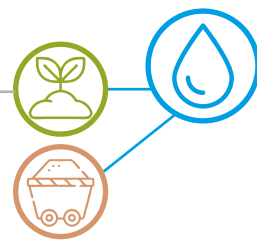




- ACTIVITIES WITH LOCAL SCHOOLS



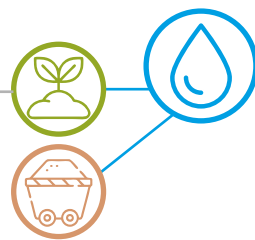






- SCIENCE FAIR IN LLICO

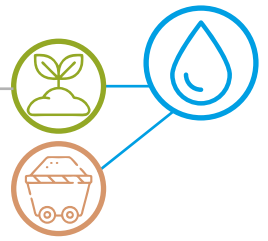










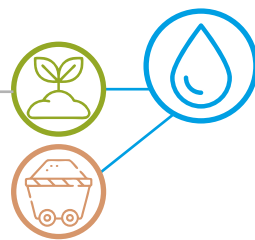


- CRHIAM STUDENTS











- CRHIAM MEDIA







# CRHIAM

CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA





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