CRHIAM

CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA

ANID/FONDAP/15130015

Annual **Report 2021**

Universidad de Concepción

UNIVERSIDAD DE LA FRONTERA

Universidad del Desarrollo
Universidad de Excelencia

Agencia Nacional de Investigación y Desarrollo
Ministerio de Ciencia, Tecnología, Conocimiento e Innovación
Gobierno de Chile

CRHIAM

CENTRO DE RECURSOS HÍDRICOS PARA LA AGRICULTURA Y LA MINERÍA

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Annual Report 2021

Water Research Center for Agriculture and Mining

1. MESSAGE FROM THE DIRECTORS

In 2021, the Water Research Center for Agriculture and Mining continued its work through the support of the Financing Fund for Research Centers in Priority Areas (FONDAP) of the National Research and Development Agency (ANID). With the experience of the previous year, all functions were maintained in teleworking mode, due to the COVID-19 pandemic.

In addition to the high scientific productivity, the link with researchers from different parts of the world and the formation of specialized human capital in both undergraduate and postgraduate courses and support for postdoctoral researchers, CRHIAM strengthened its connection with public policies through the delivery of the CRHIAM Communication Series to municipalities, regional ministerial secretariats, regional governments and ministries.

In particular, the document "CRHIAM Communication Series: Constituent Process Edition" was created, which was specially prepared to support, from scientific evidence, the discussion on water resources in the Constitutional Convention and which was sent to each of its members.

Added to the above is the participation in working groups with the public and private world, as well as the holding of seminars, summer courses, press appearances, among others, with which CRHIAM communicated the research work to various audiences. In addition to the presence in social networks, which were great allies to streaming such as the CRHIAM talk cycle, Water Forum, International Webinar, book launches, among others.

The third version of the Diploma in Water Resources for Sustainable Development was successfully executed. As in 2020, it was delivered 100% e-learning, which allowed to have professionals from different regions of the country.

For all of the above, we are especially grateful for the efforts of each of the members of the CRHIAM human team. We also acknowledge the permanent support of the National Agency for Research and Development, our National Advisory Council, the International Scientific Committee and the evaluators for contributing new ideas and suggestions to the management of the Center. We extend this gratitude to the authorities of the Universidad de Concepción, as well as to the members of our associate institutions, the Universidad de La Frontera and the Universidad del Desarrollo.

Dr. Gladys Vidal
CRHIAM Director

Dr. Pedro Toledo
CRHIAM Deputy Director

Annual Report 2021

Water Research Center for Agriculture and Mining

2. A DESCRIPTION OF CRHIAM

2.1 The Foundation of CRHIAM

Water is a vital element for human life, ecosystems and industrial production. However, climatic conditions and population dynamics have significantly affected the quantity and quality of available water resources.

Chile has been affected by a megadrought for 13 years, which, added to insufficient governance, has created a critical scenario regarding water management and impeded the path to water security. Joint work among all public and private actors driven by scientific evidence will allow progress toward more responsible and equitable water management.

To meet this great challenge, in 2014 the Water Research Center for Agriculture and Mining (CRHIAM) was founded under the framework of ANID's (formerly CONICYT) fifth funding contest, called the Fund for Research Centers in Priority Areas (FONDAP) competition. The Universidad de Concepción leads CRHIAM in association with the Universidad de La Frontera and Universidad del Desarrollo. CRHIAM obtained new funding in 2019 as an interdisciplinary and collaborative research institution in the areas of agriculture and mining for the 2019-2023 period.

Mission

To be a national authority on the creation of advanced scientific and technological knowledge on water resources for agriculture, mining and communities and contribute to the achievement of sustainable development goals.

Vision

To be a worldwide authority as a water resources research center for the sustainable development of agriculture, mining and communities, in consideration of the principles of water security.

Objectives

CRHIAM has four main objectives:

1. Promote world-class research on water resources to create knowledge and develop technologies to contribute to the water security of ecosystems, communities and production sectors.
2. Form undergraduate and especially graduate and postdoctoral human resources in order to create a critical mass that will support the development of abilities in the water resources field.
3. Create networks with the main domestic and international research institutions and the public and private sectors to benefit common interests regarding research, innovation and development in water resources.
4. Contribute to better water management through communication and dissemination of scientific evidence that contributes to public policies and the knowledge of society.

2.2 Our Center and its Associations

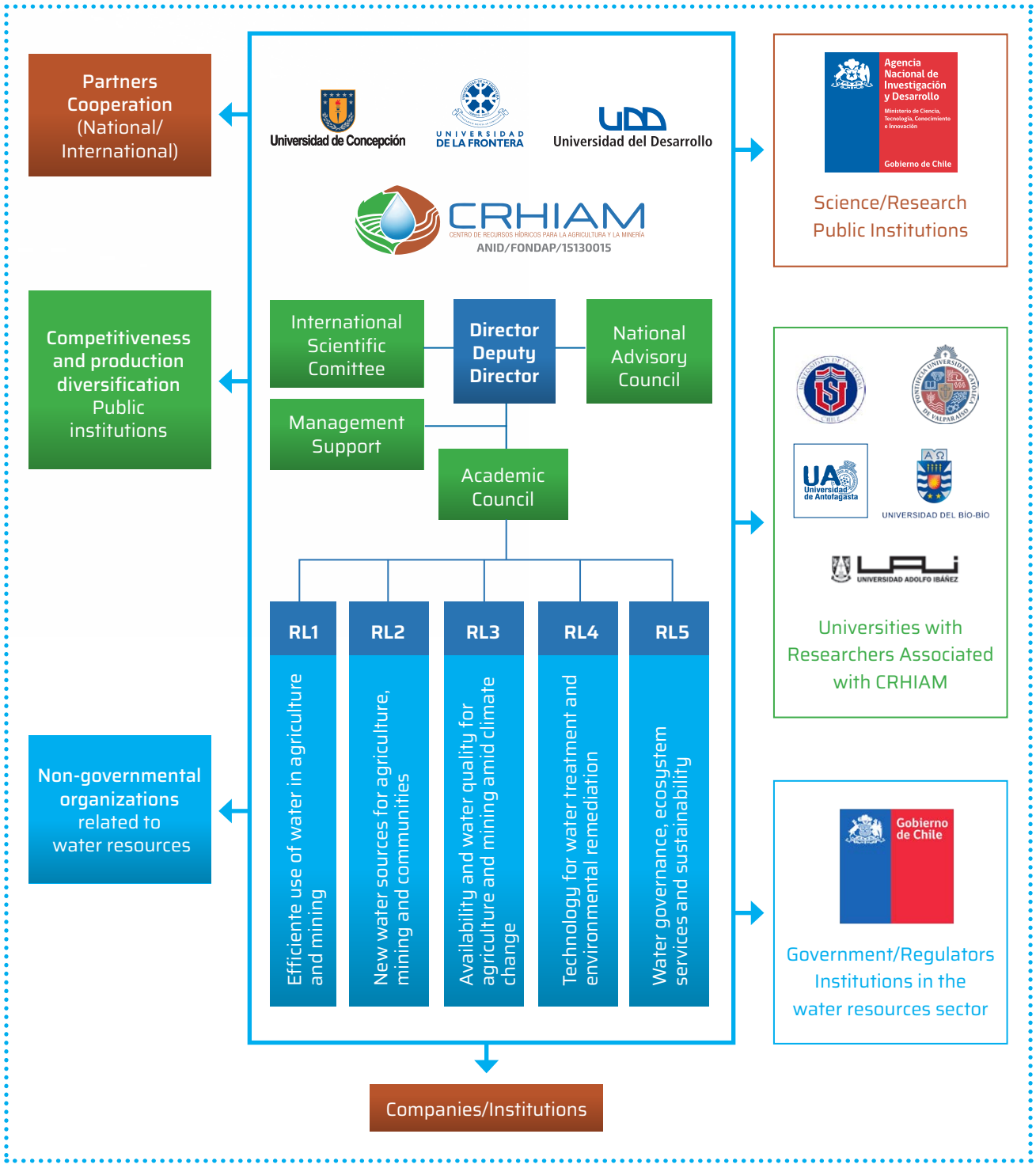


Figure 1. CRHIAM Organizational Chart. RL: Research Line.

2.3 Our Administrative and Logistical Support Team

The CRHIAM team is led by its directors and supported by administrative and logistical staff. CRHIAM's management structure is hierarchical, as shown in Figure 2.

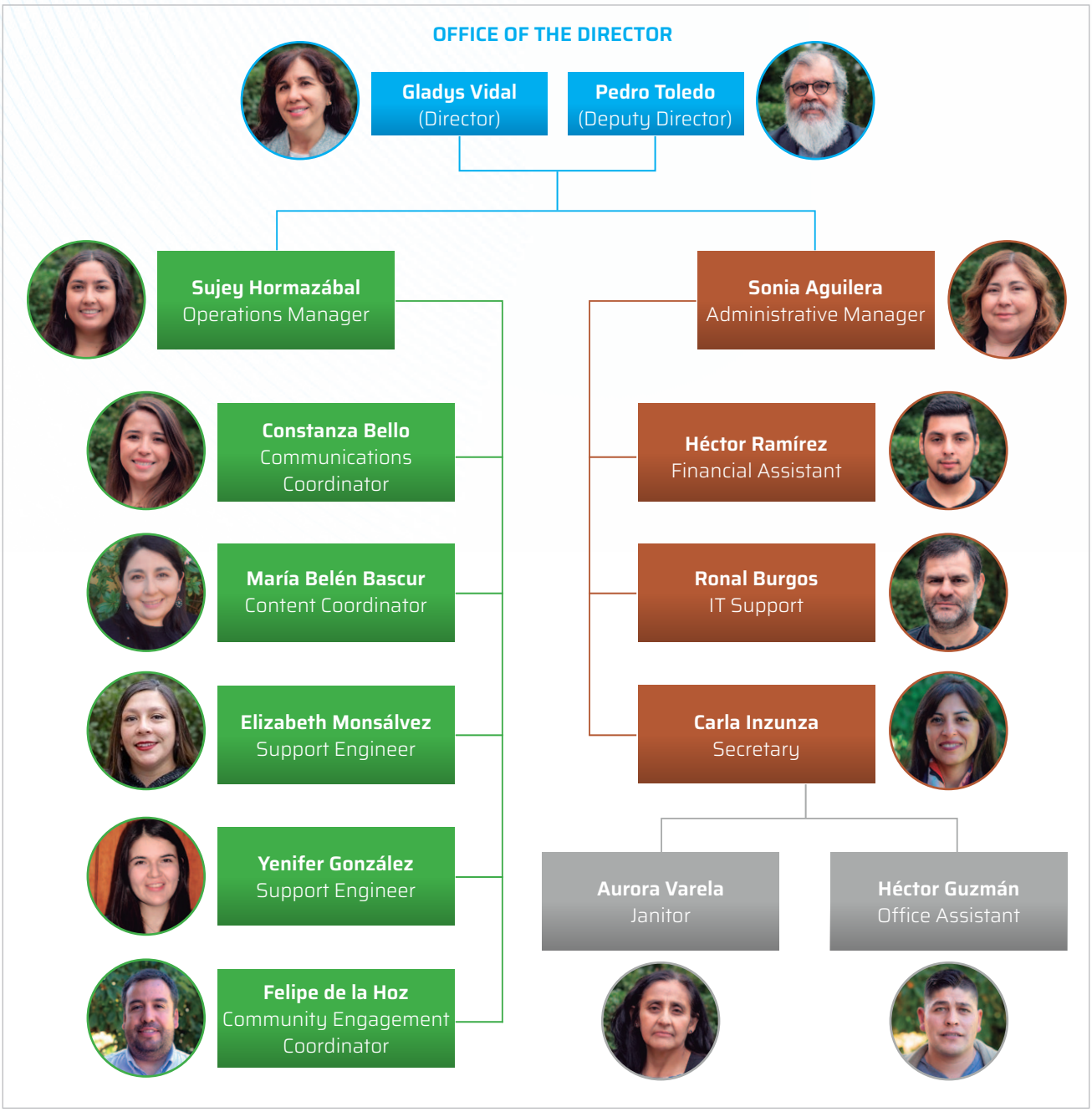


Figure 2. CRHIAM Team Organizational Chart.

2.4 Scientific Committee

The meeting took place on October 13th (morning of October 14th in Australia) and included three researchers from North America (USA and Canada): Dr. Jan Hopmans, professor emeritus at the University of California, United States; Dr. Reyes Sierra, researcher at the University of Arizona, USA; and Dr. Kelly Munkittrick of the University of Calgary, Canada; and two researchers from Australia: Dr. Peter Scales of the University of Melbourne and Dr. Neil McIntyre of Queensland University (Figure 3).

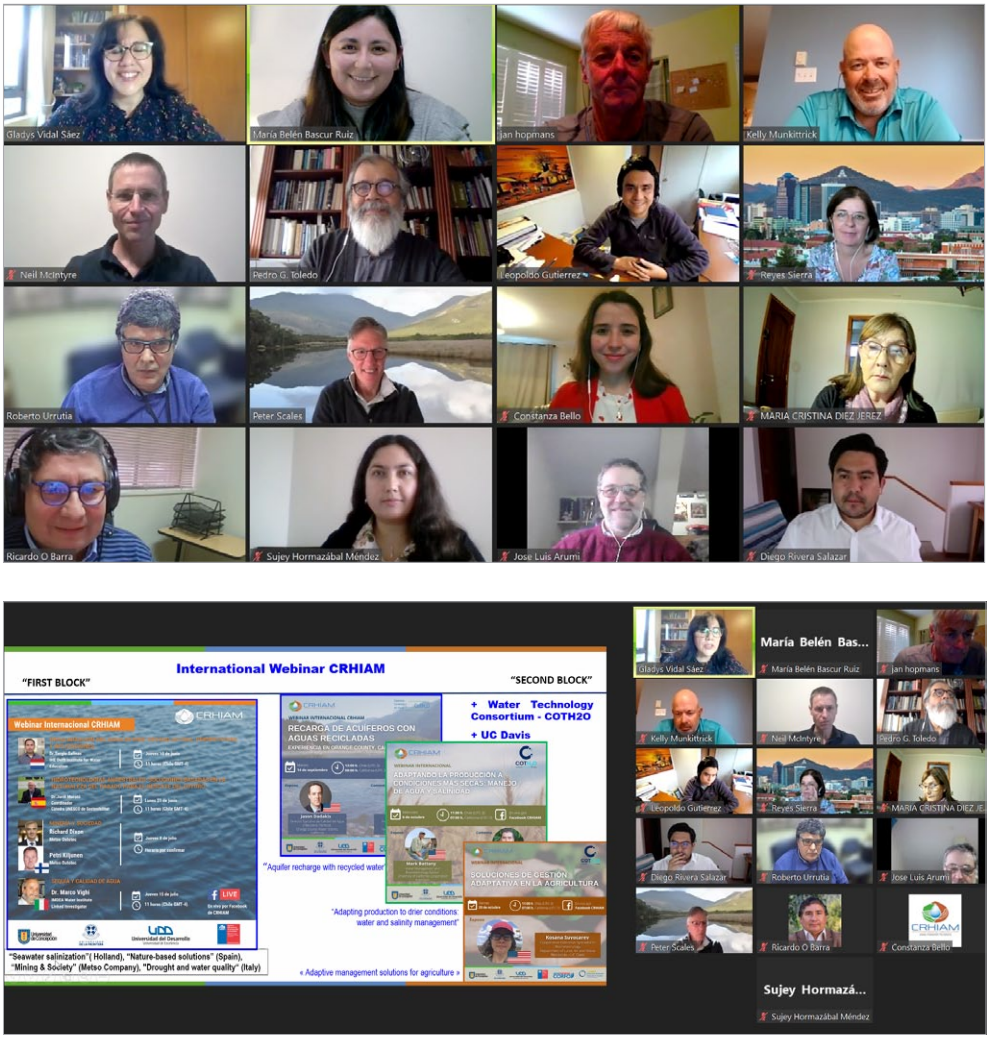
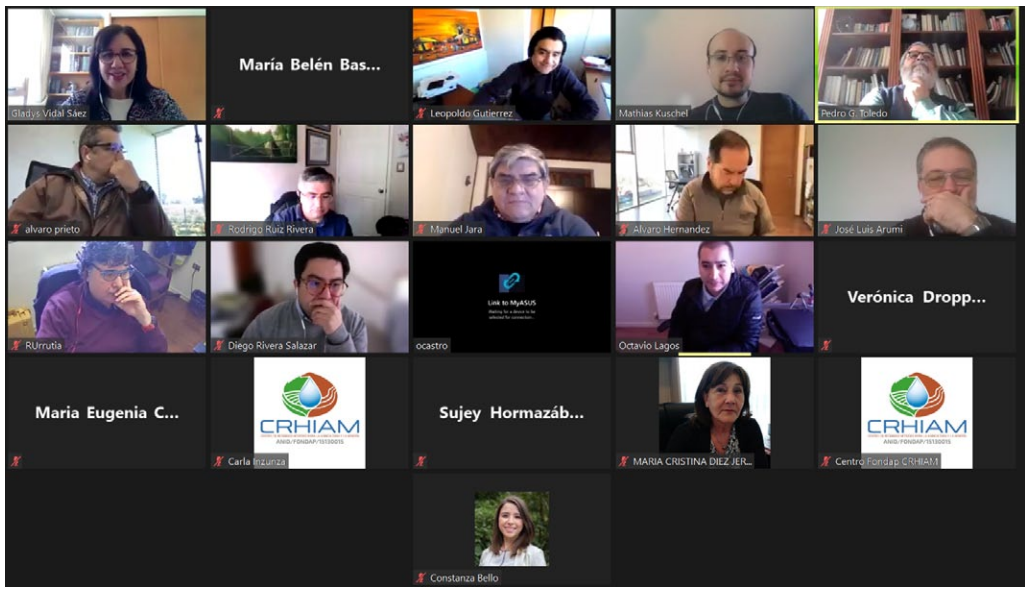


Figure 3. Scientific Committee members

2.5 Advisory Council

This council verifies the fulfillment of the center's general goals. It links CRHIAM to the community and recommends strategies for the center to connect its work to public sector institutions, government representatives, private sector organizations and society. One meeting is held per semester, in June and November. Figure 4a and Figure 4b show the participants in each meeting.

a)



b)

Figure 4. Advisory Council members. a) June 17th meeting and b) November 11th meeting.

2.6 Our Researchers

CRHIAM's research staff is made up of principal, associate and adjunct researchers. These researchers analyze various issues related to the use and care of water resources for agriculture and mining. They carry out activities both in the field and in academia, generating scientific publications and disseminating knowledge to the community. Each researcher is assigned a main Research Line (RL), although they also contribute to the development of CRHIAM's other research lines with the objective of carrying out interdisciplinary work.

Academic Council & Principal Researchers

GLADYS VIDAL
(Director)

RL4: Technology for water treatment and environmental remediation

Doctorate in Chemical Sciences, Universidad de Santiago de Compostela, Spain.

Industrial Engineering with a Minor in Agroindustry, Universidad de la Frontera, Chile.

PEDRO TOLEDO
(Deputy Director)

RL2: New water sources for agriculture, mining and communities

Doctorate in Chemical Engineering, University of Minnesota, USA.

Chemical Engineering, Universidad de Concepción, Chile.

DIEGO RIVERA

RL1: Efficient use of water in agriculture and mining

Doctorate in Agricultural Engineering, Universidad de Concepción, Chile.

Civil Engineering, Universidad de Concepción, Chile.

JOSÉ LUIS ARUMÍ

RL5: Water governance, ecosystem services and sustainability

Doctorate in Engineering, University of Nebraska, Lincoln, USA.

Chemical Engineering, Universidad Técnica Federico Santa María, Valparaíso, Chile.

MARÍA CRISTINA DIEZ

RL4: Technology for water treatment and environmental remediation

Doctorate in Food Sciences, Universidad Estatal de Campinas, SP, Brazil.

Master of Food Science and Technology, Universidad Federal de Viçosa, MG, Brazil.

Laboratory Chemistry, Universidad de Chile, Chile.

ROBERTO URRUTIA

RL3: Water availability and quality for agriculture and mining under climate change

Doctorate in Environmental Sciences, Universidad de Concepción, Chile.

Biology, Universidad de Concepción, Chile.

LEOPOLDO GUTIÉRREZ

RL1: Efficient use of water in agriculture and mining

Doctorate in Mineral Processing, University of British Columbia, Canada.

Master of Applied Science, Mineral Processing, University of British Columbia, Canada.

Metallurgical Engineering, Universidad de Concepción, Chile.

RICARDO BARRA

RL5: Water governance, ecosystem services, and sustainability

Doctorate in Environmental Sciences, Universidad de Concepción, Chile.

Biochemistry, Universidad de Concepción, Chile.

Associate Researchers

ALEX GODOY

RL1: Efficient use of water in agriculture and mining

Doctorate in Engineering Sciences with a Concentration in Chemistry and Bioprocesses, Pontificia Universidad Católica de Chile, Chile.

Bioprocess Biology, Pontificia Universidad Católica de Chile, Chile.

AMAYA ALVEZ

RL5: Water governance, ecosystem services and sustainability

Doctorate in Law, York University, Canada.

LLM in Law, University of Toronto, Canada.

Law, Universidad de Concepción, Chile.

DAVID JEISON

RL4: Technology for water treatment and environmental remediation

Doctorate in Environmental Sciences, Wageningen University, Netherlands.

Biochemical Engineering, Pontificia Universidad Católica de Valparaíso, Chile.

EDUARDO HOLZAPFEL

RL1: Efficient use of water in agriculture and mining

Doctorate in Water Resources Engineering, University of California, USA.

Agricultural Engineering, Universidad de Concepción, Chile.

FERNANDO BETANCOURT

RL1: Efficient use of water in agriculture and mining

Doctorate in Applied Sciences with a Concentration in Mathematical Engineering, Universidad de Concepción, Chile.

Chemical Engineering, Universidad de Chile, Chile.

FERNANDO CONCHA

RL1: Efficient use of water in agriculture and mining

Doctorate in Metallurgical Engineering, University of Minnesota, USA.

Chemical Engineering, Universidad de Concepción, Chile.

JORGE ROJAS

RL5: Water governance, ecosystem services and sustainability

Doctorate in Sociology, University of Hannover, Germany.

Master of Arts in Sociology and Political Science (undergraduate training).

Sociology, Institute of Sociology, University of Hannover, Germany.

JOSÉ LUIS CAMPOS

RL4: Technology for water treatment and environmental remediation

Doctorate in Chemical Sciences, Universidad de Santiago de Compostela, Spain.

Chemical Sciences, Universidad de Santiago de Compostela, Spain.

MARIO LILLO

RL1: Efficient use of water in agriculture and mining

Doctorate in Computer Science, Universidad Politécnica de Madrid, Spain.

Master of Engineering Sciences with a specialization in Electrical Engineering, Universidad de Concepción, Chile.

Electrical Engineering, Universidad de Concepción, Chile.

OCTAVIO LAGOS

RL1: Efficient use of water in agriculture and mining

Doctorate in Engineering, University of Nebraska, Lincoln, USA.

Master of Agricultural Engineering with a Concentration in Water Resources, Universidad de Concepción, Chile.

Agricultural Engineering, Universidad de Concepción, Chile.

OLGA RUBILAR

RL4: Technology for water treatment and environmental remediation

Doctorate in National Resource Sciences, Universidad de La Frontera, Chile.

Environmental Engineering, Universidad de la Frontera, Chile.

PABLO CORNEJO

RL4: Technology for water treatment and environmental remediation

Doctorate in Physical Sciences, Universidad de Concepción, Chile.

Master of Mechanical Engineering, Universidad de Concepción, Chile.

RAIMUND BÜRGER

RL1: Efficient use of water in agriculture and mining

Dr. rer. nat., Mathematik, Universität Stuttgart, Germany.

Diplom-Mathematiker, TU Darmstadt, Germany.

RICARDO FIGUEROA

RL5: Water governance, ecosystem services and sustainability

Doctorate in Biological Sciences, Universidad de Málaga, Spain.

Master of Sciences with a Concentration in Zoology, Universidad de Concepción, Chile.

Biology Education, Universidad de Concepción, Chile.

RICARDO OYARZÚN

RL3: Water availability and quality for agriculture and mining under climate change

Doctorate in Engineering Science, Washington State University, USA.

Master of Agricultural Engineering with a Concentration in Water Resources, Universidad de Concepción, Chile.

Agriculture Engineering, Universidad de La Serena, Chile.

ROBERTO PONCE

RL5: Water governance, ecosystem services and sustainability

Doctorate in Science and Management of Climate Change, Ca'Foscari University, Italy.

Master of Economics of Natural Resources and Environment, Universidad de Concepción, Chile.

Business, Universidad de Concepción, Chile.

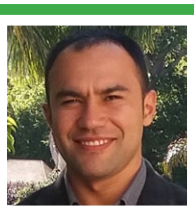
Adjunct Researchers

PATRICIO NEUMANN

RL4: Technology for water treatment and environmental remediation

Doctorate in Environmental Sciences, Universidad de Concepción, Chile.

Environmental Engineering, Universidad de la Frontera, Chile.



RICARDO JELDRES

RL2: New water sources for agriculture, mining and communities

Doctorate in Engineering Sciences with a Concentration in Chemical Engineering, Universidad de Concepción, Chile.

Chemical Engineering, Universidad de Concepción, Chile.

ROBERTO ROZAS

RL2: New water sources for agriculture, mining and communities

Doktor rer. Nat. Institut für Physikalische Chemie, Universität zu Köln, Alemania.

Master of Chemical Engineering, Universidad de Concepción, Chile.

Chemical Engineering, Universidad de Concepción, Chile.

ROBINSON TORRES

RL5: Water governance, ecosystem services and sustainability

Doctorate in Environmental Social Science, Arizona State University, USA.

Master of Social Research and Development, Universidad de Concepción, Chile.

Sociology, Universidad de Concepción, Chile.

Postdoctoral Researchers

CHRISTIAN SANTANDER
Universidad de La Frontera

FABIÁN FIGUEROA
Universidad de Concepción

GUSTAVO DÍAZ
Universidad de Concepción

KRISHNENDU PRAMANIK
Universidad de La Frontera

RODRIGO YEPSEN
Universidad de Concepción

JAVIERA PARADA
Universidad de La Frontera

OMAR ALVARADO
Universidad de Concepción

EDWARD HERMOSILLA
Universidad de La Frontera

CLAUDIO LAMILLA
Universidad de La Frontera

LORETTO ARRIAGADA
Universidad del Desarrollo

GONZALO QUEZADA
Universidad de Concepción

ÓSCAR FRANCHI
Universidad Adolfo Ibáñez

JAVIERA TOLEDO
Pontificia Universidad Católica de Valparaíso

STEFANIA SHORT
Universidad de La Frontera

REBECA MARTÍNEZ
Universidad de Concepción

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3. 2021: A YEAR OF ACHIEVEMENTS

3.1 Our Research in Numbers

Despite the global COVID-19 pandemic, all the research indicators have been met. The effort and solid commitment of CRHIAM researchers are reflected in the results of CRHIAM's eighth year of operation. The number of published papers was 64.6% higher than expected for this period (107 papers indexed in WoS from December 2020 to November 2021). Moreover, the average impact factor was 4.43 (expected value of 2.6 for 2021). In addition, 96.26% of the publications were published in Q1/Q2 journals. Meanwhile, advanced human capital training exceeded the expected value, as there are 15 postdoctoral researchers (expected value: 10) actively working, and several students graduated during 2021: 7 PhD students, 8 master's students, and 48 professionals/undergraduates. CRHIAM has extended its "establishing collaborative networks" and "dialogue, outreach and technology transfer" efforts using social networks. This new work strategy, developed as a response to the COVID-19 pandemic, has clearly favored the presence of CRHIAM on the different social networks (Facebook, Instagram, YouTube, Twitter, Spotify/Anchor and linkedin), raising the profile of the center's work on water security not only nationally but also internationally. As can be seen (Figure 5), the achieved numbers far exceed the indicators committed to.

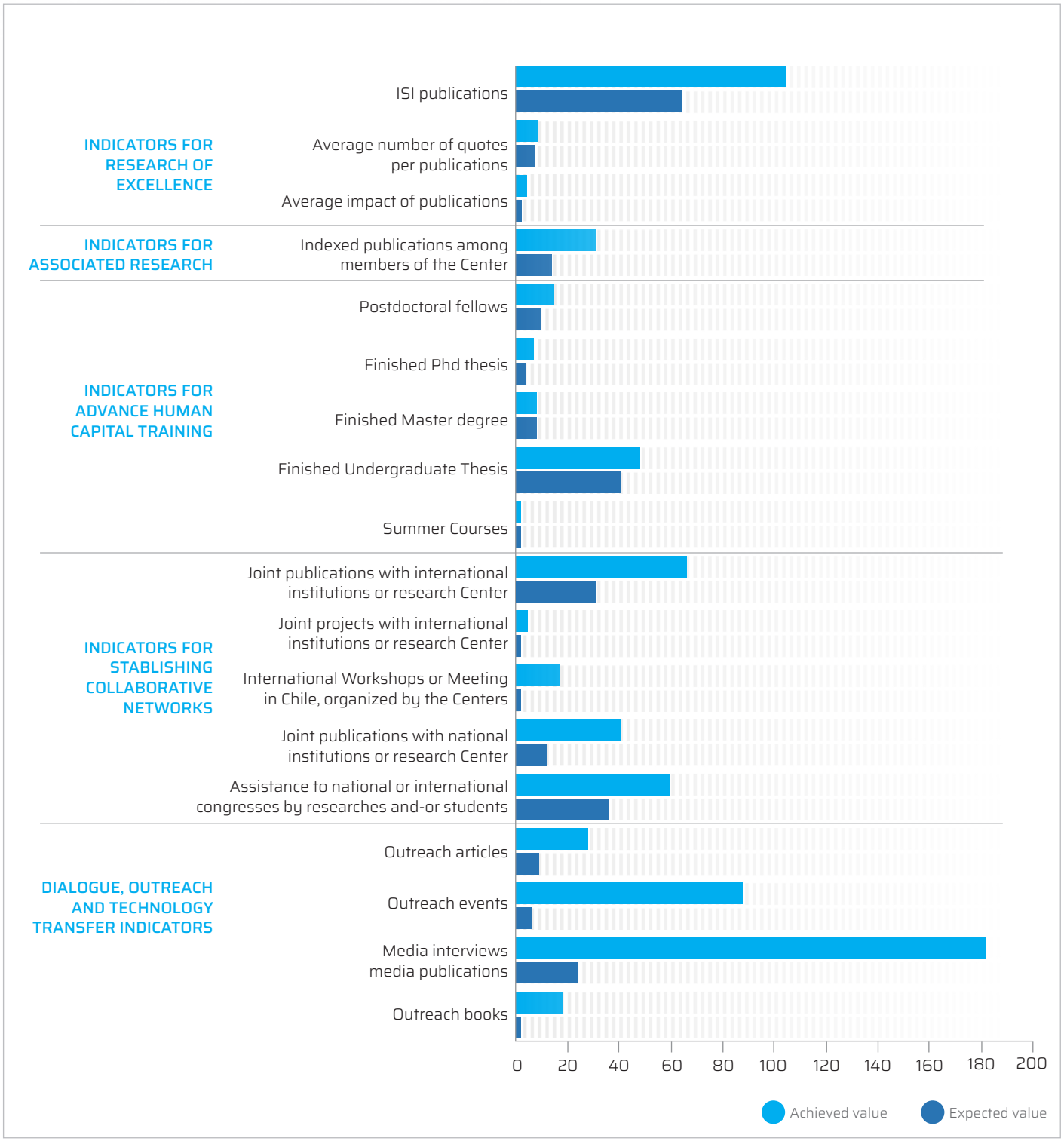

Figure 5. Selected CRHIAM indicators for year eight.

CRHIAM: Joint and Interdisciplinary Work

Since the last report, the center has increased opportunities for collaboration among researchers to increase interdisciplinarity. In 2021, we doubled the number of publications among researchers from different research lines. To promote the creation of products between RLs, we expanded opportunities for undergraduate and graduate students and postdoctoral fellows to publish their research findings in Communication Series volumes and opinion pieces in newspapers and other media. For instance, three opinion columns were published in CIPER Académico (Center for Journalistic Investigation of Chile for Academia), a highly regarded academic venue, consulted by the public sector for its work. In addition, 19 short outreach pieces were published as part of the CRHIAM Communication Series, which covers a wide range of topics and provides a new venue for making our research available to the public (see Item 5.4).

The center currently hosts four postdoctoral fellows (half of whom are women), who are supervised by two researchers from different research lines, which has been the case since the implementation of a requirement that the topics involve at least two research lines. Current postdoctoral fellows are working on water, mining, agriculture, and environmental science issues, and they are already publishing high-quality papers.

The metric for evaluating synergy and collaboration among research lines is the number of joint WoS publications. Here, we consider publications having two or more (co-) authors from different research lines and within the same research line to present synergy and collaboration among research lines. It should be noted that each research line is composed, by design, of researchers from different disciplines. Table 1 summarizes the collaboration among the center's members and among research lines. During 2021, the center published 107 papers indexed in WoS (see Item 5.1). Almost one third of them are co-authored by members of the same research line, while 6 papers resulted from collaboration among RLs. It is worth noting that RL1 has increased its collaboration with another research line by linking mineral processing and chemical modelling, while RL5 has maintained strong collaboration with other research lines by exploring new methods and approaches in mountain hydrology.

Table 1. Summary of intra- and inter-RL publications in the 2021 period.

RL	RL1	RL2	RL3	RL4	RL5
RL1	19[&](3*)	2[#]	0	1[#]	0
RL2		11(6*)	1[#]	0	0
RL3			10(2*)	0	2[#]
RL4				45(12*)	0
RL5					16(2*)

CRHIAM Research Line (RL). RL1: Efficient use of water in agriculture and mining; RL2: New water sources for agriculture, mining, and communities; RL3: Water availability and quality for agriculture and mining amid climate change; RL4: Technology for water treatment and environmental remediation; RL5: Water governance, ecosystem services and sustainability.

[&]The first number in the diagonal of the matrix indicates the total WoS publications of the RL.
*WoS publications with two or more CRHIAM researchers from the same research line as authors.
[#]Number of WoS publications between researchers from different RL.

Regarding collaboration on WoS publications among members of the same RL, RL2 shows strong collaboration, with about 55% of total productivity. Meanwhile, RL4 accounts for 42% of the center's total productivity. This highlights the importance of incorporating early and mid-career scientists who contribute new multidisciplinary ideas and coordinate (RL4 has postdoc co-authors among the researchers in its working group). Such strong collaboration is less evident in other RLs; therefore, the center has started to take action to foster intra- and inter-RL collaboration. Other RLs present collaboration resulting from co-supervised graduate theses and work with international collaborators. It is worth noting that RL2 also demonstrates strong internal collaboration coordinated by postdoctoral fellows.

The periodic publication of CRHIAM Communication Series volumes has significantly fostered multidisciplinary work. Each publication uses plain language to disseminate the scientific achievements of the center's members and contributes to the current discussion on water issues in Chile. CRHIAM also edited a document entitled "CRHIAM Communication Series: Constituent Process Edition" with information from researchers from all RLs. This publication includes different excerpts such as "The human right to water", "Governance and water management in the framework of water security" and "Reservoirs and their sustainable management under the scenario of water scarcity". It also includes information on the use of pesticides, groundwater protection, and the challenges of urban wastewater reuse, among others, covering a total of nine topics. The document was delivered to each of the 155 members of the council in charge of writing Chile's new Constitution (see Item 7.2).

The document also outlines other titles and audiovisual material available to both conventional constituents and the community at large. During 2021, CRHIAM published 18 series entries covering a wide range of topics (see Item 5.4). It is worth noting that each publication is co-authored by members of at least two different research lines. In addition, three columns on drought and pollution, current water institutions, and environmental issues related to pesticides use were published in CIPER Académico. Each column was written by researchers from a different RL (see Item 5.2).

Further evidence of increasing collaboration among lines is the submission of two large projects. In both cases, members of different RLs participated in the inception, writing and submission of the project. The Water Technology Consortium (COTH2O) awarded 4 MM USD to fund a portfolio of 13 projects covering technology transfer and knowledge production to tackle water problems in the south-central macro-zone (from the Metropolitan Region to Ñuble) to face the water crisis scenario by closing five gaps in water management: efficiency, reuse, quality, information, and new sources. The main institution is the Universidad de Concepción and its partners are INIA, UC Davis, the universities of Chile, Bernardo O'Higgins, Diego Portales and the Pontificia Universidad Católica de Chile. CRHIAM researchers from each RL make up a large portion of the consortium's members and are responsible for much of its portfolio. The second submission, still under evaluation by ANID, is a 500 MM USD project to accelerate the knowledge transfer of the center's scientific production to the community and policy makers.

3.3 Developing Human Capital in Water Resources

Within the four objectives, CRHIAM has committed itself to the development of human resources at the undergraduate level by supporting thesis projects and especially at the graduate and postdoctoral levels to generate a critical mass that will support the development of capacities in water resources.

CRHIAM actively participated in advanced human capital development through doctoral programs in the center's national network of universities that are accredited by the National Accreditation Commission (CNA) of Chile. Principal and associate researchers supervised and advised students in the doctoral programs, mainly in the Environmental Sciences, Water Resources and Energy for Agriculture, Metallurgical Engineering, Engineering Sciences with a Concentration in Chemical Engineering, and Applied Sciences with a Concentration in Mathematical Engineering doctoral programs, among others. Similarly, the center participated in the training of master's students through the Master of Engineering Sciences with a Concentration in Chemical Engineering, Master of Agricultural Engineering, and Master of Metallurgical Engineering. The center also took part in the training of undergraduate students by promoting the participation of young researchers that are active in CRHIAM's operations.

Exchange agreements with foreign universities, particularly those associated with the center's international collaboration network, were also made. CRHIAM is currently in its eighth year as a project and is proud to have become a center for the development of human capital. In its first seven years of operation (2014-2020), the center worked with 1,070 students (undergraduate and graduate) and postdoctoral researchers from different schools of the Universidad de Concepción, Universidad del Desarrollo, Universidad de La Frontera, Universidad de Antofagasta, Universidad de La Serena, Universidad Adolfo Ibáñez and Pontificia Universidad Católica de Valparaíso.

Figure 6 shows information on the students (undergraduate and graduate) and postdoctoral researchers connected to CRHIAM through its researchers and/or by scholarships granted by the center; the information is presented in cumulative terms and by year, allowing a comparison with 2021. In 2021, 126 undergraduate students, 93 graduate students (35 master's and 58 doctoral students), and 15 postdoctoral researchers worked with CRHIAM, and 24 students graduated from the Water Resources for Sustainable Development Diploma course.

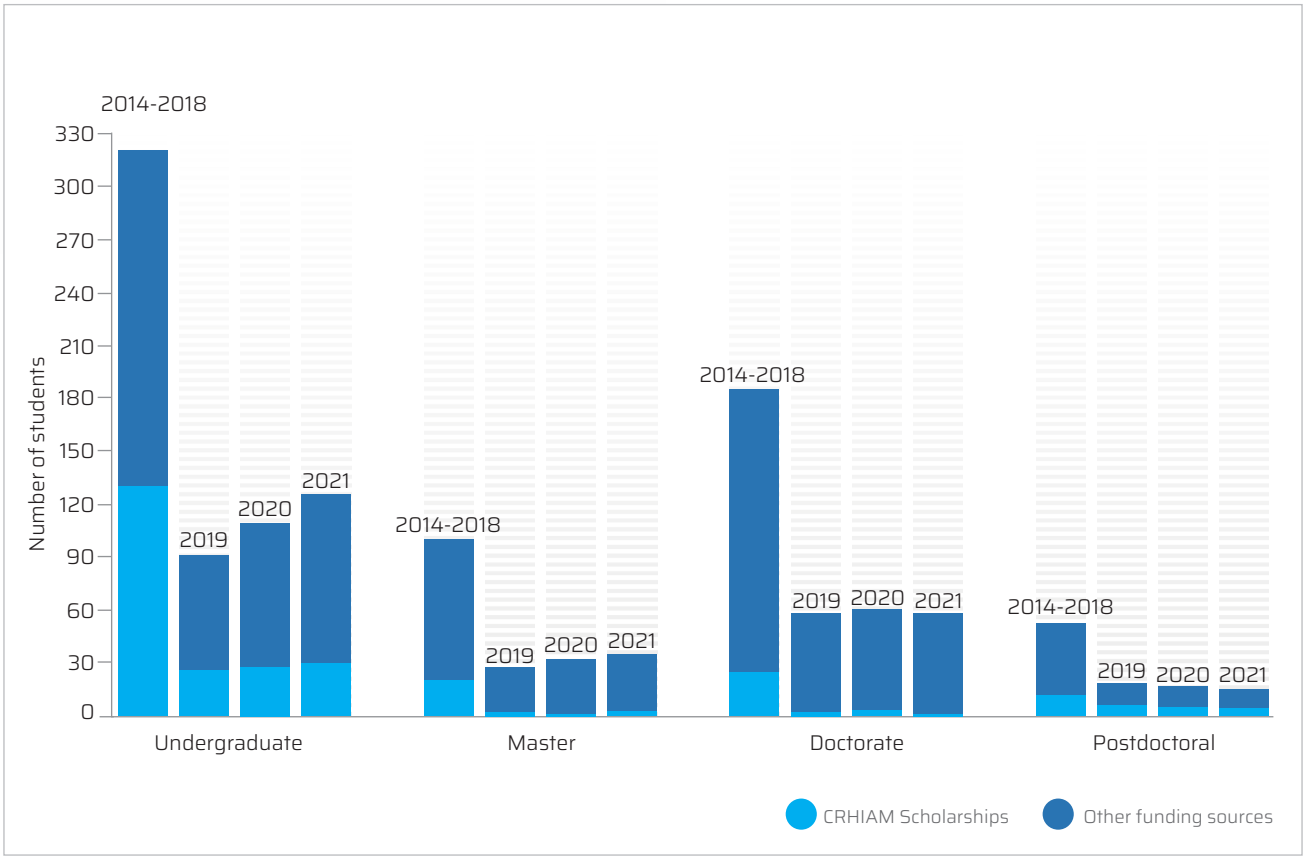

Figure 6. Number of postdoctoral fellows and graduate and undergraduate scholarships.

Below is a list of 2021 CRHIAM scholarship students in the different academic degree programs: postdoctoral researchers, doctoral, master's and undergraduate students.

Table 2. 2021 CRHIAM postdoctoral fellows

NAME	RESEARCH TOPIC	ADVISOR NAME	INSTITUTION
Loretto Arriagada Merino	Evaluation of water vulnerability against scenarios of land-use change and drought in coastal basins of south-central Chile	Diego Rivera and Roberto Ponce	Universidad del Desarrollo
Rebeca Martínez Retureta	Water regulation in pre-mountain basins of south-central Chile in the face of future scenarios of land-use/cover and climate change	Octavio Lagos and Ricardo Barra	Universidad de Concepción
Omar Alvarado Carripán	Water clarification, treatment of irrigation water and purification of large water bodies: An approach from first principles	Pedro Toledo and Leopoldo Gutiérrez	Universidad de Concepción
Rodrigo Yepsen Ferreira	Study of dispersants in the rheological properties of a pulp made up of a Cu-Mo ore with muscovite and biotite and seawater at alkaline pH, and the effect of said dispersants on the viscosity of a polyacrylamide-type flocculant	Leopoldo Gutiérrez and Pedro Toledo	Universidad de Concepción

Table 3. 2021 CRHIAM doctoral scholarship students

NAME	DISSERTATION TITLE	ADVISOR NAME	DEGREE-CONFERRING UNIVERSITY
Natalia Julio González	In search of Water Security through adaptive governance: Analysis of the Rapel and Biobío basins	Ricardo Figueroa	Universidad de Concepción

Table 4. 2021 CRHIAM master's scholarship students

NAME	THESIS TITLE	ADVISOR NAME	DEGREE-CONFERRING UNIVERSITY
Aníbal Rojo Sandoval	Evaluation of the effect of solids retention time on the performance of High Rate Algal Pond microalgae-bacteria reactors with membrane filtration for biomass retention in wastewater treatment	David Jeison	Pontificia Universidad Católica de Valparaíso
François Crouchett Catalán	Modeling of a microalgae-bacteria consortium for water treatment: Evaluation of the effect of solids retention	David Jeison	Pontificia Universidad Católica de Valparaíso
Zeinab Ameneh Morhell	Kinetics study of pathogen removal from anaerobic digested sludge	José Luis Campos	Universidad Adolfo Ibáñez

Table 5. 2021 CRHIAM undergraduate scholarship students

NAME	THESIS TITLE	ADVISOR NAME	DEGREE-CONFERRING UNIVERSITY
Naomí Monsalves Flores	Evaluation of operational parameters on the elimination of bacteria and resistance genes from wastewater in constructed wetlands	Gladys Vidal	Universidad de Concepción
Pedro Baltierra Méndez	Simulation of the behavior of a bubble in a flotation column with media of different rheological characteristics using ANSYS simulation software	Leopoldo Gutiérrez	Universidad de Concepción
Pablo Peñaloza Gaete	Analysis of collision behavior and particle-bubble interaction in various rheological media using ANSYS simulation software	Leopoldo Gutiérrez	Universidad de Concepción
Ayleen Herrera Espinoza	Evaluating the effectiveness of recovery and protection measures for wetlands in coastal basins from the Maule Region to the Los Ríos Region	Roberto Urrutia	Universidad de Concepción
Ignacio Huenupi Contreras	Mining-geological factors in the north and central macrozones of Chile related to water consumption in the processing of copper minerals	Leopoldo Gutiérrez	Universidad de Concepción
Constanza Alveal Ramírez	Community desalination plant as water justice? Participatory process for the installation and eventual social legitimation of a community desalination plant in the Hualpén Commune	Robinson Torres	Universidad de Concepción
Karla Rodríguez Galleguillos	Design and modeling of drainage systems for Magellanic plains	José Luis Arumí	Universidad de Concepción
Oscar Viveros Pino	Comparison of actual and potential water demand of European hazels using remote sensing	Eduardo Holzapfel and Camilo Souto	Universidad de Concepción

Table 5 (cont.). 2021 CRHIAM undergraduate scholarship students

NAME	THESIS TITLE	ADVISOR NAME	DEGREE-CONFERRING UNIVERSITY
Rodrigo Bascur Araneda	Water management and irrigation systems in apple trees	Eduardo Holzapfel and Camilo Souto	Universidad de Concepción
Eduardo Mella Sepúlveda	Water contribution of the Pencahue Canal to the agriculture of the Pencahue Valley	José Luis Arumí	Universidad de Concepción
Camila Jara Miranda	Evaluation and identification of chronic toxicity in the waters of the Itata River	Roberto Urrutia	Universidad de Concepción
Andrés Huenchupan Inostroza	Collection of information on biosurfactants in the protection of water resources	María Cristina Diez	Universidad de La Frontera
Ana María Ramírez Arriagada	Social-technical evaluation of the reuse of mining waste as irrigation water in the Antofagasta Region	Leopoldo Gutiérrez	Universidad de Concepción
Carlos Hermosilla Ponce	Construction and testing of a fluidized bed for separation of mineral particles	Pedro Toledo and Jorge Saavedra	Universidad de Concepción
Nicolás Esparza Loyola	Factors that determine the availability of water for human consumption in the hydrographic basin of Lake Lanalhue, Arauco Province	Gerardo Azócar and Robinson Torres	Universidad de Concepción
Cristian Soto Peña	Effect of flocculants on chalcopyrite flotation	Leopoldo Gutiérrez	Universidad de Concepción
Jorge Lagos Guajardo	Study of the impact of polyacrylamide on the buoyancy of enargite ore	Leopoldo Gutiérrez	Universidad de Concepción
Valentina Garcés Henríquez	Effect of anionic polyacrylamides on the flotation of chalcopyrite in seawater	Leopoldo Gutiérrez	Universidad de Concepción
Javier Zárate Rodríguez	Risk analysis of drinking water supply through wells in three Chilean cities	José Luis Arumí	Universidad de Concepción
Sebastián Rojas Aqueveque	Degradation of pesticides by fungi from a pesticide biopurification system (SBS)	María Cristina Diez	Universidad de La Frontera

Table 5 (cont.). 2021 CRHIAM undergraduate scholarship students

NAME	THESIS TITLE	ADVISOR NAME	DEGREE-CONFERRING UNIVERSITY
Sandra Ponce Mascaró	Technical-economic evaluation of a municipal wastewater treatment plant for small communities using consortiums of microalgae and bacteria	David Jeison	Pontificia Universidad Católica de Valparaíso
César Llafquén Calfuin	Evaluating biosurfactants produced by bacteria isolated from a biopurification system in the degradation of pesticides for the protection of water resources.	María Cristina Diez	Universidad de La Frontera
Daniel Henríquez Letelier	Social acceptance of Gray Water reuse in the north and south of Chile	Gladys Vidal	Universidad de Concepción
Camilo Solar Carrera	Determination of bubble coalescence times in a dynamic bubbling system using computational image processing techniques	Pedro Toledo and Jorge Saavedra	Universidad del Bío-Bío
Joaquim Contreras Torres	Study of parameters that influence the stability of fluid interfaces. Case study: Behavior of foaming agents in flotation with saline water	Pedro Toledo and Jorge Saavedra	Universidad del Bío-Bío
Ignacio Novoa Fuentes	Study of the impact of anionic polyacrylamides on bornite buoyancy	Leopoldo Gutiérrez	Universidad de Concepción
Daniela Tapia Ramos	Evaluating the state of Andean wetlands near the lithium mining operations and analyzing community perception, Salar de Atacama	Ricardo Barra	Universidad de Concepción
Bárbara Luengo Carriel	Analysis of the influence of land uses on the water quality of the Biobío River basin	Ricardo Figueroa	Universidad de Concepción
Patricio Soto Oyarzún	Study of the effect of rheological properties on particle classification by hydrocyclones	Dennis Vega and Fernando Betancourt	Universidad de Concepción
Yanira Ulloa Torres	Study of the behavior of bubbles in aqueous solutions of MIBC and NaCl by image analysis of a dynamic bubbling system in a thin wall column	Jorge Saavedra and Pedro Toledo	Universidad del Bío-Bío

Water Resources for Sustainable Development Diploma

This is the third year that CRHIAM has offered the Water Resources for Sustainable Development Diploma course and the second year that it has been delivered as an e-learning course. The program aims to provide an update to professionals working in different sectors who need a current, interdisciplinary vision of water resources. Table 6 shows the components of the Water Resources for Sustainable Development program.

Table 6. Water Resources for Sustainable Development program components

MODULE	TEACHERS	HOURS
MODULE 1 Climate change, ecosystems and their effects on water resources. **Coordinator:** Dr. Roberto Urrutia	Dr. Alberto Araneda	4
	Dr. Roberto Urrutia	5
	Dr. José Luis Arumí	4
	Dr. Ricardo Figueroa	5
MODULE 2 Production processes, communities and water resources. **Coordinator:** Dr. Leopoldo Gutiérrez	Dr. Pedro Toledo	4
	Dr. Leopoldo Gutiérrez	5
	Dr. Diego Rivera Dr. Eduardo Holzapfel	4
	Dr. Carolina Baeza	5
	Dr. Patricio Neumann	4
MODULE 3 Water technology for sustainability. **Coordinator:** Dr. Gladys Vidal	Dr. Gladys Vidal	5
	Dr. Patricia González	4
	Dr. Daniela López	4
	Dr. Gladys Vidal	5
MODULE 4 Water conflicts, institutions and instruments of water resources management in Chile. **Coordinator:** Dr. José Luis Arumí	Dr. Amaya Alvez	5
	Dr. Verónica Delgado	4
	Dr. José Luis Arumí	4
	Dr. Ricardo Barra	4
	Dr. Jorge Rojas	3
COURSES		
Course 1: Formulation of projects for innovation under climate change	Marcela Cabezas, MSc.	6
Course 2: Elective	Elective supervisor	6

In the class of 2021, there were 24 professionals from different backgrounds (Table 7): engineers in various fields (chemical, environmental, agricultural, natural resources, mechanical, and industrial), publicists, journalists, and lawyers, among others. In addition, thanks the e-learning format of the course, the new students attended from different cities throughout the long country, from the north to south of Chile, that is, from Copiapó to Los Ángeles. Each study module is led by CRHIAM researchers from the schools of Engineering, Agricultural Engineering, Environmental Sciences, Legal and Social Sciences, and Social Sciences, all with extensive experience in water resources; guest lecturers further enrich the curriculum. The total number of professionals who have updated their knowledge with CRHIAM in the last three 3 years is 69 (2019-2021).

Table 7. Water Resources for Sustainable Development certification program class of 2021

NAME	PROFESSION OR ACADEMIC BACKGROUND
Catalina Barrios Benavente	Journalist
Constanza Bello Silva	Journalist
Cristhian Castillo Miranda	Environmental Engineer
Matías Campos Garagay	Degree in Biochemistry
Cristian Cortés Cortés	Laboratory Chemist
Romina De Ríos Chacón	Bachelor of Science in Natural Resources
Javiera Godoy Muñoz	Bachelor's Degree in Conservation of Natural Resources
Francisco Gutiérrez Valderrama	Agronomist
Anita María Inguerzon Quiroga	Agricultural Engineer
Bárbara Miller Catalán	Environmental Engineer
Tatiana Miranda Mena	Environmental Civil Engineer
Jocelyn Mujica González	Execution Engineer in Bioprocesses
David Poblete Martínez	Advertising Technician
Luciano Ponce Martínez	Civil Engineer
Gonzalo Puga Córdova	Execution Engineer in Environment
Fernando Quezada Cartes	Forestry Engineer
Giselle Redondo Silva	Lawyer
Hernán Rivas Herrera	Bachelor of Science, with a Concentration in Geophysics
Diego Rodríguez Godoy	Mechanical Civil Engineer
Fernanda Sánchez Rodríguez	Industrial Civil Engineer
Javiera Torres Mendoza	Chemical Civil Engineer
Luis Urbina Parra	Environmental Engineer
Rodrigo Vásquez Panizza	Environmental Engineer
Marcia Yáñez Acevedo	Agricultural Engineer

Figure 7 shows the students who participated in the e-learning version (2021) of the program led by the center.

Figure 7. Water Resources for Sustainable Development Diploma program class of 2021.

The 24 professionals who were part of the third version of the Water Resources for Sustainable Development Diploma course officially concluded their studies with a virtual closing ceremony (Figure 8). The meeting was held on August 7th and provided an opportunity to talk with the students and learn about their experiences and opinions of the program and what it meant for them to take it online.

Figure 8. Virtual closing ceremony for the 2021 version of the program.

4. WHAT DID OUR RESEARCH LINES DO DURING 2021?

4.1 RL1. Efficient use of water in agriculture and mining

The United Nations states that water security is the "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability." This research line contributes to water security by addressing different dimensions of water security and different uses. Research in agriculture focuses on efficient use of water and information technologies and data analysis applied to complex production systems. For mining the focus is on improving water recovery in copper concentrators with outputs closely connected to real world problems, along with contributions to policy analysis, rural communities and citizen science and increasing efficiency of water use. The team is involved in several outreach activities through participation in conferences, applied projects and books, among others. The main challenges, ultimate goals, outcomes and progress achieved during 2021 are summarized in the following sections.

RL1 has strengthened collaboration with other RLs via eight Communication Series entries and three manuscripts that link mineral processing and chemical modeling (Yepsen *et al.*, 2021; Sepúlveda *et al.*, 2021; Echeverry *et al.*, 2021), but more collaboration is needed to achieve interdisciplinary research. Therefore, we will continue to link our research topics with other lines, with a focus on agricultural issues.

Regarding international networking, four papers were co-authored by scholars abroad, including one on a global scale assessment of nitrogen isotope composition in rivers. We also contributed to a textbook on the circular economy, introducing the link of water security and SDGs to the circular economy. All four postdoctoral positions are currently associated with RL1 and connected to RL5 or RL2. Half of the postdoctoral researchers are women. Thirteen undergraduate theses are in progress and four are finished.

Agriculture

The water demand group contributes to research on water security by improving water efficiency. We approached water efficiency and efficacy in two ways: field research to optimize irrigation practices and remote sensing and data analytics for catchment-scale modeling. We also contributed by approaching water diplomacy and global-scale nitrogen issues.

During the last year, we also produced academic outputs (book chapters, briefs) apart from indexed publications. We submitted various research proposals to continue research lines and open collaboration with other Chilean groups. Finally, we made important contributions to policymaking by participating in high-level panels.

I) Optimization of applied water and yield estimation

An indicator for estimating sorghum yields is the number of crop heads in different branching arrangements. Gonzalo-Martin *et al.* (2021) approached some drawbacks of processing sorghum images due to differences in the shape and color of sorghum heads. They proposed a methodology to detect sorghum heads using an unmanned aerial vehicle and test-time-augmentation techniques. The method uses a set of geometrical and color transformations and four different ensemble learning methods.

Valdivia *et al.* (2021) evaluated the effect of diminishing soil water content from grain filling to physiological maturity on yield and grain quality, leaf water potential and maximum quantum yield in four long-photoperiod quinoa genotypes. They applied a canonical field technique to compare irrigation treatments. The results show, for instance, that total proteins, albumins and globulins varied between seasons, with almost no differences among irrigation treatments; thus, it is possible to grow quinoa under irrigation deficit while maintaining yields and nutritional quality.

Lecaros-Arellano *et al*. (2021) evaluated the effects of water distribution patterns in drip irrigation on fruit production and fruit quality during two seasons in two commercial orchards of Gala Brookfield apple trees, grafted onto M.9 dwarf rootstock. Applied water was compared against the water use estimated by the AQUASAT platform (platform created by CRHIAM, reported on in previous years). The results showed significant differences in production among treatments, which varied only in the volume of wetted soil. This result emphasizes the need to wet sufficient soil volume under drip irrigation, regardless of irrigation amounts, in light-textured soils in particular.

Marino *et al.* (2021) evaluated the effects of salinity and sodicity on the seasonal dynamics of actual evapotranspiration and surface energy balance components in mature micro-irrigated pistachio orchards. The results show that the main driver of evapotranspiration was net radiation, which supplied most of the energy to vaporize water, irrespective of the growth period and level of salinity/sodicity. This article provides insights to improve irrigation management of salt-affected pistachio through integration of weather measurements, energy balance components and plant-based parameters.

II) Catchment scale water management

Lillo-Saavedra *et al.* (2021) developed a new methodology integrating data from multiple sources, such as observations from the Landsat-8 (L8) and Sentinel-2 (S2) satellites, with information gathered in field campaigns and information from different public databases, in order to characterize the water demand of crops (potential and estimated) in a spatially and temporally distributed manner. The results obtained allowed it to be concluded that the availability of spatio-temporal information on water availability and demand pairing allows a closing of the water gap—i.e., the difference between supply and demand—allowing for better management of water resources in a watershed. The research has been expanded to upper catchments that feed downstream uses.

Thus, Rivas *et al.* (2021) explored wildfire-induced soil alterations that have a long-term impact on soil organic matter (SOM) quality and downstream water quality.

In addition, Flores *et al.* (2021) compared three daily rainfall-runoff hydrological models using four evapotranspiration models in four small, forested watersheds with different land covers in south-central Chile.

III) Other publications

Pihl *et al.* (2021) discussed new insights in climate science 2020, with Dr. Alex Godoy contributing to the food-water-energy nexus.

Herrera and Godoy-Faúndez (2021) explored the roles of local mobility patterns, socioeconomic conditions and lockdown policies in shaping the patterns of COVID-19 spread, also considering potential effects on the water-food-energy nexus.

In Matiatos *et al.* (2021), we teamed up with a large network of researchers to analyze global patterns of nitrate isotope composition in rivers and adjacent aquifers to reveal reactive nitrogen cascading. It is also worth noting that methods developed in RL1 have been used for other applications such as microdensitometry in tree rings.

The team also contributed to building capacities by contributing to a textbook on the circular economy, where they linked the circular economy in a Water-Energy-Food Security Nexus to an SDG framework. In the same line, we contributed to a Communication Series entry (led by Dr. Gutiérrez) related to the current situation of the Chilean mining industry, soil microbiology and an economic valuation of transporting water from central to northern Chile.

IV) Research proposals

Since November 2020, the team has submitted 3 FONDECYT proposals (totaling 750k USD), 2 FONDEF proposals (250k USD) and 3 FONDEQUIP proposals (1000k USD). All proposals are directly related to results from previous years. We also teamed up with colleagues from UDEC, UFRO and UDD to advance in the understanding of streamflow generation in the Andes, focusing on supply to agriculture through a recent three-year, 500k USD grant. A member of RL1 is leading a large grant project (1000k USD) to propose and implement technological solutions to water-related industrial problems. Most of the group members are participating in the COTH2O consortium. This project is opening new opportunities to work on real-world problems.

Mining

The Chilean mining industry is facing various challenges, including shortages of strategic resources such as water, the need for its production operations to comply with the restrictions imposed by society and environmental regulations, and the effects associated with the complexity of the minerals to be processed, among others. To achieve a sustainable world, it is necessary to have a mining industry that carries out its activities in a sustainable way over time. Thus, Chilean public policies are tending to promote the creation of an ecosystem that allows green mining for the future development of Chile. Green mining is defined as a concept of comprehensive management of production and sustainability indicators that promotes efficiency in the use of resources (water) and energy, the security, inclusion, empowerment, and quality of life of people and communities, and resilience against climate change, among other elements (Chile, 2021 Minería Verde (green mining), Desafíos y Oportunidades. Corporación Alta Ley). CRHIAM's activities as a multidisciplinary center of excellence in water resources are aligned with the development of green mining for our country.

From a technical perspective, the decline of the ore grades that are fed to concentrators is perhaps the most challenging problem of the Chilean mining industry. These changes in the ore's characteristics lead to the processing of larger tonnages to maintain copper-molybdenum production and the use of more water. The reduction of ore grades is also closely related to the increase of processing of ores rich in problematic gangue such as phyllosilicates, species that are be found as fine and ultra-fine particles in the mineral processing plants and affect the efficiency of all the unit operations such as crushing, grinding, froth flotation, thickening, dewatering, and final disposal. To reduce the impact of this problem, slurry dilution is usually applied, which leads to more water consumption. Thus, the decline of ore grades is directly proportional to the water needed in the mineral processing plants. Because of water restrictions, non-conventional sources of water such as seawater or high-ionic-strength water sources to process copper/molybdenum ores by flotation are being used, which limits the processes from a metallurgical point of view. Ions induce heterocoagulation between phyllosilicates and copper/molybdenum sulfides, lowering recoveries and changing pulp rheology (Uribe *et al.*, 2017).

Therefore, mining production in Chile will be affected by the treatment of more complex ores and by the fact that these complex minerals require more water consumption. We think that a holistic approach that considers the entire processing chain and the interactions between mining operations and the hydrographic basins that surround them will be needed to achieve green mining (mining for society). Some projects are being carried out in order to achieve this objective and to improve the efficiency of the use of water in mining (RL1), which are described as follows:

I) Mining/crushing/grinding/classification

Fragmentation in cave mining and crushing are the most important dry comminution operations. Their efficiency has a significant influence on subsequent wet milling, classification and concentration processes, since it determines the particle size distribution of the feed mineral. A project is being carried out to develop secondary fragmentation to describe using the Block Caving Comminution Model, which replicates the fragmentation mechanics between particles under drawn and vertical loads in a draw column (Moncada *et al.*, 2021). This model is based on a kinetic and population balance approach, in which non-normalized and normalized assumptions can be used depending on material and comminution system behavior. It is expected that the development of these models will help to control the granulometric profile of the feed to grinding and thus reduce energy and water consumption.

In the area of grinding/classification a project entitled "Small hydrocyclones for removal of ultra-fine particles from clarified water in mineral processing" is ongoing at the center (Vega *et al.*, in progress). The decline of ore grades leads to the processing of more complex minerals such as clays in the gangue, which lowers the metal recoveries. A significant fraction of the process water used in mineral processing ends up in tailing dams, and since clay mineral particles have very low settling velocities, they are returned to the plant with the recycled water, increasing the negative effects on processing. Removing fine particles from clarified water will reduce both the slime coating and freshwater consumption, which is a key factor in areas where water stress is high. The use of small hydrocyclones (e.g., 10 mm in diameter) for the separation of particles in the micron range is of growing interest in industry because of the cut sizes that these devices can achieve. Small hydrocyclones exhibit a bypass fraction that is larger than the water recovery, resulting in a high particle recovery to the underflow, as well as low water recovery, which is convenient for dewatering processes. Advances in this research were presented by Dr. Dennis Vega and Dr. Leopoldo Gutiérrez at Water Congress 2021.

Another ongoing project addresses the online operational control of hydrocyclones with the aim of optimizing hydrocyclone operation by correlating the hydrocyclone mechanical vibrations with the flow pattern (roping, spray, semi-roping) in the underflow stream (Daza *et al.*, 2020). It is expected that the online operational control of hydrocyclones will help optimize their operation and thereby reduce water consumption in the concentrator plants. The team is looking for funding to test this idea in a Chilean concentrator.

II) Froth flotation

In the flotation field, BCR technology is being developed for the correct conditioning of the reagents used in the flotation of copper and molybdenum minerals to improve recovery in processes that use conventional water and seawater (COPEC UC FUNDATION 2019.R.1150 "Tecnología BCR para mejorar la recuperación de Cu y Mo" Project Gutiérrez *et al*. 2019). Pilot plant tests showed that BCR technology increases the recovery of copper and molybdenum by more than 5 and 10 percentage points, respectively. The use of this technology reduces the consumption of reagents and improves the quality of the water, which is afterwards recirculated to the processes. This project was submitted for "Technology Speed Up Voucher" funding from the Integrated Mining Technologies Piloting Center (CIPTEMIN); the application was successful and we obtained funding to run an industrial test in a Chilean concentrator plant.

Another project is aimed at developing a process for the generation of additives based on polysaccharides extracted from wheat straw to improve copper recovery from high-clay ores (Castillo *et al*., 2020; FONDEF ID18I10117 Project Gutiérrez *et al*. 2018). The use of these green reagents should also change pulp rheology and help optimize water consumption in flotation. The use of different reagents to reduce the deleterious effect of clay minerals in the process of flotation of copper and molybdenum sulfides using seawater (RL-2) continues under consideration (Ramírez *et al*., 2020a,b). A patent on this topic was filed at INAPI in 2020 (N° Solicitud: 202003090 Proceso para la recuperación de cobre y molibdeno por flotación producto del procesamiento de minerales ricos en filosilicatos y minerales de arcilla).

Seawater flotation is being studied from a fundamental and practical perspective (Ramírez *et al*., 2020a,b; Gutiérrez *et al*., 2020; Maldonado *et al*., 2020; Yepsen and Gutiérrez, 2020); a patent on this topic was filed at INAPI at the end of 2019 (Gutiérrez *et al*., N° Solicitud CL201903655, "Proceso de pretratamiento-acondicionamiento-adición para aumentar recuperaciones de molibdeno y cobre por flotación de minerales sulfurados de cobre y molibdeno por flotación en aguas salinas").

III) Solid-liquid separation and water recovery

The design of ultraflocculator reactors to flocculate fine particles and clays has been carried out at CRHIAM, with good results (Betancourt *et al*., 2020). Likewise with the development of instruments to determine settling parameters (researcher: F. Concha). The effect of the air temperature on filtration dewatering performance is a topic that is also under consideration (Concha *et al*., 2021).

IV) Mathematical modelling in mineral processing

An application was submitted for ANID "Anillos de Investigación" funding for the project titled "Development and validation of a new theory for column flotation". This project is focused on generating a model framework for the design, simulation, and control of a flotation column that should cover the basic multiphase gas-liquid-solid hydrodynamics, properties of flotation foam stability, and description of the process of adsorption of hydrophobic particles. Furthermore, we intend to characterize and predict the mechanism of nanoparticles. Simulation models will be validated experimentally and be mathematically robust (Bürger *et al.*, 2020a,d). It is expected that these new models will be used to achieve better online control of flotation plants, improve metal recoveries, and reduce water consumption.

V) Online rheology

The rheological behavior of mineral suspensions affects the entire mineral processing chain. The design and implementation of an online rheometer was devised with the support of SMI-Ice Chile and CRHIAM (patent was filed in 2017 CL01274-2017. Researcher: L. Gutiérrez). The technology was patented and transferred to a Chilean company, which signed a contract with CODELCO-CHILE to validate this sensor in the DIVISION ANDINA, and a contract for services is close to being signed with CODELCO DIVISION ANDINA and other divisions of CODELCO. For this company, the technology is key to improving productivity and reducing water consumption in all its concentrator plants (Andina, Chuquicamata, Ministro Hales, El Teniente).

VI) Multidisciplinary project: geology/mining/agriculture/hydric basins.

A multidisciplinary project that includes all the research lines (RL1 to RL5), titled "Evaluation of the interaction between mine sites, agricultural activities and other water users, incorporating a risk analysis of variability patterns and weather change," started in August 2020 (researchers: José Luis Arumí/Ricardo Barra/Diego Rivera (hydrology, agriculture, social science), Leopoldo Gutiérrez/Fernando Betancourt (mineral processing), Ramon Díaz (mining engineering), Enrique Sáez/Ursula Kelm/Oscar Jerez (geology)). The purpose of the project is to integrate knowledge and experiences from mine sites, geology and mineralogy, drainage basins, agriculture, and ecosystems, along with society and local community organizations, under climate change conditions.

The first deliverable of this project was a CRHIAM Communication Series entry entitled "Radiography of the Chilean Mining: Present and Future," published in December 2020. In this multidisciplinary project, an important objective is to characterize each of the existing deposits at present and those that are projected for the future (medium and long term) in order to get an estimate of the projected concentrations of phyllosilicates in the ores. With this information it will be possible to make a much more rigorous estimate of the projected water consumption for the mining industry and to contrast this information with existing information to evaluate possible areas for improvement. This project was presented to the Director of Water Resources of CODELCO-CHILE, who expressed great interest, which led CRHIAM to be close to signing a collaboration agreement with this important Chilean mining company.

4.2 RL2. New water sources for agriculture, mining and communities

The mining industry continues to make great efforts to close the water cycle; however, the "loss" of water to tailing dams remains. Disruptive ideas for new cost-effective solid-liquid separation technologies surgically focused on saving water are needed. The research carried out in 2021 addresses various aspects, with varying degrees of progress, aimed at sustainable use of water with a significant shrinkage of the environmental footprint. The objectives for 2021 have been achieved through a good mix of experienced and young researchers, effectively connected with quality centers abroad, with carefully selected students in a suitable research atmosphere. Strong, productive collaboration with other research lines and Chilean universities – Antofagasta, Bío-Bío, Arturo Prat, and Pontificia Católica de Valparaíso – and foreign universities – Aalto (Finland), Politécnica de Cartagena (Spain), Complutense de Madrid (Spain), Heinrich Heine (Germany), and CSIRO (Australia) – stands out. Interdisciplinary work with researchers from RL2, RL3, and RL5 also stands out. An account of the 2021 results follows.

I) Phosphorus control in large bodies of water

Abatement with a clay spray. Phosphorus in the form of phosphates is a crucial macronutrient for all organisms, as are water, carbon, nitrogen, and oxygen. Large amounts of phosphates are necessary for the survival of cells. However, in some cases, undesirable algae overgrowth occurs, requiring phosphorous levels to be kept under control. The excess of phosphate originates from industrial and household wastewater discharges into waterways and directly into water bodies, in addition to natural leaching processes. For large bodies of water, cost-effective, ecosystem-friendly methods are required for phosphate export. An important conclusion is that the use of clays to control phosphate and algal blooms by flocculation is the most promising method in seawater. Clays are very attractive because they are non-toxic, sand and local soils only could pose less ecological risk, and they are available almost everywhere. Clay applications are advancing but are not as widespread in part because the mechanisms of nutrient adsorption on clay particles are not fully understood. The aim of this work during 2021 was to evaluate kaolinite as a phosphate adsorbent by molecular simulation in saltwater. We used the quantitative methodology consolidated in 2020 which is based on ab initio calculations and molecular simulation techniques (MMT) for studying the adsorption of two species of phosphates that prevail at neutral pH, dihydrogen phosphate and hydrogen phosphate ions in a 1:1 ratio, on the three principal planes of kaolinite, in low-concentration aqueous salt solutions (García *et al.*, 2021). Detailed information about the anchoring mechanisms of phosphate solvates on kaolinite and the role played by salt was obtained. The adsorptive capacity of kaolinite (ca. 25 mmol phosphate per kg of kaolinite), which compares well with the few available experimental results obtained under conditions that are not exactly the same as those here (average of 50 mmol phosphate per kg of kaolinite), increases with salt concentration. The lability of hydration layers in phosphates and kaolinite is low, and the mean residence times of the water molecules are higher than in water, and much higher at the hydrophilic surfaces of kaolinite; however, the adsorption mechanisms show that both phosphates and kaolinite relinquish their water layers at the contact points to favor adsorption. These results show that common clays such as kaolinite can be used to control phosphates in large bodies of water and suggest the adsorption mechanisms. An extension to phosphorus control with clays in salty water is well advanced, and is of interest in salmon farming. García (2021), in her doctoral thesis, is working on the experimental portion. The simulation component in García's thesis is being strongly supported by Quezada (2021), an ANID postdoc. The work is led by RL2 and has effective participation from RL1, RL3, and RL5. An ambitious plan for 2022 is to migrate from the lab to a pilot plant.

II) Is there a selective collector for lithium-rich spodumene in saltwater?

Several research groups have reported on the utility of using molecular modeling tools for understanding mineral–reagent interactions as a complement to the expensive trial and error experiments that are used today and that do not ensure optimal results. In our group, we showed that molecular modeling (quantum + molecular dynamics) provides a sound method to quantify nano-scale forces at the mineral-water interface, the crystal structure of minerals, and the crystal structure specificity of diverse organic molecules for different mineral systems. Spodumene is of interest for various reasons: it is a complex mineral whose interaction with water has not yet been fully elucidated, which delays the production of this mineral, which is key to electromobility, it faces the challenge of being concentrated in low-quality, salty or partially desalinated water and finally, it is of interest in Chile because of increasing evidence that it exists in the country. It is a great opportunity for us to test our quantum molecular simulation strategy and contribute to the production strategy of this valuable mineral. In 2021, we adapted the molecular methodology and applied it to the recovery of spodumene (in presence of albite and clays) with selective collectors chosen ex-ante, compatible with the environment and effective in seawater. The results so far include the complexation of alkali and alkaline-earth metal cations at spodumene-saltwater interfaces and the impact on oleate adsorption (Quezada and Toledo, 2021). In parallel, the methodology has been used to study the adsorption of flocculating polymers on gangue minerals such as quartz, clays, and brucite in seawater (Quezada *et al*., 2021a,b). In addition, to study the adsorption and hydrophobicity printed by polyacrylic acid on quartz, in an experimental work last year we noticed that the flocs formed are more deformable and repel water, which is very welcome in relation to the time to recover water from tailings (Quezada *et al*., 2021c). The sizeable computational infrastructure required includes the cluster of our research group and the Southern GPU-cluster (SGPU-C) UDEC funded by FONDEQUIP EQM150134. This year we added a quantum chemist to our group, Dr. Omar Alvarado, who has a CRHIAM postdoctoral position for 2021. Research lines involved: RL2 and RL1.

III) Inorganic fouling: A pending issue when using saltwater in processes

The substitution of freshwater with water with varying degrees of salinity will continue to advance due to water scarcity and water stress. One possibility is to desalinate, and another is to adapt the processes. Both options are now familiar. Avoiding fouling seems unlikely. Thus, the pressing task is to maintain some control. This can be accomplished by cost-effective “green” antifouling agents acting in sub-stoichiometric doses concerning the amount of salt in the water and meeting the condition of being biodegradable, with low aquatic and human toxicity. The design/evaluation of antiscalants can take great advantage of molecular simulation methods (MMT). The most promising green antiscalants studied in 2021 include polymaleates (PMA) such as maleic-acrylic acid copolymer (MA-AA), polyaspartates (PASP) and polyepoxysuccinate (PESA), as well as various derivatives including copolymers with polyacrylate (PA) such as sodium polyacrylate salts (PAAS). A fundamental advance in 2021 on nucleation, crystal growth, and interfacial properties was made based on calculations of molecular dynamics (Rozas *et al*., 2021). This issue, which is complex and somewhat distant from the general public, has been reported on in a simple way in a CRHIAM Communication Series entry now in press (Toledo *et al*., 2021) Research lead by RL2 with collaboration from RL1.

IV) Artificial vision and machine learning for the analysis of bubble coalescence in dynamic flow processes

The coalescence of air bubbles in a liquid phase deteriorates the efficiency of processes such as foam flotation, wastewater treatment, and paper recycling. Bubble coalescence begins with the thinning of the liquid between the bubbles until it becomes a thin film that eventually breaks. The vast majority of studies focus on the coalescence of two bubbles in the absence of interactions with many bubbles as in a typical process. Our goal in 2021 was to improve the current understanding of how foaming agents modify the surface properties of bubbles in mineral flotation processes and the effects of electrolytes in these systems. We are developing a machine vision system capable of tracking individual bubbles in a bubbling system from the entrance of the bubbles to their exit (Saavedra *et al*., 2021; Solar, 2021; Contreras, 2021; Veloso, 2021). We use a 960-fps slow-motion recording system and the collected images are analyzed using particle recognition techniques. Later, this information is processed for bubble tracking based on identifying neighboring particles and using machine learning techniques. This allows the positions and velocities of bubbles to be tracked spatially and temporally and data on bubble burst frequencies, collision frequencies, coalescence frequencies, area perimeter and bubble shape factors, among others, to be accessed. In addition to these properties, it is possible to determine the time when two bubbles remain together before coalescing, which we call the coalescence time. All this information, obtained from a single experiment, makes it possible to correlate properties of different frother types and doses. It is of great interest to answer two questions in 2022: to what extent does the frequency of bubble collisions affect coalescence events, and to what extent does bubble coalescence determine the mean size of bubbles?. This effort is led by RL2, with great interest from RL1.

V) Water recovery from tailings

A criterion for estimating the strength of flocculated aggregates in salt solutions: A simple criterion was proposed during 2021 to quantitatively estimate the resistance of aggregates based on incremental mechanical shear disturbances (Jeldres *et al*., 2021a). The rupture is reached with considerably lower agitation increases at higher salinity than at low salinity. This criterion is expected to help improve the efficiency of solid-liquid separation processes, especially in plants operating with seawater, be it raw or partially desalinated.

VI) Controlling (reducing) rheological properties of tailings in seawater:

It is well known that chemical reagents of different natures reduce the rheological properties of suspensions; however, their application in seawater has been little addressed. In 2021, we used molecular simulation to analyze the yielding and viscoelasticity of synthetic tailings in seawater when a dispersing agent such as sodium polyacrylate is added (Jeldres *et al*., 2021b). The results corroborated experimental findings in late 2020 indicating that polyacrylate is effective as a dispersant. The increase of the hydrophobic effect between the particles decreases the water trapped in aggregates and decreases the resistance of the flocs to flow. In 2021, several other dispersants, in addition to polyacrylic acid, were also analyzed to enhance the dispersion of concentrated kaolin slurries in seawater (Leiva *et al*., 2021a; Yepsen *et al*., 2021). Preliminarily, it seems to be a good option to use dispersants to improve tailings management in hypersaline media, especially to deal with the problems caused by complex clay-rich gangues.

VII) Structure of tailing aggregates

In 2021 we studied the temporal evolution of the structure of tailings aggregates flocculated in seawater (Leiva *et al*., 2021b) and various other aspects related to flotation in saltwater (Cruz *et al*., 2021; Gutiérrez *et al*., 2021). Finally, early in 2021, a correction to the Smooth Particle Hydrodynamics method was published. The corrected method allows modeling of particles of different sizes and shapes that interact in a fluid medium (Achim *et al*., 2021). During the year we have started the construction of an experimental system for the fluidization of particles from which to obtain data for a benchmark of the model (Hermosilla, 2021). Research lines involved: RL2 and RL1.

VIII) Other major impacts in 2021

Special issues in Minerals (MDPI Journal) on Interactions of Polymers with Minerals Surfaces (Guest editor: R. Jeldres), Interactions of Chemical Reagents with Clay Minerals (Guest editor: R. Jeldres), and Flocculation Process of Tailings (Guess editor: P.G. Toledo). CRHIAM Communication Series entries published, in press, and others being reviewed. Students involved: MSc: F. Pulgar (P. Toledo with R. Jeldres, U Antof), PhD: K. Pérez (P. Toledo with R. Jedres, U Antof), K. García (P. Toledo with J. Arumí, UdeC), Postdoc: G. Quezada (Proyecto ANID), Rodrigo Yepsen (P. Toledo with L. Gutiérrez), O. Alvarado (P. Toledo with R. Rozas and L. Gutiérrez). Interview in national media: Ciper Académico: "In Chile, agriculture would have to work with half the water it currently uses" May 1, 2021 (P. Toledo). Plenary talk, 134th Anniversary of the former School of Mines: "Challenges and decisions for the sustainable development of mining in Chile: Crossing the Rubicon" 26 August 2021 (P. Toledo).

4.3 RL3. Water availability and quality for agriculture and mining under climate change

Inter/transdisciplinary work of RL3 researchers

One of the important achievements of 2021 was the publication of the first article of an interdisciplinary effort that aims to find solutions to water quality problems that are affecting agricultural production and water bodies that receive that impact of pollutant transport such as the small lagoons of central Chile (Garcia *et al*., 2001). In a parallel interdisciplinary project, we are developing monitoring tools to study the quality of lakes, the first product of which is the recently published article of Araneda *et al.* (2021).

Advances in development of monitoring and data analysis

Through the doctoral dissertation of Francisco Balocchi, we are studying the hydrological connectivity of a watershed and the generation of streamflow and the occurrence of minimum flow in watersheds of the coastal mountains; the first article published this year analyzed recession flow (Balocchi *et al*., 2021).

Dr. Oyarzún is researching the monitoring and assessment of heavy metal transport and fate in mining-affected mountain streams of north-central Chile. Based on that research the work of Rossi *et al*. (2021) was published. This work involved an analysis based on historical water quality data to identify when complex water quality modeling approaches may be necessary and when simpler approaches may be sufficient for estimating water quality in river confluence zones, with an emphasis on water constituents related to mining activity or geological imprint. It was observed that whereas SO4 and Cu concentrations (downstream confluences) were adequately approximated by a simple conservative mixing model, estimates of As and Fe concentrations exhibited larger errors due to the more reactive behavior of these constituents. The fact that the simple, conservative mixing model describes SO4 transport was a valuable result, as this constituent is known to be one of the primary indicators of mining-related contamination in rivers. Also, the approach could be a useful starting point for further evaluations of the effects of climate change and hydrological variability on the water quality of rivers, especially in headwater contexts.

The doctoral thesis of Dr. D. Castillo (Doctorado Energía, Agua y Ambiente de la U. La Serena; https://doctoradoeama.userena.cl/alumnos/) is underway. This work is guided by Dr. Oyarzún and its doctoral committee includes the Dr. Arumí. Partial results of the work in progress were presented in Castillo and Oyarzún (2021). This contribution described the determination of parameters and conditions associated with the characterization and modeling of pollutant transport in river systems (e.g., dispersion coefficient, role of storage zones). It also presented preliminary results from the use of the WASP model for metal transport and fate.

Finally, it is important to mention several works presented at Water Congress that addressed different aspects related to water security (e.g., an analysis of the use of groundwater models in environmental impact studies, the development and implementation of secondary water quality regulations, and the use of isotopes for hydrologic-environmental studies). These contributions (Díaz and Oyarzún, 2021; Núñez and Oyarzún, 2021; Olivares *et al*., 2021; Oyarzún *et al*., 2021b; Rojas and Oyarzún, 2021; Urrea and Oyarzún, 2021) corresponded to undergraduate projects (Civil and Environmental Engineering, U. La Serena) that were or are being supported by CRHIAM.

Applications on lake analysis

Remote sensing was used as an early alert tool for water clarity changes in five Araucanian lakes in south-central Chile (Rodriguez *et al.*, 2021). Turbidity records are scarce or unavailable over large and remote areas on which information is needed to fully understand the factors associated with turbidity, and their spatial-temporal representation remains a limitation. This work aimed to develop and validate empirical models to estimate turbidity values from Landsat images and determine the spatial distribution of estimated turbidity in the selected Araucanian lakes. This in turn was used to develop and validate a set of empirical models to predict turbidity based on four single bands and 16 combination bands from 15 multispectral Landsat images. The best empirical models predicted turbidity over the range of 0.3–12. In the same context, Landsat 8 satellite images were used to estimate Chl-a values in Araucanian lakes (Rodriguez *et al.*, 2021). Chlorophyll-a (Chl-a) is an optically active compound commonly used as a proxy for phytoplankton biomass and trophic state in an aquatic system. These models will be used in the future to reconstruct large datasets that allow analysis of transparency trends and monitoring of chlorophyll changes associated with algal blooms in these lakes.

Lake temperature has proven to act as a good indicator of climate variability and change. Thus, a surface temperature analysis at different temporal scales is important, as this parameter influences the physical, chemical, and biological cycles of lakes. Here we analyzed monthly, seasonal, and annual surface temperature trends in south central Chilean lakes during the 2000–2016 period using MODIS satellite imagery. To this end, 14 lakes with a surface area greater than 10 km^2 were examined. Results show that lakes presented a statistically significant increase in surface temperature, with a rate of 0.10 °C/decade (0.01 °C/year) over the period. Furthermore, some of the lakes in the study present a significant upward trend in surface temperature, especially in spring, summer, and winter. In general, a significant increase in surface water temperature was found in lakes located at higher altitudes, such as Maule, Laja, and Galletué lakes. These results contribute to the provision of useful data on Chilean lakes for managers and policymakers (Collazo *et al.*, 2021). The results of this research are part of the PhD thesis in Environmental Sciences of Arnaldo Collazo of the Universidad de Concepción.

Reconstruction of environmental and climate change using lacustrine sediments

We continue working on the reconstruction of environmental and climate variability during recent millennia using sedimentological records present in lake sediments. In this context we reconstructed primary production and sedimentological changes spanning the past 2500 years in two coastal lakes in south-central Chile. A multiproxy approach including sedimentological, biogenic silica, carbon and nitrogen isotopes, and fossil pigment analysis of sediment cores was performed in Laguna Grande (LGSP) and Laguna Chica de San Pedro (LCSP). A marked change in the sedimentology of the lakes was observed, likely related to the terrigenous sediment inputs resulting from a transition from arid conditions in the mid-Holocene to more humid conditions in the late Holocene that favored the establishment of an arboreal forest during 100 BC–AD 150. A period of low primary production was identified between 850 and 1050 AC for LCSP, suggesting moist and cold conditions that were possibly related to La Niña events. In recent decades, there have been increases in primary production, probably resulting from anthropogenic disturbances. These likely include the clearance of native vegetation, the introduction of exotic tree species, and urbanization, which in turn resulted in nutrient inputs and hence eutrophication (Montes *et al*., 2021).

I) Applications in Patagonia

Paleoclimate studies in Patagonia show high Holocene climate variability, strongly controlled by the intensity and latitudinal position of the Southern Westerly Winds. In this study, winter precipitation over recent centuries was reconstructed through sedimentological and geochemical analyses of a sediment core from Lake Jeinimeni. According to the results, the sandy laminae correspond to the deposition of a high sedimentary load delivered by austral spring snowmelt, whereas the clayey silt laminae result from particle settling in the water column during low hydrodynamical conditions. Thicker varves observed in dry conditions underline the importance of aeolian transport in sedimentary deposition. The sandy and gravelly layers record massive erosional events due to proximal watershed perturbation driven by climatic or tectonic mechanisms. The clastic varves of Lake Jeinimeni document environmental decadal to multidecadal variability in East Patagonia over recent centuries. The more pronounced sediment transition around 1750 CE is consistent with the inception of the Little Ice Age-type event, in agreement with North Patagonian paleoclimate reconstructions derived from glacier advances, lacustrine varve thickness, and tree-ring records (Fagel *et al*., 2021).

II) Hydro-sedimentary characterization of an endorheic watershed in the Atacama Desert during "extreme" precipitation events

Desert ecosystems are mainly defined by water scarcity, where water inputs are highly variable in both space and time, with many of these ecosystem functions being pulse driven. These environments create areas that are vital for different species of flora and fauna and are fundamental for maintaining diversity. Aridity is most commonly defined according to the ratio between potential evaporation and precipitation; in arid zones this ratio is larger than unity. Runoff and channel activation depend on the occurrence of 'major' rainfall events. As vegetation cover is sparse, the soil is unprotected from raindrop impact and the generation of runoff is therefore Hortonian. Physical and biogenic crusts play a major role in the response of desert soils to raindrop impact and to runoff generation. These are typically fast rising floods, often advancing as a bore over a dry bed, with recessions lasting minutes to hours. Due to the lack of vegetative cover, ephemeral floods transport much sediment, most of which is in suspension, with a bedload at least one order of magnitude higher than in temperate climates. Due to aridity, flood waters are in some places directed to stock ponds and small reservoirs, where the sediment is deposited. Our study is focused on historic to present day hydrologic processes in this most intriguing part of our globe, where the presence of short-lived floods is evaluated based on event signatures of water and sediment in a small, ephemeral pond (Alcayaga *et al.*, submitted to Geomorphology).

4.4 RL4. Technology for water treatment and environmental remediation

Inter/transdisciplinary work of RL4 researchers

The researchers of RL4 are making efforts to connect the members of their research line and generate products with other research lines. Thus, during 2020 RL4 has generated the following CRHIAM Communication Series titles: "Use of pesticides in agriculture: Basic concepts, risks and solutions", "Arbuscular mycorrhizal fungi: Sustainable biotechnology for agriculture in the face of climate change", "Sustainability and water security" and "Microbiology and wastewater treatment under the concept of "One Health". The documents generated come from an inter/transdisciplinary look at the issues arising from the research work of the different research lines. This agreement can be used to deliver integrated knowledge to generate public policies and/or as knowledge for the dissemination to the community in general. In addition, during 2021 the book "Nature-based solutions for point and diffuse discharge decontamination" was launched. This book contains research that comes from different authors who have worked on nature-based solutions to contribute to water security or climate change issues. Under CRHIAM, two consolidated lines of research have come together from the School of Engineering and Sciences of the Universidad de La Frontera and another from the School of Environmental Sciences of the U. de Concepción.

Collaboration with international and national companies

Researchers of RL4 have several cooperation initiatives with Greece, Argentina, Costa Rica, Germany, Spain, and Brazil, with funds from specific programs for them. RL4 researchers currently maintain international cooperation projects with the University Federal do ABC of Brazil (ANID/FAPESP 2018/08194-2), Greece (ANID/MEC80190057), and Germany (ANID/MEC 80190080). In addition, six regular and postdoctoral Fondecyt projects (FONDECYT 1211738, 1181089, 1191230, FONDECYT Postdoctorado 3200963, 3190922 and 3180279) and 3 doctoral dissertations and 1 master's thesis are currently underway. With the results obtained from these investigations we want to contribute to science to obtain products that can support companies related to agriculture and the environment. The topics of the cooperation are: "Network for pesticide risk reduction: new strategies and opportunities", "Nanotechnology for agriculture: new strategies and opportunities and their environmental risk", "Impact of micro-pollutants on the reuse of treated wastewater in scenarios of water scarcity: generation of undergraduate and graduate human capital," and "Strengthening scientific capacities in environmental biotechnology for the protection of water resources from pesticide pollution", among others. RL4 has also been developing a collaboration framework with Dr. Olivier Bernard from INRIA (France) in the context of a joint cooperation project (Blue Edge, Programme Equipes Associées, INRIA). As part of this collaboration, an MSc student and a PhD student are working in this field of research.

RL4 researchers are also collaborating with a company to scale the investigated technology. At the moment, they have a project running through the EAGON-Lautaro Company and Universidad de La Frontera (Temuco) to evaluate a "Pilot plant for a treatment system for the removal and degradation of wastewater from the chip spray field of the board plant" for recirculation purposes. The technology implemented in this pilot plant has been developed by researchers from RL4 working on biopurification systems (BPS). The pilot plant was installed and is in the start-up phase, with one-year evaluations of its performance. In addition, during 2020 CORFO (the Chilean Corporation for Production Promotion) recently granted funding, under the line of social validation, for the project "Resilience and adaptability to the water crisis: sponge cities and sustainable fields through wastewater-purifying wetlands". The project will be executed among the Valdivia Wetlands Center (CEHUM), CAREP (Rural Cooperative) and CRHIAM, as the technology accreditation Center. The project will validate two constructed wetland prototypes (horizontal and vertical) to treat gray water. The prototypes will be operated in a rural cooperative and a rural house. All the purified water will be applied in two different systems: family farming and infiltration to underground waters. The project also considers a business model and transfer of knowledge on the efficiency of water treatment using a constructed wetland as a final product.

Contribution of scientific evidence for the country's public policies

During 2021 hard work has been done to meet CRHIAM's 4th objective: provide scientific evidence for the country's public policies. RL4 has contributed to joint work with other research lines and the following contributions were published online, disseminated through CIPER Chile (Center for Journalistic Investigation of Chile): "Water footprint: a fundamental tool for sustainable water management and enhancing water security", "The problem is not only the scarcity of water, but its contamination", "Protecting our soils: Another pending task" and "The water highway is a short-term measure. It is a lot of effort and money, just to spread poverty".

RL4 research topics: The main forces that drive this line of research in order to connect "water and the environment" through technology are: i) Circular economy: from recovery to reuse, ii) Technologies: wastewater treatment by conventional and non-conventional technologies, advanced membrane process for water treatment/reclamation, and nanotechnology, iii) Technology strategies for pesticide biodegradation using biopurification systems and their adaptation for industrial wastewater treatment, and iv) Sustainable management of the rhizosphere for soil-water remediation (see more details in section 9.1: Annexes).

I) Circular economy: "from recovery to reuse"

RL4 is working on two main topics related to the circular economy: a) Resource recovery and b) Reuse.

Regarding **resource recovery**, we are working on providing new sources of nutrients to agriculture. *Pseudomonas* sp. strain ABC1 is a new bacterium discovered in Chile that is capable of both removing organic matter from wastewater and simultaneously generating siderophores, compounds that promote plant growth (Valenzuela-Heredia *et al.*, 2021a). Regarding water scarcity, the choice of such technologies should be carefully analyzed. In this context, a methodology to select the more appropriate non-conventional water resource, out of municipal wastewater and seawater, was developed (Crutchik and Campos, 2021).

Reuse. Global crop production is limited by water, nitrogen, and phosphorous availability. However, these materials may contain different pollutants arising from, among other sources, human and veterinary health care, industry, cleaning media, or leakages from plastics or textiles. RL4 is working on the topic "Compounds of emerging concern as new plant stressors linked to water reuse and biosolid application in agriculture" in a circular economy context (Mansilla *et al.*, 2021). From this same perspective, the reuse of treated wastewater has been considered a suitable alternative for agriculture and for achieving water security and management (Leiva *et al.*, 2021a). Also, work on technology related to sludge stabilization and quality evaluation of the final biosolid has been done (Venegas *et al.*, 2021).

II) Technologies: wastewater treatment by conventional and non-conventional technologies and advanced membrane process for water treatment/reclamation

RL4 is working in conventional wastewater treatment and non-conventional technologies. On the one hand, advances in conventional technologies like aerobic granulation for nitrogen removal regarding a new control strategy to maintain granule integrity based on this parameter have been studied (Pavissich *et al.*, 2021). In addition, studies on partial nitritation and anammox processes also have been carried out during 2021 (Bonassa *et al.*, 2021) and the nitrogen removal performance and increase in the ammonia loading rate have been evaluated (Valenzuela-Heredia *et al.*, 2021b, Pedrouso *et al.,* 2021). On the other hand, non-conventional technologies like green technologies or nature-based solutions (NBS) for wastewater treatment in rural communities and reuse for local agriculture have been studied. In particular, phosphorus retention by plants like *Schoenoplectus californicus* and *Phragmites australis* was evaluated in a pilot-scale system (Carrillo *et al.*, 2021) and the removal of micropollutants like triclosan and ibuprofen in vertical subsurface flow constructed wetlands was studied (Leiva *et al.,* 2021b). Ana María Leiva and Valentina Carrillo are working on a PhD dissertation in the line of research of green technology. In addition, to improve NBS performance, we started work with a constructed wetland connected to a microbial fuel cell to evaluate organic matter removal and nitrogen transformation. The results obtained show positive impacts on CW development by enhancing anaerobic degradation without forced aeration (González *et al.*, 2021).

The advanced membrane process for water treatment/reclamation has also been studied. During the last few years, research has been conducted on the development of forward osmosis (FO) as an alternative for high quality water reclamation from wastewater from different sources. This year research was published on the use of forward osmosis/reverse osmosis for micropollutant removal (D'Haese *et al.*, 2021). In addition, the paper published by Cabrera-Castillo *et al.* (2021) addresses the use of membrane distillation in combination with forward osmosis, including an economic assessment of this alternative. Membranes can be used not only for filtration of water suspensions; they can also be a tool for dosing chemicals when treating wastewater by biological means. For example, membranes have been used to control oxygen dosage in different biotechnological applications. In the paper of Valdés *et al.* (2020) membranes are used for micro-oxygenation of UASB (Upflow Anaerobic Sludge Blanket) reactors. This process enables the in-situ oxidation of sulfides, producing two clear benefits when anaerobic digestion is applied to wastewater treatment: reduction of sulfide content in the biogas, facilitating its use as a source of renewable energy, and reduction of dissolved sulfides, enhancing treated water quality and preventing drawbacks associated with problematic odors during the treatment process.

III) Advanced nanotechnology for recovery of water for mining and agriculture and other applications

Metal nanoparticles (Me-NPs) for application in medicine, wastewater treatment, and the generation of value-added products have been synthetized using biological and chemical methods. Cisternas *et al.* (2021) developed a new biomimetic method for the synthesis of silver nanoparticles based on fungal metabolites, with antimicrobial activity against human and plant pathogens. The synthesis of superparamagnetic iron oxide nanoparticles (SPIONS) doped with metal oxide nanoparticles (TiO_2 and ZnO) has been effectively developed for further pesticide treatment (Herrera, 2021). In an international project, different Me-NPs were synthesized through plant extracts to be embedded in garlic and eucalyptus essential oil to evaluate their antimicrobial activity against phytopathogens (CONICYT-FAPESP 2018/08194-2). In addition, a novel spectrophotometric assay for determining the oxidase-like activity of manganese ferrite nanoparticles ($MnFe_2O_4$ NPs) was developed with potential use for detecting several analytes in the medical and environmental fields (Hermosilla *et al.*, 2021).

IV) Sustainable management of the rhizosphere for soil-water remediation, efficient water use, and agricultural production

Biotechnological aspects that consider the use of microorganisms with plant growth promotion potential to favor bioremediation processes in contaminated soil and water, as well as their use to enhance plant growth under conditions of water stress (drought and salinity) have been studied (Cornejo, 2021). A Communication Series volume was produced based on our scientific experience, which includes the use of mycorrhizal fungi as a biotechnological tool to face the problems generated by climate change (Santander *et al.*, 2021), aimed especially at plant production in conditions of drought and salinity. Meanwhile, Aponte *et al.* (2021) reported the application of an important tool based on enzymatic biological indicators to assess the quality of soils that have been affected by the deposition of toxic elements in the Puchuncaví Valley, central Chile, which is of great interest due to the possible wide-ranging use of this methodology in the description of soil quality indicators.

4.5 RL5. Water governance, ecosystem services and sustainability

Inter/transdisciplinary work of RL5 researchers

One of the objectives for the 2021 period was to increase interdisciplinary work, considering that water governance, ecosystem services, and sustainability are crucial to transformation given the critical water scarcity scenario that impedes the water security our center aims to achieve. This year our research line completed an interdisciplinary work product in the form of a new book: *Common Goods, Cultural Biodiversity in Times of Crisis: Water Scarcity, Pandemics and Climate Change*, edited by Dr. Jorge Rojas, Patricio Silva, Ricardo Barra, Ricardo Figueroa, José Luis Arumí, and Gunhild Hansen (2021). It provides a reflection on the issue of adaptation to water scarcity, offering an opportunity to look back to traditional and indigenous knowledge as a source of adaptation to water shortage periods. The research team agreed that the issue of water as a common good is a basic condition to improve its management, as demonstrated by the traditional practices of the first nations in Chile. Rojas *et al.* (2021) addressed the issue of local knowledge and the role of collaboration in facing both pandemics and climate change challenges in a bottom-up approach, in which social resilience relies on community values. The COVID-19 pandemic also presents an opportunity to rethink local possibilities to improve resilience and face global challenges such as climate change and the associated multi-crisis. Given the extent of the megadrought in Chile, one of the first responses is to look to groundwater as a supplementary source of water. As our water code does not adequately protect this resource, our colleague José Luis Arumí, together with former CRHIAM researcher Dr. Verónica Delgado, released a book in 2021 addressing the Chilean model of groundwater regulation, *A Critique from Environmental Law and Environmental Sciences* (2021), in which a series of recommendations are made for decision-makers. It is important to note that this is one of the first legal books written by lawyers and engineers in Chile.

i) Advances in groundwater management

We have continued collaborating with the Diguillín River Board on the supervision of an artificial groundwater recharge (AGR) project. This cooperation was also enriched by the process of forming the Itata River Survey Board. The joint experience of implementing artificial groundwater recharge and the creation of the water users' organization that can manage the recharge led us to publish two papers on the gaps regarding the implementation of AGR in Chile (Arumí and Melo, 2021; Arumi and Delgado, 2021).

II) Concept of water extractivism

From colonial times through globalization, all extractivisms have been increasing their water use. Water extractivism is defined as a mode of appropriation of nature with historical-geographical, political, and socioenvironmental roots and processes by which water is extracted from the territories of life at large scales or high intensity, mainly to be exported to the Global North through different types of commodities without processing or with minimal processing—for instance, minerals, food, forestry monocultures, wood, cellulose pulp, palm oil, meat, avocado, copper, lithium, and so on. The water extractivism concept could be applied to any of those or other specific commodities because they all imply large-scale, intensive extraction and export of water. This water is extracted from local water bodies such as wetlands, surface water (rivers, lagoons), glaciers, aquifers, and so on. Along with other colleagues, we addressed water extractivism and decolonial struggles associated with lithium mining (Jerez *et al.*, 2021) and forestry monocultures in Chilean and Mapuche territories (Torres *et al.,* 2021).

III) Ecosystem services.

In a new study (Boyero *et al.*, 2021a), a strong link between detritivore diversity and plant litter decomposition in streams at the global scale was discovered. Further, it was shown that species extinctions in this key group of animals are particularly worrying in the tropics, with potentially severe consequences for stream ecosystem functioning at these latitudes. This study also reveals the importance of restoring native riparian vegetation. Litter decomposition is a crucial process in stream ecosystems and plays a notable role in the exchange of carbon between the biosphere and atmosphere, implying potential climate feedback. An experiment in this area conducted by over 40 research teams worldwide resulted in the publication of a paper in Science Advances (Boyero *et al.*, 2021b) that demonstrates the importance of riparian plant diversity for leaf litter decomposition in stream ecosystems and that stream ecosystem functioning could be particularly vulnerable to forestry practices. Therefore, biodiversity protection is crucial to the sustainability of aquatic ecosystems, and with their loss we are more vulnerable to adverse impacts to reverse the negative aspects of climate change.

Other impacts of climate change and human interventions are the possible functional changes from perennial to intermittent rivers with a possible impact on aquatic biodiversity and human well-being. Our studies (Banegas *et al.*, 2021) identify a prolongation of the zero flow in recent decades and a variation in communities between periods of dry rivers and those with water flows. The importance of isolated pools as a refuge for endemic species and therefore, a conservation challenge, is also recognized. The macroinvertebrate biodiversity of forest wetlands has also been studied, along with the importance of defining which sampling methods allow a better representation of these communities, especially in environments recognized as biodiversity hotspots and poorly studied (Correa Araneda *et al.*, 2021). Figueroa was also interviewed by Ciper Académico; he highlighted the promotion of a true change in the way water is used and cared for in Chile through "watershed management," a model that goes beyond current geographic and administrative limits. While its implementation involves modification of the Water Code and the Constitution, governors (new political figures in Chile) can advance in developing local environmental management, in which water is valued not only as a productive input and its use, consumption, and care are discussed in a participatory manner.

IV) Water regulations

In 2021 one of the important regulatory issues addressed by this line was the modification by the Ministry of the Environment of the regulations on emissions into surface water in Supreme Decree 90. These regulations establish the permitted concentrations for 36 parameters impacting water quality in rivers, lakes, and coastal zones throughout Chile. We discussed how to improve the current regulatory model in order to promote sustainability and control pollution, since many issues such as endocrine disruption and loss of biodiversity are not addressed at all by the current regulatory scheme. In fact, the issue of emerging contaminants impacting water resources is not covered in any way, besides the evidence showing the occurrence and effects of industrial and urban effluents on fish fauna in Chilean rivers, as described by Barra *et al.* (2021a). Some recommendations were made by CRHIAM in order to improve the regulation through the inclusion of toxicity bioassays and the necessary control in the receiving environment in an opinion letter on the CIPER web site in June 2021 (Barra *et al.*, 2021b). Although Dr. Verónica Delgado is no longer an associate researcher at CRHIAM, she is the head of the DAAC (Derecho Ambiental y Cambio Climático) Program; we continue working together and a formal agreement will be signed. Dr. Delgado and Dr. Arumí collaborate actively with the Water Resources Committee of the Chilean Senate and have contributed to the modification of several articles of the New Chilean Law on Climate Change (DACC, 2021). Research regarding the use of Indicators in Strategic Environmental Assessments of Urban-Planning was recently published (Reicher, 2021).

V) Water and the economy

During this period, we have advanced on understanding the behavior of different economic agents regarding water consumption. Considering water demand for agriculture and urban households at the basin level, we found that urban households are likely to bear the largest economic burden of a climate-induced decrease in water availability. Within this context, we found that a flexible water allocation mechanism could improve the adaptation options of households (Ponce Oliva *et al.*, 2021a). Also at the basin level, we proposed a new nexus approach – food, water, and welfare – for the assessment of climate change impacts. We found that all the nexus components will be negatively affected by climate change, with the less water-intensive sector better off due to water transfers from other sectors (Ponce Oliva *et al.,* 2021b). Finally, we made a significant contribution to the empirical approach used for estimating water demands at the household level, highlighting the potential of using aggregated data for elasticity estimation (Flores *et al.*, 2021b).

VI) Water and the new constitution

As the constitutional convention unfolds, one of our researchers was elected as a constituent. Dr. Amaya Álvez is now one of the 155 people who will write Chile's new constitution. We think that this demonstrates the major impact of the work that Dr. Álvez and her colleagues at the university and CRHIAM have been carrying out in Chile over the last 8 years on issues of constitutional regulation of water resources in the country. We envisage that the scientific research will be a foundation for better water management regulations at the national and basin levels. In 2021 one of the key issues in the public debate is the Chilean constituent process, which must address, among other matters, the fundamental statute of water, currently viewed only in relation to the ownership of use rights. Thus, the center has carried out reviews of constitutional justice in relation to reforms in water matters (Álvez and Castillo, 2021a).

Likewise, another subject of contention amid the constitutional debate is the enshrinement in Chile of the human right to water, which currently exists only at the level of international instruments, but if express constitutional consecration. We commented on this lack of consecration and problems in the effective exercise of this right in relation to recent court cases (Álvez and Castillo, 2021b). This article also reviews the exercise problems associated with the country's water shortage, aggravated in the context of the COVID-19 pandemic (Álvez and Castillo, 2021c). Finally, it highlights, in terms of content for a new constitution, research related to the consecration of the rights of nature, and its relationship to the jurisprudential line regarding cases related to water and river management in Latin America (Álvez *et al.*, 2021).

5. OUR SCIENTIFIC WORK PUBLISHED IN 2021

5.1 Publications Indexed by Web of Science (WoS)

1. Achim, C., Rozas, R. and Toledo, P. 2021. Semi-decoupled first-order correction for smoothed particle hydrodynamics. Applied Mathematical Modelling, 93: 314-325. (Synergy between researchers from the same line of Research - RL2: New water sources for agriculture, mining and communities).
2. Aponte, H., Mondaca, P., Santander, C., Meier, S., Paolini, J., Buttler, B., Rojas, C., Diez, M.C. and Cornejo, P. 2021. Enzyme activities and microbial functional diversity in metal(loid) contaminated soils near to a copper smelter. Science of The Total Environment, 779: 146423. (Synergy between researchers from the same line of Research – RL4: Technology for water treatment and environmental remediation).
3. Araya-Castro, K., Tzu-Chiao, C., Durán-Vinet, B., Cisterna, C., Ciudad, G. and Rubilar, O. 2021. Green Synthesis of Copper Oxide Nanoparticles Using Protein Fractions from an Aqueous Extract of Brown Algae Macrocystis pyrifera. Processes, 9(1): 78.
4. Aranda, A.C., Rivera-Ruiz, D., Rodríguez-López, L., Pedreros, P., Arumí-Ribera, J.L., Morales-Salinas, L., Fuentes-Jaque, G. and Urrutia, R. 2021. Evidence of Climate Change Based on Lake Surface Temperature Trends in South Central Chile. Remote Sensing, 13(22): 4535. (Synergy between researchers from the same line of Research – RL3: Water availability and quality for agriculture and mining amid climate change).
5. Baeza, A., Bürger, R., Martí, M., Mulet, P. and Zorío, D. 2021. On approximate implicit Taylor methods for ordinary differential equations. Computational and Applied Mathematics, 39: 304.
6. Baird, G., Bürger, R., Méndez, P.E. and Ruiz-Baier, R. 2021. Second-order schemes for axisymmetric Navier-Stokes-Brinkman and transport equations modelling water filters. Numerische Mathematik, 147: 431-479.
7. Balocchi, F., Flores, N., Arumí, J.L., Iroumé, A., Silberstein, R. and Ramírez de Arellano, P. 2021. Comparison of streamflow recession between plantations and native forests in small catchments in Central-Southern Chile. Hydrological Processes, 35(6): e14182.
8. Banegas-Medina, A., Montes, I., Tzoraki, O., Brendonck, L., Pinceel, T., Diaz, G., Arriagada, P., Arumi, J.L., Pedreros, P. and Figueroa, R. 2021. Hydrological, Environmental and Taxonomical Heterogeneity during the Transition from Drying to Flowing Conditions in a Mediterranean Intermittent River. Biology, 10(4): 316. (Synergy between researchers from the same research line – RL5: Water governance, ecosystem services and sustainability).
9. Barra, R., Chiang, G., Saavedra M.F., Orrego, R., Servos, M.R., Hewitt, L.M., McMaster, M.E., Bahamonde, P., Tucca, F. and Munkittrick K.R. 2021. Endocrine disruptor impacts on fish from Chile: The influence of wastewaters. Frontiers in Endocrinology, 12: 611281.
10. Bonassa, G., Chiapetti-Bolsan, A., Hollas, C.E., Venturin, B., Candido, D., Chini, A., De Prá, M.C., Goldschmidt, Antes, F., Campos, J.L. and Kunz, A. 2021. Organic carbon bioavailability: Is it a good driver to choose the best biological nitrogen removal process?. Science of The Total Environment, 753: 142075.

11. Boyero, L., López-Rojo, N., Tonin, A.M., Pérez, J., Correa-Araneda, F., Pearson, R.G., Bosch, J., Albariño, R.J., Anbalagan, S., Barmuta, L.A., Basaguren, A., Burdon, F.J., Caliman, A., Callisto, M., Calor, A.R., Campbell, I.C., Cardinale, B.J., Casas, J.J., Chará-Serna, A.M., Chauvet, E., Ciapała, S., Colón-Gaud, Ch., Cornejo, A., Davis, A.M., Degebrodt, M., Días, E.M., Díaz, M.E., Douglas, M.M., Encalada, A.C., Figueroa, R., Flecker, A.S., Tadeusz, F., García, E.A., García, G., García, P.E., Gessner, M.O., Gómez, J.E., Gómez, S., Gonçalves Jr, J.F., Gwinn, D.C., Hall Jr, R.O., Hamada, N., Hui, C., Imazawa, D., Iwata, T., Kariuki, S.K., Landeira-Dabarca, A., Laymon, K., Leal, M., Marchant, R., Martins, R.T., Masese, F.O., Maul, M., McKie, B.G., Medeiros, A.O., M'Erimba, C., Middleton, J.A., Monroy, S., Muotka, T., Negishi, J.N., Ramírez, A., Richardson, J.S., Rincón, J., Rubio-Ríos, J., dos Santos, G.M., Sarremejane, R., Sheldon, F., Sitati, A., Tenkiano, N.S.D., Tiegs, S.D., Tolod, J.R., Venarsky, M., Watson, A. and Yule, C.M. 2021. Impacts of detritivore diversity loss on instream decomposition are greatest in the tropics. Nature communications, 12: 3700.
12. Boyero, L., Pérez, J., López-Rojo, N., Tonin, A., Correa-Araneda, F., Pearson, R., Bosch, J., Albariño, R., Anbalagan, S., Barmuta, L., Beesley, L., Burdon, F., Caliman, A., Callisto, M., Campbell, I., Cardinale, B., Casas, J., Chará-Serna, A., Ciapała, S., Chauvet, E., Colón-Gaud, C., Cornejo, A., Davis, A., Degebrodt, M., Dias, E., Díaz, M.E., Douglas, M., Elosegi, A., Encalada, A., Eyto, E., Figueroa, R., Flecker, A., Fleituch, T., Frainer, A., França, J., García, E., García, G., García, P., Gessner, M., Giller, P., Gómez, J., Gómez, S., Gonçalves, J., Graça, M., Hall, R., Hamada, N., Hepp, L., Hui, C., Imazawa, D., Iwata, T., Junior, E., Kariuki, S., Landeira-Dabarca, A., Leal, M., Lehosmaa, K., M'Erimba, C., Marchant, R., Martins, R., Masese, F., Camden, M., McKie, B., Medeiros, A., Middleton, J., Muotka, T., Negishi, J., Pozo, J., Ramírez, A., Rezende, R., Richardson, J., Rincón, J., Rubio-Ríos, J., Serrano, C., Shaffer, A., Sheldon, F., Swan, C., Tenkiano, N., Tiegs, S., Tolod, J., Vernasky, M., Watson, A., Yegon, M. and Yule, C. 2021. Latitude dictates plant diversity effects on instream decomposition. Science Advances, 7(13): eabe7860.
13. Brito, G., Jerez, O. and Gutiérrez, L. 2021. Incorporation of Rheological Characterization in Grinding and Tailings Slurries to Optimize the CMP Magnetic Separation Plant. Minerals, 11(4): 386.
14. Bürger, R., Kumar, S., Mora, D., Ruiz-Baier, R. and Verma, N. 2021. Virtual element methods for the three-field formulation of time-dependent linear poroelasticity. Advances in Computational Mathematics, 47: 2.
15. Bürger, R., Chalons, C., Ordoñez, R. and Villada, L.M. 2021. A multiclass Lighthill-Whitham-Richards traffic model with a discontinuous velocity function. Networks and Heterogeneous Media, 16: 187-219.
16. Bürger, R., Chowell, G. and Lara-Díaz, L.Y. 2021. Measuring differences between phenomenological growth models applied to epidemiology. Mathematical Biosciences, 334: 108558.
17. Bürger, R., Gavilán, E., Inzunza, D., Mulet, P and Villada, L.M. 2021. Exploring a convectiondiffusion-reaction model of the propagation of forest fires: computation of risk maps for heterogeneous environments. Mathematics, 8: 1674.
18. Bürger, R., Careaga, J. and Diehl, S. 2021. A method-of-lines formulation for a model of reactive settling in tanks with varying cross-sectional área. IMA Journal of Applied Mathematics, 86: 514-546.
19. Bürger, R., Fernández-Nieto, E. and Osores, V. 2021. A multilayer shallow water approach for polydisperse sedimentation with sediment compressibility and mixture viscosity. Journal of Scientific Computing, 85: 49.
20. Buzolic, B., Arumí, J.L. and Jiménez, J. 2021. How Much Does Water Management Cost? The Case of the Water Market in the Ñuble River of South-Central Chile. Water, 13(3): 258.
21. Cabrera-Castillo, E., Castillo, C., Ciudad, G., Jeison, D. and Ortega-Bravo, J.C. 2021. FO-MD setup analysis for acid mine drainage treatment in Chile: An experimental-theoretical economic assessment compared with FO-RO and single RO. Desalination, 514: 115164.

22. Calderón, C., Levío, M., Diez. and M.C. 2021. Cadmium removal for marine food application: comparative study of different adsorbents. International Journal of Environmental Science and Technology, *in press*.
23. Castillo, D., Runkel, R. L., Duhalde, D., Pastén, P., Arumí, J. L., Oyarzún, J., Núñez, J., Maturana, H. and Oyarzún, R. 2021. A simple low-cost approach for transport parameter determination in mountain rivers. River Research and Applications, 38: 173-181. (Synergy between researchers from different research lines - RL3: Water availability and quality for agriculture and mining amid climate change; RL5: Water governance, ecosystem services and sustainability).
24. Cisternas, C., Tortella, G., Seabra, A.B., Pieretti, J., Araya-Castro, K., Hermosilla, E., Diez, M.C. and Rubilar, O. 2021. Development of a new biomimetic method for the synthesis of silver nanoparticles based on fungal metabolites: optimization and antibacterial activity. Journal of Chemical Technology & Biotechnology, 96(7): 1981-1990. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
25. Correa, F., Núñez, D., Díaz, M.E., Gómez, F., Figueroa, R., Acuña, J., Boyero, L. and Esse, C. 2021. Comparison of sampling methods for benthic macroinvertebrates in forested wetlands. Ecological Indicators, 125: 107551.
26. Crutchik D. and Campos J.L. 2021. Municipal Wastewater Reuse: Is it a Competitive Alternative to Seawater Desalination?. Sustainability, 13(6): 3481.
27. De Souza Campos, P., Borie, F., Cornejo, P., Meier, S., López-Ráez, J., López-García, A. and Seguel, A. 2021. Wheat root trait plasticity, nutrient acquisition and growth responses are dependent on specific arbuscular mycorrhizal fungus and plant genotype interactions. Journal of Plant Physiology, 256: 153297.
28. D'Haese, A., Ortega, J.C., Harmsen, D., Vanhaecke, L., Verliefde, A., Jeison, D. and Cornelissen, E. 2021. Analysing organic micropollutant accumulation in closed loop FO–RO systems: A pilot plant study. Journal of Membrane Science, 626: 119182.
29. Duran-Llacer, I., Arumí, J.L., Arriagada, L., Aguayo, M., Rojas, O., González-Rodríguez, L., Rodríguez-López, L., Martínez-Retureta, R., Oyarzún, R. and Singh, S. 2021. A new method to map groundwater-dependent ecosystem zones in semi-arid environments: A case study in Chile. Science of The Total Environment, 816: 151528. (Synergy between researchers from different research lines - RL3: Water availability and quality for agriculture and mining amid climate change; RL5: Water governance, ecosystem services and sustainability).
30. Echeverry, L., Estrada, D., Toledo, P. and Gutiérrez, L. 2021. The depressing effect of an anionic polyacrylamide on molybdenite flotation and the importance of polymer Anionicity. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 612: 126015. (Synergy between researchers from different research lines - RL1: Efficient use of water in agriculture and mining; RL2: New water sources for agriculture, mining and communities).
31. Fagel, N., Pedreros, P., Álvarez, D., Tylmann, W., Namur, O., Da Silva, A.C., Jana, P., Araneda, A., Billy, I., Schmidt, S. and Urrutia, R. 2021. Last millennium climate variability of the varved Lake Jeinimeni geochemical record from NE Chilean Patagonia. Quaternary Science Reviews, 269: 107134.
32. Fernández, G., Venegas, M. and Vidal, G. 2021. Effect of Pretreatment on Nutrient Leaching and Phytotoxicity of Biosolids from Anaerobic Digestion in Silty Loam Soil. Water Air and Soil Pollution, 231: 549.
33. Fincheira, P., Quiroz, A., Tortella, G., Diez, M.C. and Rubilar O. 2021. Current advances in plant-microbe communication via volatile organic compounds as an innovative strategy to improve plant growth. Microbiological Research, 247: 126726. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).

34. Fincheira, P., Jofré, I., Tortella, G., Medina, C., Quiroz, A., Seabra, A.B., Nascimento, M., Diez, M.C. and Rubilar, O. 2021. The prospection of plant response to 2-ketones released from nanostructured lipid 2 carriers. The prospection of plant response to 2-ketones released from nanostructured lipid 2 carriers, 21: 1474-1483. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
35. Fincheira, P., Rubilar, O., Tortella, G., Medina, C., Seabra, A.B., Nascimento, M.H., Diez, M.C. and Quiroz, A. 2021. Formulation of a Controlled-Release Carrier for 2-ketones Based on Solid Lipid Nanoparticles to Increase Seedling Growth in Lactuca sativa and Solanum lycopersicum. Journal of Soil Science and Plant Nutrition, 21: 3002–3015. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
36. Fincheira, P., Tortella, G., Seabra, A.B., Quiroz, A., Diez, M.C. and Rubilar, O. 2021. Nanotechnology advances for sustainable agriculture: current knowledge and prospects in plant growth modulation and nutrition. Planta, 256: 66. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
37. Flores, N., Rodríguez, R., Yépez, S., Osores, V., Rau, P., Rivera, D. and Balocchi, F. 2021. Comparison of Three Daily Rainfall-Runoff Hydrological Models Using Four Evapotranspiration Models in Four Small Forested Watersheds with Different Land Cover in South-Central Chile. Water, 13(22): 3191.
38. Flores Arévalo, Y., Ponce Oliva, R., Fernández, F.J. and Vásquez, F. 2021. Sensitivity of Water Price Elasticity Estimates to Different Data Aggregation Levels. Water Resources Management, 35: 2039-2052.
39. García, K., Quezada, G., Arumí, J.L., Urrutia, R. and Toledo P.G. 2021. Adsorption of phosphate ions on the basal and edge surfaces of kaolinite in low salt aqueous solutions using molecular dynamics simulations. Journal of Physical Chemistry C, 125: 21179. (Synergy between researchers from different research lines - RL2: New water sources for agriculture, mining and communities; RL3: Water availability and quality for agriculture and mining amid climate change).
40. García-Pedrero, A., Gonzalo-Martín, C. and Lillo-Saavedra, M. 2021. Improving Deep Learning Sorghum Head Detection through Test Time Augmentation. Computers and Electronics in Agriculture, 186: 106179.
41. García-Hidalgo, M., García-Pedrero, A., Caetano-Sánchez, C., Gómez-España, M., Lillo- Saavedra, M., and Olano, J.M. 2021. ρ-MtreeRing: A Graphical User Interface for X-ray Microdensity Analysis. Forests, 12(10): 1405.
42. González, T., Puigagut, J. and Vidal, G. 2021. Organic matter removal and nitrogen transformation by a constructed wetland-microbial fuel cell system with simultaneous bioelectricity generation. Science of the Total Environment, 753: 142075.
43. Hermosilla, E., Seabra, A.B., Lourenço, I.M., Ferreira, F.F., Tortella, G. and Rubilar, O. 2021. Highly sensitive oxidation of MBTH/DMAB by $MnFe_2O_4$ nanoparticles as a promising method for nanozyme-based sensor development. Biology, 621: 126585.
44. Jeldres, M., Ayala, L., Robles, P., Gálvez, E., Leiva, W., Toledo, P. and Jeldres, R. 2021. A Criterion for Estimating the Strength of Flocculated Aggregates in Salt Solutions. Minerals, 11(7):713. (Synergy between researchers from the same research line - RL2: New water sources for agriculture, mining and communities).
45. Jeldres, M., Robles, P., Toledo, P., Saldaña, M., Quezada, L. and Jeldres, R. 2021. Improved dispersion of clay-rich tailings in seawater using sodium polyacrylate. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 612: 126015. (Synergy between researchers from the same research line - RL2: New water sources for agriculture, mining and communities).

46. Jerez, B., Garcés, I. and Torres, R. 2021. Lithium extractivism and water injustices in the Salar de Atacama, Chile: The colonial shadow of green electromobility. Political Geography, 87: 102382.
47. Julio, N., Figueroa, R. and Ponce, R. 2021. Water Resources and Governance Approaches: Insights for Achieving Water Security. Water, 13(21): 3063. (Synergy between researchers from the same research line - RL5: Water governance, ecosystem services and sustainability).
48. Kasargodu-Anebagilu, P., Dietrich, J., Prado-Stuardo, L., Morales, B., Winter, E. and Arumi, J.L. 2021. Application of the theory of planned behavior with agent-based modeling for sustainable management of vegetative filter strips. Journal of Environmental Management, 284: 112014.
49. Lamilla, C., Schalchli, H., Briceño, G., Leiva, B., Donoso-Piñol, P., Barrientos, L., Rocha, V., Freire, D. and Diez, M.C. 2021. A Pesticide Biopurification System: A Source of Biosurfactant- Producing Bacteria with Environmental Biotechnology Applications. Agronomy, 11(4): 624.
50. Lecaros-Arellano, F., Holzapfel, E., Fereres, E., Rivera, D., Muñoz, N. and Jara, J. 2021. Effects of the number of drip laterals on yield and quality of apples grown in two soil types. Agricultural Water Management, 248: 106781. (Synergy between researchers from the same research line - RL1. Efficient use of water in agriculture and mining).
51. Leiva, W., Toro, N., Robles, P., Gálvez, E., and Jeldres, R. 2021. Use of Multi-Anionic Sodium Tripolyphosphate to Enhance Dispersion of Concentrated Kaolin Slurries in Seawater. Metals, 11(7): 1085.
52. Leiva, W., Fawell, P., Goñi, C., Toro, N. and Jeldres, R. 2021. Temporal evolution of the structure of tailings aggregates flocculated in seawater. Minerals Engineering, 160: 106708.
53. Leiva, A.M., Piña, B. and Vidal, G. 2021. Antibiotic resistance dissemination in wastewater treatment plants: a challenge for the reuse of treated wastewater in agricultura. Reviews in Environmental Science and Bio/Technology, 20: 1043-1072.
54. Levio, M., Schalchli, H., Briceño, G., Bornhardt, C., Tortella, G., Rubilar, O. and Diez, M.C. 2021. Performance of an optimized fixed-bed column packed with an organic biomixture to remove atrazine from aqueous solution. Environmental Technology & Innovation, 21: 101263. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
55. Levio-Raiman, M., Briceño, G., Leiva, B., López, S., Schalchli, H., Lamilla, C., Bornhardt, C. and Diez, M.C. 2021. Treatment of Pesticide-Contaminated Water Using a Selected Fungal Consortium: Study in a Batch and Packed-Bed Bioreactor. Agronomy, 11(4): 743.
56. Levio-Raiman, M., Briceño, G., Schalchli, H., Bornhardt, C. and Diez, M.C. 2021. Alternative treatment for metal ions removal from acid mine drainage using an organic biomixture as a low cost adsorbent. Environmental Technology & Innovation, 24: 101853.
57. Lillo-Saavedra, M., Gavilán, V., Rivera, D., Somos, M., García-Pedrero, A. and Gonzalo- Martín, C. 2021. Ex Post Analysis of Water Supply Demand in an Agricultural Basin by Multi-Source Data Integration. Remote Sensing, 13(11): 2022. (Synergy between researchers from the same research line - RL1: Efficient use of water in agriculture and mining).
58. Mansilla, S., Portugal, J., Bayona, J.M., Matamoros, V., Leiva, A.M., Vidal, G. and Piña, B. 2021. Compounds of emerging concern as new plant stressors linked to water reuse and biosolid application in agricultura. Journal of Environmental Chemical Engineering, 9(3): 105198.
59. Medina, J., Calabi-Floody, M., Aponte, H., Santander, C., Paneque, M., Meier, S., Panettieri, M., Cornejo, P., Borie, F. and Knicker, H. 2021. Utilization of inorganic nanoparticles and biochar as additives of agricultural waste composting: Effects of end-products on plant growth, C and nutrient stock in soils from a Mediterranean región. Agronomy, 11(4): 767.

60. Molenaar, A., Vandorpe, T., Degenhart, G., De Batist, M., Urrutia, R., Pino, M., Strasser, M. and Moernaut, J. 2021. What controls the remobilization and deformation of surficial sediment by seismic shaking? Linking lacustrine slope stratigraphy to great earthquakes in South-Central Chile. Sedimentology, 68(6): 2365-2396.
61. Moncada, M., Betancourt, F., Toledo, P. and Rodríguez, C. 2021. Torque Analysis of a Gyratory Crusher with the Discrete Element Method. 2021. Torque Analysis of a Gyratory Crusher with the Discrete Element Method. Minerals, 11(8): 878.
62. Montes, Y., Banegas-Medina, A., Fagel, N., El Ouahabi, M., Verleyen, E., Alvarez, D., Torrejón, F., Schmidt, S., Lepoint, L., Diaz, G., Pedreros, P. and Urrutia, R. 2021. Late Holocene Paleonvironmental Evolution of Two Coastal Lakes in Mediterranean Chile and Its Implications for Conservation Planning. Applied Sciences, 11(8): 3478.
63. Nahuelcura, J., Ruiz, A., Gómez, F., and Cornejo, P. 2021. The effect of arbuscular mycorrhizal fungi on the phenolic compounds profile, antioxidant activity and grain yields in wheat cultivars growing under hydric stress. Journal of the Science of Food and Agriculture, 102(1): 407-416.
64. Orrego, R., Guchardi, J., Beyger, L., Barra, R., Hewitt, L.M. and Holdway, D. 2021. Sex-Related Embryotoxicity of Pulp Mill Effluent Extracts in Medaka (*Oryzias latipes*) Female Leucophore-free FLFII Strain. Environmental Toxicology and Chemistry, 40: 2297- 2305.
65. Ortega-Martínez, E., Chamy, R. and Jeison, D. 2021. Thermal pre-treatment: Getting some insights on the formation of recalcitrant compounds and their effects on anaerobic digestion. Journal of Environmental Management, 282: 111940.
66. Oyarzún, J., Maturana, H., Paulo, A., Lillo, J., Pastén, P., Núñez, J., Duhalde, D., González, C., Portilla, A. and Oyarzún, R. 2021. Environmental Aspects of a Major ARD Source at El Indio Au-Cu-As District, North-Central Chile. Mine Water and the Environment, 41:210-224.
67. Pavissich, J.P., Camus, N., Campos, J.L., Franchi, O., Pedrouso, A., Carrera, P., Val del Rio, A. and Mosquera-Corral, A. 2021. Monitoring the stability of aerobic granular sludge using fractal dimension analysis. Environmental Science-Water Research & Technology, 7: 706-713.
68. Pedrouso, A., Vázquez-Padín, J.R., Crutchik, D. and Campos, J.L. 2021. Application of Anammox-Based Processes in Urban WWTPs: Are We on the Right Track?. Processes, 9: 78.
69. Pérez, R., Tapia, Y., Antilén, M., Casanova, M., Vidal, C., Santander, C., Aponte, H. and Cornejo, P. 2021. Interactive effect of compost application and inoculation with the fungus *Claroideoglomus claroideum* in *Oenothera picensis* plants growing in mine tailings. Ecotoxicology and Environmental Safety, 208: 111495.
70. Pérez, R., Tapia, Y., Antilén, M., Casanova, M., Vidal, C., Silambarasan, S. and Cornejo, P. 2021. Rhizosphere Management for Phytoremediation of Copper Mine Tailings. Journal of Soil Science and Plant Nutrition, 21, 3091–3109.
71. Ponce, R., Arias, E., Fernández, F., Vásquez, F. and Stehr, A. 2021. Water Use and Climate Stressors in a Multiuser River Basin Setting: Who Benefits from Adaptation?. Water Resources Management, 35: 897-915.
72. Ponce, R., Fernández, F., Vásquez-Lavín, F., Arias, E., Julio, N. and Stehr, A. 2021. Nexus Thinking at River Basin Scale: Food, Water and Welfare. Water, 13(7): 1000.
73. Pulgar, F., Ayala, L., Jeldres, M., Robles, P., Toledo, P., Salazar, I. and Jeldres, R. 2021. Lime/sodium carbonate treated seawater to improve flocculation and sedimentation of clay-based tailings. Polymers, 13(23): 4108. (Synergy between researchers from the same research line - RL2: New water sources for agriculture, mining and communities).

74. Quezada, G., Rozas, R. and Toledo, P. 2021. Polyacrylamide adsorption on (1 0 1) quartz surfaces in saltwater for a range of pH values by molecular dynamics simulations. Minerals Engineering, 162: 106741. (Synergy between researchers from the same research line - RL2: New water sources for agriculture, mining and communities).
75. Quezada, G., Toro, N., Saavedra, J., Robles, P., Salazar, I., Navarra, A. and Jeldres, R. 2021. Molecular Dynamics Study of the Conformation, Ion Adsorption, Diffusion and Water Structure of Soluble Polymers in Saline Solutions. Polymers, 13(20): 3550.
76. Quezada, G. and Toledo, P. 2021. Complexation of Alkali and Alkaline-Earth Metal Cations at Spodumene-Saltwater Interfaces by Molecular Simulation: Impact on Oleate Adsorption. Minerals, 11(1): 12.
77. Quezada, G.R., Piceros, E., Robles, P., Moraga, C., Gálvez, E., Nieto, S. and Jeldres, R.I. 2021. Polyacrylic acid to improve flotation tailings management: understanding the chemical interactions through molecular dynamics. Metals, 11(6): 987.
78. Quiroz-Jara, M., Casini, S., Fossi, M.C., Orrego, R., Gavilán, J.F. and Barra, R. 2021. Integrated Physiological Biomarkers Responses in Wild Fish Exposed to the Anthropogenic Gradient in the Biobio River, South-Central Chile. Environmental Management, 67(6): 1145-1157.
79. Reicher, O., Delgado, V. and Arumí, J.L. 2021. Use of Indicators in Strategic Environmental Assessments of Urban-Planning Instruments: A Case Study. Sustainability, 13(22): 12639.
80. Rivas, Y., Retamal-Salgado, J., Knicker, H., Matus, F. and Rivera, D. 2021. Neutral Sugar Content and Composition as a Sensitive Indicator of Fire Severity in the Andisols of an Araucaria–Nothofagus Forest in Southern Chile. Sustainability, 13(21): 12061.
81. Rodríguez-López, L., Durán-Llacer, I., González-Rodríguez, L., Abarca-del-Río, R., Cárdenas, R., Parra, O., Martínez-Retureta, R. and Urrutia, R. 2021. Spectral analysis using LANDSAT images to monitor the chlorophyll-a concentration in Lake Laja in Chile. Ecological Informatics, 60: 101183.
82. Rodríguez-López, L., Durán-Llacer, I., González-Rodríguez L., Cárdenas, R. and Urrutia, R. 2021. Retrieving Water Turbidity in Araucanian Lakes (South-Central Chile) Based on Multispectral Landsat Imagery. Remote Sensing, 13(16): 3133.
83. Rossi, C., Oyarzún, J., Pastén, P., Runkel, R.L., Núñez, J., Duhalde, D., Maturana, H., Rojas, E., Arumí, J.L., Castillo, D. and Oyarzún, R. 2021. Assessment of a conservative mixing model for the evaluation of constituent behavior below river confluences, Elqui River Basin, Chile. River Research and Applications, 37(7): 967-978. (Synergy between researchers from the same research line - RL3: Water availability and quality for agriculture and mining amid climate change).
84. Rozas, R.E., MacDowell, L.G., Toledo, P.G. and Horbach, J. 2021. Crystal Growth of BCC Titanium from the Melt and Interfacial Properties: A Molecular Dynamics Simulation Study. Journal of Chemical Physics, 154: 184704. (Synergy between researchers from the same research line - RL2: New water sources for agriculture, mining and communities).
85. Ruan, Z., Wu, A., Bürger, R., Betancourt, F., Wang, Y., Wang, Y., Jiaoa, H. and Wang, S. 2021. Effect of interparticle interactions on the yield stress of thickened flocculated copper mineral tailings slurry. Powder Technology, 392: 278-285. (Synergy between researchers from the same line of Research - RL1: Efficient use of water in agriculture and mining).

86. Salgado, P., Frontela, J.P. and Vidal, G. 2021. Optimization of Fenton technology for recalcitrant compounds and bacteria inactivation. Catalysts, 10(12): 1483.
87. Santander, C., Aroca, R., Cartes, P., Vidal, G. and Cornejo, P. 2021. Aquaporins and cation transporters are differentially regulated by two arbuscular mycorrhizal fungi strains in lettuce cultivars growing under salinity conditions. Plant Physiology and Biochemistry, 158: 396-409. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
88. Santander, C., García, S., Moreira, J., Aponte, H., Araneda, P., Olave, J., Vidal, G. and Cornejo, P. 2021. Arbuscular Mycorrhizal Fungal Abundance in Elevation Belts of the Hyperarid Atacama Desert. Fungal Ecology, 51: 101060. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
89. Sepúlveda, S., Duarte-Nass, C., Rivas, M., Azócar, L., Ramírez, A., Toledo-Alarcón, J., Gutiérrez, L., Jeison, D. and Torres-Aravena, A. 2021. Testing the Capacity of *Staphylococcus equorum* for Calcium and Copper Removal through MICP Process. Minerals, 11(8): 905. (Synergy between researchers from different research lines - RL1: Efficient use of water in agriculture and mining; RL4: Technology for water treatment and environmental remediation).
90. Silambarasan, S., Logeswari, P., Sivaramakrishnan, R., Kamaraj, B.,Thuy Lan Chi, N. and Cornejo, P. 2021. Cultivation of *Nostoc* sp. LS04 in municipal wastewater for biodiesel production and their deoiled biomass cellular extracts as biostimulants for *Lactuca sativa* growth improvement. Chemosphere, 280: 130644.
91. Silambarasan, S., Logeswari, P., Sivaramakrishnan, R., Pugazhendhi, A., Kamaraj, B., Ruiza, A., Ramados, G. and Cornejo, P. 2021. Polyhydroxybutyrate production from ultrasoundaided alkaline pretreated finger millet straw using *Bacillus megaterium* strain CAM12. Bioresource Technology, 325: 124632.
92. Silambarasan, S., Logeswari, P., Sivaramakrishnan, R., Incharoensakdi, A., Cornejo, P., Kamaraj, B., Lan-Chi, N.T. 2021. Removal of nutrients from domestic wastewater by microalgae coupled to lipid augmentation for biodiesel production and influence of deoiled algal biomass as biofertilizer for *Solanum lycopersicum* cultivation. Chemosphere, 268: 129323.
93. Tereucán, G., Ruiz, A., Nahuelcura, J., Oyarzún, P., Santander, C., Winterhalter, P., Avelar- Ferreira, P. and Cornejo, P. 2021. Shifts in biochemical and physiological responses by the inoculation of arbuscular mycorrhizal fungi in *Triticum aestivum* growing under drought conditions. Journal of The Science of Food and Agriculture, 102: 407-416.
94. Tereucán, G., Ercoli, S., Cornejo, P., Winterhalter, P., Contreras, B. and Ruiz, A. 2021. Stability of antioxidant compounds and activities of a natural dye from coloured-flesh potatoes in dairy foods. LWT, 144: 111252.
95. Tortella, G.R., Pieretti, J.C., Rubilar, O., Fernández-Baldo, M., Benavides-Mendoza, A., Diez, M.C. and Seabra, A.B. 2021. Silver, copper and copper oxide nanoparticles in the fight against human viruses: progress and perspectives. Critical Reviews in Biotechnology, 7:1-19. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).
96. Tortella, G., Rubilar, O., Diez, M.C., Padrao, J., Zille, A., Pieretti, J.C. and Seabra, A.B. 2021. Advanced Material Against Human (Including Covid-19) and Plant Viruses: Nanoparticles as a Feasible Strategy. Global Challenges, 5(3): 2000049. (Synergy between researchers from the same research line - RL4: Technology for water treatment and environmental remediation).

97. Urgiles-Gómez, N., Ávila-Salem, M.E., Loján, P., Encalada, M., Hurtado, L., Araujo, S., Collahuazo, Y., Guachanamá, J., Poma, N., Granda, K., Robles, A., Senés, C. and Cornejo, P. 2021. Plant Growth-Promoting Microorganisms in Coffee Production: From Isolation to Field Application. Agronomy, 11(8): 1531.
98. Valdivia-Cea, W., Bustamante, L., Jara, J., Fischer, S., Holzapfel, E. and Wilckens, R. 2021. Effect of Soil Water Availability on Physiological Parameters, Yield, and Seed Quality in Four Quinoa Genotypes (*Chenopodium quinoa* Willd). Agronomy, 11(5): 1012.
99. Valenzuela-Heredia, D., Panatt, C., Belmonte, M., Franchi, O., Crutchik, D., Dumais, J., Vázquez-Padín, J.R., Lesty, Y., Pedrouso, A., Val del Río, A., Mosquera-Corral, A. and Campos, J.L. 2021. Performance of a two-stage partial nitritation-anammox system treating the supernatant of a sludge anaerobic digester pretreated by a thermal hydrolysis process. Chemical Engineering Journal, 429: 131301.
100. Valenzuela-Heredia, D., Henríquez-Castillo, C., Donoso, R., Lavín, P., Ringel, M.T., Brüser, T. and Campos J.L. 2021. An unusual overrepresentation of genetic factors related to iron homeostasis in the genome of the fluorescent *Pseudomonas* sp. ABC1. Microbial Biotechnology, 14(3): 1060-1072.
101. Valenzuela, K., Alarcón, E. and Torres, R. 2021. From Resistance to Creation: Socio- Environmental Activism in Chile's "Sacrifice Zones". Sustainability, 13(6): 3481.
102. Venegas, M., Leiva, A., Reyes-Contreras, C., Neumann, P., Piña, B. and Vidal, G. 2021. Presence and fate of micropollutants during anaerobic digestion of sewage and their implications for the circular economy: A short review. Journal of Environmental Chemical Engineering, 9(1): 104931. (Synergy between researchers from the same line of Research - RL4: Technology for water treatment and environmental remediation).
103. Vidal, C., Carrillo-Varela, I., Reyes-Contreras, P., Gutiérrez, L. and Teixeira-Mendonça, R. 2021. Sulfomethylation of radiata pine kraft lignin and its use as molybdenite depressant in selective chalcopyrite-molybdenite separation by flotation. BioResources, 16(3): 5646.
104. Vidal, C., Larama, G., Riveros, A., Meneses, C. and Cornejo, P. 2021. Main Molecular Pathways Associated with Copper Tolerance Response in *Imperata cylindrica* by De novo Transcriptome Assembly. Plants, 10(2): 357.
105. Vidal., G., González, Y., Piña, B., Jarpa, M. and Gómez, G. 2021. Minimization of environmental impact of Kraft pulp mill effluents: Current practices and future perspectives towards sustainability. Sustainability, 13(16): 9288.
106. Yepsen, R., Roa, J., Toledo, P. and Gutiérrez, L. 2021. Chalcopyrite and Molybdenite Flotation in Seawater: The Use of Inorganic Dispersants to Reduce the Depressing Effects of Micas. Minerals, 11(5): 539. (Synergy between researchers from different research lines - RL1. Efficient use of water in agriculture and mining; RL2. New water sources for agriculture, mining and communities).
107. Zurita, A., Aguayo, M., Arriagada, P., Figueroa, R., Díaz, M.E. and Stehr, A. 2021. Modeling Biological Oxygen Demand Load Capacity in a Data-Scarce Basin with Important Anthropogenic Interventions. Water, 13(17): 2379.

5.2 Publications in Center for Journalistic Investigation of Chile for Academia (CIPER Académico)

In 2021, 13 publications were disseminated through CIPER Académico, three of which were the result of collaboration between researchers from different RLs (Table 8).

Table 8. 2021 Publications in CIPER Académico

TITLE	PUBLICATION TYPE	AUTHOR OR INTERVIEWEE	DATE
1. Today it is built where there will be catastrophic floods. Why?	Opinion column	Dr. José Luis Arumí	February 4th
2. Water 4.0: a way to face climate risk in Chile and move towards water security	Opinion column	Dr. Diego Rivera, Dr. Mario Lillo and Dr. Alex Godoy	February 27th
3. "The water highway is a short-term measure. It is a lot of effort and money, just to spread poverty"	Interview	Dr. Gladys Vidal	March 20th
4. Plastic: why can't we get rid of it, but have to?	Opinion column	Dr. Ricardo Barra	March 26th
5. Why can't the human right to water be exercised in Chile?	Opinion column	Dr. Amaya Alvez and Rodrigo Castillo	April 16th
6. "In Chile, agriculture would have to run on half the water it currently uses"	Interview	Dr. Pedro Toledo	May 1st
7. Protecting our soils: another pending task	Opinion column	Dr. Pablo Cornejo	May 8th
8. Water footprint: a fundamental tool for sustainable water management and enhancing water security	Opinion column	Dr. Patricio Neumann and Dr. Gladys Vidal	May 29th
9. The problem is not only the scarcity of water, but its contamination	Opinion column	Dr. Ricardo Barra, Dr. Gladys Vidal, Dr. Carlos Valdovinos and Paula Nieto	June 4th
10. Can governors radically change water management in their regions?	Interview	Dr. Ricardo Figueroa	June 23rd
11. "Implementing the new constitution is going to take us at least a generation"	Interview	Dr. Amaya Alvez	June 30th
12. "If we manage agriculture well, we can make it more sustainable"	Interview	Dr. Eduardo Holzapfel	June 30th
13. How to improve the water institutions in Chile?	Opinion column	Dr. José Luis Arumí and Dr. Diego Rivera	July 2nd

5.3 Books and Book Chapters

• Books

1. Videla, S. 2021. Historia del Agua en el Norte Grande. Universidad de Concepción/Concepción/Chile. 123 pages.
2. Vidal, G., Gómez, G. and Diez, M.C. 2021. Soluciones Basadas en la Naturaleza para la descontaminación de descargas puntuales y difusas. Universidad de Concepción/Concepción/Chile. 132 pages.
3. Mosquera, A., Val del Río, Á. and Campos, J.L. 2021. Treatment and Valorisation of Saline Wastewater: Principles and Preactice. IWA Publishing/London/United Kingdom. 188 pages.
4. Delgado, V. and Arumí, J.L. 2021. El modelo chileno de regulación de las aguas subterráneas: críticas desde el derecho ambiental y las ciencias ambientales. Tirant Lo Blanch/Valencia/España. 400 pages.
5. Videla, S. 2021. Historia del Agua en el Norte Chico. Universidad de Concepción/Concepción/Chile. 176 pages.
6. Rojas, J., Silva, P., Barra, R., Arumí, J.L. and Hansen-Rojas, G. 2021. Bienes comunes y diversidad biocultural en tiempos de crisis. Escasez hídrica, pandemia y cambio climático. RIL Editores/Santiago/Chile. 132 pages.
7. Concha, F. and Bouso, J.L. 2021. Fluid Mechanics Fundamentals of Hydrocyclones and Its Applications in the Mining Industry. Springer/Cham/Switzerland. 296 pages.

• Book chapters

1. Giácoman-Vallejos, G., Ponce-Caballero, C., Méndez-Novelo, R. and Vidal, G. 2021. Monitoreo de calidad del agua de mar en la región costera del municipio de Progreso, Yucatán. In: Investigaciones marinas en el golfo de México y mar Caribe mexicano. Editorial Universidad de Colima/Colima/México. ISBN 978-607-8549-81-8. 55-83.
2. Godoy A., Rivera D., Aikten D., Herrera M. and El Youssif L. 2021. Circular Economy in a Water-Energy-Food Security Nexus Associate to an SDGs Framework: Understanding Complexities. In: An Introduction to Circular Economy. Springer Nature/Cham/Switzerland. ISBN 978-981-15-8509-8. 219-239.
3. Alvez, A. and Castillo, R. 2021. Emergencia y acceso al agua. Covid-19 como una crisis dentro de la crisis. In: La ley de la emergencia. Ensayos sobre el derecho, la excepción y la pandemia. DER Ediciones/Santiago/Chile. ISBN 978-956-9959-91-2, 187-200.
4. Arumí, J.L. and Oyarzún, R. 2021. Capítulo 1. Sobre las Aguas Subterráneas en Chile. In: El Modelo Chileno de Regulación de las Aguas Subterráneas: Críticas desde el Derecho Ambiental y las Ciencias Ambientales. Editorial Tirant Lo Blanch/Valencia/España. ISBN 978-84-1378-294-2. 27-58.
5. Arumí, J.L. 2021. Capítulo 2. Comprendiendo las Interacciones Agua Superficial-Subterráneas en la Zona Central de Chile y su Relación con el Principio de Unidad de Corriente. In: El Modelo Chileno de Regulación de las Aguas Subterráneas: Críticas desde el Derecho Ambiental y las Ciencias Ambientales. Editorial Tirant Lo Blanch/Valencia/España. ISBN 978-84-1378-294-2. 59-82.
6. Melo, O., Delgado, V., Retamal, M.R, Sandoval, M.I. and Arumí, J.L. 2021. Capítulo 5. La Gestión del Agua Subterránea en Chile “A la Deriva”. Propuestas para el Fortalecimiento de las Comunidades de Agua. In: El Modelo Chileno de Regulación de las Aguas Subterráneas: Críticas desde el Derecho Ambiental y las Ciencias Ambientales. Editorial Tirant Lo Blanch/Valencia/España. ISBN 978-84-1378-294-2. 199-244.

7. Arumí, J.L. and Delgado, V. 2021. Capítulo 6. La Extracción Ilegal de Aguas Subterráneas en Chile: Un Nuevo Modelo de Control "Menos Privado". In: El Modelo Chileno de Regulación de las Aguas Subterráneas: Críticas desde el Derecho Ambiental y las Ciencias Ambientales. Editorial Tirant Lo Blanch/Valencia/España. ISBN 978-84-1378-294-2. 254-274.
8. Arumí, J.L. and Delgado, V. 2021. Capítulo 9. Sobre la Necesidad de Considerar en Chile Áreas de Protección de las Aguas Subterráneas para Captaciones de Agua Potable. In: El Modelo Chileno de Regulación de las Aguas Subterráneas: Críticas desde el Derecho Ambiental y las Ciencias Ambientales. Editorial Tirant Lo Blanch/Valencia/España. ISBN 978-84-1378-294-2. 363-399.
9. Salgado, P., Frontela, J.L. and Vidal, G. 2021. Optimization of Fenton Technology for Recalcitrant Compounds and Bacteria Inactivation. In: Prime Archives in Chemistry. Vide Leaf/Telangana/India. ISBN 978-81-953047-5-2. 1-27
10. Basualto, S. and Barra, R. 2021. Gestión de aguas en escenarios de cambio climático en Chile. In: El cambio climático visto desde diferentes enfoques y escenarios territoriales. Editorial Ibañez/Bogotá/Colombia. 159-175.
11. Rojas-Hernández, J., Silva-Ávila, P. and Barra-Ríos, R. 2021. Local Knowledge, Community Experiences, Nature, Collaboration, and Resilience in Times of Pandemic, Uncertainty, and Climate Change in the Anthropocene Era. In: Anxiety, Uncertainty, and Resilience During the Pandemic Period - Anthropological and Psychological Perspectives. Intechopen/London/United Kingdom. ISBN 978-1-83968-126-4. 2-23.

5.4 CRHIAM Communication Series, Providing Evidence and Knowledge for Public Policies

1. Centro de Recursos Hídricos para la Agricultura y la Minería (CRHIAM). 2021. Edición proceso constituyente. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), edición especial, 66p.
2. Gutiérrez, L., Rivera, D., Arumí, J.L., Barra, R., Kelm, U. and Jerez, O. 2021. Radiografía de la minería chilena: presente y futuro. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 11, 52p.
3. Ponce, R., Rivera, D., Godoy, A. and Figueroa, R. 2021. Evaluación económica de un proyecto de carretera hídrica. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 12, 28p.
4. Arumí, J.L., Delgado, V., Stehr, A., Sandoval, M.I. and Urrutia, R. 2021. Los embalses y su gestión sustentable bajo el escenario de escasez hídrica. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 13, 27p.
5. Neumann, P., Riquelme, C., Alvez, A. and Castillo, R. 2021. Aspectos ambientales y desafíos del tratamiento y reutilización de las aguas residuales urbanas. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 14, 49p.
6. Julio, N., Figueroa, R. and Ponce, R. 2021. Gobernanza y gestión del agua en el marco de la seguridad hídrica. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 15, 38p.

7. Figueroa, F., Pedreros, P., Bravo, G., Barra, R. and Urrutia, R. 2021. Uso de especies invasoras de agua dulce: una potencial estrategia de economía circular. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 16, 30p.
8. Díaz, M.E., Julio, N., Vidal, G. and Figueroa, R. 2021. Sustentabilidad y seguridad hídrica. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 17, 20p.
9. Santander, C., Cornejo, P., Vidal, G. and Holzapfel, E. 2021. Hongos micórricos arbusculares: Biotecnología sustentable para la agricultura frente al cambio climático. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 18, 30p.
10. Parra, B., Barra, R., Diez, M.C. and Vidal, G. 2021. Uso de plaguicidas en la agricultura: conceptos básicos, riesgos y soluciones. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 19, 34p.
11. Díaz, G., Figueroa, R., Urrutia, R. and Barra, R. 2021. Más que pesca: un análisis de los servicios ecosistémicos que proveen los peces de agua dulce chilenos. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 20, 26p.
12. Duarte, C., Ramírez, A., Gutiérrez, L. and Jeison, D. 2021. Biotecnologías de precipitación para recuperación de metales en aguas de la minería del cobre. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 21, 25p.
13. Gómez, G., Ortega, M.J., Figueroa, R., González, Y. and Vidal, G. 2021. Microbiología y tratamiento de aguas servidas bajo el concepto de "One Health". Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 22, 27p.
14. Yepsen, R., Gutiérrez, L. and Toledo, P.G. 2021. Procesamiento de minerales de cobre y el recurso agua: conceptos, desafíos y soluciones. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 23, 23p.
15. Garrido, E., Arumí, J.L., Aguayo, M. and Urrutia, R. 2021. Recarga artificial de aguas subterráneas. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 24, 30p.
16. Saavedra, M.F., Álvarez, D., Barra, R. and Urrutia, R. 2021. Biomarcadores de calidad de agua: Situación actual chilena y proyecciones futuras. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 25, 34p.
17. Muñoz, B., Arumí, J.L., Uribe, H., Lagos, O. and Rojas, O. 2021. La escasez de agua del secano interior. Del desastre a la evolución. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 26, 30p.
18. Correa, C., Romero, R., Salazar, A., Lagos, O., Vidal, G., Castillo, R. and Lillo, M. 2021. Análisis comparado de la gobernanza del agua en Latinoamérica. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 27, 35p.
19. Sabag, M., Leiva, A.M., Gómez, G., Rivera, D. and Vidal, G. 2021. Seguridad alimentaria en la agricultura: desafíos para el reúso de aguas servidas en el marco del nexo salud humana, animal y ambiental. Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 28, 26p.

6. TRANSFER OF OUR SCIENTIFIC KNOWLEDGE TO THE COMMUNITY

6.1 CRHIAM Talks Cycle

The format of the talks consists of a presenter speaking on a topic that he or she is working on, allowing a look at work carried out in conjunction with other members of his or her cluster and other CRHIAM teams. It also offers a space for broad discussion that promotes an exchange of ideas between the presenter and the audience. From April to December, the CRHIAM Talks Cycle was held for the second consecutive year; it was broadcast live on Facebook due to the pandemic. Thus, the talks could be seen in real time in different cities of the country and recordings were published on the center's social networks. This year included topics such as water governance, water economy, and recovery of phosphorus, among others. Table 9 presents each of the topics addressed in the online 2021 CRHIAM Talks Cycle.

Table 9. 2021 CRHIAM Talks Cycle

PRESENTER	PRESENTATION TITLE	DATE
Dr. (c) Natalia Julio	Government or governance: Where are we going?	April 1st
Dr. Patricio Neumann	Circular economy in the water cycle	May 6th
Dr. (c) Marcela Levío	Complex wastewater treatment: applications in agriculture and industry	June 3rd
Dr. (c) Valentina Carrillo	Phosphorus in sewage: recovery principles and technologies	July 1st
Dr. Diego Rivera	Is agriculture moving south?	August 5th
Dr. Roberto Ponce	Water economy	September 2nd
Dr. Alex Godoy	Climate change and water, energy, and food Security	October 7th
Dr. Robinson Torres	Water, communities and extractivisms	November 4th
Dr. (c) Karien García	A sustainable alternative to reduce excess nutrients, salts and metals in lake and irrigation waters	December 2nd

Figure 9 shows all the researchers who presented in the 2020 Talks Cycle.

Figure 9. CRHIAM researchers presenting in the 2021 Talks Cycle.

6.2 CRHIAM International Webinar

To strengthen its international networks, CRHIAM held an International Webinar between June and October. Different international experts addressed issues such as desalination of seawater, reuse of water in mining and aquifer recharge, among others. A CRHIAM researcher participated in each of the events, with the aim of commenting and addressing the audience's questions to internationally renowned scientists. Details on the 2021 CRHIAM International Webinar are presented below.

• Seawater desalination: current status, perspectives and applications

This presentation was made by Dr. Sergio Salinas, academic at the IHE Delft Institute for Water Education. It analyzed the factors that drive this method of water treatment, current trends in desalination around the world, energy consumption, costs and applications. The presentation was given on June 10th via Facebook Live and moderated by Dr. David Jeison, CRHIAM associate researcher (Figure 10).

Figure 10. First presentation of the 2021 International Webinar, June 10th.

"Desalination is an interesting process that can be considered unlimited. Seawater is a water source that is not affected by droughts, does not depend on river flows, rainfall, reservoir levels or climate change. In this sense, desalination can be an option to alleviate the scarcity in industry and coastal cities," said Dr. Salinas. This method has become a means of providing clean drinking water, especially in a context where drought, water scarcity and rapidly declining quality of water bodies have become an undeniable reality.

• Ancestral hydrotechnologies: Nature-based solutions of the past for the rescue of the future

This event was the second presentation of the CRHIAM International Webinar, made by the Coordinator of the UNESCO Chair on Sustainability of the Technical University of Catalonia, Dr. Jordi Morató. The presentation focused on making known different ancestral technologies related to water management, from a current point of view, to evaluate their viability as appropriate technologies in a global context of climate, health and food emergency.

The talk revealed how different civilizations designed and built sophisticated water systems based on the natural hydrological cycle as an adaptive response to face problems such as water conservation. Of these systems, the Zenú canals or "camellones" in Colombia or the Amunas in Peru stand out. CRHIAM researcher Dr. Gladys Vidal participated as a panelist (Figure 11).

Figure 11. Second 2021 International Webinar talk, June 21st.

During the talk, Dr. Morató highlighted the resilience of ancestral peoples in the face of extreme natural events such as water scarcity. "All communities throughout their development, from millennia of facing a territory, have developed socio-cultural and technical capacities to live in a certain place. Populations have always coexisted with climatic extremes and have known how to manage this experience of adaptation to the environment".

"If properly managed, these technologies could become an effective adaptation solution as multifunctional tools for diffuse pollution management, food and health security, flood and drought control, ecosystem services, biodiversity conservation and economic development, among others", said Dr. Morató.

• Water reuse in mining

The sustainable management of mining tailings and recovery and reuse of water are essential for mining operations, especially in the scenario of water scarcity that the country faces in the north, the main site of this production activity.

This topic was discussed in the CRHIAM International Webinar presentation "Water Reuse in Mining" made by Richard Dixon, Technology Manager for Water and Petri Kiljunen, Director of Plant Solutions South America at Metso: Outotec. First, the webinar addressed part of the work of this technology company, which focuses on developing technologies to facilitate the dewatering of tailings and their safe disposal to maximize the recovered water. In the second part, the presentation focused on chemistry and water reuse in mining, delving into the importance of this element for the mining industry and how water quality also affects processes. Alternatives to optimize water consumption such as desalination and recirculation were discussed. The third talk of the CRHIAM International Webinar took place on July 8th via Facebook (Figure 12). Questions from the audience were taken; they were moderated by Dr. Leopoldo Gutiérrez, CRHIAM principal researcher.

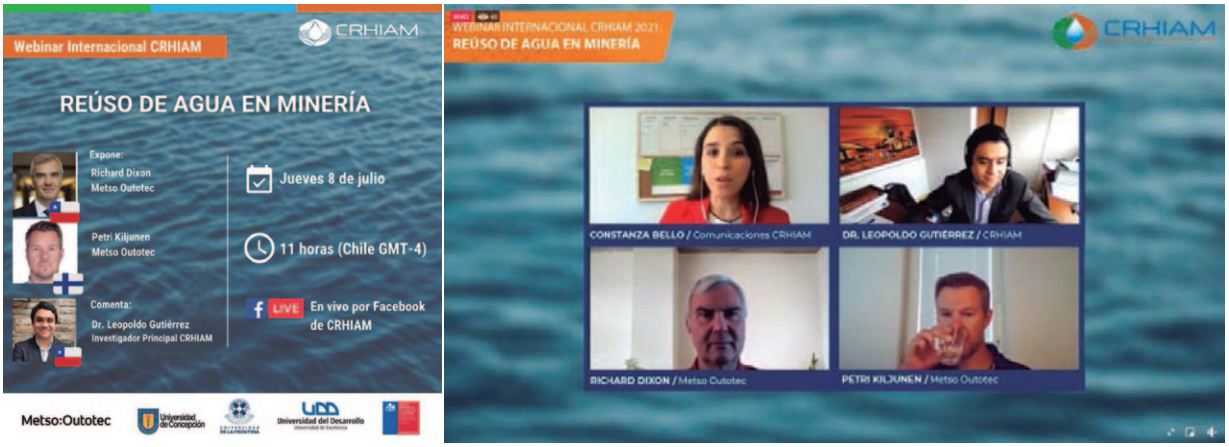

Figure 12. Third 2021 International Webinar presentation, July 8th.

• Drought and water quality

Water scarcity, aggravated by climate change and deficiencies in water management, is a worrisome problem worldwide. Its impact on aquatic ecosystems is combined with other stressors such as chemical pollution, leading to exacerbated ecological risks. To address this issue, Dr. Marco Vighi, associate researcher at the IMDEA Water Institute (Spain), made a presentation on July 15th via Facebook (Figure 13).

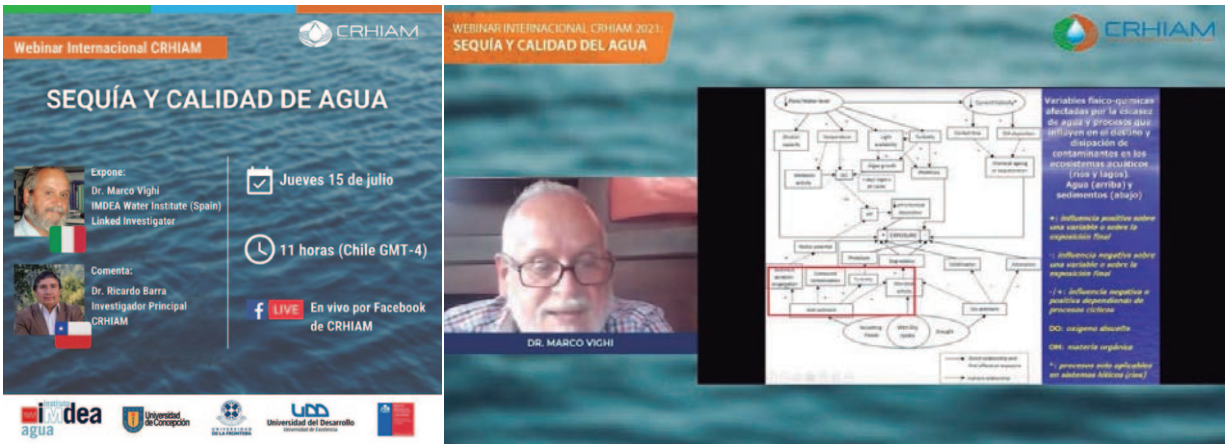

Figure 13. Fourth 2021 International Webinar talk, July 15th.

The international researcher analyzed some of the consequences of the combination of water scarcity and chemical contamination in rivers and lakes, as substantial changes can occur in the structure and functioning of aquatic communities. In addition, Dr. Vighi specified that biodiversity can be greatly reduced in favor of less vulnerable species capable of adapting to these stress conditions. Experimental, laboratory, and field studies can help develop models for prospective aquatic risk assessment in arid zones. This event was moderated by Dr. Ricardo Barra, CRHIAM principal researcher.

• Aquifer recharge with recycled water

This presentation was organized by CRHIAM in conjunction with the Water Technology Consortium (CoTH2O). It detailed the program for artificial aquifer recharge in the Orange County Water District (OCWD) in California, United States.

The talk was delivered by Jason Dadakis, Executive Director of Water Quality and Technical Resources for the Orange County Water District. Dr. José Luis Arumí, CRHIAM principal researcher, also participated in the activity, commenting on the talk.

The Orange County Water District has implemented sustainable management plans for its groundwater basin since 1933, thanks to its legal and administrative structure whereby the demand for groundwater pumping is controlled through volumetric assessments, while incentivizing artificial recharge to support additional pumping. The presentation was made on September 14th via Facebook (Figure 14).

Figure 14. Fifth 2021 International Webinar talk, September 14th.

One of the key components of the aquifer recharge program is the use of recycled water. The presentation highlighted the example of the Santa Ana River, which currently has 11 main wastewater treatment plants. "Most of the river's base flow is treated wastewater from the cities above the county, and as the population has increased so has their output of treated wastewater", Dadakis explained. To conclude the talk, the main communication measures that were implemented to educate citizens about the use of treated wastewater were presented.

• Adapting production to drier conditions: water and salinity management

The water shortage can cause an increase in the salt content in water intended for irrigation, resulting in various production problems. This was the focus of the second talk of the International Webinar organized by CRHIAM and the CoTH2O. The presentation was made by Mark Battany, who has 20 years of experience as a farm advisor for the UC Cooperative Extension in water management and biometeorology. His specialty addresses various topics such as soil and water management, soil salinity, frost protection, and climate and weather evaluation.

During the presentation, Battany explained how to achieve more efficient irrigation, considering the consequences of drought and overexploitation of water sources. He offered California as an example, a place where he has carried out a large part of his research work. This event was held on October 6th via Facebook and moderated by Dr. Octavio Lagos, CRHIAM associate researcher (Figure 15).

Figure 15. Sixth 2021 International Webinar talk, October 6th.

Regarding soil and water salinity, he stressed that "salinity has a very important link with irrigation. The quality of the waters is not the same, the rain is quite pure and of good quality. When we use canal or well water, it contains minerals, and the quantity is highly variable depending on its origin. For a producer, the use of that water is going to change the quality and productivity of the soil."

After the presentation, CRHIAM associate researcher and Director of the CoTH2O Dr. Octavio Lagos commented on the importance of studying this topic, especially considering the water scarcity that affects a large part of the country.

• Biometeorology Extension Program: adapting to climate change

Agriculture is one of the production activities most affected by climate change due to the scarcity of water for crops, a scenario faced by various places worldwide. This was precisely the focus of the third talk of the CRHIAM-CoTH2O International Webinar, given on October 29th via Facebook (Figure 16).

The presentation was made by Dr. Kosana Suvocarev, Cooperative Extension System Specialist at UC Davis, California, and moderated by Dr. Octavio Lagos, CRHIAM associate researcher and Director of the CoTH2O. Dr. Suvocarev presented different practical field research experiences, and how his research group has developed productive systems that are more resilient to climate change in different crops, such as cherry trees, olive trees, almond trees and rice, among others, reducing water consumption and greenhouse gas emissions.

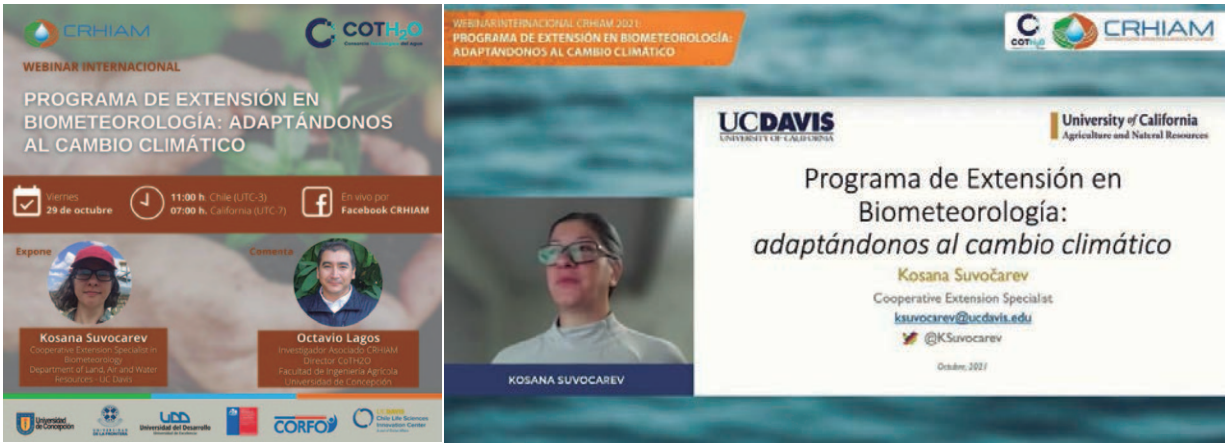

Figure 16. Seventh 2021 International Webinar talk, October 29th.

"In California we have a lot of problems with the drought, just like in Chile. We have areas where there is more water and others where it is scarce, so we are implementing fallow for the crops in the north, where there is more water, to transfer it to the south. We hope that the information we are collecting will be useful to better adapt the management of agricultural fields", emphasized Dr. Suvocarev. This was the last talk of the International Webinar organized by CRHIAM and the CoTH2O, which sought to be a meeting space with leading international researchers.

6.3 CRHIAM Podcast: "Water Has its Science"

CRHIAM's podcast was called "El agua tiene su ciencia" (Water Has its Science). The main objective of this initiative was to learn about water and how we relate to it through interviews with the center's researchers and representatives of the public and private spheres. This year the podcast was done in two phases; in the first, 3 interviews were carried out between December 2020 and January 2021 (Summer Edition, Figure 17), and the second was developed between April and November 2021, with a total of 15 interviews (Figure 18) that addressed different topics associated with water

resources such as water governance, green mining, glaciers, culture and scientific dissemination, among others. Four indicators measured the audience of each episode: a) starts, defined as how many people started episode playback, b) streams, defined as how many people listened for at least 1 minute, c) listeners, defined as unique users and d) performance, defined as the percentage of users who reached the end of the episode. Most of the episodes (14 of 18) had a performance equal to or over 50%. Below are the files of all the interviews.

• Season 1: Summer Edition

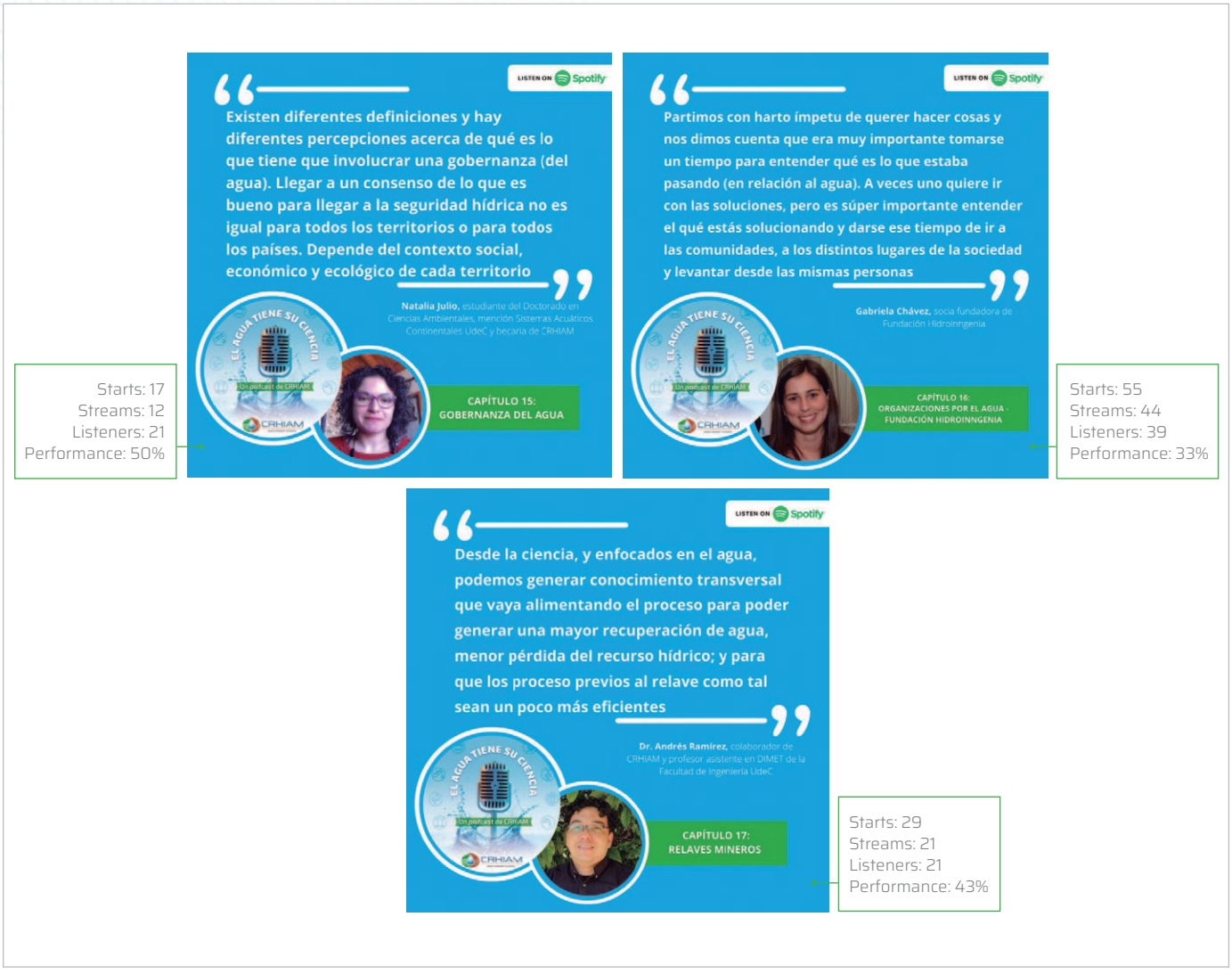

Figure 17. Summer Edition CRHIAM Podcast 2021.

• Season 2

Starts: 59
Streams: 41
Listeners: 39
Performance: 43%

Starts: 26
Streams: 22
Listeners: 18
Performance: 54%

Starts: 32
Streams: 20
Listeners: 19
Performance: 67%

Starts: 34
Streams: 30
Listeners: 30
Performance: 67%

Starts: 50
Streams: 39
Listeners: 34
Performance: 67%

Starts: 19
Streams: 19
Listeners: 12
Performance: 67%

Starts: 49
Streams: 42
Listeners: 38
Performance: 50%

Starts: 25
Streams: 18
Listeners: 20
Performance: 60%

Starts: 29
Streams: 21
Listeners: 24
Performance: 50%

Starts: 27
Streams: 22
Listeners: 24
Performance: 67%

Starts: 28
Streams: 17
Listeners: 21
Performance: 50%

Starts: 24
Streams: 14
Listeners: 18
Performance: 60%

Figure 18. CRHIAM Podcast 2021.

6.4 Outreach

• 2021 CRHIAM Communication Series

In 2021, 19 documents were published, including a special edition contributing to the Constitutional Process that is being carried out in Chile. The other documents addressed different issues associated with water resources such as environmental aspects related to the treatment and reuse of wastewater, sustainability and water security and water governance in South America, among others. Figure 19 shows the cover of each document, which can be downloaded via the following link: https://www.crhiam.cl/series-comunicacionales/.


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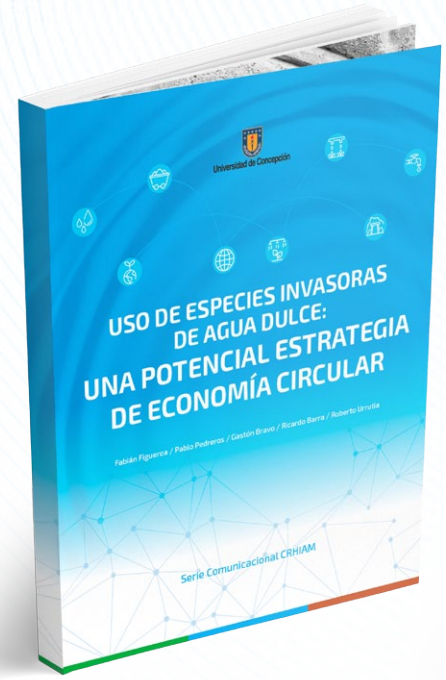
EVALUACIÓN ECONÓMICA DE UN PROYECTO DE CARRETERA HÍDRICA
Roberto Ponce / Diego Rivera / Alex Godoy / Ricardo Figueroa
Serie Comunicacional CRHIAM
Universidad de Concepción
LOS EMBALSES Y SU GESTIÓN SUSTENTABLE BAJO EL ESCENARIO DE ESCASEZ HÍDRICA
José Luis Arumí / Verónica Delgado / Alejandra Stehr / María Ignacia Sandoval / Roberto Urrutia
Serie Comunicacional CRHIAM
Universidad de Concepción
ASPECTOS AMBIENTALES Y DESAFÍOS DEL TRATAMIENTO Y REUTILIZACIÓN DE LAS AGUAS RESIDUALES URBANAS
Patricio Neumann / Cristian Riquelme / Amaya Alvez / Rodrigo Castillo
Serie Comunicacional CRHIAM
Universidad de Concepción
GOBERNANZA Y GESTIÓN DEL AGUA EN EL MARCO DE LA SEGURIDAD HÍDRICA
Natalia Iutis / Ricardo Figueroa / Roberto Ponce
Serie Comunicacional CRHIAM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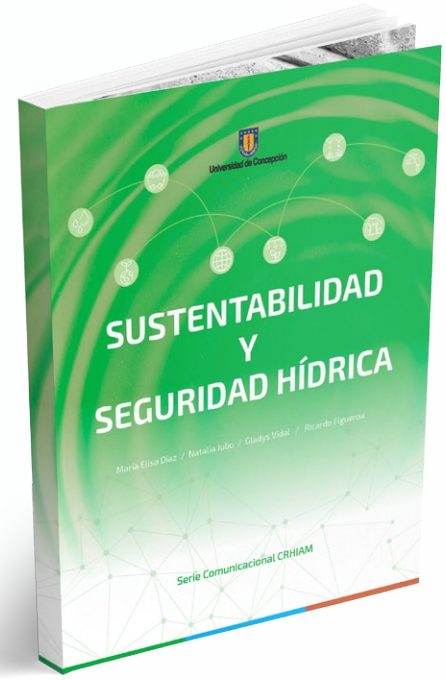
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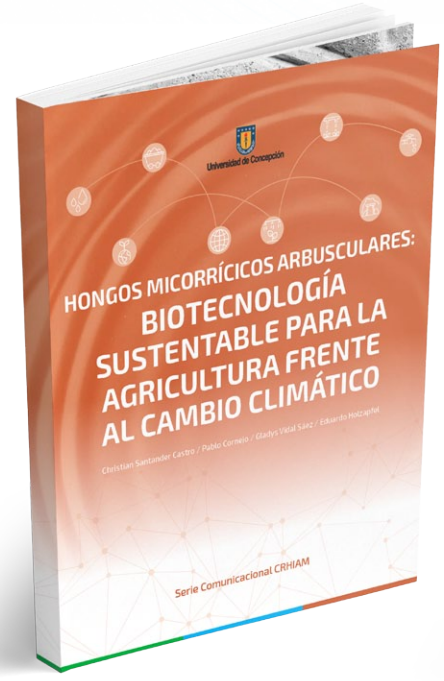
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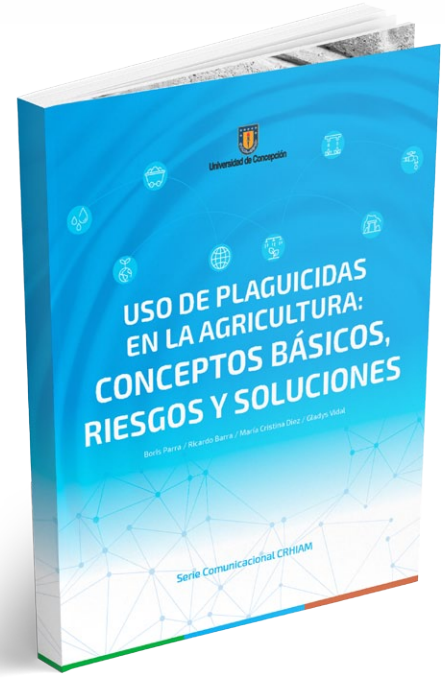
HONGOS MICORRÍCICOS ARBUSCULARES: BIOTECNOLOGÍA SUSTENTABLE PARA LA AGRICULTURA FRENTE AL CAMBIO CLIMÁTICO
Serie Comunicacional CRHIAM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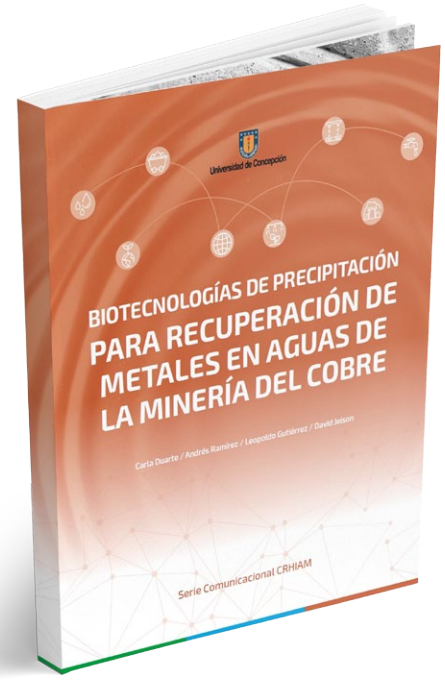
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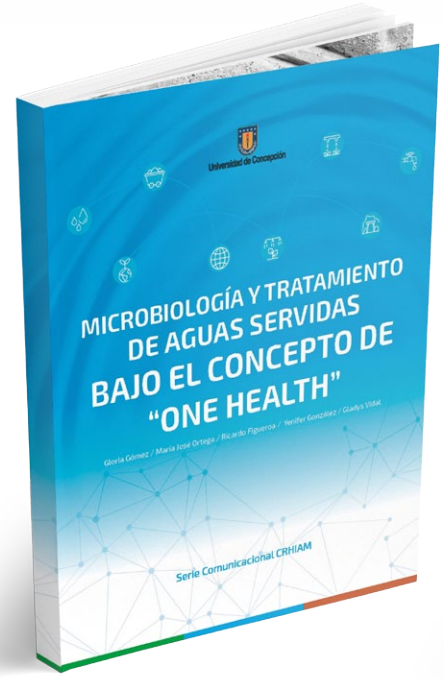
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MICROBIOLOGÍA Y TRATAMIENTO DE AGUAS SERVIDAS BAJO EL CONCEPTO DE "ONE HEALTH"
Gloria Gómez / María José Ortega / Ricardo Figueroa / Yenifer González / Gladys Vidal
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PROCESAMIENTO DE MINERALES DE COBRE Y EL RECURSO AGUA: CONCEPTOS, DESAFÍOS Y SOLUCIONES
Rodrigo Yepsen / Leopoldo Gutiérrez / Pedro G. Toledo
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RECARGA ARTIFICIAL DE AGUAS SUBTERRÁNEAS
Emmanuel Garrido / José Luis Arumí / Mauricio Aguayo / Roberto Urrutia
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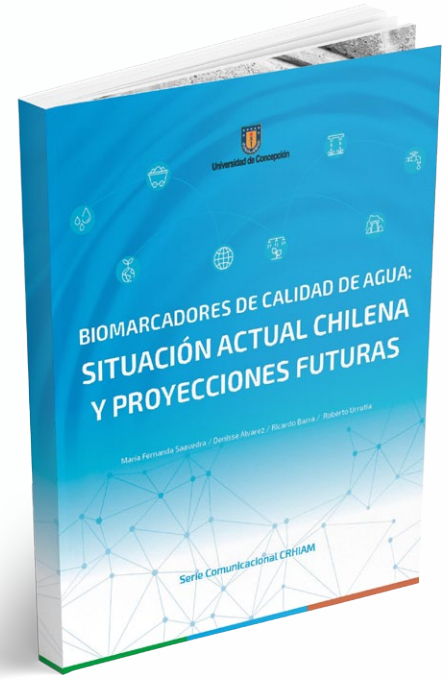
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BIOMARCADORES DE CALIDAD DE AGUA: SITUACIÓN ACTUAL CHILENA Y PROYECCIONES FUTURAS
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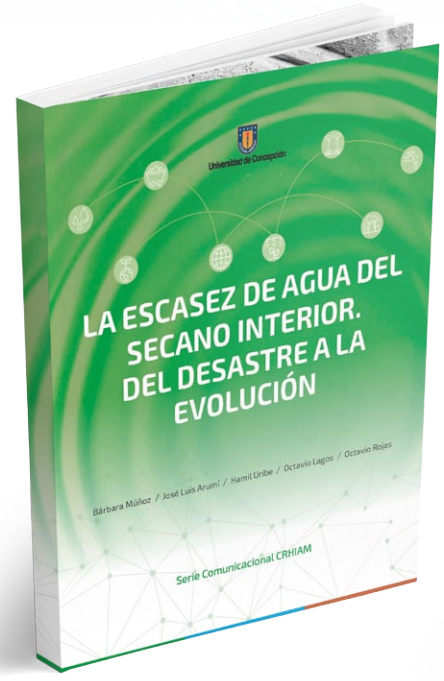
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LA ESCASEZ DE AGUA DEL SECANO INTERIOR. DEL DESASTRE A LA EVOLUCIÓN
Bárbara Muñoz / José Luis Arumí / Hamit Uribe / Octavio Lagos / Octavio Rojas
Serie Comunicacional CRHIAM


Universidad de Concepción
ANÁLISIS COMPARADO DE LA GOBERNANZA DEL AGUA EN LATINOAMÉRICA
Cindy Yurani Correa Villa / Rodrigo Antonio Romero Yara / Alejandra Salazar Cañas
Octavio Lagos / Gladys Vidal / Rodrigo Castillo / Mario Lillo Saavedra
Serie Comunicacional CRHIAM

Figure 19. 2021 CRHIAM Communication Series.

• Workshop – "Sewage: its pollutants, environmental effects and regulations"

CRHIAM Director and principal researcher Dr. Gladys Vidal led this workshop as part of the "Resilience and Adaptability to the water crisis: sponge cities and sustainable fields through wastewater purifying wetlands" project. The talk was given on December 18th, 2020 (Figure 20).

Dr. Vidal explained what pollutants are present in sewage, its treatment options, the diseases associated with its handling, and the regulations related to the emission and management of gray water. "Our focus is on SDG 6, clean water and sanitation, since we have to think about how to contribute to sustainability, without losing sight of ecosystems. When we talk about wastewater and its contaminants, now much more due to climate change, we must do so thinking about managing its origin. For example, in our homes we can differentiate between black water (from toilets and urinals) and gray water (from bathtubs, washing machines, dishwashers, among others)", explained the CRHIAM director.

In this context, the "Resilience and Adaptability to the water crisis: sponge cities and sustainable fields through wastewater purifying wetlands" project involves the construction of two water-purifying wetlands as an experimental prototype (one in a rural area and the other in a peri-urban area) that will treat their gray wastewater through a system designed specifically for its zone of the country (place where it will be built), one sized for a demonstration center and another for an average home. In the case of rural areas, the recycled water will be used for irrigation.

Figure 20. Workshop on sewage water.

• Course - "Science from Home"

Fourth to seventh grade science teachers from municipal and private establishments in the Araucanía Region participated in the course "Science from Home", an initiative led by the Universidad de la Frontera, which began on January 4th with a talk led by CRHIAM Director Dr. Gladys Vidal (Figure 21).

The title of the presentation was "Climate change: the effect on the water cycle and on our lives", Dr. Vidal explained the different uses of water – in production sectors and for human consumption – and how universities and research centers are contributing scientific evidence to the study of this vital element.

The final objective of the course is to help teachers conduct research with their students without leaving home. After the training session, they should have created an original research project with an emphasis on life sciences, the environment and/or natural resources.

Figure 21. "Science from Home" course.

• Talk – Telemetry in Agriculture

Through a virtual meeting (Figure 22), in January a talk on telemetry in agriculture was given to professionals from the Education for Development Foundation (FAUTAPO) in Bolivia. At the meeting, the importance of moving from a technology-based approach to one focused on people was addressed, considering the technology gaps for small farmers.

Figure 22. "Telemetry in Agriculture" talk.

• Talk – Water

Water is an irreplaceable element that is essential for life on the planet. This was the basis for a talk entitled "El Agua" ("Water") given to children and adolescents from the 21 communes of the Ñuble Region by CRHIAM principal researcher Dr. Diego Rivera (Figure 23), within the framework of the Scientific Workshops Live Science in Ñuble, organized by Par Explora Ñuble.

The activity was held on March 12th via Zoom, where more than 60 schoolchildren learned about the importance of water and why it is necessary to use it responsibly. The presentation began with an explanation of how agriculture was established as the main reason for the settlement of nomadic peoples and then focused on the different ways in which water is used today.

The hydrological cycle and the water footprint were also addressed; in the latter case, it was illustrated how many liters of water are required for different daily activities such as washing clothes, showering, and food production.

Figure 23. "Water" talk.

• Game launch – Ecobrigadas

With the aim of providing tools and teaching material related to the importance of caring for water resources and the environment, so that in the future good water management decisions can be made, CICAT, in alliance with ESSBIO and CRHIAM, launched the "Ecobrigadas" card game card game (Figure 24).

The activity was held on March 17th via Zoom and included teachers from the Biobío region who will work with this tool.

CRHIAM Director Dr. Gladys Vidal detailed the origin of the game and the processes that are shown in it. "The availability of water is affected by climate change, which is why with this game we hope to raise awareness among children and those around them about the care of this resource," she said.

Figure 24. Launch of the Ecobrigadas card game.

• Workshop - “Nuestro APR” platform

Validation Workshop with APR administrators and managers from the O'Higgins Region, on the “Nuestro APR” platform, developed within the framework of the FIC project “APR Information Management from the O'Higgins Region” (Figure 25).

Figure 25. “Nuestro APR” platform workshop.

• Microcourse – Regenerative Fields

From May to October, the Centro de Humedales del Río Cruces (CEHUM) will carry out the "Regenerative Fields" microcourse within the framework of the "Resilience and Adaptability to the water crisis: sponge cities and sustainable fields through wastewater purifying wetlands" project, an initiative which is also supported by CRHIAM.

The first course, held on May 13th via Zoom (Figure 26), was focused on small farmers in rural areas, who learned about irrigation and hydraulics through a theoretical-practical workshop.

The following meetings will address plant health, agroecology, machinery, and the rural design of an orchard with sustainability techniques. This initiative focuses on the rural line of the project, which is also supported by Fomento Los Ríos and is co-executed with CAREP.

Figure 26. "Regenerative Fields" microcourse.

• Workshop – dissemination and digital literacy: "Nuestro SSR" web tool

The activity took place between May and June 2021 and consisted of a workshop on dissemination of and digital literacy related to the "Nuestro SSR" web tool, created to contribute to the standardization and systematization of administrative, financial and technical information on rural sanitation services (SSR: Servicio Sanitario Rural) in the O'Higgins Region (Figure 27).

The workshop was aimed at management professionals and managers of the SSR of the O'Higgins Region, who were introduced to all the components of the web tool, as well as the procedures for its use and associated benefits, through practical exercises. Attendees were also able to have all their questions answered.

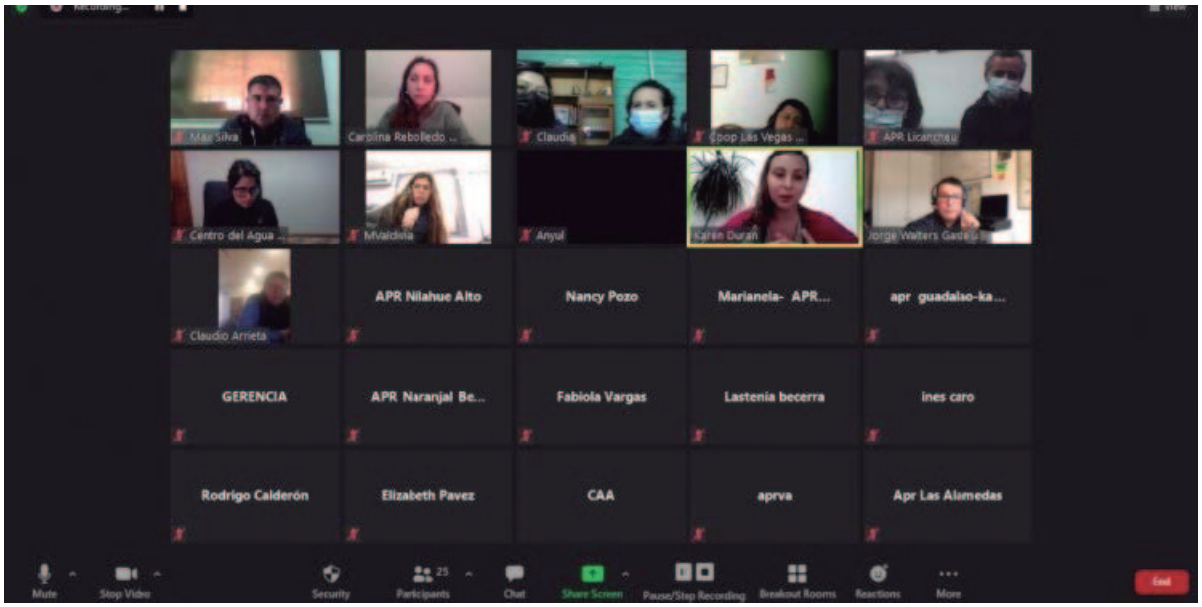


Figure 27. Workshop on dissemination of and digital literacy related to the "Nuestro SSR" web tool.

• Online Talks Cycle – organized by FEDEFRUTA

"The role of agriculture in advancing toward water and food security and sustainable use of water" was the theme that guided the virtual talk organized by FEDEFRUTA, in which CRHIAM researchers Dr. Diego Rivera and Dr. Alex Godoy participated, together with Dr. Felipe de la Hoz, who is in charge of the center's community relations. The activity took place in May 2021 (Figure 28).

The first presentation was led by Dr. Godoy, who gave an overview of climate change and its impact. Next, Dr. Rivera spoke of the importance for agriculture of analyzing the behavior of the climate system in Chile and some climate change adaptation strategies. Regarding the actions with the greatest impact that can be promoted to achieve sustainability in the territories, Dr. de la Hoz indicated that "It is necessary to have an information platform for the different users, to have access to the data of the monitoring networks and prioritize cadaster requirements, and it is very important that they arise from the territories".

Figure 28. Online Talks Cycle organized by FEDEFRUTA.

- **Technical course - Management and technology for the management of water for human use, in agriculture and in mining, under water scarcity and climate change**

In order to provide a broad vision of the effects of climate change on the management and reuse of water in general terms in the territory, the technical course "Management and technology for the management of water for human use, in agriculture and mining, under water scarcity and climate change" was organized by CRHIAM, within the framework of the pre-congress courses of Water Congress 2021 (Figure 29).

The course, which took place on July 5th, was attended by more than 90 people. Meanwhile, the 9th International Congress on Water Management in Mining and Industrial Processes, Water Congress 2021, took place between July 7th and 9th. This initiative was organized by Gecamin, CRHIAM and Wageningen University & Research.

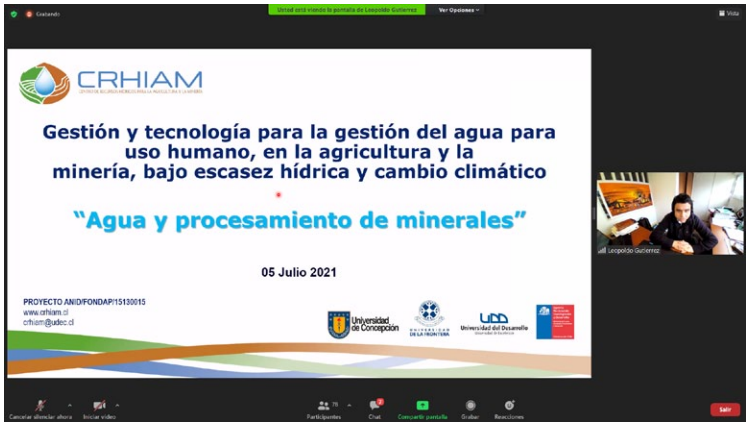


Figure 29. Water Congress 2021: pre-congress course.

• Scientific conversation – The Taste of Knowledge

As part of the "Open Science, Shared Knowledge" activity of the Ministry of Science, Technology, Knowledge and Innovation Explora program, the "El Sabor del Saber" ("The Taste of Knowledge") conversation program debuted on Thursday, August 5th. The program is an audiovisual initiative that will address different scientific topics (Figure 30). In the kitchen and with innovative experiments, researchers dealt with current issues.

The first episode of this program focused on "Water and Climate Change", Dr. (c) Ana María Leiva participated on behalf of CRHIAM, presenting an experiment on emerging pollutants in bodies of water to the community.

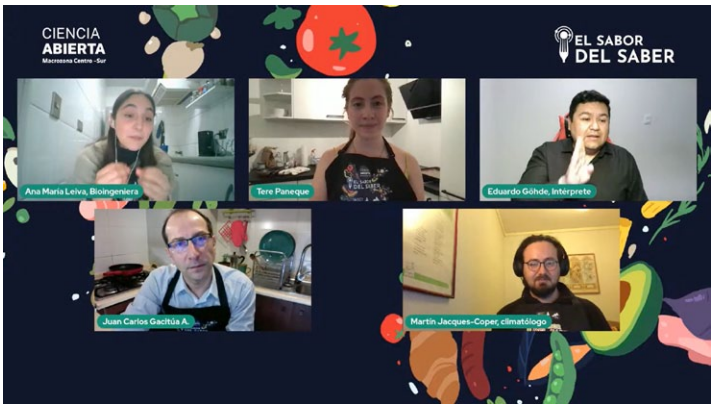


Figure 30. "The Taste of Knowledge" scientific conversation.

• Course for teachers in Bolivia – Irrigation Hydraulics

This course deepens participants' knowledge and ability to analyze and design technical irrigation systems, in terms of both hydraulic principles that determine their design and the characteristics of their operation. The objective of the course was to train the students to solve real hydraulic design situations in closed flow conditions for technical irrigation systems (Figure 31). This activity was held on August 6th.

Figure 31. Course for teachers in Bolivia.

- **Days of reflection and learning - Sustainable Cultural Self-Management, Plaza Perú, Concepción**

This project was carried out in the historic Plaza Perú neighborhood with the neighborhood council, a group of local business representatives, and waste pickers of the city of Concepción (Figure 32). The opening of the activity took place on August 24th.

The general objective was to design sustainable management instruments that relate environmental sciences to artistic disciplines in order to improve the environment and quality of life of residents and business owners of an iconic historic neighborhood: Plaza Peru of Concepción.

Figure 32. Reflection and learning about sustainable culture.

• Educational talk – Care and Importance of Water

With the aim of educating the community about the care and importance of water, two talks were held on October 14th in the Sagrada Familia Commune, located in the Maule Region (Figure 33). These presentations were carried out thanks to an invitation made by the city hall of the town.

Yenifer González, an environmental engineer and member of the CRHIAM administrative team, gave both talks. The first took place in the kindergarten and nursery of JUNJI Alma de Niños, where the preschool educators were able to learn about water and caring for the environment, since they are applying for environmental certification. The next audience was made up of members of territorial and functional organizations of the commune, who listened to the "Management of water resources in the face of water scarcity" talk that covered topics such as climate change, the description of water resources, availability worldwide and in Chile, conventional and unconventional sewage treatment, and the water footprint.

Figure 33. Educational talk in the Maule Region.

• Science festival (FECI) – CRHIAM participation

The "FECI 2021" Science Festival, an initiative led by the Regional Associative Projects – PAR Explora – that seek to celebrate curiosity and bring scientific knowledge closer to citizens, was held From October 20th to 24th. This year CRHIAM participated virtually in activities organized by PAR Explora Ñuble and PAR Explora RM Sur Oriente.

"Water beyond H_2O" was the talk given by Lorenzo Cigarra, a PhD student in Water Resources and Energy for Agriculture at the University of Concepción, within the framework of the activities carried out by PAR Explora Ñuble. He discussed how water is managed in Chile and the importance of using this resource sustainably in the context of the mega-drought that affects the country.

Meanwhile, CRHIAM principal researcher Dr. Diego Rivera participated in the discussion "Let's take care of ourselves: the natural risks of our territory", managed by PAR Explora RM Sur Oriente, which focused on the most dangerous areas of the southeastern zone of the Metropolitan Region in the face of natural disasters and the care that citizens must have in preventing and dealing with them (Figure 34).

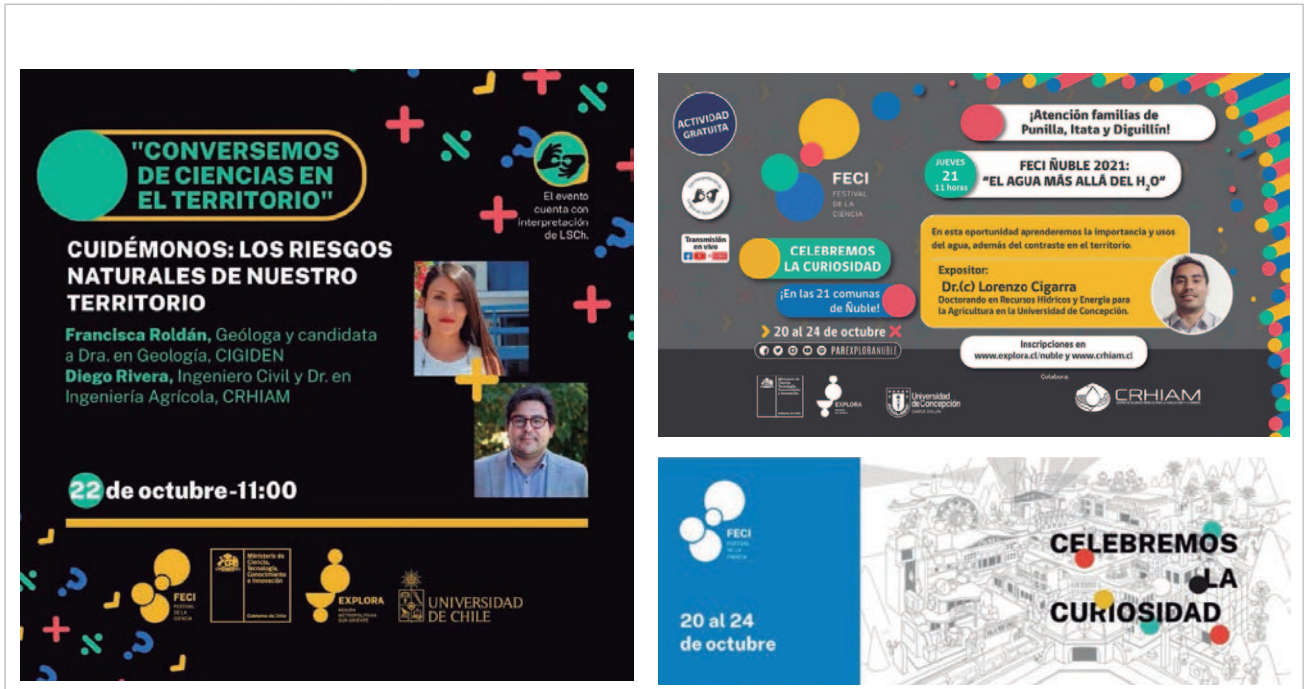


Figure 34. CRHIAM participation in 2021 Science Festival.

• Training session in the Maule Region – Irrigation with Solar Energy

CRHIAM associate researcher Dr. Eduardo Holzapfel led a training session on irrigation and solar energy in the town of Parral (Maule Region) for 30 small farmers from the Institute for Agricultural Development (INDAP).

The course addressed the availability of energy provided by solar panels for irrigation, with the aim of ascertaining the capacity required to irrigate a certain surface. Thus, farmers will have more tools to optimize water consumption using this type of energy. The training session was conducted in person on October 26th (Figure 35) and included the delivery of the book "Water Management Technology for Sustainable Intensive Agriculture", a text prepared by CRHIAM.

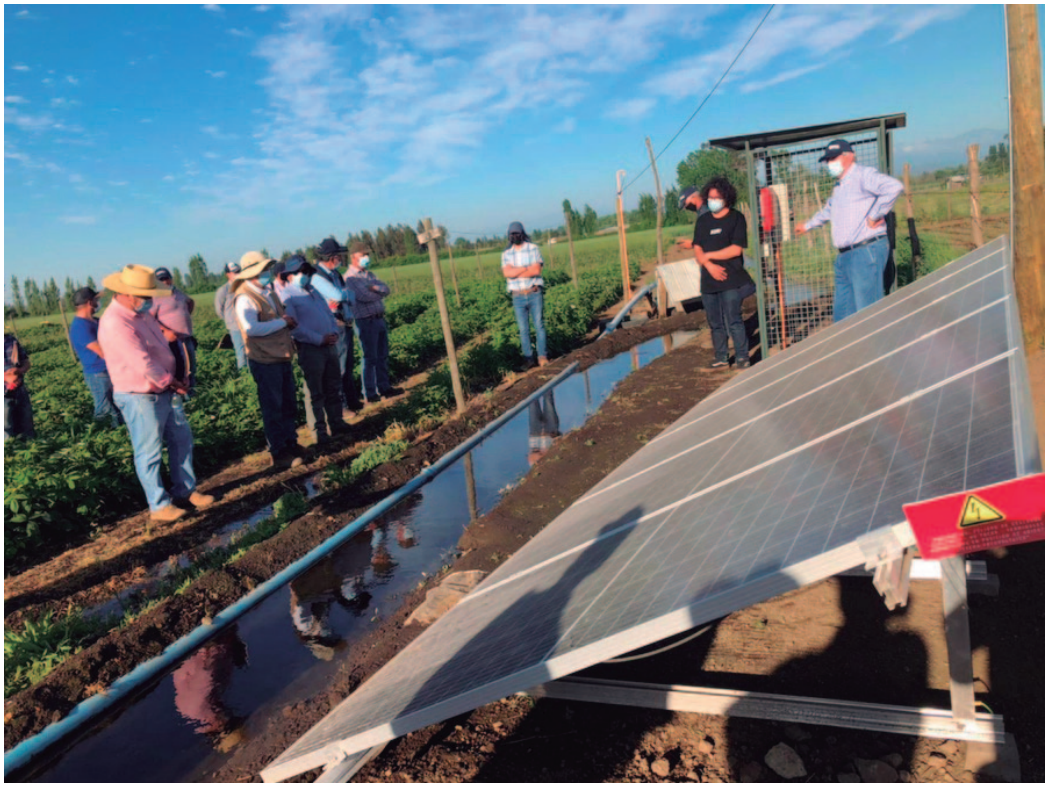


Figure 35. "Irrigation with Solar Energy" training session.

• Executive support – World Skills Chile Olympics

With the participation of more than 400 students and experts, the fifth version of the World Skills Chile Olympics, a competition that tests the skills of students from high schools and technical and professional higher education institutions, was held from November 8th to 12th (Figure 36). CRHIAM played a supporting role in the event by providing training for competitors and experts.

CRHIAM member Dr. Felipe de la Hoz participated as National Expert Head of Skill #97 – Technical Micro Irrigation – a position he has held for three years. His role was to coordinate the competitions, design the module tests, and coordinate the support of institutions and companies for the development of skills. In addition, courses were held prior to the competition on October 21st. These training sessions were aimed at the experts and competitors of the Irrigation Laboratory of the Liceo Agrícola El Carmen de San Fernando. The topics addressed were the components of drip irrigation systems, their operation, and the correct installation of hydraulic and electrical components.

Figure 36. Fifth World Skills Chile Olympics.

• Talk in the framework of sustainable self-management project – Circular Economy for the Community

The talk was given by Dr. Yannay Casas and Dr. Patricia González, professors of the School of Environmental Sciences of the University of Concepción. This activity took place on December 1st (Figure 37). The academics discussed the importance of consuming products responsibly, highlighting the need to recycle, reuse, and repair what we acquire many times to reduce the unnecessary consumption of goods. This project seeks to promote a culture of sustainable self-management using environmental sciences and art to improve the quality of life of residents, tenants and the community in general.

CRHIAM also participated in two recorded sessions. The first talk was given by environmental engineer Yenifer González, who spoke about water management and community responsibility. The second was given by lawyer Rodrigo Castillo, who addressed environmental regulations and sustainability seals.

Figure 37. CRHIAM participation in Learning Journey.

6.5 Other Activities Organized by CRHIAM in 2021

• Co-organization of international meeting – CRHIAM together with the NATURA Network

With the participation of 50 Latin American researchers, the "Benefits and Opportunities of Nature-Based Solutions" meeting, an activity carried out by the Latin American group "LAC Natura Regional Group", was held on February 26th (Figure 38). CRHIAM Director Dr. Gladys Vidal participated as the moderator, along with researchers Dr. Carlos Arias of Aarhus University Dr. Elizabeth Cook of Barnard College and NATURA, and Dr. Rosario Pastor of the UNESCO Chair on Sustainability. The facilitator of this event was Dr. Jordi Morató of the UNESCO Chair on Sustainability.

This initiative was organized by NATURA, the UNESCO Chair of Sustainability at the UPC (Spain), CRHIAM and Aahrus University (Denmark). It was sponsored by the University of La Salle, RECNET, the National Agrarian University of La Molina, the Federal University of Bahia and the University of Cauca. The event was part of the "NATURA's Second Virtual All-Hands Meeting" that took place during the Nature of Cities Festival, which ran from February 22nd to 26th and focused on facilitating transdisciplinary dialogue, small group workshops, artistic participation, and fostering collaboration around solutions for the urban future.

Figure 38. CRHIAM participation in international meeting.

• Forum organization – Water Forum

"What does water mean to you?" That was the question that guided the discussion organized by CRHIAM, which invited representatives from the public, private, and academic sectors to discuss the meaning and value of water (Figure 39). This activity was part of "Water Forums: Research on Water Resources at the Service of the Community", an initiative that the center organizes each year to start the World Water Day celebrations.

The event, which was held on March 19th through a live feed on CRHIAM's Facebook page, had five panelists: Amerindia Jaramillo, Head of the Aquatic Ecosystems Department of the Ministry of the Environment (MMA); Jessica López, Executive President of the National Association of Health Services Companies (ANDESS); José Miguel Stegmeier, President of the Biobío Agricultural Society (SOCABIO); Diego Hernández, President of the National Mining Society of Chile (SONAMI); and José Luis Arumí, CRHIAM principal researcher and UdeC academic. The panelists gave their opinions on the various meanings that water has in their institutions and what aspects should be considered to improve the management of water resources in Chile, considering the principles of water security and the historic moment that the country is experiencing amid the constituent process.

Figure 39. Water Forum.

• Book launch – History of Water in the Norte Grande. XIX Century

Within the framework of International Book Day, CRHIAM launched the book "History of water in the Norte Grande. XIX Century" (Figure 40), a work that gathers and explains how water has influenced the social and economic development of an area that has historically suffered from water scarcity.

The event was held via the CRHIAM YouTube channel, with the participation of its author, Dr. Sebastián Videla. Bolívar Ruiz, an expert lawyer in environmental law and Dr. Gladys Vidal, CRHIAM Director participated as panelists. The CRHIAM director was also the editor of this text. In the words of the author, the XIX century is the foundation for understanding what has happened in the production systems of Chile during the following centuries; therefore, it is important to study and analyze how water has been managed from ancestral cultures to the period current. This text can be reviewed and downloaded for free on the CRHIAM website: https://www.crhiam.cl/publicaciones/libros/

Figure 40. Book Launch event.

- ## Book launch – Nature-based Solutions for the Decontamination of Point-source and Diffuse Discharges

With a dialogue focused on highlighting the importance of better managing and planning our environment, the book "Nature-based Solutions for the Decontamination of Point-source and Diffuse Discharges", a text prepared under the auspices of CRHIAM that focuses on publicizing research on and applications of these tools in Latin America, was launched on July 13th (Figure 41).

The presentation of this work led by Dr. Joan García, professor of the Department of Civil and Environmental Engineering of the Polytechnic University of Catalonia, who began by talking about how these solutions are presented as an opportunity to face problems related to water management, especially amid climate change. Also present at the activity were the editors of the book, CRHIAM Director Dr. Gladys Vidal and CRHIAM principal researcher Dr. María Cristina Diez. Gloria Gómez, a collaborator of the center, also participated as an editor of the text and is the co-author of some of the chapters.

Figure 41. Book Launch event.

- **Event organized by Mirador Interactive Museum (MIM) – Participation of CRHIAM principal researcher in "DIVULGACON" scientific event**

To bring science and technology closer to the public, with entertaining, simple and familiar language, the scientific event "DIVULGACON", an initiative organized by the Mirador Interactive Museum (MIM), was held on June 4th and 5th. CRHIAM principal researcher Dr. Diego Rivera participated (Figure 42).

The activity, which was a virtual scientific marathon, highlighted the work of national scientists and their reflections on multiple current issues such as artificial intelligence, Mars explorations, the megadrought, and the changes that our brain has undergone during the pandemic.

Dr. Rivera was part of the "Science to the rescue of water" panel, which addressed the national water situation from different disciplines. The panelists discussed the effects of climate change, megadrought projections for the coming years and what we can do as individuals to be part of the solution to these problems.

Figure 42. Participation of CRHIAM principal researcher in "DIVULGACON".

• Launch of CRHIAM Communication Series - Constituent Process Edition

Amid one of the longest droughts in the history of Chile, in a context of climate change and days before the sessions began to draft the new constitution, CRHIAM launched the "Communication Series: Constituent Process Edition", a document that seeks to highlight scientific evidence on water resources, which was prepared especially for the 155 members of the Constitutional Convention. This event was held on June 24th via Youtube (Figure 43).

The text collects a selection of titles from the usual CRHIAM Communication Series – books that are part of the center's dissemination work – which aims to transform evidence published in the scientific language of high-impact international journals into easy-to-read material that contributes to society with an interdisciplinary perspective on water resources.

The "CRHIAM Communication Series: Constituent Process Edition" addresses issues such as "The human right to water", "Water governance and management in the framework of water security" and "Reservoirs and their sustainable management under the scenario of water scarcity", among others.

Figure 43. Launch of CRHIAM Communication Series special edition.

• CRHIAM support for free national network hackathon – Agua Go!

The objective of "Agua Go!" was to open spaces to co-create innovative proposals related to efficient water management and its impact on communities. This event was the first free national hackathon to be held in the health sector and was organized by the Hidroinngenia Foundation, with the support of Essbio, Nuevosur, Esval, Aguas del Valle and CRHIAM (Figure 44). The activity was held from August 23rd to 27th.

The activity invited professionals from various industries with an interest in water issues, final-year students from universities and institutes and recently graduated professionals to develop their ideas. The challenges of "Agua Go!" were to develop solutions related to hydro-efficient consumption in the home, generate shared value, promote universal access to water and open spaces for solutions for fire management in times of drought, minimizing the impact on drinking water sources.

"Agua Go!" was the result of a public-private alliance, which is sponsored by the Inter-American Development Bank (IDB), UNESCO, the Agency for Sustainability and Climate Change, and the Ministries of Public Works, Social Development, and Science, Technology, Knowledge and Innovation, in addition to Cidere Biobío, CRHIAM, the School of Physical Sciences and Mathematics of the University of Chile, the School of Engineering of the Universidad del Desarrollo (UDD), and the School of Engineering and Sciences of Adolfo Ibañez University.

Figure 44. Event launch.

• Organization of international conference – 1st Chile-US West Conference on Water Law and Policy

With presentations by leading international researchers, the 1st Chile-US West Conference on Water Law and Policy, an initiative that analyzed limitations in water laws and water management in both countries, was held virtually on July 6th and 8th (Figure 45).

The speakers included Paul Kibel, Professor of Law and Co-Director of the LLM Environmental Law Program; Leon Szeptycki, Professor of Law and General Faculty Associate Director of the UVA Environmental Resilience Institute; Michael Hanemann, Professor and Julie A. Wrigley Chair in Sustainability and Director of the Center for Environmental Economics & Sustainability Policy Department of Economics, Arizona State University; Francisco Riestra, Superintendent of Regulatory Risk Management at Minera Los Pelambres of the AMSA Group and representative of CONAPHI Chile for the Ecohydrology Program of UNESCO's IHP; and Camila Boettiger Philips, Professor of Environmental Law and Natural Resources and researcher at the UDD Center for Regulatory Law and Business.

The event was organized by the UDD, Center for Climate and Resilience Research, Universidad Mayor, Center for Environmental Economics & Sustainability Policy, the Water in the West program of Stanford University, CRHIAM, the UC Center for Water Law and Management and the UC Center for Applied Ecology & Sustainability.

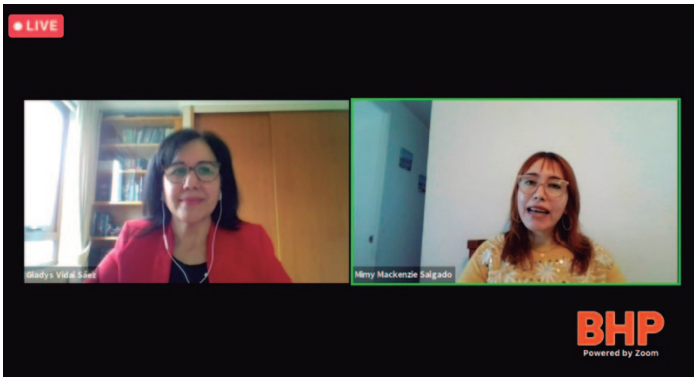
Figure 45. International Conference on limitations in water laws and management.

• Organization of international congress – 2021 Water Congress

With the purpose of contributing from different perspectives to the efficient use of water resources, the 9th International Congress on Water Management in Mining and Industrial Processes, Water Congress 2021, was held from July 7th to 9th (Figure 46). The event organized was by Gecamin, CRHIAM, and Wageningen University & Research.

This year the congress was attended by more than 300 executives, professionals, academics and students. The technical program included more than 100 applied presentations on topics related to industry, mining, sanitation, agriculture and forestry by authors from 17 countries such as Australia, Canada, the Netherlands, Peru and Spain. The aim was to present different challenges and experiences to help face the water scarcity scenario that affects the country.

This year, researchers and students linked to the center made 34 on-demand presentations for the congress in the following sessions: Assessment and studies of water resources; Security and sustainability of the water supply; Climate change: adaptation of water management; Water quality: evaluation and control; Innovative wastewater and effluent treatment; Efficient use of water and water reuse; Innovative water management in the mining industry; and Innovative water management in agriculture.



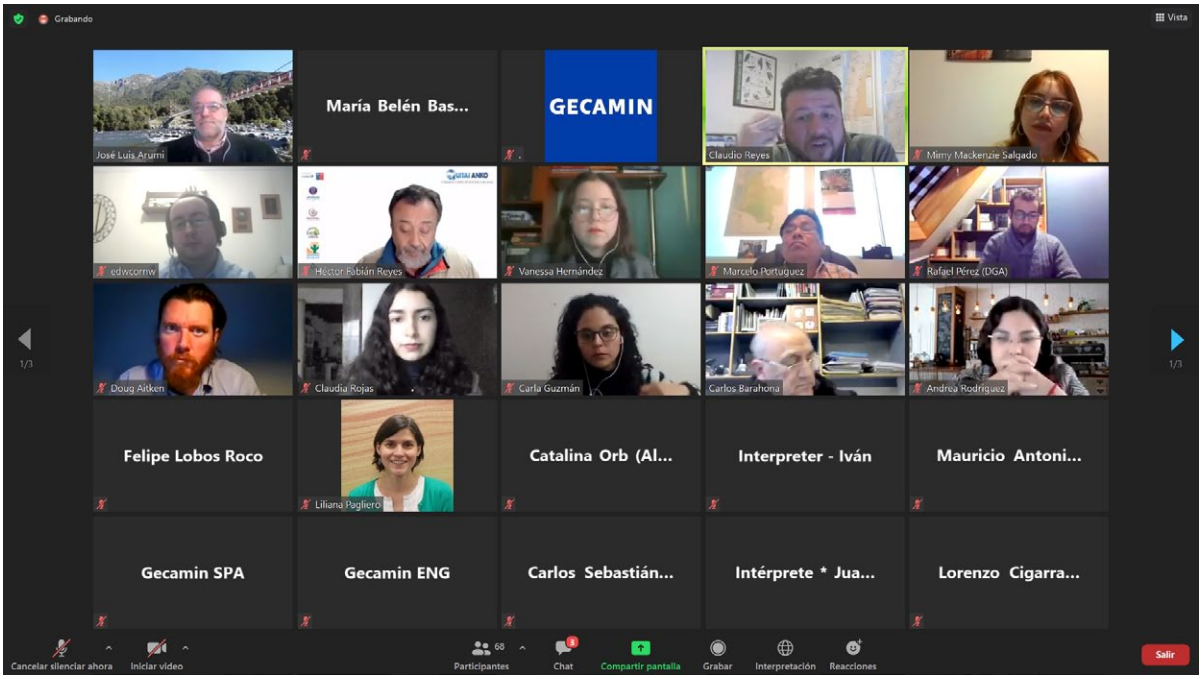


Figure 46. Organization of "2021 Water Congress".

• Collaboration in the organization of international webinar – Strategies and opportunities for reducing environmental pollution by pesticides

Within the framework of the ANID-REDES project "Network for pesticide risk reduction: new strategies and opportunities", the international webinar "Strategies and opportunities for reducing environmental pollution by pesticides" was held, an activity organized by the CIBAMA center of the Universidad de la Frontera, in collaboration with CRHIAM (Figure 47). The event took place on September 3rd.

Presenters from Greece, Argentina, Germany, Peru, Costa Rica and Chile shared their progress and experiences regarding the use of biotechnological tools and monitoring systems to minimize the negative impacts on soils of pesticide use.

CRHIAM principal investigator and CIBAMA Director Dr. María Cristina Diez thanked the speakers for their participation. "This seminar is being carried out based on a network project led by Dr. Gabriela Briceño (CIBAMA researcher), but we also have the collaboration of BIOREN, the scientific nucleus in bio-resources and CRHIAM. I thank all the presenters for their presentations and experiences that they shared with us in this activity, which undoubtedly help us to strengthen our work together", said the researcher.

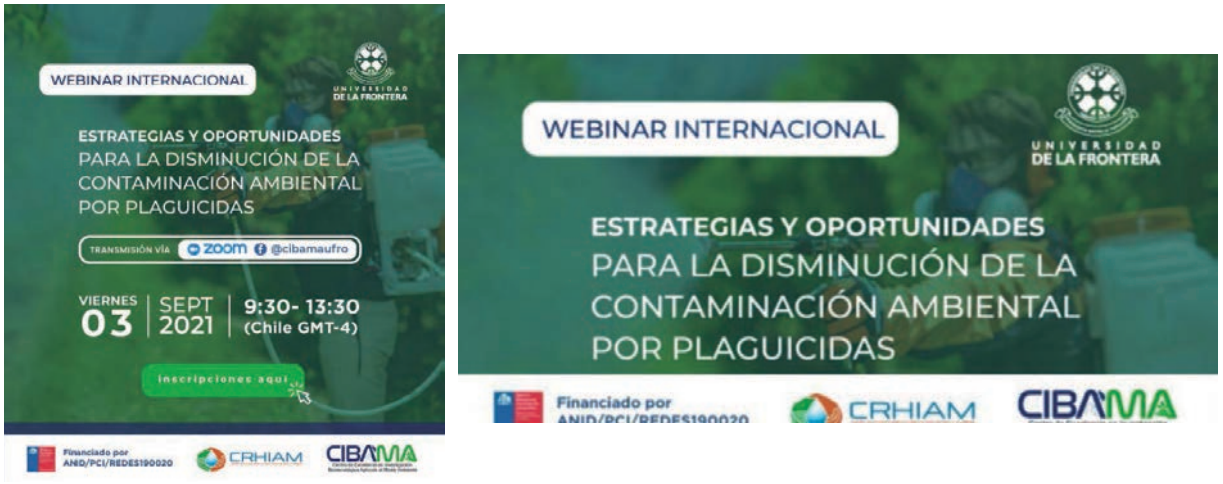


Figure 47. International webinar.

• Co-organization of talk – Intergovernmental Panel on Climate Change (IPCC)

In order to talk about the most relevant data from the latest IPPC report and its impacts on Chile, a discussion entitled "The physical bases of climate change" was held on September 9th, an activity organized jointly by CRHIAM, the Department of Sociology, the School of Social Sciences, the School of Environmental Sciences and the EULA Center of the University of Concepción (Figure 48).

The report was presented by Dr. Maisa Rojas, Director of the (CR)^2 Center, who was one of its main authors. During her speech, she stressed that human influence has warmed the climate at an unprecedented rate. "The planet in the last decade has been 1.1 degrees warmer. If you want to find another period in the past in which the temperatures were equal to or warmer than this last decade, you have to go back 125 thousand years", said the researcher.

CRHIAM Director Dr. Gladys Vidal, principal researcher Dr. Ricardo Barra and associate researcher Dr. Jorge Rojas analyzed the results of the report from the perspectives of their work areas.

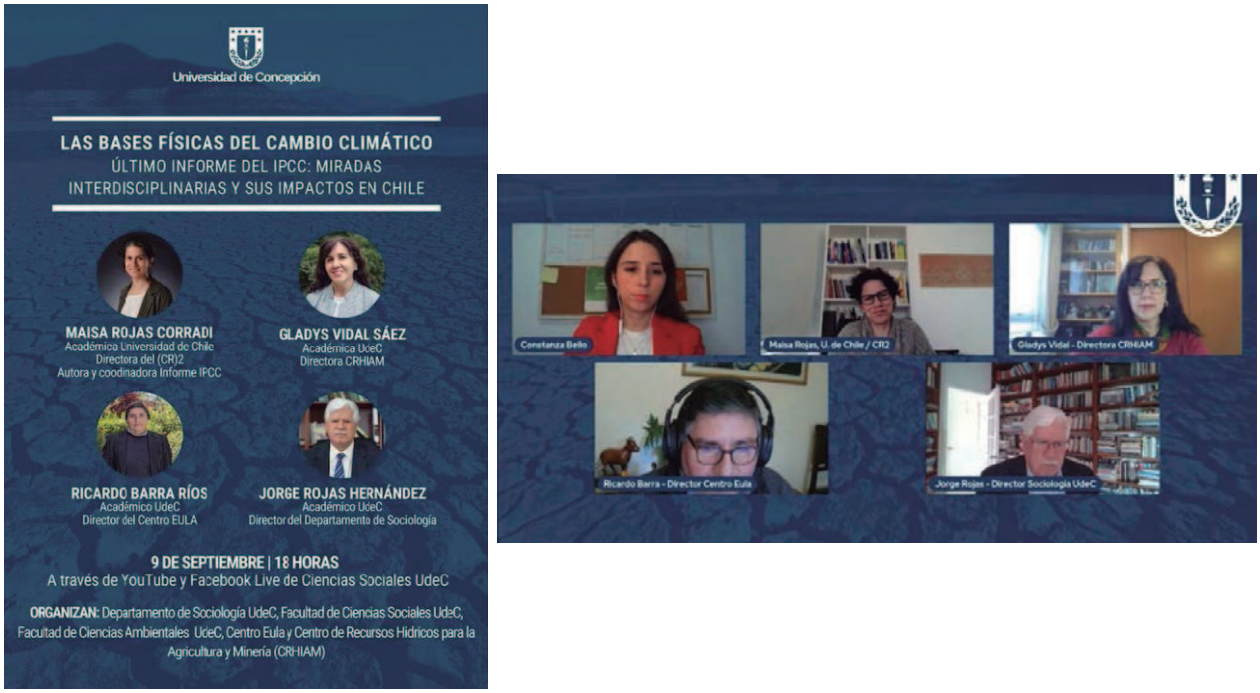


Figure 48. Talk about latest IPCC report.

• Book launch – History of Water in the Norte Chico. XIX Century

The north of Chile has always been characterized as an area lacking water, where this resource must be shared by the population and production sectors, leading to conflicts over its use. However, the Norte Chico is a territory with special characteristics, in which its transverse valleys present unique natural conditions for the development of production activities that are vital to the country such as agriculture and mining.

The book presents the history of this area and reviews past experiences. It was prepared under the auspices of CRHIAM and is the second in a series that the author, Dr. Sebastián Videla, has started on the history of water in Chile; a previous volume was dedicated to the Norte Grande in the XIX century. The book launch was held on October 20th and attended by the author and CRHIAM Director Dr. Gladys Vidal, who was the editor of the text (Figure 49). An academic from the Federal University of Paraná, Dr. Junior García, participated as a commentator, highlighting the research work that went into the book.

Figure 49. Book launch event.

- **Participation in Chilean and Inter-American Congress – AIDIS Sanitary and Environmental Engineering**

The XXIV Chilean Congress of Sanitary and Environmental Engineering and X Congress of the IV Region of Inter-American AIDIS was held virtually for the first time. The event addressed the challenges of the sanitation industry and environmental management in the context of climate change and took place between November 9th and 11th (Figure 50).

CRHIAM Director Dr. Gladys Vidal, together with the Director of the School of Biochemical Engineering of the PUCV, Dr. María Cristina Schiappacasse, moderated the roundtable "Water resources and sustainable development", in which they also participated as panelists with the Director of the PUCV Climate Action Center, Dr. Marcelo Mena; the Executive Director of Fundación Newenko, Evelyn Vicioso; and the General Manager of Essbio, Cristian Vergara.

The discussion addressed the nexus between water security and sustainable development to guarantee the reliable and timely provision of water in terms of quantity and quality for human consumption, the conservation of water ecosystems, and the production of goods and services. Meanwhile, Naomí Monsalves, Ana María Leiva, and Dr. Gladys Vidal presented the work "Presence of antibiotic resistance genes in sewage and effluent from treatment plants".

Figure 50. 2021 AIDIS Chilean and Inter-American Congress

• Story contest launch – Water Tales

An adventure through glaciers, the mysteries of a river, and how to save a town from the drought are the topics of just some of the stories that could be part of the short story contest "Water Tales" which seeks to show, through literature, the different ways in which the community values and perceives water.

The contest is organized by CRHIAM and seeks original texts between 350 and 700 words; it is open to all residents of Chile over 12-years old (Figure 51).

The first-place story author won a Kindle, while the second and third place authors won wireless headphones and a Smartband, respectively. These stories, along with the honorable mentions, were disseminated on the CRHIAM platforms and were part of a book.

Figure 51. Short story contest about water.

• Discussion - Conversations on Science and Public Policies: How do we approach water?

To present different views on how water is managed in the country, CRHIAM organized "Conversations on Science and Public Policies: How do we approach water?". Evelyn Vicioso, Executive Director of the Newenko Foundation; Eduardo Baeza, researcher at the Parliamentary Technical Advisory Office of the Library of the National Congress; and CRHIAM Director Dr. Gladys Vidal participated. This event took place on November 30th via Youtube (Figure 52).

The conversation sought to be a space for dialogue to draw attention to the water crisis in our country and the effects of climate change, with different water-related actors from social organizations, academia, and the public policy sphere presenting their experiences.

Figure 52. Conversation about water science and public policies.

7. CONTRIBUTION TO THE PUBLIC AND PRIVATE SPHERES

7.1 Contribution to Public Policies and Meetings with Private and Public Actors

7.1.1 Meetings with Authorities and Participation in Public Bodies (Senate and Chamber of Deputies)

- **CRHIAM principal researcher is part of the Scientific Advisory Committee for Public Policies on Sustainable Agriculture – December 11th, 2020**

To contribute to the design and implementation of public policies, the Minister of Science, Technology, Knowledge and Innovation, Andrés Couve, together with the Minister of Agriculture, Antonio Walker, introduced the new Scientific Advisory Council for Sustainable Agriculture, which will make recommendations based on the best scientific evidence as an input for decision-making at the Ministry of Agriculture (Figure 53).

CRHIAM principal investigator Dr. José Luis Arumí is one of the six scientists that make up this scientific advisory committee, along with three representatives of public technological institutes of the agriculture and food sector. The council seeks to contribute to the implementation of the National Policy for Rural Development and the strengthening of the forestry, agriculture and food sectors in Chile.

Figure 53. Introduction of the Scientific Advisory Council for Sustainable Agriculture.

• CRHIAM researcher joins Water for Agriculture Board – March 2021

Since March of this year, CRHIAM principal investigator Dr. Diego Rivera has been a member of the Water for Agriculture Board of the Ministry of Agriculture as a representative of the Water Resources Research Network (Red H2O). This public-private group seeks to establish a long-term sectoral vision and actions to face the water crisis, ensuring the sustainable use of water and its availability in terms of quantity, quality and opportunity.

The objective of the commission is to strengthen collaborative work in order to identify the main information gaps in water and agriculture, including the measurement of water variables in agriculture. It also aims to establish agreement on the mechanisms and actions necessary to advance in these matters and contribute to the creation of awareness and timely action in the sector against climate change.

- ## Associate researcher presented at seminar on Regional Water Management – March 26th, 2021

With the participation of regional authorities and academics linked to the study of water resources, the seminar and discussion "Regional Water Strategy: Sustainable management of water resources, a challenge for everyone" was held on March 26th. CRHIAM associate researcher Dr. Octavio Lagos spoke about the strategic plan for water management in the Biobío basin (Figure 54).

The activity, organized by the Regional Ministerial Secretary of Public Works and the Regional Government, took place as part of the commemoration of World Water Day, with a view to unifying intersectoral work to strengthen water management and governance through a water management strategy for the region.

The preliminary portfolio of initiatives included infrastructure studies to carry out irrigation and water use efficiency assessments, institutional and private management of aquifer exploitation, monitoring of the water resources of the basin, risks associated with the water of the basin, water quality, strengthening of water user organizations, the social and cultural environment and information on the water market.

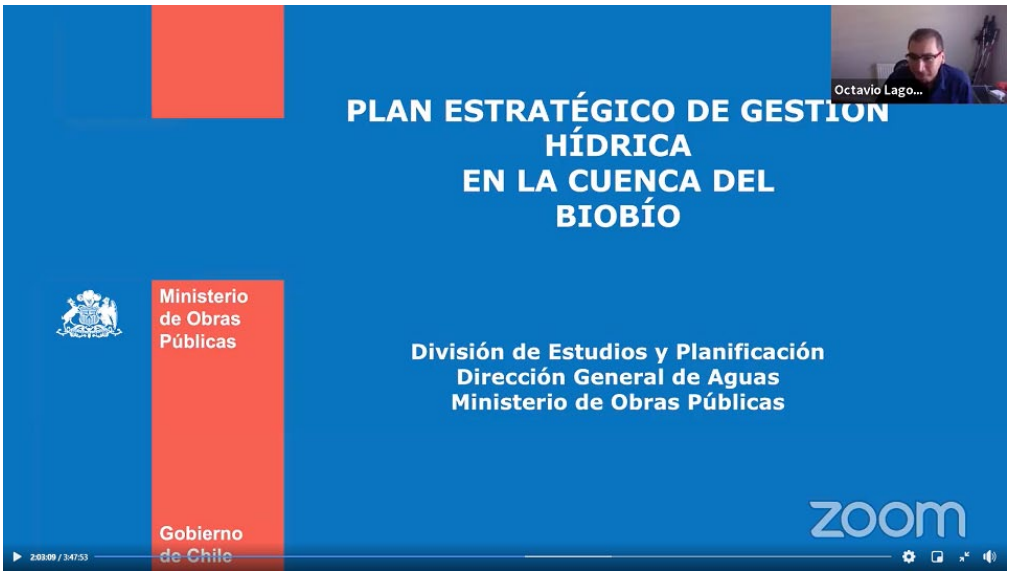


Figure 54. CRHIAM associate researcher's presentation at regional seminar.

- **Ministry of the Environment (MMA) conducted a webinar on the draft revision of Supreme Decree N° 90 – April 14th, 2021**

With the participation of representatives of the public sector, NGOs, and academia, the third webinar on the Preliminary Draft for the revision of Supreme Decree No. 90, organized by the Ministry of the Environment, was held on April 14th. CRHIAM Director Dr. Gladys Vidal participated (Figure 55).

Regarding the changes to this decree that are being proposed, Dr. Vidal stated: "The considered changes to DS 90 in the discharges into ecosystems are very important to reduce the pressure of the pollutants that are discharged into bodies of water, and thus to give space to regulating ecosystem services that allow biodiversity to be conserved."

The discussion addressed the Citizen Consultation Process for the review of this regulatory instrument, which aims to prevent the contamination of the country's marine and continental surface water by controlling pollutants associated with liquid waste that are discharged into these bodies of water.

Figure 55. Webinar on draft revision of Supreme Decree N° 90.

- **Associate researcher presented before the Chamber of Deputies Water Resources and Desertification Committee – April 29th, 2021**

CRHIAM associate researcher Dr. Amaya Álvez was invited to present before the Chamber of Deputies Water Resources and Desertification Committee as part of the discussion on the contamination of the Chaimávida estuary in Concepción, a situation that was caused by the rupture of a pipeline in the Hidronor landfill (Figure 56).

During the session, the researcher also presented new perspectives on this type of problem, calling for a debate on the distribution of environmental burdens, a guarantee for more spaces for citizen participation related to environmental issues and consideration of nature as an autonomous entity, highlighting its ecosystem richness and the particularities of the basin.

Figure 56. Presentation before the Chamber of Deputies.

• CRHIAM researchers held a meeting with the Biolanthanides Project – May 13th, 2021

Members of the CRHIAM Academic Council participated in an informative meeting with representatives of the Biolanthanides Project, an initiative focused on the exploration and production of lanthanides, better known as rare earths or REE (Figure 57).

The meeting, held on Thursday, May 13th, was aimed at presenting information on the execution of the project and discussing the framework agreement for technology transfer and professional training on rare earth mining with the University of Concepción, which CRHIAM is also a part of. Biolantánidos is the first company in Chile dedicated to the production of rare earths and it intends to build an extraction plant for these minerals in the Penco Commune.

Figure 57. Meeting between CRHIAM and Biolanthanides Project representatives.

• CRHIAM principal investigator spoke before Senate Special Commission– June 2nd, 2021

CRHIAM principal investigator Dr. José Luis Arumí was invited to the Senate Special Commission on Water Resources, Desertification and Drought to discuss water quality in Chile in a session held on June 2nd (Figure 58).

Regarding groundwater recharge, Dr. Arumí's area of expertise, he pointed out that it is essential to understand the mechanismos of groundwater recharge and the areas where it occurs to protect the quality of these aquifers. He added that institutional coordination between agencies linked to water management should be improved. In this regard, he indicated that there is an opportunity for regional governments to develop regional technical secretariats for water and the environment focused on coordination between actors.

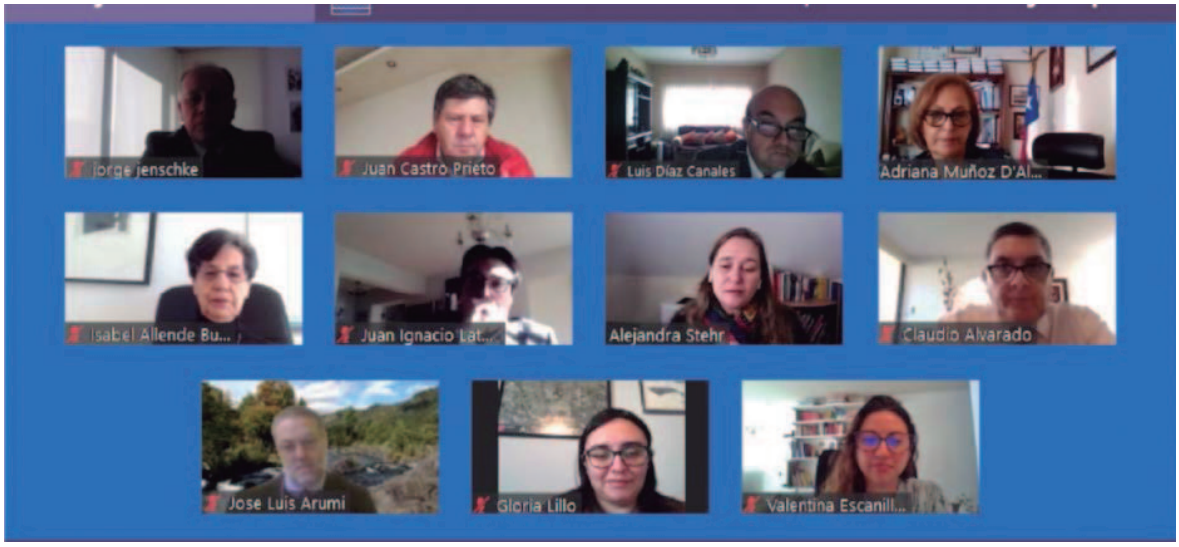


Figure 58. CRHIAM principal researcher's participation in Senate Special Commission.

• CRHIAM researchers participated in business meetings at Water Congress – July 2021

At the 9th International Congress on Water Management in Mining and Industrial Processes, Water Congress 2021, CRHIAM participated in business meetings with different entities (Figure 59). This year meetings were held with representatives of CORFO, CODELCO and SUEZ.

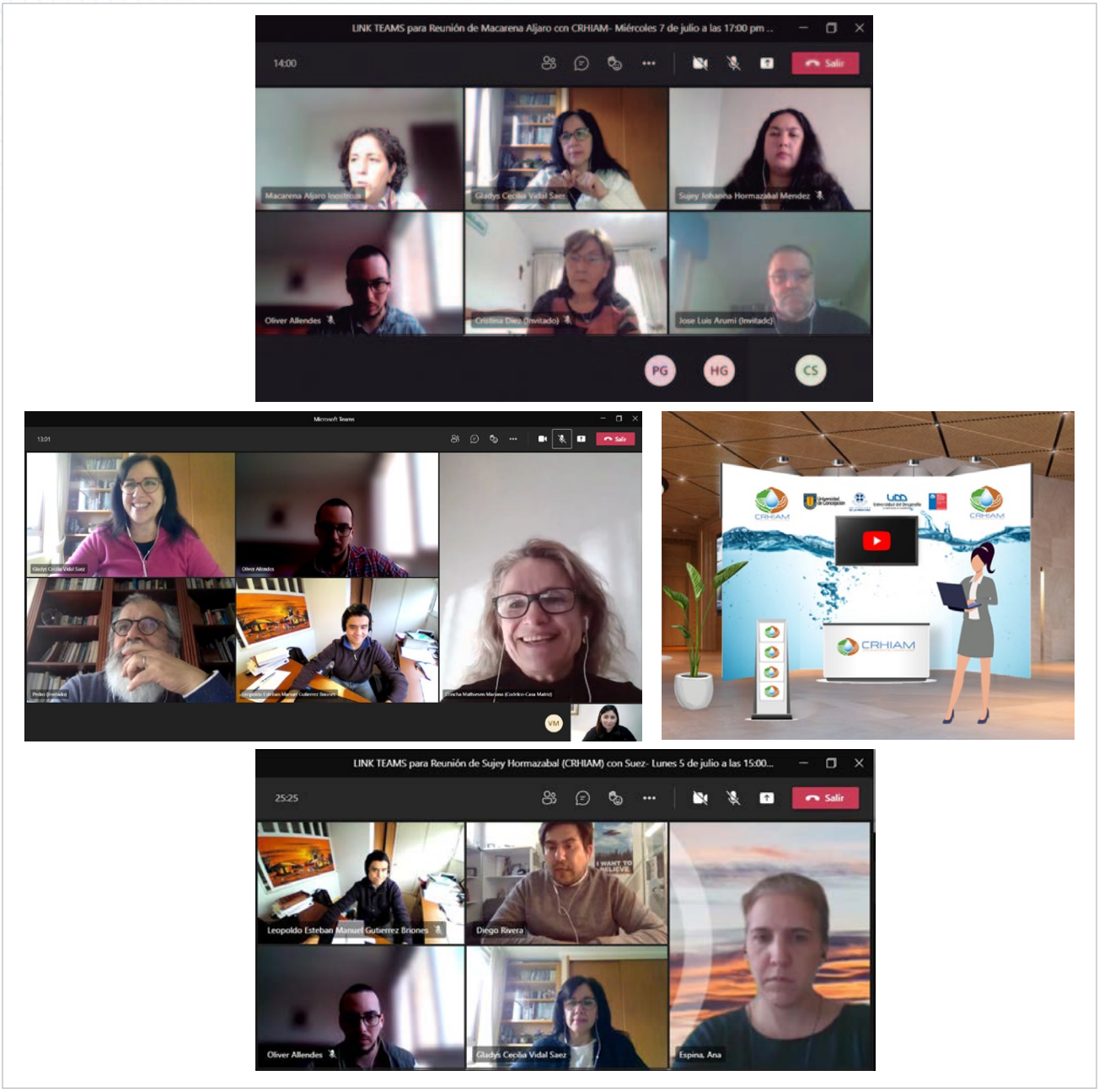


Figure 59. Business meetings at Water Congress.

- ## CRHIAM director participated in discussion on National Gender Policy in Science – July 28th, 2021

A meeting focused on the First National Gender Policy in CTCI was held with the Undersecretary of Science, Technology, Knowledge and Innovation (CTCI), Carolina Torrealba; the SEREMI of CTCI of the South Central Macrozone, Paulina Assmann; and vice-rectors of research and directors of Biobío research centers (Figure 60).

CRHIAM Director Dr. Gladys Vidal was invited to represent the center in this discussion, which addressed the importance of promoting the equitable participation of men and women in CTCI to positively impact the sustainability and productivity of the country. This initiative began in 2019, when intense work was carried out to collect background information, ideas and reflections on gender gaps in the CTCI ecosystem. This policy seeks to provide a framework of consistency and continuity to decisively advance in the removal of the barriers that prevent the participation and full development of women in research and development.

Figure 60. CRHIAM director's participation in discussion on national science policy.

• Shipping of CRHIAM material to national authorities – August 2021

Once some of the restrictions due to the pandemic were eased, CRHIAM sent the different titles of the Communication Series to authorities in the private and public spheres to extend its contribution to the country's public policies on matters related to water (Figure 61).

Public sphere authorities who were sent material included the Ministers of Science, Technology, Knowledge and Innovation; Public Works; Agriculture; Environment; and Mining. Likewise, these documents were received by the senators and deputies on water resources commissions, regional governors and mayors. This material and books published by CRHIAM were also sent to the Library of National Congress as part of a collaboration agreement with this entity.

Figure 61. CRHIAM material sent to national authorities.

- ## CRHIAM researcher participated in the Constitution of the Regional Water Table in Ñuble – August 11th, 2021

The hyper drought that Chile is experiencing requires urgent measures with a territorial approach to ensure the water supply for communities and production sectors. With this view, representatives of municipalities, CORFO, INDAP, ONEMI and GORE took part in the first meeting held by the Regional Water Table in Ñuble, a workspace in which the CRHIAM researcher Dr. José Luis Arumí also participates (Figure 62).

The meeting addressed the water emergency that the region will have to face in summer, with a special focus on water availability for people, drinking water and forage production for animals, and the danger of forest fires. This first meeting was held in person on August 11th and was chaired by the Regional Governor, Óscar Crisóstomo, together with the head of the GORE Infrastructure and Transportation Division, Víctor Toro.

Figure 62. Regional Water Table.

• CRHIAM Academic Council meets with CODELCO representatives – August 19th, 2021

To discuss possible joint collaborations, CRHIAM principal researchers met with representatives of the CODELCO company on August 19th. The meeting was held with the Corporate Water Manager Mariana Concha and the Corporate Director of Water Planning and Governance Claudia Núñez (Figure 63).

The meeting focused on publicizing CRHIAM's research lines in order to find areas where the center could contribute to guarantee more sustainable mining, especially in the context of water scarcity that affects the country. The two entities discussed water reuse for the mining industry and human consumption, the importance of measuring the water footprint in processes and the supply of desalinated water for industry, among other topics.

Figure 63. Meeting between CRHIAM Academic Council and CODELCO.

- ## CRHIAM researcher presented on the use of groundwater in the Senate – September 8th, 2021

To continue the study of the bill that allows the sustainable use of groundwater, CRHIAM principal investigator Dr. José Luis Arumí was invited to present before the Senate Commission on Water Resources, Desertification and Drought (Figure 64).

This is the second time that the CRHIAM researcher has been invited to this commission as an expert, so before starting his presentation he offered a few words of thanks. "I feel particularly honored to be back in front of you (the commission) and to be able to contribute in some way to this discussion that is so necessary for our country," said Dr. Arumí. The bill proposes that groundwater not be exploited without scientific and technical data that account for water availability and sustainability, with the exception of use for human consumption and subsistence. The CRHIAM researcher focused his presentation on the fears raised by this proposal.

Figure 64. CRHIAM principal researcher's presentation before the Senate.

- **Regional government presented the Green Infrastructure Committee to strengthen road and digital connectivity in the region – September 20th, 2021**

A master plan will be the main product prepared by the newly constituted Green Infrastructure Committee, an entity presented by Biobío Regional Governor Rodrigo Díaz, the purpose of which is to visualize strategic investments in response to the needs of road and digital connections, considering the current climate emergency (Figure 65).

Various public and private actors will be on the committee, including CRHIAM Director Gladys Vidal. After the meeting, the researcher stressed that "the main contribution of the center will be to contribute scientific evidence to support this planning and to be able to look towards the future in a climate change scenario with a very evident effect on the region's water resources." This committee will consider information that will serve as inputs for the Regional Development Strategy, the Metropolitan Regulatory Plan of Greater Concepción, and the Regional Plan for Territorial Organization, which will be presented in March 2022, among other initiatives.

Figure 65. Biobío Region Green Infraestructure Committee presentation.

- **CRHIAM Principal researcher was part of FRUITTRADE 2021, the National Convention of Fruit and Vegetable Producers – September 28th and 29th**

With technical seminars focused on the water crisis, the worker shortage, and climate change, FRUITTRADE 2021, the National Convention of Fruit and Vegetable Producers, organized by the Federation of Fruit Producers of Chile (Fedefruta), was held on September 28th and 29th.

Prominent national and international speakers participated, leading different panels such as "Analysis of the Water Crisis from the Macro to the Micro", in which CRHIAM principal researcher Dr. José Luis Arumí spoke (Figure 66). The researcher addressed artificial groundwater recharge, analyzing four gaps for its implementation: knowledge of groundwater systems and recharge processes, technical capacity for its implementation, approaches to groundwater recharge projects and administration of these recharges by water user organizations.

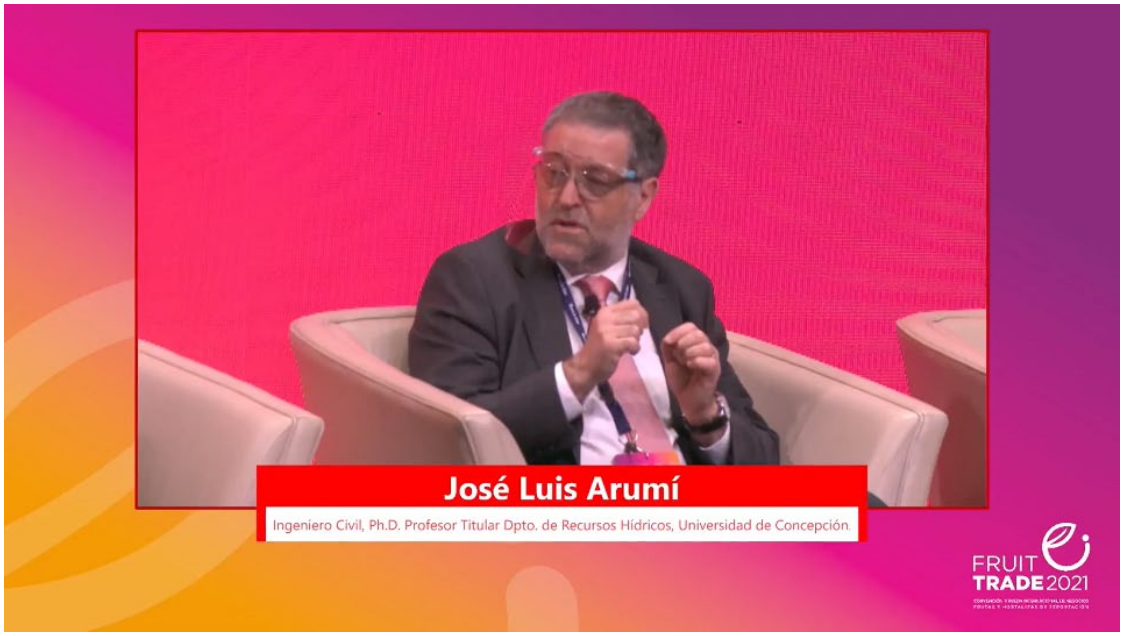


Figure 66. FRUITTRADE 2021 national convention.

- **CRHIAM researcher participated as a guest expert in the Joint Senate Commission on Agriculture, Environment and Water Resources – October 6th, 2021**

In the framework of the study of a bill that would modify Law No. 18,450 – which approves regulations for the promotion of private investment in irrigation and drainage works – and extend the period in which it is force, CRHIAM principal investigator Dr. José Luis Arumí was invited to present before the Senate (Figure 67).

The session was held on October 6th by the Joint Commission on Agriculture, Environment and National Assets, and Water Resources, Desertification and Drought. Ministry of Agriculture Advisor Andrés Meneses; Executive Secretary of the National Irrigation Commission Federico Errázuriz; Governor of the Valparaíso Region Rodrigo Mundaca; territorial organizations of the O'Higgins, Valparaíso, and Coquimbo regions; the Rio Choapa Oversight Board; and President of the Federation of Oversight Boards of the Maule and its Tributaries Máximo Correa participated.

Figure 67. CRHIAM principal researcher's presentation before the Senate.

- **CRHIAM members met with representatives of the Superintendency of Sanitary Services (SISS) – October 27th, 2021**

CRHIAM members are preparing the report "Environmental quality of drinking water sources of water service companies in Chile, 2014-2020 period" (Figure 68) in order to publicize the quality parameters of groundwater and surface water sources. This document will be delivered in 2022 to the SISS.

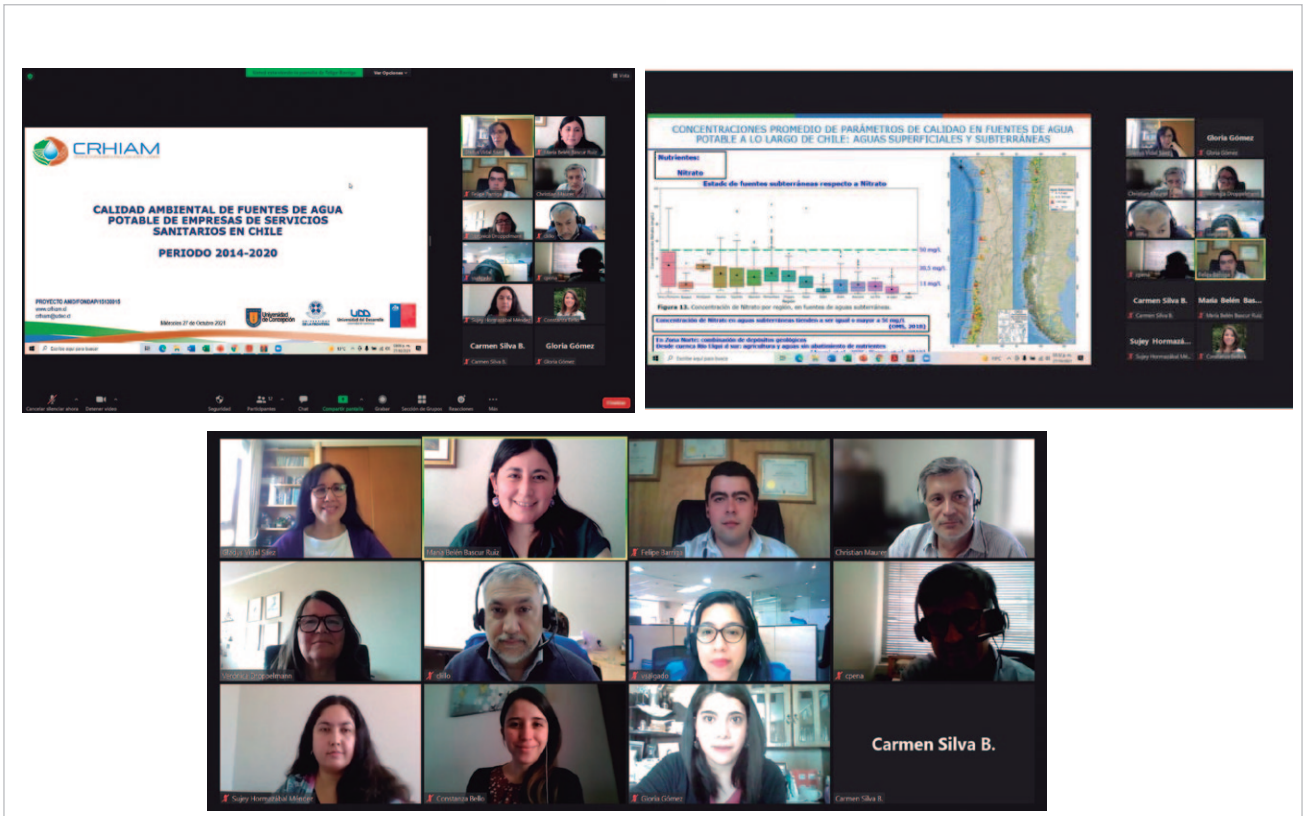


Figure 68. Meeting between CRHIAM members and SISS representatives.

- **CRHIAM conversation reflected on the nexus between public policies and water – November 30th, 2021**

To present different views on how water is managed in the country, CRHIAM held a discussion entitled "Conversations on Science and Public Policies: How do we approach water?" Evelyn Vicioso, Executive Director of the Newenko Foundation; Eduardo Baeza, researcher at the Parliamentary Technical Advisory Office of the Library of the National Congress; and CRHIAM Director Dr. Gladys Vidal participated in the activity (Figure 69).

The conversation sought to be a space for dialogue to draw attention the water crisis in Chile and the effects of climate change, with different water-related actors from social organizations, academia and the public policy sphere presenting their experiences.

Figure 69. Conversation about water science and public policy.

7.2 Joint work between CRHIAM and the Constitutional Convention

- **CRHIAM presented the document "Communication Series: Constituent Process Edition" – June 24th, 2021**

In the midst of one of the longest droughts in the history of Chile, against the backdrop of climate change, and days before sessions began to draft the new constitution, CRHIAM launched the "CRHIAM Communication Series: Constituent Process Edition" (Figure 70), a document that seeks to highlight scientific evidence on water resources that was prepared especially for the 155 members of the Constitutional Convention.

The document collects a selection of titles from the usual CRHIAM Communication Series – books that are part of the center's dissemination work – which aims to transform evidence published in the scientific language of high-impact international journals into easy-to-read material that contributes to society with an interdisciplinary perspective on water resources. The "CRHIAM Communication Series: Constituent Process Edition" addresses issues such as the human right to water and water governance and management in the framework of water security, among others.

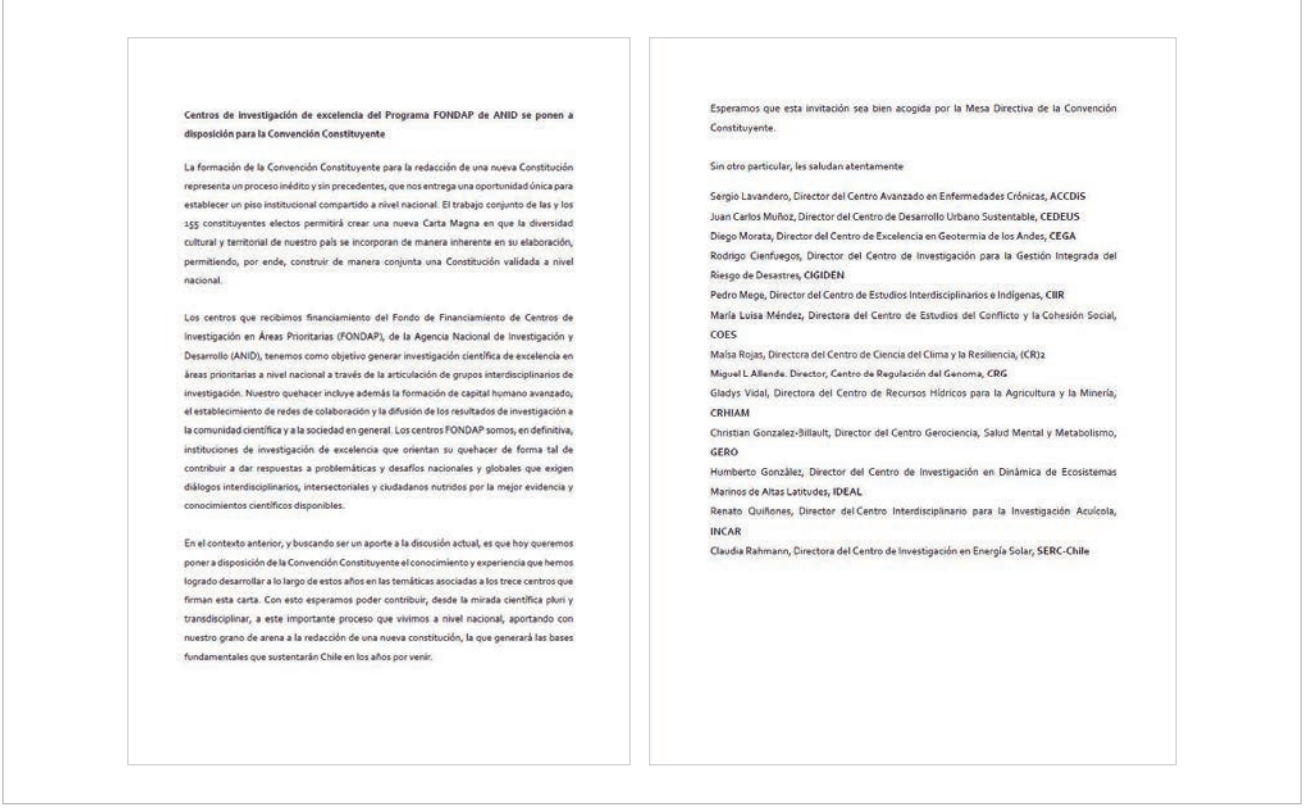
Figure 70. Launch of special constituent process edition of the Communication Series.

• ANID FONDAP Program Research Centers of Excellence made knowledge available to the Constitutional Convention – August 2nd, 2021

The directors of the thirteen FONDAP Research Centers of Excellence in Priority Areas made their knowledge and experience in different topics of national interest available to the convention in charge of drafting the country's new constitution.

To this end, they sent a letter to the President and Vice President of the Board of Directors of the Constitutional Convention (Figure 71), in which they expressed their willingness to contribute to the drafting of the new constitution from multi-disciplinary and transdisciplinary scientific perspectives.

CRHIAM sent the document "CRHIAM Communication Series: Constituent Process Edition" to the convention, a text that includes a selection of titles from the usual CRHIAM Communication Series, which aim to transform evidence published in the scientific language of high-impact international journals into easy-to-read material that contributes to society with an interdisciplinary perspective on water resources.



Centros de investigación de excelencia del Programa FONDAP de ANID se ponen a disposición para la Convención Constituyente

La formación de la Convención Constituyente para la redacción de una nueva Constitución representa un proceso inédito y sin precedentes, que nos entrega una oportunidad única para establecer un piso institucional compartido a nivel nacional. El trabajo conjunto de las y los 155 constituyentes electos permitirá crear una nueva Carta Magna en que la diversidad cultural y territorial de nuestro país se incorporan de manera inherente en su elaboración, permitiendo, por ende, construir de manera conjunta una Constitución validada a nivel nacional.

Los centros que recibimos financiamiento del Fondo de Financiamiento de Centros de Investigación en Áreas Prioritarias (FONDAP), de la Agencia Nacional de Investigación y Desarrollo (ANID), tenemos como objetivo generar investigación científica de excelencia en áreas prioritarias a nivel nacional a través de la articulación de grupos interdisciplinarios de investigación. Nuestro quehacer incluye además la formación de capital humano avanzado, el establecimiento de redes de colaboración y la difusión de los resultados de investigación a la comunidad científica y a la sociedad en general. Los centros FONDAP somos, en definitiva, instituciones de investigación de excelencia que orientan su quehacer de forma tal de contribuir a dar respuestas a problemáticas y desafíos nacionales y globales que exigen diálogos interdisciplinarios, intersectoriales y ciudadanos nutridos por la mejor evidencia y conocimientos científicos disponibles.

En el contexto anterior, y buscando ser un aporte a la discusión actual, es que hoy queremos poner a disposición de la Convención Constituyente el conocimiento y experiencia que hemos logrado desarrollar a lo largo de estos años en las temáticas asociadas a los trece centros que firman esta carta. Con esto esperamos poder contribuir, desde la mirada científica pluri y transdisciplinar, a este importante proceso que vivimos a nivel nacional, aportando con nuestro grano de arena a la redacción de una nueva constitución, la que generará las bases fundamentales que sustentarán Chile en los años por venir.

Esperamos que esta invitación sea bien acogida por la Mesa Directiva de la Convención Constituyente.

Sin otro particular, les saludan atentamente

Sergio Lavandero, Director del Centro Avanzado en Enfermedades Crónicas, **ACCDiS**
Juan Carlos Muñoz, Director del Centro de Desarrollo Urbano Sustentable, **CEDEUS**
Diego Morata, Director del Centro de Excelencia en Geotermia de los Andes, **CEGA**
Rodrigo Cienfuegos, Director del Centro de Investigación para la Gestión Integrada del Riesgo de Desastres, **CIGIDEN**
Pedro Mege, Director del Centro de Estudios Interdisciplinarios e Indígenas, **CIIR**
María Luisa Méndez, Directora del Centro de Estudios del Conflicto y la Cohesión Social, **COES**
Maisa Rojas, Directora del Centro de Ciencia del Clima y la Resiliencia, **(CR)2**
Miguel L Allende. Director, Centro de Regulación del Genoma, **CRG**
Gladys Vidal, Directora del Centro de Recursos Hídricos para la Agricultura y la Minería, **CRHIAM**
Christian Gonzalez-Billault, Director del Centro Gerociencia, Salud Mental y Metabolismo, **GERO**
Humberto González, Director del Centro de Investigación en Dinámica de Ecosistemas Marinos de Altas Latitudes, **IDEAL**
Renato Quiñones, Director del Centro Interdisciplinario para la Investigación Acuícola, **INCAR**
Claudia Rahmann, Directora del Centro de Investigación en Energía Solar, **SERC-Chile**

Figure 71. Launch of special edition of the Communication Series on the constituent process.

• CRHIAM Director participated in the UdeC forum on the Constitutional Convention

Within the framework of the activities organized jointly by the University of Concepción and the Constitutional Convention, the forum "Knowledge, Higher Education and University. Views from the Biobío Region" was held, in which the CRHIAM Director Dr. Gladys Vidal participated as a panelist (Figure 72).

The objective of the meeting was to create an open space for the UdeC community and the convention itself, in order to present academic views on knowledge and higher education on topics selected as strategic for the development of the Biobío Region and the country so convention members could become familiar with the work the university has done and knowledge it has created.

In her presentation, Dr. Vidal highlighted the work carried out by the Fondap centers in connecting the research carried out at universities with public policies, especially at the regional level.

Figure 72. UdeC forum on the Constitutional Convention.

8. CRHIAM'S CONTRIBUTIONS TO SUSTAINABLE DEVELOPMENT GOALS

CRHIAM has committed to the 2030 Agenda and has made strict alignment with Sustainable Development Goals (SDGs) related to water access and quality for sustainable consumption and production (CRHIAM, 2018) one of its key strategies.

CRHIAM has established four main objectives regarding research, people, networking and communication. Each aims to contribute the achievement of SDGs. Therefore, and considering the critical role of research and funding institutions in supporting this historic UN agenda, the following report aims to outline CRHIAM's contributions by showing how its scientific output published in journals indexed by Scopus is related to this challenge.

It is important to emphasize that the scope of this report considers only one type of contribution and does not account for CRHIAM's other results and activities that also support the achievement of SDGs (e.g., outreach, collaboration, policy briefing and other types of published documents).

As part of the methodology, specific algorithms to search complex databases (e.g., Web of Science or Scopus) and identify relevant research articles for each goal were needed. Elsevier 2021 SDG mapping queries (Rivest *et al.*, 2020) and Scopus were used as sources and 247 papers were identified as contributing to at least one SDG. Due to the multi- and interdisciplinary nature of the goals and the related research required to address them, each article may contribute to more than one SDG, such that the number of "contributions" may be larger than the number of unique document.
Results

8.1 Results

• SDG-related research

Between 2013 and 2021 (May), CRHIAM published nearly 570 scientific papers distributed among different sources, mainly journals indexed by Web of Science or Scopus.

For the purposes of this analysis, only research available in Scopus, from which 532 documents were retrieved successfully, was considered. This research output is shown in Table 10.

There has been a consistent annual increase, with a growth ratio of +1.95 in the last five-year period (2016-2020). International collaboration is strong and more than half of the papers are led by the center's researchers, as determined by the corresponding author belonging to the CRHIAM research staff (28 academics).

Table 10. CRHIAM Scopus research output features

CRHIAM	Nº docs	Citations (Scopus retrived 01.06.2021)	Average Citation per doc.	Docs h-index	Inter.Collab. (%)	Leadership (%)
Scopus output	532	4730	8,9	29	63.3	34.4

Inter. Collab.: International Collaboration

As the UN 2030 Agenda was launched in 2015, the output analysis includes only research published starting in 2016. Document types were also restricted: only articles, reviews and letters were included.

In summary, 225 documents are related to 15 of the 17 goals; thus 47.4% of the documents are SDG-related research.

No matching results were found for Quality education (goal 4) and Gender equality (goal 5).

The phrase "sustainable development goal" was explicitly mentioned in the title, abstract, or keywords of only two articles:

1. Barra, R.O. (2020). The 2019 global environment outlook and global chemicals outlook: Challenges for environmental toxicology and chemistry in Latin America. Current Opinion in Green and Sustainable Chemistry, 25. doi: 10.1016/j.cogsc.2020.100352.

2. Barra, R. and González, P. (2018). Sustainable chemistry challenges from a developing country perspective: Education, plastic pollution, and beyond. Current Opinion in Green and Sustainable Chemistry, 9, 40-44. doi: 10.1016/j.cogsc.2017.12.001.

The main features of this publication set are shown in Table 11. There are no great differences between all documents and SDG-related documents, except for the h-index, which decreases in the SDG-related set and leadership, which increases from 31% to 51%.

Table 11. CRHIAM Scopus SDGs-Related Research Output

CRHIAM	Nº docs	SDG Related Nº Docs	SDG Output Contributions	Citations (Scopus retrived 01.06.2021)	Average Citation per doc.	Docs h-index	Inter. Collab (%)	Leadership (%)
Scopus output (2016-2011) (article, review letters)	474	225	362	1938	8.6	21	63.5	51.1

SDG: Sustainable Development Goal and Inter. Collab.: International Collaboration.

Table 12 shows how the SDGs are represented in the current CRHIAM research landscape.

Table 12. CRHIAM SDG-related Scopus research output, results per SDG

CRHIAM SDG-relate Output 2016-2021 (DT: article, review and letters)	Output Contributions	Citations (Scopus retrived, 01.06.2021)	Average Citation per doc.	Dos h-index
SDG1 No poverty	5	69	13.8	3
SDG2 Zero hunger	19	165	8.6	9
SDG3 Good health and well-being	23	235	10.2	9
SDG4 Quality Education	-	-	-	-
SDG5 Gender Equality	-	-	-	-
SDG6 Clean water and sanitation	142	1127	7.9	17
SDG7 Affordable and clean energy	16	264	16.5	8
SDG8 Decent work and economic growth	18	145	8.0	7
SDG9 Industry, innovation and infrastructure	20	149	7.45	8
SDG10 Reduced inequalities	1	15	15	1
SDG11 Sustainable cities and communities	22	287	13.0	11
SDG12 Responsible consumption and production	16	98	6.1	6
SDG13 Climate action	29	333	11.4	11
SDG14 Life below water	17	97	5.7	6
SDG15 Life on land	31	131	4.2	7
SDG16 Peace, justice and strong institutions	1	0	0	0
SDG17 Partnerships for the goals	2	57	28.5	2

DT: Document Type and SDG: Sustainable Development Goal.

- **Connecting research lines with CRHIAM's 4th strategic focus (Strict alignment with SDG Goals related to water access and quality for sustainable consumption and production)**

To determine the role of the center's research lines in SDG-related output, a detailed authorship analysis was required, under the assumption that each researcher represents one unique research line. Therefore, papers with co-authors from multiple lines are a result of a **multidisciplinary work.**

All research lines are represented in the SDG-linked publication set. RL4 and RL5 are major contributors, with similar output results and publications in twelve and fifteen of the total goals, respectively (Figure 73).

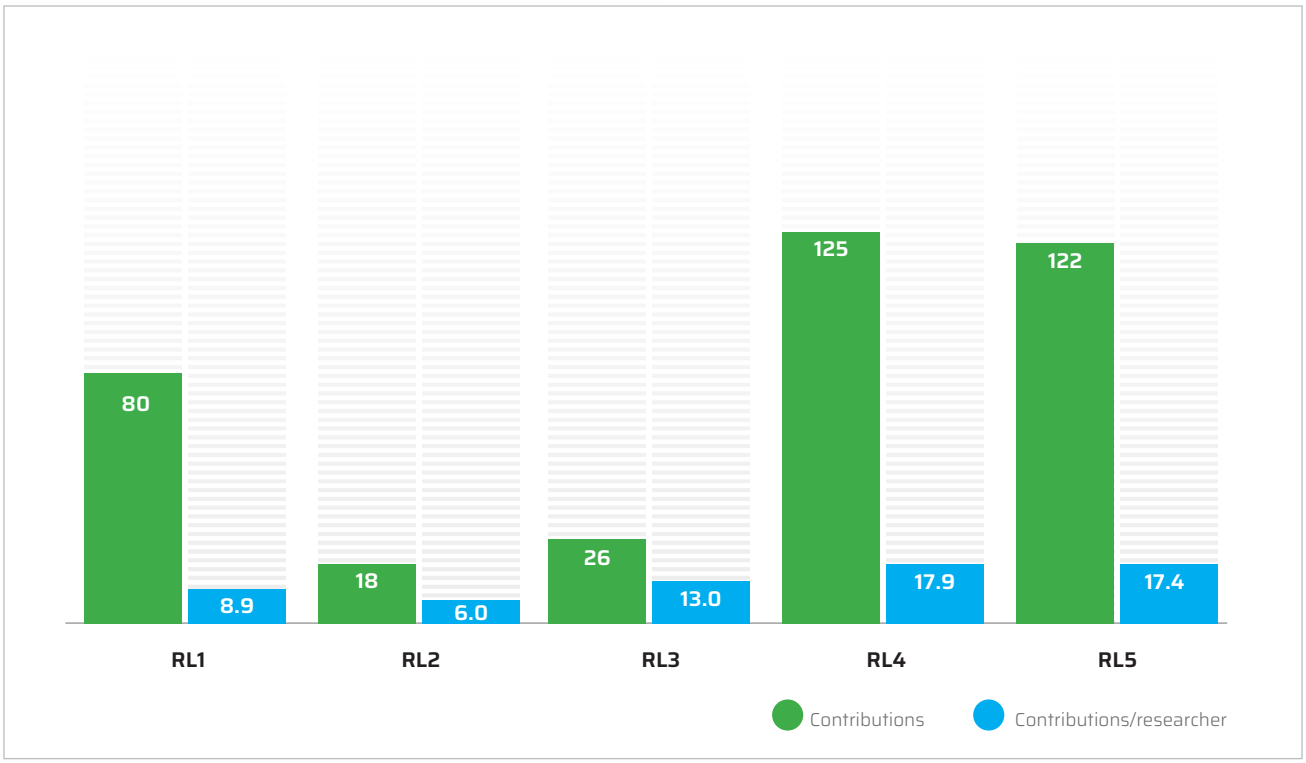


Figure 73. CRHIAM SDG-related Scopus research output by research line. RL: Research Line

• Multi- and interdisciplinarity

CRHIAM researchers are the main actors in developing interdisciplinary research in their different research lines.

This study also aims to quantify two types of collaboration between disciplines and peers: (i) multidisciplinary efforts to support SDGs (Figure 74) and (ii) interdisciplinary approaches among CRHIAM's researchers as part of these efforts (represented by scientific papers) (Figure 75).

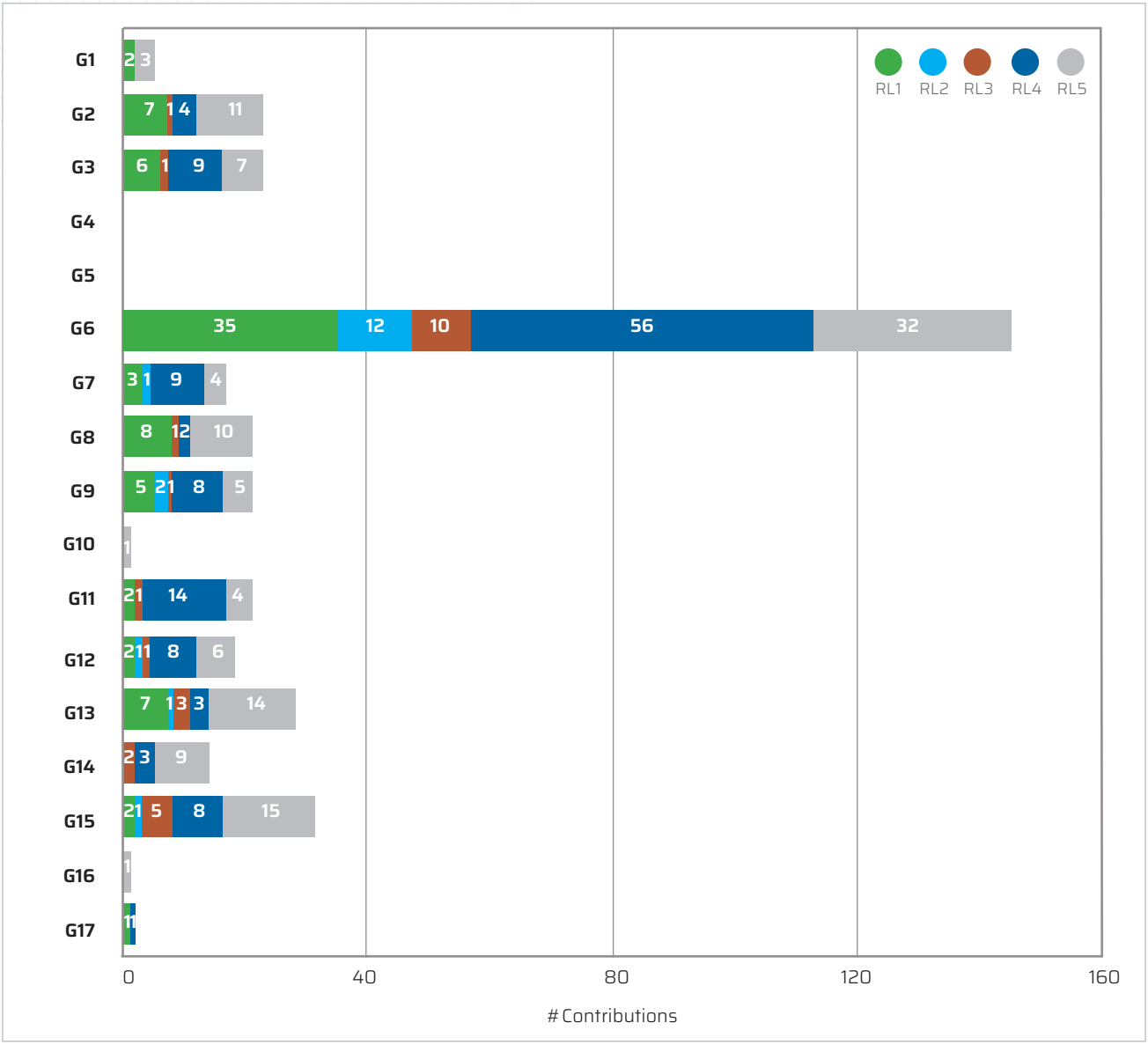


Figure 74. CRHIAM SDG-related Scopus research output by research line. RL: Research Line; G: Goal (Sustainable Development Goal).

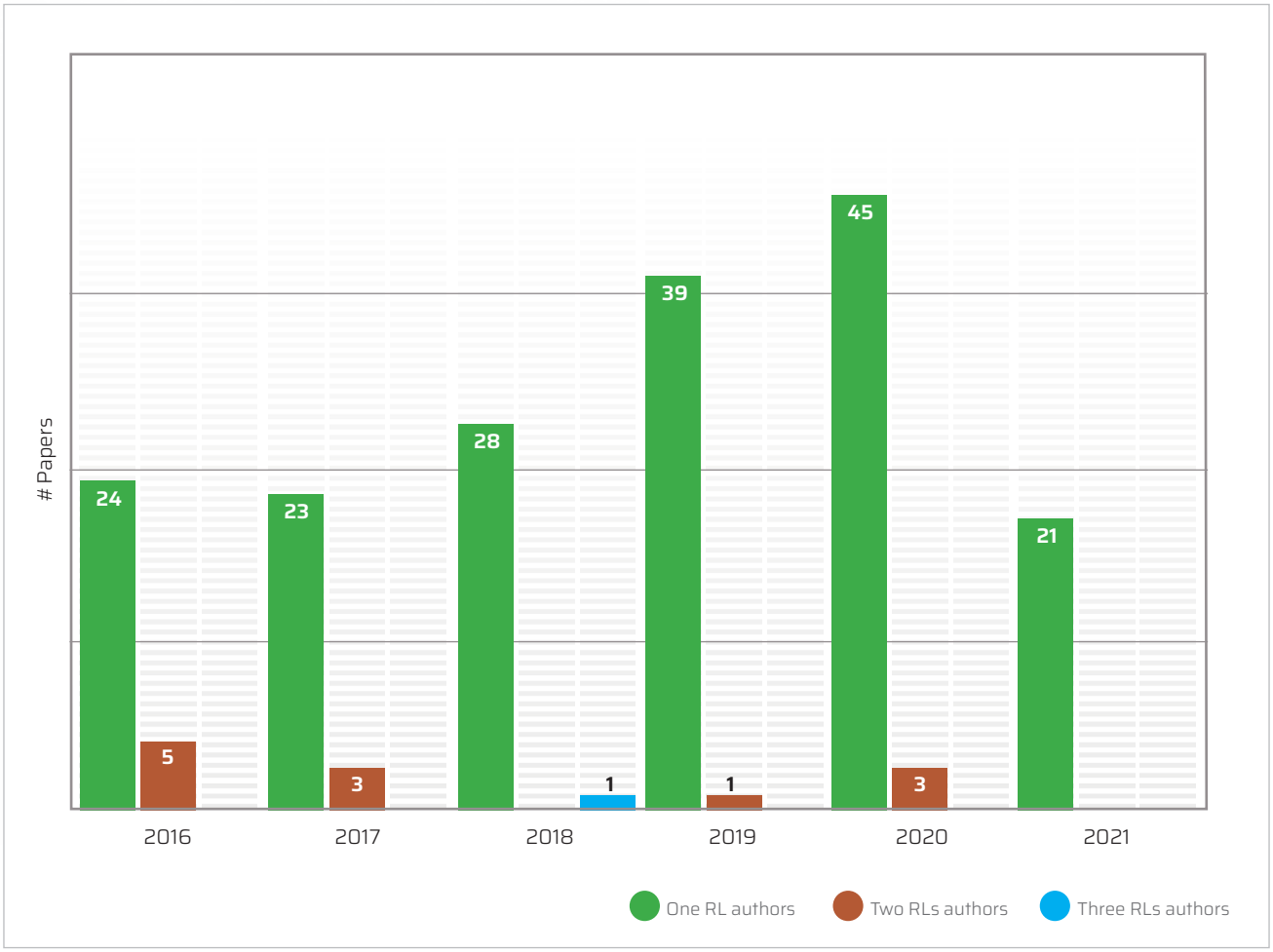


Figure 75. CRHIAM SDG-related research output. Interdisciplinary paper. RL: Research Line

8.2 Discussion

This study was carried out to assess how CRHIAM's research output supports one or more sustainable development goals. The results reveal that at least 47% of its scientific articles in Scopus-indexed journals are SDG-related, with an increasing number of results per year on these topics.

Therefore, and since "water security" is a core concept for CRHIAM and because "water" linkages between other proposed SDGs, wide contributions are expected as results, where achieving "water security" is vital to long-term sustainable development. This fact can be observed, every SDG has contributions from different research lines, confirming that CRHIAM main objectives (Research, People, Networking and Communications) are indeed supporting SDGs achievement. It bears mentioning that this study is limited in terms of coverage, given that the scientific publications indexed in WOS or Scopus do not represent all the efforts and documents published or disseminated by CRHIAM.

The center, as described on its web page, has published Communication Series issues, books and newsletters, among other documents. All of them aim to share interdisciplinary knowledge, studies and experiences on water resource management with the community and public or private decision-makers. These "other" publications have a lot to say within SDGs, especially targets related to SDG 6 such as Target 6.5: "By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate" and Target 6.a "Support and strengthen the participation of local communities in improving water and sanitation management".

Other CRHIAM publications, Science Education efforts and Outreach also contribute significantly to all specific SDG targets, with these activities aimed at bringing knowledge and expertise to people and communities. The center makes resources available through various media, including scientific talks and international webinars streamed on Facebook, podcasts, publications on the CIPER Foundation website, and information on several social media platforms with active followers (2,818 on Facebook, 1,350 on Twitter, 248 on YouTube, 1,848 on Instagram, 1,367 on LinkedIn and 1,848 in Spotify).

Interdisciplinary work among researchers is still a challenge. In spite of multi research lines approaches across CRHIAM's contributions to SDGs, authors from different research lines collaborated on only 5.7% of SDG-related papers.

To expand this analysis, it could be useful to study Scopus or WOS research publications not related to the goals and determine the main research topics addressed by them and how they affect the scientific community, society in general, and policy makers. In addition, explicitly labeling research relevant to SDG concepts, if applicable, could be an interesting tool to enhance research output visibility and thus its potential impact.

Another important issue is the possible difference between SDG-related output as considered in this report and research on SDGs; the latter incorporates SDG-related intention or direct links to the cores of SDGs (Bautista-Puig *et al*., 2021) by, for example, mentioning "Sustainable Development Goal" in the papers.

Last, but not least, SDG achievement is measured globally against various targets and indicators (United Nations, 2021). Some of them could be broken down to a local operational level in order to provide comprehensive knowledge on how Chile is impacting these quantitative indicators, identify local gaps and support direct research on SDGs to address them through CRHIAM's perspective.

8.3 Conclusions

CRHIAM has an outstanding research output, with 362 publications distributed among 15 goals, 4,730 citations, international collaboration on 63% of its publications, and at least 21 publications with 21 citations (h-index). It has also proven its capacity to head research projects, with a 51.1% leadership index of its output (over 34.4% in unrelated output).

The methodology of this study assumes that scientific outcome on each SDG can be assumed as an indicator for contribution of the respective SDG. The results suggest that CRHIAM is aligned with these challenges and contributes through its research output (225 scientific articles, 47.4% of its overall output) to fifteen of the seventeen goals.

There are three SDGs that CRHIAM committed to addressing for which it has not contributed related publications in Scopus or has only contributed 1 document: Quality education (Goal 4), Reduce inequalities (Goal 10) and Peace, justice and strong institutions (Goal 16). And not predicted but yet contributed, there are 4 goals (SDG3, SDG7, SDG8 and SDG14).

SDG 6 has the highest number of contributions, with 142 papers that garnered 1,127 citations from the scientific community (7.9 citation average, 17 h-index). Associative work between territories and affiliations is demonstrated.

Contributions to SDGs are made from multiple research lines, although according to the authorship analysis, each paper tends to be the result of work in a single discipline (94%). Improvements in this area can be made.

CRHIAM also has other types of publications and activities not covered in this study that are certainty contributing to the achievement of SDGs, including its diploma, outreach efforts and policy briefs.

9. ANNEXES

9.1 References, Research Projects, International and National Collaboration Projects and Some Details by Research Line

RL1. Efficient use of water in agriculture and mining

References

Betancourt F., Celi D., Cornejo P., del Río M., Macera L., Pereira A. and Rulyov N. 2020. Comparison of ultra-flocculation reactors applied to fine quartz slurries. Minerals Engineering 148: 106074.

Bürger R., Diehl S., Martí M.C. and Vásquez Y. 2020a. Flotation with sedimentation: Steady states and numerical simulation of transient operation. Minerals Engineering 157: 106419.

Bürger R., Diehl S., Martí M.C. and Vásquez Y. 2020b. Simulation and control of dissolved air flotation and column froth flotation with simultaneous sedimentation. Water Science and Technology 81: 1723-1732.

Bürger R., Diehl S., Martí M.C. and Vásquez Y. 2020c. A difference scheme for a triangular system of conservation laws with discontinuous flux modeling threephase flows. In preparation.

Bürger R., Diehl S., Martí M.C. and Vásquez Y. 2020d. On degenerate parabolic equations modeling froth flotation with drainage. In preparation.

Castillo I., Gutierrez L., Hernandez V., Díaz E. and Ramirez A. 2020. Hemicelluloses monosaccharides and their effect on molybdenite flotation. Powder Technology 373: 758-764.

Corporación Alta Ley. 2021. Minería Verde, Desafíos y Oportunidades (Green Mining, Challenges and Opportunities). Available at: https://corporacionaltaley.cl/wp-content/uploads/2021/05/2021_Mineria-Verde_Oportunidades-y-Desafios_version-ligera.pdf.

Concha F., Vergara T, Vergara M. and Pereira A. 2021. Effect of the air temperature on the filtration dewatering performance. Ref: MINE-D-21-00507. In Revision Minerals Engineering.

Daza J., Cornejo P., Rodríguez C., Betancourt F. and Concha F. 2020. Influence of the feed particle size distribution on roping in hydrocyclones. Minerals Engineering 157: 106583.

Flores N., Rodríguez R., Yépez S., Osores V., Rau P., Rivera D. and Balocchi F. 2021. Comparison of Three Daily Rainfall-Runoff Hydrological Models Using Four Evapotranspiration Models in Four Small Forested Watersheds with Different Land Cover in South-Central Chile. Water 13: 3191.

FONDEF ID18I10117. Title: "Aprovechamiento de residuos agrícolas y forestales para mejorar la eficiencia y sustentabilidad del procesamiento de minerales de Cu arcillosos a través de flotación (Utilization of agricultural and forestry residues to improve the efficiency and sustainability of clay Cu ore processing through flotation)". Director: Leopoldo Gutierrez.

García-Hidalgo M., García-Pedrero Á.M., Caetano-Sánchez C., Gómez-España M., Lillo-Saavedra M. and Olano J.M. 2021. MtreeRing: A Graphical User Interface for X-ray Microdensity Analysis. Forests 12: 1405.

Godoy-Faúndez A., Rivera D., Aitken D., Herrera M. and El Youssfi L. 2021. Circular Economy in a Water-Energy-Food Security Nexus Associate to an SDGs Framework: Understanding Complexities. In: Liu L., Ramakrishna S. (eds) An Introduction to Circular Economy. Springer, Singapore.

Gonzalo-Martín C., García-Pedrero A. and Lillo-Saavedra M. 2021. Improving deep learning sorghum head detection through test time augmentation. Computers and Electronics in Agriculture 186: 106179.

Gutierrez L. and Vega D. 2019. COPEC UC FUNDATION 2019.R.1150 "Tecnología BCR para mejorar la recuperación de Cu y Mo (BCR technology to improve Cu and Mo recovery)".

Gutierrez L., Betancourt F., Uribe L. and Maldonado M. 2020. Influence of Seawater on the Degree of Entrainment in the Flotation of a Synthetic Copper Ore. Minerals 10(7): 615.

Gutierrez L. 2017. Un reómetro para determinar en línea las propiedades reológicas de suspensiones minerales con contenidos de sólidos entre 20-70%, evitando los errores asociados a sedimentación de partículas (A rheometer for on-line determination of the rheological properties of mineral suspensions with solids contents between 20-70%, avoiding errors associated with particle sedimentation). Filed number CL201701274.

Gutierrez L. Proceso para la recuperación de cobre y molibdeno por flotación producto del procesamiento de minerales ricos en filosilicatos y minerales de arcilla (Process for the recovery of copper and molybdenum by flotation from the processing of minerals rich in phyllosilicates and clay minerals). Filed number 202003090.

Herrera M. and Godoy-Faúndez A. 2021. Exploring the roles of local mobility patterns, socioeconomic conditions, and lockdown policies in shaping the patterns of COVID-19 spread. Future Internet 13(5): 112.

Lecaros-Arellano F., Holzapfel E., Fereres E., Rivera D., Muñoz N. and Jara J. 2021. Effects of the number of drip laterals on yield and quality of apples grown in two soil types. Agricultural Water Management 248: 106781.

Lillo-Saavedra M., Gavilán V., García-Pedrero A., Gonzalo-Martín C., de la Hoz F., Somos-Valenzuela M. and Rivera D. 2021. Ex Post Analysis of Water Supply Demand in an Agricultural Basin by Multi-Source Data Integration. Remote Sensing 13(11): 2022.

Marino G., Zaccaria D., Lagos L.O., Souto C., Kent E.R., Grattan S. R., Shapiro K., Sanden B. and Snyder R. 2021. Effects of salinity and sodicity on the seasonal dynamics of actual evapotranspiration and surface energy balance components in mature micro-irrigated pistachio orchards. Irrigation Science 39(1): 23-43.

Matiatos I., Wassenaar L.I., Monteiro L.R., Venkiteswaran J.J., Gooddy D.C., Boeckx P., Sacchi E., Yue F.J., Michalski G., Hernández C., Biasi C., Bouchaou L., Edirisinghe N., Fadhullah W., Fianko J., García-Moya A., Kazakis N., Li S.L., Luu M., Priyadarshanee S., Re V., Rivera D., Romanelli A., Sanyal P., Tamooh F., Trinh D., Walters W. and Welti N. 2021. Global patterns of nitrate isotope composition in rivers and adjacent aquifers reveal reactive nitrogen cascading. Communications Earth & Environment 2(1): 1-10.

Moncada M., Toledo P., Betancourt F. and Rodríguez C. 2021. Torque Analysis of a Gyratory Crusher with the Discrete Element Method. Minerals 11: 878.

Maldonado M., Martinez J. and Gutierrez L. 2020. A Method to Predict Water Recovery Rate in the Collection and Froth Zone of Flotation Systems. Minerals 10(7): 630.

Pihl E., Alfredsson E., Bengtsson M., Bowen K.J., Broto V.C., Chou K.T., Cleugh H., Ebi K., Edwards C., Fisher E., Friedlingstein P., Godoy-Faúndez A., Gupta M., Harrington A., Hayes K., Hayward B., Hebden S., Hickmann T., Hugelius G., Ilyna T., Jackson R., Keenan T., Lambino R., Leuzinger S., Malmaeus M., McDonald R., McMichael C., Miller C., Muratori M., Nagabhatla N., Nagendra H., Passarello C., Penuelas J., Pongrats J., Rockstrom J., Romero-Lankao P., Roy J., Scaife A., Schlosser P., Schuur E., Scobie M., Sherwood S., Sioen G., Skovgaard J., Sobenes E., Sonntag S., Spangenberg J., Spijkers O., Srivastava L., Stammer D., Torres P., Turetsky M., Ukkola A., van Vuuren D., Voigt C., Wannous C. and Zelinka M.D. 2021. Ten new insights in climate science 2020–a horizon scan. Global Sustainability 4: 1-18.

Ramirez A., Gutierrez L. and Laskowski J. 2020a. Use of “oily bubbles” and dispersants in flotation of molybdenite in fresh and seawater. Minerals Engineering 148: 106197.

Ramirez A., Gutierrez L., Vega-Garcia D. and Reyes-Bozo L. 2020b. The Depressing Effect of Kaolinite on Molybdenite Flotation in Seawater. Minerals 10(6): 578.

Rivas Y., Retamal-Salgado J., Knicker H., Matus F. and Rivera D. 2021. Neutral Sugar Content and Composition as a Sensitive Indicator of Fire Severity in the Andisols of an Araucaria-Nothofagus Forest in Southern Chile. Sustainability 13: 12061.

Uribe L., Gutiérrez L., Laskowski J. and Castro S. 2017. Role of calcium and magnesium cations in the interactions between kaolinite and chalcopyrite in seawater. Physicochemical Problems in Mineral Processing 53(2): 737-749.

Valdivia W., Bustamante L., Jara J., Fischer S., Holzapfel E. and Wilckens R. 2021. Effect of Soil Water Availability on Physiological Parameters, Yield, and Seed Quality in Four Quinoa Genotypes (Chenopodium quinoa Willd.). Agronomy 11(5): 1012.

Vega-Garcia D. and Gutiérrez L. 2021. Small hydrocyclones for removal of ultra-fine particles from clarified water in mineral processing. WATER CONGRESS 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Chile.

Yepsen R. and Gutierrez L. 2020. Effect of Eh and pH on the flotation of enargite using seawater. Minerals Engineering 159: 106612.

RL2. New water sources for agriculture, mining, and communities

References

Achim C.V., Rozas R.E. and Toledo P.G. 2021. Semi-decoupled first-order correction for smoothed particle hydrodynamics. Applied Mathematical Modelling 93: 314-325.

Alvarado O. 2021. In search of a selective collector of lithium-rich spodumene in saltwater: Taking advantage of quantum chemistry calculations and molecular dynamics simulations. 2021 CRHIAM Postdoctoral position.

Contreras J. 2021. Undergrad thesis (ongoing). Bubble coalescence in aqueous solutions of frothers and electrolytes. (Supervisors: Saavedra, J.H., Toledo, P.G.).

Cruz C., Botero Y.L., Jeldres R.I., Uribe L. and Cisternas L.A. 2021. Current status of the effect of seawater ions on copper flotation: Difficulties, opportunities, and industrial experience. Mineral Processing and Extractive Metallurgy Review 1-19.

García K., Quezada G., Arumí J., Urrutia R. and Toledo P. 2021. Adsorption of phosphate ions on the basal and edge surfaces of kaolinite in low salt aqueous solutions using molecular dynamics simulations. The Journal of Physical Chemistry C 125(38): 21179–21190.

García K. 2021. A sustainable alternative to reduce excess nutrients, salts and metals in lake and irrigation waters. Doctoral thesis in progress (registered on 16-04-2021) (Supervisors: Arumí, J.L., Toledo, P.G.).

Gutiérrez L., Echeverry L., Estrada D. and Toledo P.G. 2021. The effect of an anionic polyacrylamide on molybdenite flotation and the importance of polymer anionicity.Colloids and Surfaces A 629: 127506.

Hermosilla C. 2021. Undergrad thesis (ongoing). Construction and testing of a fluidized bed for mineral particle separation. (Supervisors: Toledo, P.G., Saavedra, J.H.).

Jeldres M., Ayala L., Robles P., Gálvez E., Leiva W.H., Toledo P.G. and Jeldres R.I. 2021a. A Criterion for Estimating the Strength of Flocculated Aggregates in Salt Solutions. Minerals 11: 713.

Jeldres M., Robles P., Toledo P.G., Saldaña M., Quezada L. and Jeldres R.I. 2021b. Improved dispersion of clay-rich tailings in seawater using sodium polyacrylate. Colloids and Surfaces A: Physicochemical and Engineering Aspects 612: 126015.

Leiva W., Toro N., Robles P., Gálvez E. and Jeldres R.I. 2021a. Use of multi-anionic sodium tripolyphosphate to enhance dispersion of concentrated kaolin slurries in seawater. Metals 11: 1085.

Leiva W.H., Fawell P.D., Goñi C., Toro N. and Jeldres R.I. 2021b. Temporal evolution of the structure of tailings aggregates flocculated in seawater. Minerals Engineering 160: 106708.

Quezada G.R. 2021. ANID FONDECYT 3200978

Quezada G.R. and Toledo P.G. 2021. Complexation of alkali and alkaline-earth metal cations at spodumene-saltwater interfaces by molecular simulation: Impact on oleate adsorption. Minerals 11: 1-11.

Quezada G.R., Jeldres M., Toro N., Robles P., Toledo P.G. and Jeldres R.I. 2021a. Understanding the flocculation mechanism of quartz and kaolinite with polyacrylamide in seawater: A molecular dynamics approach. Colloids and Surfaces A-Physicochemical and Engineering Aspects 608:125576.

Quezada G.R., Rozas R.E. and Toledo P.G. 2021b. Polyacrylamide adsorption on (101) quartz surfaces in saltwater for a range of pH values by molecular dynamics simulations. Minerals Engineering 162: 106741.

Quezada G.R., Piceros E., Robles P., Moraga C., Gálvez E., Nieto S. and Jeldres R.I. 2021c. Polyacrylic acid to improve flotation tailings management: Understanding the chemical interactions through molecular dynamics. Metals 11: 987.

Rozas R.E., MacDowell L.G., Toledo P.G. and Horbach J. 2021. Crystal growth of bcc titanium from the melt and interfacial properties: A molecular dynamics simulation study. Journal of Chemical Physics 154: 184704.

Saavedra J.H., Sobrevía F.E., Quezada G.R. and Toledo P.G. Coalescence time of bubbles in aqueous solutions of frothers with electrolytes (submitted).

Solar C. 2021. Undergrad thesis (ongoing). Artificial vision for the analysis of bubble coalescence in dynamic processes. (Supervisors: Saavedra, J.H., Toledo, P.G.).

Toledo P.G., Rozas R.E., Saavedra J.H., Quezada G.R. and Gutiérrez L. ¿Sal o no sal? Esa es la cuestión en procesos con agua salada (Salt or not salt? That is the question in processes with salt water). Serie Comunicacional CRHIAM, in the press.

Veloso R. 2021. Undergrad thesis (ongoing). Literature review of bubble coalescense. (Supervisors: Toledo, P.G., Saavedra, J.H.).

Yepsen R., Roa J., Toledo P.G. and Gutiérrez L. 2021. Chalcopyrite and Molybdenite Flotation in Seawater: The Use of Inorganic Dispersants to Reduce the Depressing Effects of Micas. Minerals 11(5):539.

RL3. Water availability and quality for agriculture and mining amid climate change

References

Balocchi F., Flores N., Arumí J.L., Iroumé A., Silberstein R. and Ramírez de Arellano P. 2021. Comparison of streamflow recession between plantations and native forests in small catchments in Central-Southern Chile. Hydrological Processes 35: e14182.

Boll J., Fremier A., Padowski J., Stone M. and Walsh-Dilley M. 2018. Project CNH-RCN: A research network for the resilience of headwater systems and water availability for downstream communities across the Americas. NSF-CNH 133635. Duration: Nov 2018-Oct 2022.

Castillo D. and Oyarzún R. 2021. Modelación preliminar del transporte de metales pesados en la cuenca alta del Elqui (Preliminary modeling of heavy metal transport in the upper Elqui river basin). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Collazo A., Rivera-Ruiz D., Rodríguez-López L., Pedreros P., Arumí-Ribera J.L., Morales-Salinas L., Fuentes-Jaque G. and Urrutia R. 2021. Evidence of Climate Change Based on Lake Surface Temperature Trends in South Central Chile. Remote Sensing 13(22): 4535.

Díaz N. and Oyarzún R. 2021. Análisis de potenciales factores determinantes de la disponibilidad de aguas subterráneas en la cuenca del estero Punitaqui, Región de Coquimbo (Analysis of potential determinants of groundwater availability in the Punitaqui estuary basin, Coquimbo Region). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Fagel N., Pedreros P., Alvarez D., Tylmann W., Namur O., Da Silva A.C., Jana P., Araneda A., Billy I., Schmidt S. and Urrutia R. 2021. Last millennium climate variability of the varved Lake Jeinimeni geochemical record from NE Chilean Patagonia. Quaternary Science Reviews 269: 107134.

Hernández V. and Oyarzún R. 2021. Relaciones caudal-concentración de la cuenca del Río Choapa: análisis histórico y proyecciones (Flow-concentration relations of the Choapa River basin: historical analysis and projections). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Núñez V. and Oyarzún R. 2021. Análisis de la evolución temporal del almacenamiento subterráneao de cuencas hidrográficas de los ríos Elqui, Choapa y La Ligua, Chile (Analysis of the temporal evolution of groundwater storage in the Elqui, Choapa and La Ligua river basins, Chile). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Olivares E., Aguilera R. and Oyarzún R. 2021. El caso de la Laguna de Aculeo: Un análisis hidrológico-ambiental bajo el enfoque de dinámica de sistemas (The case of the Aculeo Lagoon: A hydrological-environmental analysis under the system dynamics approach). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Oyarzún J., Maturana H., Paulo A., Lillo J., Pastén P., Núñez J., Duhalde D., González C., Portilla A. and Oyarzún R. 2021a. Environmental Aspects of a Major ARD Source at El Indio Au-Cu-As District, North-Central Chile. Mine Water and the Environment 1-15.

Oyarzún R., Carvajal R. and Rojas M. 2021. Evaluación de herramientas de apoyo para la implementación de normas de calidad ambiental en Chile (Evaluation of support tools for the implementation of environmental quality standards in Chile). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Molenaar A., Vandorpe T., Degenhart G., De Batist M., Urrutia R., Pino M., Strasser M. and Moernaut J. 2021. What controls the remobilization and deformation of surficial sediment by seismic shaking? Linking lacustrine slope stratigraphy to great earthquakes in South-Central Chile. Sedimentology 1-32.

Montes I., Banegas-Medina A., Fagel N., El Ouahabi M., Verleyen E., Alvarez D., Torrejón F., Schmidt S., Lepoint G., Diaz G., Pedreros P. and Urrutia R. 2021. Late Holocene Paleonvironmental Evolution of Two Coastal Lakes in Mediterranean Chile and Its Implications for Conservation Planning. Applied Sciences 11(8):3478.

Portuguez-Maurtua M., Arumi J.L., Lagos O. and Stehr A. Uso de técnicas de machine learning en relleno de series de precipitación faltante (Use of machine learning techniques in missing precipitation series filling). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Rodriguez-López L., Duran-Llacer I., González-Rodríguez L., Cardenas R. and Urrutia R. 2021a. Retrieving Water Turbidity in Araucanian Lakes (South-Central Chile) Based on Multispectral Landsat Imagery. Remote Sensing 13(16): 3133.

Rodriguez-López L., González-Rodríguez L., Duran-Llacer I., Cardenas R. and Urrutia R. 2021b. Spatio-temporal analysis of chlorophyll in six Araucanian lakes of Central-South Chile from Landsat imagery. Ecological Informatics 65:101431.

Rojas C. and Oyarzún R. 2021. Análisis crítico del uso de modelos de aguas subterráneas en estudios de impacto ambiental en Chile (Critical analysis of the use of groundwater modeling in environmental impact studies in Chile). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

Rossi C., Oyarzún J., Pastén P., Runkel R.L., Núñez J., Duhalde D., Maturana H., Rojas E., Arumí J.L., Castillo D. and Oyarzún R. 2021. Assessment of a conservative mixing model for the evaluation of constituent behavior below river confluences, Elqui River Basin, Chile. River Research and Applications 37(7): 967-978.

Urrea P. and Oyarzún R. 2021. Análisis del uso actual y potencial de herramientas isotópicas para estudios hidrológico-ambientales en Chile, con énfasis en la actividad minera (Analysis of the current and potential use of isotopic tools for hydrological-environmental studies in Chile, with emphasis on mining activity). Water Congress 2021, 9th International Congress on Water Management in Mining and Industrial Processes. Santiago, Chile.

RL4. Technology for water treatment and environmental remediation

Some details

RL4 research topics. The main forces that drive this line of research in order to connect "water and the environment" through technology are: i) Circular economy: from recovery to reuse, ii) Technologies: wastewater treatment by conventional and non-conventional technologies, advanced membrane process for water treatment/reclamation, and nanotechnology, iii) Technology strategies for pesticide biodegradation using biopurification systems and their adaptation for industrial wastewater treatment and iv) Sustainable management of the rhizosphere for soil-water remediation.

-Circular economy: from recovery to reuse

Resource recovery. Agriculture is an activity that has a high impact on the economic development of Chile. Given the country's water shortage, it is necessary to take advantage of available unconventional water resources such as urban wastewater. *Pseudomonas* sp. strain ABC1, a new bacterium discovered in Chile, is capable of both removing organic matter from wastewater and simultaneously generating siderophores, compounds that are plant growth promoters (Valenzuela-Heredia *et al.,* 2021a). Therefore, its application in urban wastewater treatment will make it possible to obtain water with an appropriate quality for reuse in agriculture and that contains siderophores, providing a double benefit for agricultural activities. Water scarcity is becoming a global challenge amid attempts to narrow the water demand-supply gap. To overcome this problem, it is sensible to consider alternative technologies that can exploit non-conventional water resources; however, the choice of such technologies should be carefully analyzed because any choice might be unfeasible in economic terms. In this context, a methodology to select the more appropriate non-conventional water

resource, out of municipal wastewater and seawater, was developed (Crutchik and Campos, 2021). The results showed that the reuse of municipal wastewater represents a cost-competitive alternative to seawater desalination, mainly when municipal wastewater is treated in a conventional WWTP and when water flow demand is higher than 1,500 m^3/d. In contrast, when the treatment of municipal wastewater is based on the use of submarine outfalls, seawater desalination becomes more profitable than wastewater reuse to produce water flow rates lower than 70,000 m^3/d.

Reuse. Global crop production is limited by water, nitrogen, and phosphorous availability. Reclaimed water and organic fertilizers such as crop residues, animal manure, and biosolids can mitigate these needs. However, these materials may contain different pollutants arising from, among other sources, human and veterinary health care, industry, cleaning media and leakages from plastics or textiles. Risk assessment analyses of the contaminants of emerging concern – CEC – present in soils and water bodies have been mainly focused on their consequences for human and environmental health, but there has been very little focus on their potential negative effects on crop performance and quality. RL4 published a review entitled "Compounds of emerging concern as new plant stressors linked to water reuse and biosolid application in agriculture", which presents current knowledge on macroscopic and molecular plant responses to the presence of several CECs known to abound in reclaimed waters, manure, and biosolids, with particular emphasis on crop plants, when available. With this information, and with the analysis of the potential implications of scaling these effects to the commercial agriculture level, we intend to contribute to the ongoing debate on water reuse and biosolid application in agriculture in a circular economy context (Mansilla *et al.,* 2021). Although the reuse of treated wastewater has been considered a suitable alternative for agriculture and for achieving water security and management, the practice may contribute to the dissemination of antibiotic resistance genes into the environment, a matter of global concern. Leiva *et al.* (2021a) studied the reuse of treated wastewater in agriculture under the perspective of the risks associated with ARG dissemination. The study shows the reduction of antibiotic resistance genes loads in conventional, non-conventional, and advanced treatments. Regarding the distribution of antibiotic resistance genes in crops and soil irrigated by treated wastewater, higher abundances were observed in soil than in edible parts of crops. The occurrence of ARGs in crops may represent a significant source of human exposure to antibiotic resistance gene-harboring bacteria, and therefore, a potential human health risk that requires the establishment of safe procedures and legislation to assure safe reuse of treated wastewater (Leiva *et al.*, 2021a). In addition, the presence and fate of micropollutants during anaerobic digestion of sewage and their implications for the circular economy were evaluated in a short review. It was found that anaerobic digestion is an attractive technology to "close the loop" because this system is focused on maximizing the reuse of resources and minimizing their depreciation through the reuse of biogas and the land disposal of biosolids. Despite the benefits for soil properties, this sewage sludge contains different micropollutants such as pharmaceuticals and personal care products, per- and polyfluoroalkyl substances, metallic trace elements, and polycyclic aromatic hydrocarbons, which are associated with negative effects for human health and the environment. Owing to micropollutant detection and treatment difficulties, concentration reduction the source needs to be emphasized through legislation, restricting the environmental release of the compounds, and public awareness. Despite progressive developments in conventional and advanced anaerobic digestion, significant limitations still exist. Future research must obtain biosolids with physical and chemical properties for reusability as a soil amendment but without biological activity due to MPs in order to end the cycle sustainably (Venegas *et al.,* 2021).

Technologies: wastewater treatment by conventional and non-conventional technologies and advanced membrane process for water treatment/ reclamation

Conventional wastewater treatment. Aerobic granulation is currently one of the most promising techniques for wastewater treatment due to its advantages over conventional treatment systems, especially when nutrient removal is required. However, the instability of granular biomass during prolonged operational periods still hinders the optimization and large-scale application of aerobic granular sludge systems. In this sense, it was found that the fractal dimension of the granules could be a useful parameter for monitoring their status. Indeed, an increase in its value during the maturation or steady-state granulation stages is an early warning of disintegration episodes. A control strategy to maintain granule integrity based on this parameter can be proposed (Pavissich *et al.*, 2021). Partial nitritation and anammox processes (PN/A) are the most economic option to remove nitrogen from effluents with low C/N ratios (Bonassa *et al.,* 2021). Nevertheless, there are still several limitations that are preventing widespread application of PN/A processes in urban WWTPs, such as: a) the loss of performance stability of the PN/A units operated at the sludge line when the sludge is thermally pretreated to increase biogas production and b) the proliferation of nitrite oxidizing bacteria (NOB) in the mainstream. In WWTPs whose sludge is thermically hydrolyzed, the implementation of a two-stage PN/A unit instead of the conventional one-stage units can improve the performance of nitrogen removal and increase the treated ammonia loading rate (Valenzuela-Heredia ***et al.***, 2021b). In order to apply the PN/A process in the mainstream, the growth of ammonia-oxidizing bacteria (AOB) should be promoted in the sludge line by supplying extra sludge to the anaerobic digesters. The generated AOB would be applied to the water line to partially oxidize ammonia and then the anammox process would be carried out. Excess nitrate generated by anammox bacteria and/or NOB can be removed by recycling a fraction of the WWTP effluent to the biological reactor to promote its denitrification (Pedrouso *et al.*, 2021).

Non-conventional technologies: Green technologies or nature-based solutions (NBS) for wastewater treatment in rural communities and reuse for local agriculture.

Constructed wetlands (CW) meet these conditions and will be studied under various engineering configurations (surface-, horizontal subsurface- and vertical subsurface-flow CW). In particular, phosphorus retention by plants such as Schoenoplectus californicus and Phragmites australis was evaluated in a pilot-scale system composed of four horizontal subsurface flow (HSSF) wetlands during long-term operation (2833 days in total). Average biomass production of CW planted with *Phragmites australis* and *Schoenoplectus californicus* was 4.8 and 12.1 kg dry weight/m^2, respectively. The phosphorus uptake by the plant increased over the years of operation from 1.8 gP/m^2 to 7.1 gP/m^2 for *Phragmites* and from 3.2 to 7.4 gP/m^2 for *Schoenoplectus* over the same periods. Moreover, efficiency was greater during the warm season, reaching 14% P uptake, compared to 9% in the cold season. These results suggest that both plants' P retention capacity in HSSF systems represents a sustainable treatment in the long term (Carrillo ***et al.***, 2021).

In addition, the influence of water quality parameters on the removal micropollutants such as triclosan and ibuprofen in vertical subsurface flow constructed wetlands was evaluated. The effects of the wetland planted with *Agapanthus*

africanus and the other unplanted wetland were also evaluated. The results show that triclosan and ibuprofen removal efficiencies in vertical subsurface flow constructed wetlands systems were found to vary between 60%–85% and 50%–84%, respectively. Regarding the effects of water quality parameters on triclosan and ibuprofen removal, a principal component analysis showed that triclosan removal has a strong association with oxidation–reduction potential (Leiva *et al.,* 2021b). Ana María Leiva and Valentina Carrillo are working on a PhD dissertation in the line of research of green technology. To improve NBS performance a constructed wetland connected to microbial fuel cell was used. Microbial fuel cells integrated into constructed wetlands have been studied previously. Nevertheless, their application as a suitable treatment for wastewater is still in the developmental stage. In this context, the aim of this study was to evaluate organic matter removal and nitrogen transformation by a microbial fuel cell integrated into a constructed wetland. The results show that wastewater treatment performance was improved due to anaerobic oxidation that occurred on the anodes. With respect to the performance of microbial fuel cells, the maximum power density (8.6 mW/m^2) was achieved at an organic loading rate of 7.9 g chemical organic demand /m^2 d with an internal resistance and coulombic efficiency of 251 Ω and 2.4%, respectively. The results obtained in this work can have positive impacts on CW development by enhancing anaerobic degradation without forced aeration (González *et al*., 2021).

Advanced membrane process for water treatment/reclamation. During the last 3 decades, membrane technology has played an important role in the development and applications of processes for (waste)water treatment and resources reclamation. Membranes have been used both as a post-treatment for more classical technologies and in combination with chemical and/or biological transformation operations. During the last few years, research has been conducted on the development of forward osmosis (FO) as an alternative for high-quality water reclamation from wastewater of different origins. This year research was published on the use of forward osmosis/reverse osmosis for micropollutant removal (D'Haese *et al.,* 2021). FO has been also studied as an alternative to recover water during mining operations, specifically from acid mine drainage. The paper recently published by Cabrera-Castillo ***et al.*** (2021) addresses the use of membrane distillation in combination with forward osmosis, including an economic assessment of this alternative. Membranes can also be used in combination with biological processes, for biomass retention, and/or clarification. As stated in previous reports, significant research efforts have been focused on the use of algal-bacterial consortia in combination with membranes. Development during the pandemic has enabled the restart of experimental assays on the subject, with 2 50 L reactors currently operating. Work has also been done during 2021 on the development of a mathematical model describing membrane-assisted alga-bacterial consortia for sewage treatment. The model is being used to determine the fate of carbon, nitrogen and phosphorus during the process. Work is being carried out as part of a collaboration with Dr. Olivier Bernard from INRIA (France) in the context of a joint cooperation project (Blue Edge, Programme Equipes Associées, INRIA). A manuscript containing results is expected to be ready for submission by the end of the year. The MSc thesis of Crouchett and Rojo and the PhD of Arango are dedicated to this field of research. Membranes can be used not only for filtration of water suspensions, but also as a tool for dosing chemicals when treating wastewaters by biological means. For example, membranes have been used to control oxygen dosage in different biotechnological applications. In the paper of Valdés *et al.* (2020) membranes are used for micro-oxygenation of UASB reactors. This process enables the in-situ oxidation of sulfides, producing two clear benefits when anaerobic digestion is applied to wastewater treatment: reduction of sulfide content in the biogas, facilitating its use as a source of renewable energy; and reduction of dissolved sulfides, enhancing treated water quality and preventing drawbacks associated with problematic odors during the treatment process.

Improving sanitation practices. Research was conducted on the combination of thermal pretreatments with anaerobic digestion of sludge in sewage treatment plants. Several researchers have identified the formation of recalcitrant compounds during thermal pretreatments, which can affect sludge digestion and the production of colored effluents. The PhD dissertation of Ortega-Martínez was dedicated to the study of this issue. The paper of Ortega-Martínez *et al.* (2021), published this year, is one of the outcomes of that thesis.

Advanced nanotechnology for recovery of water for mining and agriculture and other applications. Metal nanoparticles for applications in medicine, wastewater treatment and the generation of value-added products have been synthetized using biological and chemical methods (Araya-Castro *et al.,* 2020; Cisternas ***et al.***, 2021, Cisternas, 2021; Fincheira ***et al.***, 2021a,b; Hermosilla ***et al.***, 2021; Herrera, 2021; Tortella *et al.*, 2021; Vera, 2021). Studies by Cisternas *et al.* (2021) demonstrated a new biomimetic method for the synthesis of silver nanoparticles based on fungal metabolites; it is a biocompatible, ecofriendly and fast method to produce silver nanoparticles with antimicrobial activity against human and plant pathogens. It was also possible to produce silver nanoparticles on a larger scale in a reactor, which is a great advance in terms of their production (FONDECYT 1191089, Figueroa, 2021). Similarly, Araya-Castro *et al.* (2021) demonstrated green synthesis of copper oxide nanoparticles using protein fractions from an aqueous extract of brown Algae *Macrocystis pyrifera,* which may also provide a suitable tool to synthesize other nanoparticles of commercial interest. Meanwhile, in the studies of Herrera (2021), the synthesis of superparamagnetic iron oxide nanoparticles (SPIONS) doped with metal oxides nanoparticles (TiO_2 and ZnO) has been effectively developed to later apply them to the transformation of the pesticides imidacloprid and chlorpyrifos in aqueous solution. Similarly, studies performed by Vera (2021) are aimed at evaluating the biogenic synthesis of Fe_3O_4@SiO_2@ZnO nanoparticles for depolymerization of kraft lignin in a photoreactor and to obtain value-added products. The results obtained in this research demonstrated that aqueous leaf extract with a higher amount of phenolic compounds (such as tannins, flavonoids, saponins and terpenoids) and good antioxidant activity is the best candidate for the formation of ZnO and magnetic iron oxide nanoparticles and the natural compounds of the extract were used as a capping agent for their functionalization. In addition, the obtainment of biogenic silica (SiO_2) nanoparticles by calcination of acid pretreated wheat straw also was developed. Likewise, different metallic nanoparticles were synthesized through plant extracts such as $MnFe_2O_4$@Ag-NPs, Ag-NPs, and Cu-NPs to be embedded in garlic and eucalyptus essential oil to evaluate their antimicrobial activity against the phytopathogenic bacterium Pseudomonas syringae. The results showed that the antimicrobial activity of the nanoparticles in essential oils was increased and was higher for the silver nanoparticles in garlic oil. These results make it possible to propose a form of application of these nanoparticles in agricultural crops, reducing the use of pesticides that can accumulate in the environment due to their excessive use (CONICYT-FAPESP 2018/08194-2). In another aspect of our research, Hermosilla *et al.* (2021) proposed a novel spectrophotometric assay for determining the oxidase-like activity of manganese ferrite nanoparticles ($MnFe_2O_4$ NPs) based on the oxidative coupling of 3-methyl-2-benzothiazolinone-hydrazone (MBTH) and 3-(dimethylamino) benzoic acid (DMAB). The results open a wide range of new potential applications in the development of more sensitive sensors based on the MBTH/DMAB reaction catalyzed by $MnFe_2O_4$ NPs to detect several analytes (including alkaline phosphatase, heavy metals and dissolved oxygen in water, among others) in the medical and environmental fields.

Increasing sustainability of mining operations. Precipitation phenomena induced by microorganisms have shown interesting potential for addressing several environmental issues associated with mining operations. Microbial-induced

calcite precipitation has been studied as a way to promote heavy metal removal from mining wastewater. The paper of Sepúlveda *et al.* (2021), recently accepted for publication, deals with the selection of suitable microorganisms to promote this process. Work is also being conducted on the testing of calcite bioprecipitation (biocementation) to control dust-blown emissions from tailing deposits. This is the subject of the PhD thesis of Zúñiga. Work will soon be presented at a tailings conference in Chile and a review on the potentials of the technology is expected to be submitted during 2021.

Sustainable management of the rhizosphere for soil-water remediation, efficient water use and agricultural production. This research topic includes biotechnological aspects that consider the use of microorganisms with plant growth promotion potential to favor bioremediation processes in contaminated soils and waters, as well as their use to enhance plant growth under conditions of water stress (drought and salinity). This research has undergone significant growth due to the impact of the deleterious consequences of the current climate emergency for water availability and food production. In Chile, this situation is especially alarming, since it is among the top 20 countries with the highest water deficits. Moreover, the high degree of degradation of productive soils and the large number of sites with the presence of pollutants highlight the urgent need to consider these environmental issues in the development of public policies, as well as in the new Chilean constitution that is currently being written (Cornejo, 2021). To facilitate access to this information and alternatives for soil and water management, a Communication Series volume based on our scientific experience was produced, which includes the use of mycorrhizal fungi as a biotechnological tool to face the problems generated by climate change (Santander *et al.*, 2021b), especially aimed at plant production in conditions of drought and salinity. This work was also deepened on a regional scale with the first description of the mycorrhizal status of the native flora present in the different altitudinal belts of the Atacama Desert in Tarapacá, northern Chile (Santander *et al.*, 2021c). These issues are also the focus of the FONDECYT projects in which members of the RL currently participate, in which the use of mycorrhizal fungi and other beneficial microorganisms to face drought and the low availability of nutrients in agricultural soils of southern Chile is covered (FONDECYT 1170264, FONDECYT 1191551, FONDECYT 1190585, FONDECYT 1210964). These investigations generated important advances in the knowledge of the molecular pathways through which mycorrhizal plants cope with saline stress, especially by modulating aquaporin genes and ionic channels, which maintain or improve cellular homeostasis (Santander *et al.*, 2021a), the existence of a genotypic interaction between plants and ecotypes of mycorrhizal fungi that increases nutrient use efficiency through root modifications (de Souza Campos *et al.*, 2021) and the role of mycorrhizal fungi in the nutritional quality of wheat grains by promoting the presence of antioxidant compounds in grains of plants grown under drought conditions (Nahuelcura *et al.,* 2021).

In addition, in the InES19 (UFRO) program, a proposal for the development of the area of climate change and sustainability as an institutional pillar of research was obtained, with the participation of Drs. Cornejo (Director) and Rubilar (Co-researcher), which will promote multidisciplinary interaction among various research lines, including nanotechnology, waste management, mitigation of climate change effects and healthy food production.

Regarding the formation of advanced human capital, the several doctoral dissertations were completed. Vidal (2021) addressed the characterization of the bioremediation effects of soils contaminated with Cu by Imperata cylindrica and Ávila-Salem (2021) studied the effects of agronomic management in production systems on Andean soils from the highlands of Ecuador. In addition, the final stage of the dissertation of Pérez (2021) is addressing the sustainable management of tailings using metallophytes; of special interest is the use of microorganisms that promote plant

growth and organic amendments. Regarding the scientific results of these dissertations, in the first of them the bioaccumulation response of I. cylindrica was analyzed, as well as its metabolic response, leading to the conclusion that it is an ideal plant species candidate for Cu phytostabilization processes given the high accumulation of this pollutant in roots (Vidal *et al.,* 2020), which was deepened at the transcriptomic level, highlighting an important cytoskeleton response suggesting an important role in plant tolerance and Cu accumulation in the roots (Vidal *et al.*, 2021). In the case of Dr. Ávila-Salem's dissertation, interesting results were obtained for adoptions of sustainable management practices (no tillage, rotation) for crops in tropical environments, which also means a strong contribution to the generation of international networks. These networks allowed the generation of important scientific products such as the article by Ávila-Salem *et al.* (2020) and subsequently the first finished thematic review on the use of bioproducts in coffee production, which is one of the most important crops worldwide (Urgiles-Gómez *et al.,* 2021). Meanwhile, the dissertation of Dr.(c) Pérez generated interesting results; a clear additive effect of the use of inoculants with mycorrhizal fungi and the use of compost allowing the growth of Oenothera picensis in acid Cu mine tailings was observed, allowing a sharp decrease in the toxicity of metals in the soil (Pérez *et al.*, 2021). In addition, a comprehensive review on the potential use of soil microorganisms that promote plant growth and amendments for the stabilization of mining tailings was produced (Pérez *et al.*, 2021b). Finally, Aponte *et al.* (2021) reported on the application of an important tool based on enzymatic biological indicators to evidence the quality of soils that have been affected by the deposit of toxic elements in the Puchuncaví Valley, central Chile, which is of great interest due to the possible transversal use of this methodology in the description of soil quality indicators.

Pesticides in the environment and mitigation technology using adsorption and biodegradation processes and their adaptation for industrial wastewater treatment. Serious disposal and treatment problems characterize pesticides in the environment, including: high loads, high toxicity, low water solubility, high half-life, high affinity for organic matter, chemical structure, etc. Pesticides can be removed efficiently using a simple and efficient technology called a biopurification system (BPS). However, some of the metabolites formed during pesticide biodegradation could be more toxic and dangerous than the original compounds. Therefore, overall knowledge about this technology is necessary, including on the microorganisms and enzymes involved in the degradation of pesticides and their metabolites, the operational conditions of the reactors used to degrade them and other chemicals, like biosurfactants, involved in their degradation. In order to elucidate some of these issues, we have identified molecularly and characterized pesticide-tolerant bacteria obtained from a BPS and evaluated these bacteria to remove some common pesticides in order to protect water resources (Briceño *et al.*, 2020). In addition, bacterial amidohydrolases and carboxamidases as a tool for IPR pesticide biodegradation have been studied as part of the doctoral dissertation of Pamela Donoso. We have evaluated the performance of an optimized fixed-bed column packed with an organic biomixture to remove atrazine from aqueous solution. This study provided the basis for implementing a novel continuous treatment system for wastewater containing the pesticide atrazine (ATZ). Based on the results of ATZ adsorption onto four biomixtures, the biomixture with wheat straw, soil, and peat was selected as the packing material for the fixed-bed column (FBC). The response surface methodology (RSM) was used to optimize the combined effect of the inlet ATZ concentration, flow rate and pH of the ATZ solution. Adsorption of ATZ decreased when the ATZ concentration and flow rate increased, especially at a basic pH. The optimum conditions for ATZ adsorption were a pH of 4.07, an influent ATZ concentration of 7.18 mg L^{-1}, and a flow rate of 34.24 mL h^{-1}, which resulted in the removal of 98.6% of the ATZ. The Thomas model described the adsorption process to be well under optimized conditions (Levio *et al.,* 2021a). Similarly, the removal of

pesticides in a continuous Packed-Bed Reactor (PBR) packed with an organic matrix inoculated with an immobilized consortium of bacteria and fungi has been studied as part of the Doctoral Thesis of Marcela Levio. She is evaluating operational conditions (organic loading rate, flow rate and hydraulic retention time) of PBR with an immobilized consortium of microorganisms that will allow more than 90% removal of a pesticide mixture containing atrazine (ATZ), iprodione (IPR) and chlorpyrifos (CHL). Treatment of pesticide-contaminated water using a selected immobilized fungal consortium (H5 and H12) in batch resulted in the efficient removal of different pesticide concentrations. The immobilization of the fungal consortium in alginate bead was effective, with the highest pesticide removal observed using an inoculum concentration of 30% wv^{-1}. The packed-bed reactor with the immobilized fungal consortium, which was operated in continuous mode at different flow rates (30, 60, and 90 mL h^{-1}), required approximately 10 d to achieve removal efficiency (atrazine: 59%; iprodione: 96%; chlorpyrifos: ~85%). The bioreactor was sensitive to flow rate fluctuations but was able to recover performance quickly. The pesticide metabolites hydroxyatrazine, 3,5-dichloroaniline, and 3,5,6-trichloro-2-pyridinol were produced, and a slight accumulation of 3,5,6-trichloro-2-pyridinol was observed. Nevertheless, reactor removal efficiency was maintained until the study ended (60 d) (Levio *et al.,* 2021b).

Biosurfactants involved in pesticide degradation. Biosurfactants produced by Antarctic bacteria in the degradation of CHL by bacterial strains isolated from a BPS are the target of the postdoctoral position of Dr. Claudio Lamilla (Fondecyt 3190918). Based on this research, we are evaluating the presence of bacterial strains with both pesticide-degradation capacity and biosurfactant production inside the BPS. The results are very important to understanding the entire pesticide degradation process. We found that the BPS is an adequate source of biosurfactant-producing bacteria with environmental biotechnology applications (Lamilla *et al.,* 2021). The chemical characterization of the biosurfactants revealed the presence of glycolipids in *P. rhodesiae* (C4) and glycopeptides in *P. marginalis* (C9). The degradation of chlorpyrifos increased from 39.2% to 51.6% when biosurfactants produced by *P. rhodesiae* (C4) were added (10%), relative to the control. In addition, in a new project (Fondecyt 1211738) we will study the enhancement of pesticide degradation by microbial consortia acting on an efficient BPS enriched with biosurfactants obtained from bacteria isolated from the BPS.

Projections of BPS for removal of another contaminant. Regarding BPS projections, we are adapting this technology for industrial effluent treatment with high organic matter content. We installed a BPS at pilot plant level (3 m^3 reactor) for treatment of wastewater in a wood processing plant located in the Lautaro Commune in the Araucania Region (EAGON-UFRO-Corfo project). We recently published a study on an alternative treatment for metal ion removal from acid mine drainage using an organic biomixture as a low-cost adsorbent (Levio *et al.,* 2021c). In addition, "cadmium removal for marine food application: comparative study of different adsorbents" is a topic we are addressing in the Doctoral Thesis of Carolina Calderon, in association with a fishing company in southern Chile (LANDES S.A.); the obtained results were submitted by Calderón *et al.* (2021).

References

Aponte H., Mondaca P., Santander C., Meier S., Paolini J., Buttler B., Rojas C., Diez C. and Cornejo P. 2021. Enzyme activities and microbial functional diversity in metal(loid) contaminated soils near to a copper smelter. Science of The Total Environment 779: 146423. DOI: 10.1016/j.scitotenv.2021.146423.

Araya-Castro K., Tzu-Chiao C., Durán-Vinet B., Cisterna C., Ciudad G. and Rubilar O. 2021. Green Synthesis of Copper Oxide Nanoparticles Using Protein Fractions from an Aqueous Extract of Brown Algae Macrocystis pyrifera. Processes 9(1): 78. DOI: 10.3390/pr9010078.

Ávila-Salem M.E. 2021. Effects of tillage, fertilization and crop rotation on the biological activities of an Ecuadorian soil from the Andean highlands: towards the optimization of soil management for a sustainable agriculture. PhD in Sciences of Natural Resources. Supervisor: Dr. Pablo Cornejo.

Barra R., Vidal G., Valdovinos C. and Nieto P. 2021. The problem is not only the scarcity of water, but its contamination. Available at:https://www.ciperchile.cl/2021/06/04/el-problema-no-solo-es-la-escasez-de-aguasino-su-contaminacion/

Bonassa G., Chiapetti Bolsan A., Ester Hollas C., Venturin B., Candido D., Chini A., De Prá M.C., Goldschmidt Antes F., Campos J.L. and Kunz A. 2021. Organic carbon bioavailability: Is it a good driver to choose the best biological nitrogen removal process?. Science of the Total Environment 786: 147390. DOI: 10.1016/j.scitotenv.2021.147390.

Briceño G., Lamilla C., Leiva B., Levio M., Donoso-Piñol P., Schalchli H., Gallardo F. and Diez M.C. 2020. Pesticides-tolerant bacteria from biopurification system to remove commonly used to pesticides to protect water resources. PLoS ONE 15(6): e0234865. DOI: 10.1371/journal.pone.0234865.

Cabrera-Castillo E.H., Castillo I., Ciudad G., Jeison D. and Ortega-Bravo J.C. 2021. FOMD setup analysis for acid mine drainage treatment in Chile: An experimentaltheoretical economic assessment compared with FO-RO and single RO. Desalination 514:115164. DOI: 10.1016/j.desal.2021.115164.

Calderón C., Levío M. and Diez M.C. 2021. Cadmium removal for marine food application: comparative study of different adsorbents. International Journal of Environmental Science and Technology, *in press*, JEST-D-20-01523-R2.

Calderon C. 2021. Cadmium removal from hydrolyzed protein of Giant Squid (Dosidicus gigas). Doctoral Thesis in Natural Resource Sciences. Universidad de La Frontera. In course.

Carrillo V., Collins C., Brisson J. and Vidal G. 2021. Evaluation of long-term phosphorus uptake by Schoenoplectus californicus and Phragmites australis plants in pilot-scale constructed wetlands. International Journal of Phytoremediation 1-12. DOI: 10.1080/15226514.2021.1960478.

Cisternas C. 2021. Study of the synthesis mechanism for the formation of Silver Nanoparticles (AgNP) with antimicrobial activity. PhD in Natural Resource Sciences. Universidad de La Frontera. In course.

Cisternas C., Tortella G., Seabra A.B., Pieretti J., Araya-Castro K., Hermosilla E., Diez M.C. and Rubilar O. 2021. Development of a new biomimetic method for the synthesis of silver nanoparticles based on fungal metabolites: optimization and antibacterial activity. Journal of Chemical Technology and Biotechnology 96(7):1981-1990. DOI 10.1002/jctb.6724.

Cornejo P. 2021a. Proteger nuestros suelos: Otra tarea pendiente (Protecting our soils: Another pending task). Available at: https://www.ciperchile.cl/2021/05/08/proteger-nuestros-suelos-otra-tareapendiente/

Cornejo P. 2021b. Proteger nuestros suelos: Otra tarea pendiente (Protecting our soils: Another pending task). Available at: https://www.ciperchile.cl/2021/05/08/proteger-nuestros-suelos-otra-tareapendiente/

Crutchik D. and Campos J.L. 2021. Municipal Wastewater Reuse: Is it a Competitive Alternative to Seawater Desalination?. Sustainability 13(12): 6815. DOI: 10.3390/su13126815.

de Souza Campos P.M., Borie F., Cornejo P., López-Ráez J.A., López-Garcia A. and Seguel A. 2021. Wheat root trait plasticity, nutrient acquisition and growth responses are dependent on specific arbuscular mycorrhizal fungus and plant genotype interactions. Journal of Plant Physiology 256: 153297. DOI: 10.1016/j.jplph.2020.153297.

Díaz M.E., Julio N., Vidal G. and Figueroa R. 2021. Sustentabilidad y seguridad hídrica (Sustainability and water security). Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 17, 21p.

Diez C., Barra R. and Vidal G. 2021. Pesticides: a two-sided coin (to appear in CIPER Chile).

D'Haese A., Ortega Bravo J.C., Harmsen D., Vanhaecke L., Verliefde A., Jeison D. and Cornelissen E. 2021. Analysing organic micropollutant accumulation in closed loop FO–RO systems: A pilot plant study. Journal of Membrane Science 626:119182. DOI: 10.1016/j.memsci.2021.119182.

Donoso P. 2021. Biochemical and molecular characterization of pesticides degrading bacteria. Doctoral Thesis in Natural Resource Sciences. Universidad de La Frontera. In course.

Fincheira P., Quiroz A., Tortella G., Diez M. and Rubilar O. 2021a. Current advances in plant-microbe communication via volatile organic compounds as an innovative strategy to improve plant growth. Microbiological Research 247, 126726. DOI: 10.1016/j.micres.2021.126726.

Fincheira P., Jofré I., Tortella G., Medina C., Quiroz A., Seabra A.B., Nascimento M., Diez M.C. and Rubilar O. 2021b. The prospection of plant response to 2-ketones released from nanostructured lipid 2 carriers. Journal of Soil Science and Plant Nutrition 21(2): 1474-1483. DOI: 10.1007/s42729-021-00454-8.

González T., Puigagut J. and Vidal G. 2021. Organic matter removal and nitrogen transformation by a constructed wetland-microbial fuel cell system with simultaneous bioelectricity generation. Science of the Total Environment 753: 142075. DOI: 10.1016/j.scitotenv.2020.142075.

Gómez G., Ortega M.J. and Vidal G. 2021a. COVID-19: Las aguas servidas y su microbiología (Wastewater and its microbiology). Revista Asociación de Ingeniería Sanitaria y Ambiental AIDIS (Sanitary and Environmental Engineering Association Journal), Chilean chapter, 60, april, p. 10-15.

Gómez G., Ortega M.J., Figueroa R., González Y. and Vidal G. 2021b. Microbiología y tratamiento de aguas servidas bajo el concepto de "One Health" (Microbiology and sewage treatment under the "One Health" concept.). Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 22, 28p.

Hermosilla E., Seabra A.B., Lourenço I.M., Ferrerira F.F., Tortella G. and Rubilar O. 2021. Highly sensitive oxidation of MBTH/DMAB by MnFe2O4 nanoparticles as a promising method for nanozyme-based sensor development. Colloids and Surfaces A: Physicochemical and Engineering Aspects 621: 126585. DOI: 10.1016/j.colsurfa.2021.126585.

Herrera W. 2021. Degradation of imidacloprid and chlorpyrifos catalyzed by metaldoped superparamagnetic iron oxide nanoparticles (SPIONS). PhD in Natural Resource Sciences. Universidad de La Frontera. In course.

InES19-VRIP-UFRO (2021-2023). Interacción biotecnología-ambiente-agricultura para la mitigación del cambio climático: Hacia la sustentabilidad productiva y resiliencia de los recursos naturales (Biotechnology-environment-agriculture interaction for climate change mitigation: Towards productive sustainability and resilience of natural resources). Responsible researcher: Dr. Pablo Cornejo. Co-Researcher: Dr. Olga Rubilar.

Lamilla C., Schalchli H., Briceño G., Leiva B., Donoso-Piñol P., Barrientos L., Rocha V.A.L., Freire D.M.G. and Diez M.C. 2021. A Pesticide Biopurification System: A Source of Biosurfactant-Producing Bacteria with Environmental Biotechnology Applications. Agronomy 11: 624. DOI:10.3390/agronomy11040624.

Leiva A.M., Piña B. and Vidal G. 2021a. Antibiotic resistance dissemination in wastewater treatment plants: a challenge for the reuse of treated wastewater in agriculture. Reviews in Environmental Science and Bio/Technology 1-30. DOI: 10.1007/s11157-021-09588-8.

Leiva A.M., Gutierrez E., Arias C.A. and Vidal G. 2021b. Influence of water quality parameters on the removals of triclosan and ibuprofen in vertical subsurface flow constructed wetlands using multivariate analysis. Environmental Technology & Innovation 24:101846. DOI: 10.1016/j.eti.2021.101846.

Levio M. 2021. Packed bed reactor for pesticide-containing wastewater treatment. Doctoral Thesis in Natural Resource Sciences. Universidad de La Frontera. In course.

Levio-Raiman M., Schalchli H., Briceño G., Bornhardt C., Tortella G., Rubilar O. and Diez M.C. 2021a. Performance of an optimized fixed-bed column packed with an organic biomixture to remove atrazine from aqueous solution. Environmental Technology and Innovation 21:101263. DOI: 10.1016/j.eti.2020.101263, 2352-1864/© 2020.

Levio-Raiman M., Briceño G., Leiva B., Lopez S., Schalchli H., Lamilla C., Bornhardt C. and Diez M.C. 2021b. Treatment of pesticides-contaminated water using a selected fungal consortium: study in batch and packed-bed bioreactor. Agronomy 11: 743. DOI: 10.3390/agronomy11040743.

Levio-Raiman M., Briceño G., Schalchli H., Bornhardt C. and Diez M.C. 2021c. Alternative treatment for metal ions removal from acid mine drainage using an organic biomixture as a low cost adsorbent. Environmental Technology & Innovation 24: 101853. DOI: 10.1016/j.eti.2021.101853.

Mansilla S., Portugal J., Bayona J.M., Matamoros V., Leiva A.M., Vidal G. and Piña B. 2021. Compounds of emerging concern as new plant stressors linked to water reuse and biosolid application in agriculture. Journal of Environmental Chemical Engeneering 9: 105198. DOI: 10.1016/j.jece.2021.105198.

Nahuelcura J., Ruiz A., Gomez F. and Cornejo P. 2021. The effect of arbuscular mycorrhizal fungi on the phenolic compounds profile, antioxidant activity and grain yields in wheat cultivars growing under hydric stress. Journal of the Science of Food and Agriculture In Press. DOI: 10.1002/jsfa.11370.

Nature-based solutions for spot and diffuse discharge decontamination. 2021. Editors: G. Vidal, G. Gómez and M. C. Diez. Ediciones Universidad de Concepción ISBN 978-956-227-465-4, Intellectual Property Registry N° 2020-A-7572 year 2020. 132p.

Neumann P., López D. Ruiz-Tagle N., Sossa K. and Vidal G. 2021. Effect of a sonothermal pre-treatment over methane production, specific activities and the microbial community of sludge anaerobic digesters. Waste and Biomass Valorization 12:1927–1941. DOI: 10.1007/s12649-020-01142-x.

Neumann P. and Vidal G. 2021. Water footprint: a fundamental tool for sustainable water management and enhancing water security. Available at: https://www.ciperchile.cl/2021/05/29/huella-del-agua-una-herramientafundamental-para-la-gestion-sustentable-del-agua-y-potenciar-la-seguridadhidrica/

Ortega-Martínez O., Chamy R. and Jeison D. 2021. Thermal pre-treatment: Getting some insights on the formation of recalcitrant compounds and their effects on anaerobic digestion. Journal of Environmental Management 282: 111940. DOI: 10.1016/j.jenvman.2021.111940.

Parra B., Barra R., Diez M.C. and Vidal G. 2021. Uso de plaguicidas en la agricultura: conceptos básicos, riesgos y soluciones (Pesticide use in agriculture: basic concepts, risks and solutions.). Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 19, 35p.

Pavissich J.P., Camus N., Campos J.L., Franchi O., Pedrouso A., Carrera P., Val del Rio A. and Mosquera-Corral A. Monitoring the stability of aerobic granular sludge using fractal dimension analysis. Environmental Science Water Research & Technology 7: 706-713. DOI: 10.1039/d1ew00015b.

Pedrouso A., Vázquez-Padín J.R., Crutchik D. and Campos J.L. 2021. Application of Anammox-Based Processes in Urban WWTPs: Are We on the Right Track? Processes 9(8): 1334. DOI: 10.3390/pr9081334.

Pérez R., Tapia Y., Antilén M., Casanova M., Vidal C., Santander C., Aponte H. and Cornejo P. 2021a. Interactive effect of compost application and inoculation with the fungus Claroideoglomus claroideum in Oenothera picensis plants growing in mine tailings. Ecotoxicology and Environmental Safety 208:111495. DOI: 10.1016/j.ecoenv.2020.111495.

Pérez R., Tapia Y., Antilén M., Casanova M., Vidal C., Silambarasan S. and Cornejo P. 2021b. Rhizosphere management for phytoremediation of copper mine tailings. Journal of Soil Science and Plant Nutrition In press. DOI: 10.1007/s42729-021-00591-0.

Santander C., Aroca R., Cartes P., Vidal G. and Cornejo P. 2021a. Aquaporins and cation transporters are differentially regulated by two arbuscular mycorrhizal fungi strains in lettuce cultivars growing under salinity conditions. Plant Physiology and Biochemistry 158: 396-409. DOI: 10.1016/j.plaphy.2020.11.025.

Santander C., Cornejo P., Vidal G. and Holzapfel E. 2021. Hongos micorrícicos arbusculares: biotecnología sustentable para la agricultura frente al cambio climático (Arbuscular mycorrhizal fungi: sustainable biotechnology for agriculture in the face of climate change). Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 18, 31p.

Santander C., García S., Moreira J., Aponte H., Araneda P., Olave J., Vidal G. and Cornejo P. 2021c. Arbuscular Mycorrhizal Fungal Abundance in Elevation Belts of the Hyperarid Atacama Desert. Fungal Ecology 51: 101060. DOI: 10.1016/j.funeco.2021.101060.

Santander C., Cornejo P., Vidal G. and Holzapfel E. 2021d. Hongos micorrícicos arbusculares: biotecnología sustentable para la agricultura frente al cambio climático (Arbuscular mycorrhizal fungi: sustainable biotechnology for agriculture in the face of climate change). Serie Comunicacional CRHIAM, Water Research Center for Agriculture and Mining, ISSN 0718-6460 (printed version), ISSN 0719-3009 (online version), number 18, 31p.

Sepúlveda S., Duarte-Nass C., Rivas M., Azócar L., Ramírez A., Toledo-Alarcón J., Gutiérrez L. and Jeison D. 2021. Testing the capacity of Staphylococcus equorum for calcium and copper removal through MICP process. Minerals, *in press*.

Tortella G., Rubilar O., Diez M.C., Padrao J., Zille A., Pieretti J.C. and Seabra A.B. 2021. Advanced Material Against Human (Including Covid-19) and Plant Viruses: Nanoparticles as a Feasible Strategy. Global Challenges 5: 2000049. DOI: 10.1002/gch2.202000049.

Treatment and Valorisation of Saline Wastewater: Principles and Practice. 2021. Editors and authors: Mosquera-Corral A., Val del Rio A., Campos J.L. IWA Publishing, Londres. ISBN13: 9781789060638, 200 pages.

Urgiles-Gómez N., Avila-Salem M.E., Loján P., Encalada M., Hurtado L., Araujo S., Collahuazo Y., Guachanamá J., Poma N., Granda K., Robles A., Senés C. and Cornejo P. 2021. Plant Growth-Promoting Microorganisms in Coffee Production: From Isolation to Field Application. Agronomy 11: 1531. DOI: 10.3390/agronomy11081531.

Valdés F., Rosseto Camiloti P., Bartacek J., Torres-Aravena A., Toledo-Alarcón J., Zaiat M. and Jeison D. 2020. Micro-Oxygenation in Upflow Anaerobic Sludge Bed (UASB) Reactors Using a Silicon Membrane for Sulfide Oxidation. Polymers 12: 1990. DOI: 10.3390/polym12091990.

Valenzuela-Heredia D., Henríquez-Castillo C., Donoso R., Lavín P., Ringel M.T., Brüser T. and Campos J.L. 2021a. An unusual overrepresentation of genetic factors related to iron homeostasis in the genome of the fluorescent *Pseudomonas* sp. ABC1. Microbial Biotechnology 1-13. DOI:10.1111/1751-7915.13753.

Valenzuela-Heredia D., Panatt C., Belmonte M., Franchi O., Crutchik D., Dumais J., Vázquez-Padín J.R., Lesty Y., Pedrouso A., Val del Río A., Mosquera-Corral A. and Campos J.L. 2021b. Performance of a two-stage partial nitritation-anammox system treating the supernatant of a sludge anaerobic digester pretreated by a thermal hydrolysis process. Chemical Engineering Journal, *in press*. DOI: 10.1016/j.cej.2021.131301.

Venegas M., Leiva A.M., Reyes-Contreras C., Neumann P., Piña B. and Vidal G. 2021. Presence and fate of micropollutants during anaerobic digestion of sewage and their implications for the circular economy: A short review. Journal of Environmental Chemical Engeneering 9(1): 104931. DOI: 10.1016/j.jece.2020.104931.

Vera J. 2021. Biogenic synthesis of Fe3O4@SiO2@ZnO nanoparticles for depolymerization of Kraft lignin in a photoreactor: Photocatalytic activity, recycling and obtaining high value added phenolic compounds. PhD in Engineering Sciences mention Bioprocesses. Universidad de La Frontera. In course.

Vidal C. 2021. Copper tolerance and accumulation in *Imperata cylindrica*; a metallophyte with potential for phytoremediation in copper contaminated environments. PhD in Sciences of Natural Resources. 2021. Supervisor Dr. Pablo Cornejo.

Vidal C., Larama G., Riveros A., Meneses C. and Cornejo P. 2021. Main Molecular Pathways Associated with Copper Tolerance Response in Imperata cylindrica by De novo Transcriptome Assembly. Plants 10: 357. DOI: 10.3390/plants10020357.

Vidal G. 2021. The water highway is a short-term measure. It is a lot of effort and money, just to spread poverty (Interview). Available at: ttps://www.ciperchile.cl/2021/03/20/la-carretera-hidrica-es-una-medida-de-corto-plazoes-mucho-esfuerzo-y-dinero-solo-para-regar-pobreza/

Research projects and international and national collaboration projects

Project - FONDECYT Regular 1211738 (2021-2025). Enhancing pesticides degradation by microbial consortia acting on an efficient biopurification system enriched with biosurfactants. Responsible researcher: Dr. M Cristina Diez.

Project - FONDECYT Regular 1191089 (2019-2023). Production of biogenic silver nanoparticles with antimicrobial activity in a fluidized bed reactor (FBR) coupled to a stirred tank reactor (STR) operated with immobilized fungal biomass. Responsible researcher: Dr. Olga Rubilar.

Project - FONDECYT Regular 1191230 (2019-2023). Enzymatic white rot fungi whole cell bioreactor pretreatment as a fundamental stage of a biorefinery of two-phase olive mill solid waste to produce biogas and a potential biofertilizer. Responsible researcher: Dr. Gustavo Ciudad. Co-Reseracher: Dr. Olga Rubilar.

Project - FONDECYT 3190918 (2019-2022) Biosurfactantes producidos por bacterias antárticas en la degradación de clorpirifos por bacterias aisladas de un sistema de biopurificación (Biosurfactants produced by Antarctic bacteria in the degradation of chlorpyrifos by bacteria isolated from a biopurification system). Resposible researcher: Dr. Claudio Lamilla. Sponsoring Researcher: Dr. M Cristina Diez.

Project - FONDECYT Postdoctorado 3200963 (2020 – 2023). Formulation of a nanocomposite that allows the sustained release of copper nanoparticles and iprodione to be used against the phytopathogenic fungus *Botrytis cinérea*. Responsible researcher: Dr. Javiera Parada. Sponsoring Researcher: Dr. Olga Rubilar.

Project - FONDECYT Postdoctorado 3190922 (2019-2022). Pretreatment of lignocellulosic biomass by Fenton-like reaction (catalyzed by superparamagnetic Fe-NPs) combined with fungal MnP enzyme. Responsible researcher: Dr. Edward Hermosilla. Sponsoring Researcher: Dr. Olga Rubilar.

Project - FONDECYT Postdoctorado 3210633 (2021-2024). Nanotecnología aplicada al desarrollo y análisis de proteínas anticongelantes para incrementar la tolerancia a la congelación de cultivos agrícolas (Nanotechnology applied to the development and analysis of antifreeze proteins to increase freezing tolerance of agricultural crops). Responsible researcher: Dr. Stefanía Short. Sponsoring Researcher: Dr. Olga Rubilar.

Project - FONDECYT regular 1170264 (2017-2021). Influence of drought on the efficiency of arbuscular mycorrhizal symbiosis in phosphorus acquisition by plants growing in Andisols from Southern Chile: wheat as a crop model. Responsible researcher: Dr. Pablo Cornejo.

Project - FONDECYT regular 1191551 (2019-2022). How precedent non-mycorrhizal crops affect soil P bioavailability, physiological root traits, and mycorrhizal symbiosis of wheat in a rotation system in volcanic soils of Chile. Responsible researcher: Dr. Fernando Borie. Co-Reseracher: Dr. Pablo Cornejo.

Project - FONDECYT regular 1190585 (2019-2023). Can the directed inoculation of arbuscular mycorrhizal fungi modify the profiles and quantity of antioxidant compounds in flesh-colored potatoes cropped under drought and P starvation conditions? Responsible researcher: Dr. Antonieta Ruiz. Co-Reseracher: Dr. Pablo Cornejo.

Project - FONDECYT regular 1210964 (2021-2025). How the management of rhizosphere microbiota can enhance plant production under drought stress: Developing a scientific basis for the design of next generation biofertilizers. Responsible researcher: Dr. Pablo Cornejo.

Project - FONDECYT Postdoctorado 3210456 (2021-2024). Recuperación de aguas subterráneas contaminadas con nitratos mediante desnitrificación hidrogenotrófica en reactores bioelectroquímicos (Recovery of nitrate-contaminated groundwater by hydrogenotrophic denitrification in bioelectrochemical reactors). Responsible research: Dr. Javiera Toledo. Sponsoring Researcher: Dr. David Jeison.

Project - FONDECYT Regular 1190664 (2019-2022, extended until 2023). Microbial and enzymatic induced calcite precipitation as a tool to improve mine tailings sustainability. Responsible research: Dr. David Jeison.

Project - FONDECYT Regular 1180498 (2018-2022) Advanced computational modeling for bioprocess optimization and design. Biochemical integration and experimental validation as key issues. Responsible research: Dr. Andrés Donoso. Coresearch: Dr. David Jeison.

Project - FONDECYT postdoctorado 3210588 (2021-2024). Biofiltración de aguas salinizadas utilizando micorrizas arbusculares: creando bases científicas para la reutilización de aguas con fines agrícola (Biofiltration of salinized water using arbuscular mycorrhizae: creating a scientific basis for agricultural water reuse). Responsable research: Dr. Christian Javier Santander Castro. Sponsoring Researcher: Dr. Gladys Vidal.

Project - INRIA Associated Team (Programme Equipes Associées) Blue Edge. Principal investigator: Olivier Bernard (INRIA) Principal investigator (Partner institution): David Jeison.

Project - CORFO, 20VEIRL-134185 -Línea Validación de la Innovación Social. “Resiliencia y adaptabilidad al cambio climático; Ciudades esponjas y campos sustentables mediante humedales depuradores de aguas residuales” (Social Innovation Validation Line. “Resilience and adaptability to climate change; Sponge cities and sustainable fields through wastewater purifying wetlands”). Funded by CORFO, 20VEIRL-134185 - Social Innovation Validation Line -. Lead Centro de Humedales del Río Cruces- CEHUM (Río Cruces Wetlands Center), Universidad Austral de Chile, Cooperativa de Aprendizaje en Restauración Ecológica y Permacultura- CAREP (Ecological Restoration and Permaculture Learning Cooperative), CRHIAM, Universidad de Concepción.

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References

Álvez A., Bañales-Seguel C., Castillo R., Acuña-Molina C. and Torres P. 2021. Legal personhood of Latin American rivers: Time to shift constitutional paradigms?. Journal of Human Rights and the Environment 12(2): 147-176.

Álvez A. and Castillo R. 2021a. Reformas en materia de fiscalización y sanciones al Código de Aguas: la objeción democrática ante la crisis hídrica (Reforms to the Water Code in terms of control and penalties: democratic objection to the water crisis) (Rol nº 3985 de 2017), in Soto. P. and Ponce V. (eds.) El Tribunal Constitucional frente al proceso constituyente. Ensayos críticos sobre su jurisprudencia y sus prácticas (The Constitutional Court facing the constituent process. Critical essays on its jurisprudence and practices) (Santiago: Thomson Reuters).

Álvez A. and Castillo R. 2021b. ¿Por qué el derecho humano al agua no se puede ejercer en Chile? (Why the human right to water cannot be exercised in Chile). CIPER. Available at: https://www.ciperchile.cl/2021/04/16/por-que-el-derechohumano-al-agua-no-se-puede-ejercer-en-chile/

Álvez A. and Castillo R. 2021c. Emergencia y acceso al agua. COVID-19 como una crisis dentro de la crisis (Emergency and access to water. COVID-19 as a crisis within the crisis), in Contreras P.(editor) La ley de la emergencia Ensayos sobre el derecho, la excepción y la pandemia (The Law of Emergency Essays on Law, Exception and Pandemic) (Santiago: DER Ediciones), pp. 187-200.

Arumí J.L. and Delgado V. What are the gaps for the implementation of AGR in Chile?. In 47th IAH Brazil Congress, XV Latin American Congress of Hydrogeology and XXI Brazilian Congress of Groundwater. Online. 23-26 august 2021.

Arumí J.L. and Melo O. 2021. Sustentabilidad de las aguas subterráneas, una mirada hacia las organizaciones de usuarios de aguas (Groundwater sustainability, a look at water user organizations). In XXIII Jornadas de derecho y gestión de aguas "Valores del agua y nueva constitución" (XXIII Water law and management conference "Water values and the new constitution). Online Congress, Chile.

Banegas-Medina A., Montes I., Tzoraki O., Brendonck L., Pinceel T., Diaz G., Arriagada P., Arumi J.L., Pedreros P. and Figueroa R. 2021. Hydrological, environmental and taxonomical heterogeneity during the transition of flow recession to the resumption in a Mediterranean intermittent river. Biology 10(4): 316.

Barra R.O., Chiang G., Saavedra M.F., Orrego R., Servos M.R., Hewitt L.M., McMaster M., Bahamonde P., Tucca F. and Munkittrick K.R. 2021a. Endocrine Disruptor Impacts on Fish From Chile: The Influence of Wastewaters. Frontiers in Endocrinology 12: 208.

Barra R., Nieto P., Valdovinos C. and Vidal G. 2021b. El Problema no solo es la escasez de agua, sino su contaminación (The problem is not only water scarcity, but also water pollution). CIPER. Available at: https://www.ciperchile.cl/2021/06/04/elproblema-no-solo-es-la-escasez-de-agua-sino-su-contaminacion/

Boyero L., López-Rojo N., Tonin AM., Pérez J., Correa-Araneda F., Pearson RG., Bosch J., Albariño RJ., Anbalagan S., Barmuta L.A., Basaguren A., Burdon F.J., Caliman A., Callisto M., Calor A.R., Campbell I.C., Cardinale B.J., Casas J.J., Chará-Serna A.M., Chauvet E., Ciapała S., Colón-Gaud C., Cornejo A., Davis A.M., Degebrodt M., Dias E.M., Díaz M.E., Douglas M.M., Encalada A.C., Figueroa R., Flecker A.S., Tadeusz F., García E.A., García G., García P.E., Gessner M.O., Gómez J.E., Gómez S., Gonçalves J.F., Gwinn D.C., Hall R.O., Hamada N., Hui C., Imazawa D., Iwata T., Kariuki S.K., Landeira-Dabarca A., Laymon K., Leal M., Marchant R., Martins R.T., Masese F.O., Maul M., McKie B.G., Medeiros A.O., Erimba C., Middleton J.A., Monroy S., Muotka T., Negishi J.N., Ramírez A., Richardson J.S., Rincón J., Rubio-Ríos J., dos Santos G.M., Sarremejane R., Sheldon F., Sitati A., Tenkiano N.S.D., Tiegs S.D., Tolod J.R., Venarsky M., Watson A. and Yule C.M. 2021a. Impacts of detritivore diversity loss on instream decomposition are greatest in the tropics. Nature communications 12(3700): 1-11.

Boyero L., Pérez J., López-Rojo N., Tonin A.M., Correa-Araneda F., Pearson R.G., Bosch J., Albariño R., Anbalagan S., Barmuta D., Beesley L., Burdon F.J., Caliman A., Callisto M., Campbell I.C., Cardinale B.J., Casas J.J., Chará-Serna A.M., Ciapała S., Chauvet E., Colón-Gaud C., Cornejo A., Davis A.M., Degebrodt M., Dias E.S., Díaz M.E., Douglas M.M., Elosegi A., Encalada A.C., Eyto E., Figueroa R., Flecker A.S., Fleituch T., Frainer A., França J.S., García E.E., García G., García P., Gessner M.O., Giller P.S., Gómez J.E., Gómez S., Gonçalves J.F., Graça M.A., Hall R.O., Hamada N., Hepp L.U., Hui C., Imazawa D., Iwata T., Junior E.S.A., Kariuki S., Landeira-Dabarca A., Leal M., Lehosmaa K., M'Erimba C., Marchant R., Martins R.T., Masese F., Maul M., McKie B.G., Medeiros A.O., Middleton J.A., Muotka T., Negishi J.N., Pozo J., Ramírez A., Rezende R.S., Richardson J.S., Rincón J., Rubio-Ríos J., Serrano C., Shaffer A.R., Sheldon F., Swan S.M., Tenkiano N.S.D., Tiegs S.D., Tolod J.R., Vernasky M., Watson A., Yegon M.J. and Yule C.M. 2021b. Latitude dictates plant diversity effects on instream decomposition. Science Advances 7(13): eabe7860.

Correa-Araneda F., Núñez D., Díaz M.E., Gómez-Capponi F., Figueroa R., Acuña J., Boyero L., Esse C. 2021. Comparison of sampling methods for benthic macroinvertebrates in forested wetlands. Ecological Indicators 125: 107551.

Delgado V. and Arumi J.L. 2021. El modelo chileno de regulación de las aguas subterráneas: críticas desde el derecho ambiental y las ciencias ambientales (The Chilean model of groundwater regulation: critiques from environmental law and environmental sciences.). Editorial Tirant Le Blanch. ISBN 9788413782942 (printed versión), ISBN 9788413782959 (Ebook version). Spain.

Figueroa R. 2021. ¿Pueden los gobernadores cambiar radicalmente la gestión del agua en sus regiones? (Can governors radically change water management in their regions?). CIPER. Available at: https://www.ciperchile.cl/2021/06/23/pueden-losgobernadores-cambiar-radicalmente-la-gestion-del-agua-en-sus-regiones/

Flores Y., Ponce Oliva R.D., Fernández F.J. and Vásquez-Lavin F. 2021. Sensitivity of Water Price Elasticity Estimates to Different Data Aggregation Levels. Water Resources Management 35(6): 2039-2052.

Jerez B., Garcés I. and Torres R. 2021. Lithium extractivism and water injustices in the Salar de Atacama, Chile: The colonial shadow of green electromobility. Political Geography 87: 102382.

Kasargodu P., Dietrich J., Prado L., Morales B., Winter E. and Arumi J.L. 2021. Application of the theory of planned behavior with agent-based modeling for sustainable management of vegetative filter strips. Journal of Environmental Management 284: 112014.

Ponce Oliva R.D., Montevechio E.A., Jorquera F.F., Vásquez-Lavin F. and Stehr A. 2021a. Water Use and Climate Stressors in a Multiuser River Basin Setting: Who Benefits from Adaptation?. Water Resources Management 35(3): 897-915.

Ponce Oliva R.D., Fernández F.J., Vasquez-Lavín F., Arias Montevechio E., Julio N. and Stehr A. 2021b. Nexus Thinking at River Basin Scale: Food, Water and Welfare. Water 13(7): 1000.

Reicher O., Delgado V. and Arumi J.L. 2021. Use of Indicators in Strategic Environmental Assessments of Urban-Planning Instruments: A Case Study. Sustainability 13:12639.

Rojas J., Silva P. and Barra R. 2021. Local Knowledge, Community Experiences, Nature, Collaboration, and Resilience in Times of Pandemic, Uncertainty, and Climate Change in the Anthropocene Era. IntechOpen. In: Anxiety, Uncertainty, and Resilience During the Pandemic Period - Anthropological and Psychological Perspectives. ISBN 978-1-83968-126-4. Italy.

Torres R., Azócar G., Mendoza J. and Gallardo R. 2021. Water extractivism and decolonial struggles in Mapuche territory, Chile. Water Alternatives (Accepted).

9.2 References of "Contribution of CRHIAM's Research Publications to SDG achievement" study

Bautista-Puig, N., Leal, S., Azeiteiro, U. and Costas, R. (2021) Unveiling the Research Landscape of Sustainable Development Goals and Their Inclusion in Higher Education Institutions and Research Centers: Major Trends in 2000–2017. Frontiers in Sustainability, 2, 12.

CRHIAM (2018). Plan de Continuidad de CRHIAM 2019 - 2023.

Rivest, M., et al., Improving the Scopus and Aurora queries to identify research that supports the United Nations Sustainable Development Goals (SDGs) 2021. 2020, Mendeley.

United Nations, D.o.E.a.S.A., The Sustainable Development Goals Report 2020. 2020 ed. 2020: United Nations.

United Nations, D.o.E.a.S.A., Statistics Divisions. SDG Indicators. [cited 2021 29/05/2021]; Available from: unstats.un.org/sdgs/indicators/database.

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